Microgrid—“A Smart Grid for Community Users”

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Abstract---Micro grids are modern, small-scale versions of the centralized electricity system, having specific local goals, such as reliability, carbon emission reduction, diversification of energy sources, and cost reduction, established by the community of users being served. This paper presents an intelligent micro grid that is installable in small localities and consists of sources like grid power, solar power etc. By efficient use of sources the overall cost for the users can be reduced. Smart switching at the user end as per the requirements so as to restrict the user for overloading. Local power generation and storage allow portions of the grid and critical facilities to operate independent of the larger grid, Smart switches and sensors automatically fix and even anticipate power disturbances, unlike today’s system where switches have to be reset manually in case of any outage.

I. INTRODUCTION

A microgrid is a localized grouping of electricity generation, energy storage, and loads that normally operate connected to traditional centralized grid. The connectivity between the microgrid and the centralized grid can be established or dislodged according to the requirement, hence enables the microgrid to function standalone. The loads and the generation points or sources are usually of low voltages. A connected microgrid can be controlled and monitored as a single entity.

Microgrids allow consumers to procure power in real-time at significantly lower costs, while using local generation to compensate power costs. The most significant environmental benefit of a smart micro grid is its ability to use local generation and the resulting “waste” heat to displace coal-fired generation. A local power generator can be renewable- or natural gas-fuelled. The smart micro grid can reuse the energy that is produced during electricity generation for heating buildings, hot water, sterilization, cooling etc.

Smart microgrids reliability significantly reduces costs. Smart meters that allow for the two-way exchange of pricing, usage data and electricity. Programmable smart appliances and devices that come on when the price of power reaches consumer’s desired price point. User-friendly home energy control systems that allow customers to interface with the smart micro grid to automatically control every aspect of a home’s power usage.

Energy efficiency improvements that help consumers use less energy and ultimately save money on monthly electricity bills. Computerized controls that constantly scan for, and even anticipate, potential instabilities to correct problems before users experience any disruption in service. One more thing is the locality can also sell the excess unutilized energy to other grids and earn revenue.

One interesting concept is vehicle to grid technology. According to which a vehicle can be used to store some energy to the smart grid after a long driving.

Microgrids can aggregate complementary distributed energy resources. Through the matching of supply and demand resources within a given microgrid, it is possible to tailor the performance of that network to provide specific operating or environmental performance characteristics. For instance, individual microgrid can be designed for interruptibility, or efficiency of generating sources and loads, or a specific level of reliability and power quality, or an
environmental emissions profile, or even to maximize economic value by selling services to the centralized grids. In this way, microgrid makes a fairly commoditized electricity system customizable to the quality needs of an individual customer.

Microgrids can ease the pressure on utilities and rates while simultaneously modernizing the grid.

II. ARCHITECTURE

The basic architecture of a microgrid system is presented in Figure 1, which shows that a microgrids system generally consists of distributed generation (DG) resource, storage systems, distribution systems, and communication and control systems.

![Microgrid Architecture](image1)

**Sources:**

Distributed generation technologies applicable for microgrids may include emerging technologies such as—wind turbine, solar PV, micro-hydropower, diesel generators.

Solar PV generation involves the generation of electricity from solar energy. Due to enormous improvement in inverter technologies, PV generation is now preferred worldwide as Distributed Energy Resources (DERs). The major advantages of a PV system are

(i) The sustainable nature of solar energy,
(ii) Positive environmental impact,
(iii) Longer lifetime and noiseless operation.

![Wind Turbine](image2)

Wind turbine converts wind energy into electrical energy using the wind energy conversion systems (WECSs). Wind energy has been popular for decades. Usually induction generators are used in WECSs. The main part of the wind turbine is the tower, the rotor, and the nacelle. The nacelle accommodates the mechanical transmission and the generator. Wind turbine captures the kinetic energy of wind flow through rotor blades and transfers the energy to the induction generator through the gearbox. The generator shaft is driven by the wind turbine to generate electric power. Wind turbines may have horizontal axis or vertical axis configuration. The average commercial turbine size is 300 kW. Micro-hydropower system uses the energy of flowing water to produce mechanical or electrical energy. This energy generation system depends on the topography and annual precipitation of the area.

![Micro Hydropower System](image3)

The system suffers from large variation of water flow due to uneven rainfall and results in a variation in generation. Run-of-river system is often used in micro-hydropower systems which do not require large storage reservoir. A portion of the river water is diverted to a water-conveyance channel to rotate a turbine or a water wheel that spins a shaft. The motion of the shaft can be used for mechanical power such as pumping water or can be used to power a generator to generate electricity.

**Energy Storage:**

One of the main criteria of successful operation of microgrid is the inclusion of energy storage devices, which balances the short-term power and energy demand with...
Generally the microgrid power systems have storage through the generator inertia. When a new load comes online, it can result in a slight change in system frequency depending on its size. Storage devices are very important to balance the power following system disturbance and/or significant load changes. In the case of sudden system changes, these devices can act as an AC voltage source. Because of their physical limitations, they have limited energy storage capacity. The backup energy storage devices should be included in microgrid systems to ensure uninterrupted power supply. Suitable storage devices for microgrid systems include batteries, flywheels and supercapacitors.

**Control System:**

The users of the community being served and the sources are connected to a centralized control system using a Local Area Network. This enables a centralized monitoring of each and every user’s activity and also the sources. At the user end smart meter enables monitoring the usage whereas the sources are monitored using sensors like temperature, pressure and others as per the requirement along with the smart meters. Standard usage monitoring and scheduling up to some extent are provided at the user end using LCD displays and keys to enhance the experience, and also leads to tracking the usage.

**III. IMPLEMENTATION OF MICROGRID**

The microgrid is implemented using 3 sources solar, wind and grid where the grid supply is used as a backup to the other sources. The control system is implemented using the Arduino open source device. Where each sources and users are monitored using smart meters, whose data like voltage, current, units consumed are retrieved by the Arduino device and are fed to a computer. The controller has a software panel by which he can control and monitor the sources.

The software is implemented using JAVA. Statistics like variations in power, energy usage etc can be obtained from the software.

Arduino communicates with the meters using the standard RS-232 protocol with the Modbus one. Where the device acts as the master and the meters act as slaves.

A computer collects the data from the hardware and stores in a database for future references. Controlling of user usage is also done by the computer. The computer acts as a server to the Local Area Network to which each user access as per the requirement. Fig.2 & Fig.3 are the screenshots of the developed applications.
IV. ADVANTAGES

In a microgrid system the sources and loads are situated at a close proximity so long distance transmission lines are not required unlike in the centralized grid systems. This exclusion gives prevention to the losses those occurs in the long running transmission lines and are accounted up to 20%.

One of the key advantages to the microgrid approach is that it allows local users to make smarter choices regarding their use of power, turning them empowered consumers in a flexible energy economy.

Recovered waste heat could also cool and dehumidify buildings, using thermally activated processes. This is doubly advantageous. Cooling buildings places tremendous strain on the power grid, and if a microgrid shares some of this load, it will help both the microgrid customer and everyone using the larger grid.

A major advantage of a Microgrid is its ability, during a utility grid disturbance, to separate and isolate itself from the utility seamlessly with little or no disruption to the loads within the Microgrid.

In peak load periods it prevents utility grid failure by reducing the load on the grid.

Significant environmental benefits made possible by the use of low or zero emission generators.

V. PROBLEMS & CONSTRAINTS

The set up cost for the microgrids are huge currently as the energy sources fetches large amount. But after a complete setup the grid supplies power to the customers at no cost except the maintenance as mostly renewable sources are used with the microgrids.

VI. CONCLUSION

Market-linked microgrids provide customers options that can help drive down costs and risks. The traditional electric customer is often a price-taker at the mercy of the utility’s pricing structure. Customer investment in efficiency and distributed resources like solar PV provide the customer with some power, but the microgrid represents the ability to completely flip the script. The microgrid puts power in the hands of the customer and opens up choices for how to manage energy risks and optimize costs.

References:

Effect of wind speed on daily yield of a Solar still operated at indoor and outdoor conditions

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Abstract - The effect of wind speed on the daily productivity of a solar still operated at indoor and outdoor conditions is studied. Numerical calculations have been carried out on different days in a year in order to see the effect of speed of wind for same masses of basin water \( m_w \) for the basin type still. It is found that for the basin type still, Productivity increases with the increase of wind speed up to a critical velocity \( V_c \) beyond which the increase in Productivity becomes insignificant for both the Indoor and Outdoor conditions.

Keywords: Solar energy; passive cooling; Wind speed; Productivity.

I. INTRODUCTION

One major problem for the whole world and, in particular, in the third world is the availability of pure clean and healthy water especially in remote areas. Desalination systems using solar energy have been used in many countries to produce fresh water. The working of solar distillation units has been broadly classified into active and passive modes of operation. It is reported that the overall thermal efficiency of a passive distiller is higher than of an active one due to the lower operating temperature range [1]. Several researchers [2, 3, 4, 5] have investigated the effects of climatic, operational and design parameters on the performance of single, double and multi-effect active and passive solar stills. It has been concluded that the productivity of the solar stills increases with the increase of solar radiation and ambient temperature [6 and7]. However, it should be pointed out that there are conflicting results about the effect of wind speed on solar still productivity. Garg and Mann [6], Cooper [8], Rajvanshi [9], Soliman [10] and Malik and Tran [11] have concluded that the increase in wind speed causes an increase in productivity; while Eibling et al. [7], Hollands [12] and Yeh and Chen [13 and 14] indicated that an increase in wind speed causes a decrease in productivity. It has also been reported by Morse and Read [15] that the wind speed has no significant effect on productivity.

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>( A_c )</td>
<td>collector area,</td>
</tr>
<tr>
<td>( S )</td>
<td>solar radiation absorbed by</td>
</tr>
<tr>
<td>( t_a )</td>
<td>ambient temperature</td>
</tr>
<tr>
<td>( h_{fg} )</td>
<td>latent heat of vaporization</td>
</tr>
<tr>
<td>( P_{ci} )</td>
<td>partial pressure of water vapor at the glass temperature, N/m(^2)</td>
</tr>
<tr>
<td>( P_d )</td>
<td>Yield or productivity</td>
</tr>
</tbody>
</table>

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η_s  
I_g  
I_{sc}  
I_b  
I_d  
C_p  
S  
I(t)  
k  
I_{tb}  
I_{td}  
II. EXPERIMENTAL SET-UP

There is a solar still which is made-up of copper sheet covered insulation, so that there is no flow of heat from still to
outside then minimize the heat loss. The sheet of copper has black painted for increasing the absorbing property of heat of copper metal. In this stil we employed two numbers of U-shape heater, whose longitudinal length was 1.5 feet and heating element capacity 1500 watt each for proper heating of water. The basin type still is closed with the help of glass sheet of thickness 0.005m which is used for condensation of vapour of water at the top of still and this glass have a slope of 11.5º for installation of condensed liquid water into drain of still from where the distilled water out from still. On above the drain we use a sharp edge of glass strip to stop the droplets of condensed water and fall down into the drain. For measuring inner temperature of basin, we employed 14 thermocouples (copper+constanton) mounted on fiber beeding. First 9 thermocouples starting from basin plate are situated 1 cm apart from each other and remaining five thermocouples 2cm apart from each other and last one is 5cm apart from second last one which give the glass inner temperature. For measuring glass outer and ambient temperature we used a thermocouple attached outside sheet, for reading the temperature of thermocouples we used a digital temperature indicator which convert heat signal into electrical signal and display digitally on the screen. This solar still is kept on a iron made stand so that we used space under the still as our requirements and also this stands prevents the heat loss from solar still to the ground. The schematic diagram is shown below in Fig. (a) & the photograph of solar still shown below in Fig. (b). Now the heater removed from the solar still and for heating water, solar energy used at outdoor condition.

III. COMPUTATIONAL PROCEDURES

A. Solar still efficiency (Outdoor-Conditions):

The efficiency of solar still is calculated on the basis of solar heat used for distillation and the incident solar radiation. It is defined as ratio of the two given below:

$$\text{Efficiency of solar still} = \frac{\text{Distillate output (kg/s) \times Latent heat of vaporization of water (J/kg)}}{\text{Solar radiation (W/m}^2\text{) \times Area of basin of still (m}^2\text{).}}$$

B. Solar still efficiency (Indoor-Conditions):

The efficiency of solar still is calculated on the basis of solar heat used for distillation and the incident solar radiation. It is defined as ratio of the two given below:
Efficiency of solar still (\( \eta \))
\[
\eta = \frac{\text{Distillate output (kg/s)} * \text{Latent heat of vaporization of water (J/kg)}}{\text{Solar radiation (W/m}^2\text{)} * \text{Area of basin of still (m}^2\text{)}}.
\]

Since distillate output in ml/h, to convert it into kg/s, Experimental results are shown in Table A

### Table A

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Time</th>
<th>Distillate output</th>
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<th>S = 39 m/s</th>
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<td>34</td>
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<td>5</td>
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</table>

### IV. RESULT AND DISCUSSION

The distillate outputs measured at different times from the start-up period are plotted in Figs. 3.1 & 3.2 for different conditions. There is no output of distillate for nearly 30 to 50 minutes from the start-up period. The effect of cooling rate of the glass cover is shown in Fig. 3.1. The distillate output, at 775 W (constant heat input) of heat input for 3 hours of heating, are 255 ml, 320 ml and 280 ml with natural cooling, wind speed of 36 m/minute and wind speed of 39 m/minute respectively, showing more output at a wind speed of 36 m/minute. This was also happen in the similar fashion for out door operated still. The distillate output for 3 hours of heating, are 165 ml, 185 ml and 160 ml with wind speed of 7 m/minute, wind speed of 8 m/minute and wind speed of 10 m/minute respectively, showing more output at a wind speed of 8 m/minute.

Figures 3.3 to 3.4 show efficiency of the still for different conditions. Higher values of efficiency are achieved at moderate cooling rate of the glass cover. The efficiency of the still after three hours of heating at the wind speeds of natural, 36
m/minute and 39 m/minute, the efficiency becomes 21.17%, 27.57% and 24.19%. This was also happen in the similar fashion for out door operated still. The efficiency of the still after three hours of heating at the wind speeds of 7 m/minute, 8 m/minute and 10 m/minute, the efficiency becomes 12.15%, 12.43% and 11.94%.

On the basis of the results obtained for the various operative conditions of the solar stills, the following conclusions may be drawn: (i) The daily productivities \( P_d \) of the basin type solar stills increase as wind speed increases up to the critical velocity \( V_c \). (ii) After the typical velocity \( V_c \), the change in \( P_d \) becomes insignificant. (iii) The value of \( V_c \) is independent on the still shape, mode of operation (active or passive) and the heat capacity of brine, but it shows some seasonal dependence. \( V_c \) is found to be 36 m/s for indoor and 8 m/s for outdoor conditions respectively. (iv) The results which have been achieved in the present study may be used to explain the conflicting results which are reported in the previous studies [10, 12, 13, 14] about the effect of wind speed on the daily productivity of the solar stills.
REFERENCES


Power Quality Issues in Dispersed Generation

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Abstract - Power quality refers to the degree to which power characteristics align with the ideal sinusoidal voltage & current waveform, with current & voltage in balance. Dispersed generation contributes to the improvement of power quality. In the areas where voltage support is difficult, distributed generation offers sufficient benefits for voltage profile & power factor corrections. Distributed generation could serve as a substitute for investments in transmission & distribution capacity. This paper describes various power quality issues like Voltage fluctuation, Voltage Sag, flicker etc. & their possible solutions. Their application is not limited to present utilities but can also be applicable for future smart grid.

As it can be expected, a great number of small generation units will be connected to distribution grids in quite near future. As due to the rise of harmonics in the grid, the machines would become more vulnerable, their faults become even more difficult to detect, so one could expect a growing number of unexpected downtimes due to different faults of the generators. This is the issue why real time condition monitoring is of utmost importance in the dispersed generation situation.

I. INTRODUCTION

Power quality concerns the electrical interaction between the network and its customers. It consists of two parts: the voltage quality concerns the way in which the supply voltage impacts equipment; the current quality on the other hand concerns the way in which the equipment current impacts the system [1].

Dispersed generation has been recommended as one of the environmentally friendly solutions for improving the energy system, decreasing the losses and increasing effectiveness [2].

Connecting new producers and generators to the distribution network can drastically change the working parameters of the grid. Dispersed units affect the current quality and through the grid also the voltage quality as experienced by other customers [2].

One of the key aspects of electricity production and distribution is the power quality and supply reliability for the customers.

II. DISPERSED GENERATION

Dispersed generation is the production of electricity at or near the point of use. Most or part of consumed energy is produced at point of use and rest of the electricity goes into the distribution grid [1].

The working group of CIGRE [3] devoted to dispersed generation defines dispersed generation as all generation units with a maximum capacity of 50MW to 100MW, that are usually connected to the distribution network and that are neither centrally planned nor dispatched.
The IEEE [4], on the other hand, defines dispersed generation as the generation of electricity by facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system.

In most cases it is assumed that the electrical current and voltage have a sinusoidal wave shape. But if hundreds or thousands of small power production plants are connected to a grid, it could mean that the sinusoidal current and voltage waveforms are distorted and the waveform is no longer sinusoidal. Also, all small generators themselves produce harmonics. So the large-scale use of renewable energy sources for the production of electricity will bring major challenges for the electricity network.

As dispersed generation means also a growing number of small power plants such as small hydro and wind applications, this harmonic problem can become a serious issue for the power quality and supply reliability in smart grid or dispersed generation situation.

III. POWER QUALITY

Connection of dispersed resources and changing dispersed generation to the distribution grid can affect the power quality in a great amount [2].

Power quality can be controlled and improved in whatever point of the electric system beginning from the means in the system or the grid and ending with single devices at the consumer level. Connection of the dispersed generation of renewable energy to distribution grid can have both positive and negative effects to the power quality. It depends on possibilities of information and communication systems to control and maintain voltage in the feeders, turn the loads in or out and replace lost power with the reserves.

IV. HARMONIC DISTORTION DUE TO DIFFERENT LOADS

Electrical devices, which are coming onto market, are becoming more and more complex. They may help to reduce energy consumption, but their performance regarding power quality is still rather improper.

The problem is that their current curve is not a perfect sinusoid. The widespread use of nonlinear loads may implicate significant reactive power and problems with higher harmonics in a grid [5].

Harmonic currents produced by nonlinear loads are injected back into the supply systems. These currents can interact adversely with a wide range of power systems equipment causing additional losses, overheating and overloading. These harmonic currents can also cause interference with telecommunication lines and errors in power metering [6]–[8]. That problem may come more important when smart grid solutions where communication is very important are adapted.

While the applied voltage is almost perfectly sinusoidal, the resulting current is heavily distorted.
Fig. 1. Currents of typical nonlinear loads versus voltage.

Harmonics generated by consumer’s appliances must not cause voltage rise in the connection point [5]. Fixing limits may become important before using numerous harmonics emitting devices together. In some papers [7] measurements with nonlinear loads are done when 5% current’s total harmonic distortion value at connection point is followed. For example most of the common compact fluorescence lamps have the total harmonic distortion over 100% [8].

Harmonic currents injected from individual end users on the system should be limited. These currents propagate toward the supply source through the system impedance, creating voltage distortion. Thus by limiting the amount of injected harmonic currents, the voltage distortion can be limited as well. This is the basic method of controlling the overall distortion levels proposed by IEEE standard 519-1992. Example for illustrating nonlinear loads influence on distribution grid a study with compact fluorescence lamps (CFLs) is made [7],[8].

V. POSSIBLE SOLUTIONS FOR POWER QUALITY

5.1 Increasing Voltage Quality and Grid Capacity by Reactive Power

While the grid capacity and grid voltage quality have primarily been provided by network expansion so far, this project aims to effectively use installations which are distributed in the grids. This is done by the use of distributed measurement technology, intelligent control of power electronics, new information and communication technology and the possibilities of the grid control.

The concept is developed and tested on the example of distributed PV systems. However the use is not restricted to this application. Efficiency generally can be increased by distributed network services. The operational status of the grid has to be measured continuously at connection points of large loads and decentralized generation. Solar inverters are equipped with data acquisition capabilities because they need to synchronize their voltage and frequency to the grid voltage. For load connection points measuring Technology is to be installed.

As shown in Fig. 2 a main computer is networked to a number of data acquisition devices and solar inverters. Data acquisition devices and solar inverters monitor
voltage, current and power flow at their locations in the grid. Data acquisition devices are located at large loads (e.g. industrial plants) and grid nodes.

The reactive power control structure consists of three different controls:

• The first part is the limitation of the grid voltage by reactive power absorption of the inverters. To avoid unnecessary losses only as many inverters as needed have to absorb only as much reactive power as needed to limit the grid voltage. Thus the main computer only activates the inverters with the highest voltage levels in the grid.

• Additionally, voltage fluctuations due to fast load and generation changes e.g. moving clouds can be compensated and smoothed by injecting and absorbing reactive power through the solar inverters.

• The inverters can also be used for local compensation of reactive power required by other loads in order to minimize power losses in the grid.

5.1.1 Reactive power compensation

Reactive power compensation to this date requires additional equipment and associated installation and commissioning costs which should be compensated by greater efficiencies. So far, compensation is mainly used in large industrial plants. Therefore, generating decentralized reactive power for compensation significantly lowers the power losses due to short transmission distances of the reactive power. For generating reactive power short term energy storage is required. This can be done with capacitors or inductors. Voltage source solar inverters usually have capacitors, so the already installed capacity can be used for reactive power. The existing reactive power reserves which are inherently present by the distributed inverters can be used to provide reactive power to the overlaid medium voltage grid or to reduce the reactive power consumption of the low voltage grid to minimize losses.

VI. CONCLUSION

If more and more dispersed generation is going to be installed all over the power networks like it seems to go then it is most important to find measures for guarantying quality and security of supply.

In the situation where generation as well as consumption produces decrease of power quality in the grid, it is essential to analyze both generation and consumption in a very thorough way. If it proves to be necessary it might make sense to limit the usage of new plants and appliances or use some other methods to decrease their negative effect to power quality.

Usage of nonlinear loads like compact fluorescent lamps has risen rapidly in the last decade, but their harmonic emission, reactive power consumption and other drawbacks have been ignored.

Beside the problem that harmonics are extremely dangerous to electrical motors, distorted supply makes the diagnostics of them more difficult. A growing number of machines are driven through frequency converters. This means that also diagnostic for appropriate setups with frequency converters should be investigated. Frequency converters add additional noise and harmonics to the traditional current spectrum of the machines and thus such drives need a slightly different approach in diagnostics than traditional grid supplied machines. Nevertheless, appropriate on-line diagnostics of dispersed generation units must be applied to guarantee sufficient power quality, supply reliability and overall
safety of customers and different facilities connected to the grid.

REFERENCE


Monitoring and Mitigation of Power Quality Issues in Dispersed Generation & Smart Grids

Debasis Tripathy¹, Manoj Pattnaik², Amar Kumar Barik³

Abstract - This paper presents an overview of the smart grid developments, analyzed from a power-quality viewpoint; describes the main relations between integration of dispersed generations to the smart grids and power quality issues. Power-quality monitoring in the smart grid is discussed in detail. Although the smart grid brings many new power-quality challenges, these should not result in unnecessary barriers against the introduction of new technology. One of the most important issues in future grids are the power quality and supply reliability issues. This paper describes how the change to dispersed generation and smart grids should look like and what are the main problems, that need quick and active solutions, so that future grids would be fully functional and reliable.

Key words – Dispersed Generation, Distribution Automation, Harmonics, Power Quality, Power-Quality Monitoring, Smart Grids.

I. INTRODUCTION

With recent developments in power system, the smart grid allows seamless integration of renewable energy sources into the conventional grid. In the ongoing discussions about dispersed generation & smart grids, power quality is an important aspect and should not be neglected. An adequate power quality guarantees the necessary compatibility between all equipment connected to the grid. It is therefore an important issue for the successful and efficient operation of existing as well as future grids.

Electrical Power quality plays an important role in smooth operation of sensitive loads, appliances & sophisticated plant processes. Most of the manufacturing industries face difficulty due to the distortion of the power supply which results to both manufacturing & production losses. Because all kinds of transducers, PLC apparatuses and automatic production processor based on computers are sensitive to small distortion of supply voltage. More attention has been given in the power quality problems [1]. Since power quality distortion has harmful effects on the electric power system, and everyone is concern about quality of products & services as those are paid for. Hence there is a need to monitor the power quality disturbances by proper instrument for accurate detection and localization so as to take proper preventive measures to assure qualitative power to the consumers.

If centralized generation is characterizing factor for nowadays energy systems, then smart grids of the future mean also the spreading of dispersed generation. The cause of these changes is the strict environmental norms and liberalization of electricity markets [2].

Dispersed generation has been recommended as one of the environmentally friendly solutions for improving the energy system, decreasing the losses and increasing effectiveness [3]. In addition increasing the ratio of small producers in electricity generation has been proposed.

Connecting new producers and generators to the distribution network can drastically change the working parameters of the grid. This situation is extremely important when the new connected power plant is equal to or even greater than the load in this particular area. In such case the new power plant affects the voltage adjustment and power flux. It is important to evaluate the existing grid, capacity and loads in this certain area of the distribution network [3].

Dispersed units affect the current quality and through the grid also the voltage quality as experienced by other customers [3]. Power quality concerns the electrical interaction between the network and its customers. It consists of two parts: the voltage quality concerns the way in which the supply voltage impacts equipment; the current quality on the other hand concerns the way in which the equipment current impacts the system [4].

For these reasons it is important changing of the loads have to be observed in smart grids as well as the growth of dispersed generation. In addition loads are getting more and more nonlinear which means that the cooperation of untraditional generation and loads affect the grid in unpredictable ways.

One of the key aspects of electricity production and distribution is the power quality and supply reliability for the customers. Traditionally the problems have been solved but as the world is moving towards smart grids and dispersed generation, those problems need more active and precise control.

As it can be expected, a great number of small generation units will be connected to distribution grids in quite near future. Most probably it would require certain online diagnostic systems to secure the full functionality and reliability of those units.

As due to the rise of harmonics in the grid, the machines would become more vulnerable, their faults become even

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more difficult to detect, so one could expect a growing number of unexpected downtimes due to different faults of the generators. This is the issue why real time condition monitoring is of utmost importance in the dispersed generation situation.

II. DISPERSED GENERATION

Dispersed generation is the production of electricity at or near the point of use. Most or part of consumed energy is produced at point of use and rest of the electricity goes into the distribution grid [5].

In most cases it is assumed that the electrical current and voltage have a sinusoidal wave shape. But if hundreds or thousands of small power production plants are connected to a grid, it could mean that the sinusoidal current and voltage waveform are distorted and the waveform is no longer sinusoidal. Also, all small generators themselves produce harmonics. So the large-scale use of renewable energy sources for the production of electricity will bring major challenges for the electricity network.

Generators are typical electrical devices that are usually setup together with frequency converters to drive them and different inverters to synchronize their work with the grid. Not only generators themselves but also frequency converters and other electronic devices produce a vast number of harmonics that can be a problem to electrical machines they are set up with and also the grid they are working in. Due to financial benefits usually no additional filters are used to lessen the amount of induced harmonics. A typical harmonic distortion of a frequency converter is shown on figure 1.

As dispersed generation means also a growing number of small power plants such as small hydro and wind applications along with renewable energy resource plants as shown in figure 2, this harmonic problem can become a serious issue for the power quality and supply reliability in smart grid or dispersed generation situation.

![Figure 1. Typical harmonic distortion of frequency converter.](image)

For showing the probability of large extent of distributed generation in near future the potential is pointed out.

III. SMART GRIDS

Smart Grid technologies are advanced electrical net-works that support new generation interactive energy and communication services for the final customer. The electrical networks must be live, available, interconnected and coupled with real-time communications [6]. Smart grid technologies are the vision of the future delivering various benefits to society in order to accomplish sustainable energy development.

The main advantage of smart grid implementation in terms of utility benefits include reduced perturbations and outages; minimal power losses and blackout prospects; lower maintenance and operational cost; lower greenhouse gas emissions; increased energy efficiency; increased large scale renewable energy and distributed generation integration; enabled micro-grid applications and Energy Management Systems (EMS); environmental benefits and economic growth through clean power markets. Similarly, the advantages of smart grid implementation in terms of customer benefits include enabled electricity consumption, enabled consumer services through distributed generation and cost savings through EMS. These benefits have a positive impact on society stimulating improvement in new power system networks as well as encouraging multiple engineers from pursuing research developments in smart grid technologies.

Smart grid technologies offer numerous characteristics to improve this state such as power quality enhancement, self healing, generation sources, optimization of asset utilization and empowerment of users[6]. Figure 3, illustrates the architecture of an integrated smart grid communications platform

IV. POWER QUALITY

Power quality disturbance is a general term used to designate a number of electromagnetic phenomena that cause voltage supply to deviate from its constant magnitude and frequency of ideal sinusoidal wave shape.

Two main groups of power quality disturbances can be defined: stationary (or quasi-stationary) and transient disturbances. Harmonic and interharmonic distortion, voltage fluctuation, voltage flicker and voltage unbalance make up the first group, whereas voltage transients, voltage dips, voltage swells, short interruptions in voltage supply and other high-frequency disturbances constitute the latter group. Categories and Characteristics of Electromagnetic Phenomena responsible for Power Quality disturbances are given in Table-1.

Connection of dispersed resources and changing dispersed generation to the distribution grid can affect the power quality in a great amount [7]. Smart distribution grid must secure the end users with power that has the demanded quality [8-10]. This is why the modern control systems, that are monitoring the important components of the distribution grid, must react precisely to the changes in power quality.

Power quality can be controlled and improved in whatever point of the electric system beginning from the means in the system or the grid and ending with single devices at the consumer level.

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Figure 2. Dispersed Generation integrated to Smart Grid

Figure 3. Architecture of integrated smart grid communications platform
Connection of the dispersed generation of renewable energy to distribution grid can have both positive and negative effects to the power quality. It depends on possibilities of information and communication systems to control and maintain voltage in the feeders, turn the loads in or out and replace lost power with the reserves.

For example small amounts of wind power have negligible effects on electricity networks, but when electricity generation from wind power exceeds a certain threshold level, investments in the power system will be required. This threshold level is known as the hosting capacity [5].

The principle of hosting capacity is explained at Figure 4. Hosting capacity does not say anything about how much generation from renewable energy sources that is connected to the grid, only how much can be connected without having to invest in measures to strengthen the grid.

![Figure 4. The principle underlining hosting capacity.](image)

### V. POWER-QUALITY ISSUES

#### 5.1 Emission by new devices

When smart grids are introduced, we expect growth both in production at lower voltage levels (distributed generation) and in new types of consumption (for example, charging stations for electric vehicles, expanded high-speed railways, etc.). Some of these new types of consumption will emit power-quality disturbances, for example harmonic emission. Preliminary studies have shown that harmonic emission due to distributed generation is rather limited. Most existing end-user equipment (computer, television, lamps, etc) emit almost exclusively at the lower odd integer harmonics (4, 10, 13 etc), but there are indications that modern devices including certain types of distributed generators emit a broadband spectrum [11,12,13]. Using the standard methods of grouping into harmonic and interharmonic groups and subgroups below 2 kHz will result in high levels for even harmonics and interharmonics. For frequencies above 2 kHz high levels have been observed for the 200-Hz groups. An example is shown in Fig. 3: the spectrum of the emission by a group of three full power converter wind turbines, where 1 A is about 1% of the emission is low over the whole spectrum, being at most 0.5% of the nominal current. The combination of a number of discrete components at the characteristic harmonics (10-14) together with a broadband spectrum over a wide frequency range, is also being emitted by other equipment like energy-efficient drives, microgenerators, and photo-voltaic installations. The levels are not always as low as for the example shown here. The existing compatibility levels are very low for some frequencies, as low as 0.2%.

Harmonic resonances are more common at these higher frequencies so that any reference impedance for linking emission limits to compatibility levels should be set rather high. Keeping strict to existing compatibility limits and existing methods of setting emission limits could put excessive demands on new equipment.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Categories</th>
<th>Typical spectral content</th>
<th>Typical duration</th>
<th>Typical Voltage magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Transients</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>Impulsive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>Oscillatory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>Short-duration variations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Instantaneous</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2</td>
<td>Momentary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.3</td>
<td>Temporary</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No.</th>
<th>Interruption, sustained</th>
<th>&gt;1 min</th>
<th>0.0 pu</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Interruption, sustainable</td>
<td>&gt;1 min</td>
<td>0.8–0.9 pu</td>
</tr>
<tr>
<td>3.2</td>
<td>Undervoltages</td>
<td>&gt;1 min</td>
<td>1.1–1.2 pu</td>
</tr>
<tr>
<td>3.3</td>
<td>Overvoltages</td>
<td>&gt;1 min</td>
<td>0.5–2%</td>
</tr>
<tr>
<td>4.0</td>
<td>Voltage unbalance</td>
<td>Steady state</td>
<td>0–0.1%</td>
</tr>
<tr>
<td>4.1</td>
<td>Waveshape distortion</td>
<td>Steady state</td>
<td>0–20%</td>
</tr>
<tr>
<td>4.2</td>
<td>Interharmonics</td>
<td>Steady state</td>
<td>0–2%</td>
</tr>
<tr>
<td>4.3</td>
<td>Notching</td>
<td>Steady state</td>
<td></td>
</tr>
<tr>
<td>4.4</td>
<td>Noise</td>
<td>Broadband</td>
<td>Steady state</td>
</tr>
<tr>
<td>6.0</td>
<td>Voltage fluctuations</td>
<td>Steady state</td>
<td>0–1%</td>
</tr>
<tr>
<td>7.0</td>
<td>Power frequency variations</td>
<td>&lt;10 s</td>
<td></td>
</tr>
</tbody>
</table>

The measurement of these low levels of harmonics at higher frequencies will be more difficult than for the existing situation with higher levels and lower frequencies. This might require the development of new measurement techniques including a closer look at the frequency response of existing instrument transformers.

The presence of emission at higher frequencies than before also calls for better insight in the source impedance at these frequencies: at the point of connection with the grid as well as at the terminals of the emitting equipment.

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5.2 Interference between devices and powerline-communication

Smart grids will depend to a large extent on the ability to communicate between devices, customers, distributed generators, and the grid operator. Many types of communication channels are possible. Power-line communication might seem an obvious choice due to its easy availability, but choosing power-line communication could introduce new disturbances in the power system, resulting in a further reduction in power quality. Depending on the frequency chosen for powerline communication, it may also result in radiated disturbances, possibly interfering with radio broadcasting and communication.

It is also true that modern devices can interfere with powerline-communication, either by creating a high disturbance level at the frequency chosen for power-line communication, or by creating a low-impedance path, effectively shorting out the power-line communication signal. The latter seems to be the primary challenge to power-line communication today [11].

So far, there have been no reports of widespread interference with sensitive equipment caused by powerline-communication, but its increased use calls for a detailed study.

5.3 Allocation of Emission Limits

When connecting a new customer to the power system, an assessment is typically made of the amount of emission that would be acceptable from this customer without resulting in unacceptable levels of voltage disturbance for other customers. For each new customer a so-called emission limit is allocated. The total amount of acceptable voltage distortion is divided over all existing and future customers. This assumes however that it is known how many customers will be connected in the future [17].

With smart grids, the amount of consumption will have no limit provided it is matched by a similar growth in production. This continued growth in both production and consumption could lead to the harmonic voltage distortion becoming unacceptably high. Also the number of switching actions will keep on increasing and might reach unacceptable values. One may say that production and consumption are in balance at the power-system frequency, but not at harmonic frequencies.

Another way of looking at this is that the system strength is no longer determined by the maximum amount of consumption and/or production connected downstream, but by the total amount of harmonic emission coming from downstream equipment. This will require a different way of planning the distribution network.

5.4 Improving Voltage Quality

One aim of smart grids is to improve the performance of the power system (or to prevent deterioration) without the need for large investments in lines, cables, transformers, etc.

From a customer viewpoint, the improvements can be in terms of reliability, voltage quality or price. All other improvements (e.g. in loading of cables or transformers, protection coordination, operational security, efficiency) are secondary to the customer.

These networks should therefore be addressed first. The same balance between “production” and “consumption” can in theory also be used for the control of harmonic voltages. When the harmonic voltage becomes too large, either an emitting source could be turned off, or a harmonic filter could be turned on, or a device could be turned on that emits in opposite phase (the difference between these solutions is actually not always easy to see). Smart grid communication and control techniques, similar to those used to balance consumption and production (including market rules), could be set up to reduce harmonic emissions. This could be a solution for the growing harmonic emission with growing amounts of production and consumption.

Microgrids with islanding capability can, in theory, mitigate voltage dips by going very quickly from gridconnected operation to island operation. The presence of generator units close to the loads allows the use of these units in maintaining the voltage during a fault in the grid.

5.5 Immunity of devices

Simultaneous tripping of many distributed generators due to a voltage-quality disturbance develops a voltage swag. As a smart grid attempts to maintain a balance between production and consumption, mass tripping of consumption could have similar adverse consequences. This should be further investigated.

5.6 Weakening of the transmission grid

The increased use of distributed generation and of large wind parks will result in a reduction of the amount of conventional generation connected to the transmission system. The fault level will consequently be reduced, and power-quality disturbances will spread further. This will worsen voltage dips, fast voltage fluctuations (flicker) and harmonics. The severity of this has been studied for voltage dips. The conclusion from the study is that even with 20% wind power there is no significant increase in the number of voltage dips due to faults in the transmission system [17].

VI. POWER QUALITY MONITORING

Growing service quality expectations and reduced possibilities for grid enforcements make advanced distribution automation (ADA) an increasingly necessary development for network operators and the next large step in the evolution of the power systems to smart grids.

The management of the distribution system is mainly based on the information collected from the power flows by an integrated monitoring system. This enables realtime monitoring of grid conditions for the power system operators. It also enables automatic reconfiguration of the network to optimize the power delivery efficiency and to reduce the extent and duration of interruptions. The basic part of the monitoring system infrastructure is based on sensors, transducers, intelligent electronic devices (IED) and (revenue) meters collecting information throughout the distribution system.
A number of network operators have already proposed that the smart grid of the future should include:

- Network monitoring to improve reliability,
- Equipment monitoring to improve maintenance,
- Product (power) monitoring to improve PQ.

In order to achieve these goals, the actual distribution system infrastructure (especially meters and remotely controlled IEDs) should be used to gather as much information as possible related to network, equipment and product (i.e., power quality and reliability) to improve the distribution system overall performance. Among the most important ADA operating systems, that a smart grid will include, it can be mentioned:

- Voltage & VAR control (VVC),
- Fault location (FL),
- Network reconfiguration or self-healing,
- Network operators with an ambitious energy efficiency program have focused on two targets:
  - Capacitor banks installation,
  - Voltage control.

There is also another important goal: to reduce the duration of interruptions. The VVC system requires a permanent monitoring of the voltage magnitude (averaged over 1 to 5 min) at the end of the distribution feeder and the installation of switched capacitor banks. Besides that, the monitoring allows the detection of power quality disturbances such as long duration under voltages and over voltages, and voltage and current unbalance.

Basically, the voltage regulation system at the substation is replaced with an intelligent system that uses network measurements to maintain a voltage magnitude for all customers within the acceptable upper and lower limits. The VVC system also analyzes the reactive-power requirements of the network and orders the switching of capacitor banks when required.

An important goal is to prevent potential power quality problems due to the switching operations of capacitor banks (with rating up to 1.2 Mvar). [18]

Another goal was to evaluate the joint impact of the VVC system and voltage dips occurring on the grid. The results of the study indicate that the impact can be quantified by two effects:

- Increasing number of shallow voltage dips is expected.
  - Voltage reduction from 2 to 4% is obtained due to VVC system. Added to this is the voltage drop due to the fault: drops of 6 to 10% (not counted as dips) become drops of 10 to 12% (which are counted as dips).
- Equipment malfunctioning or tripping: the joint contribution of the VVC system and the disturbance brings the residual voltage level below a critical threshold, around 70% of the nominal voltage for many devices.

Fault location is based either on a voltage drop fault location technique that uses waveforms from distributed power quality measurements along the feeder or on a fault current technique based on the measurement of the fault current at the substation. The average error in locating the fault with the first technique was less than 2%, in terms of the average main feeder length. An accurate fault-location technique results in a significant reduction in the duration of (especially) the longer interruptions. The information collected by the fault-location system can also be used for calculating dip related statistics and help to better understand the grid behaviour [19].

The third application, network reconfiguration or self-healing, is based either on local intelligence (belonging to major distribution equipment controllers) or on decisions taken at the power system control centre, which remotely controls and operates the equipment used for network reconfiguration (reclosers and switches).

The impact of these applications on the distribution network and its customers is permanently evaluated. The infrastructure belonging to ADA systems can be shared by a power-quality monitoring system capable of real-time monitoring. Depending on the type of ADA application or system, the monitoring can be done either at low-voltage or at medium-voltage level. In the first case monitoring devices may belong to an Advanced Metering Infrastructure (AMI) and in the second case they may belong to the distribution major equipment itself (i.e., controllers) (see Fig. 5) [20].

The smart grid will allow a continuous power-quality monitoring that will not improve directly the voltage quality but will detect quality problems helping to mitigate them.

**VII. POSSIBLE SOLUTIONS FOR POWER QUALITY FALL IN SMART GRID**

Equipment responds very differently to harmonic distortions, depending on their method of operation. For example, incandescent lights and different household heaters are not affected by them. On the other hand, induction motor windings are over-heated by harmonics, causing accelerated degradation of insulation and so the lifetime of the machine can shorten in an abrupt way. The problem is that harmonic voltages can give correspondingly higher currents than do 50 Hz voltages and one can easily underestimate the degree of additional heating in the motor [20].

It is a widely known fact that faults such as the broken rotor bars induce sideband harmonic components to the stator...
current spectrum of the induction machine. Those harmonics can be used for detecting the faults. As most of electrical machines today are used in hand with frequency converters, then those converters add additional variables to the problem. Frequency converter causes supply frequency to vary slightly in time and, as a result, some additional harmonics in the current spectrum are induced and sidebands are reduced or even hindered. This phenomenon also raises the amount of noise in the test signals, which makes the faults more difficult to detect.

In that sense it could prove to be useful to use a certain online diagnostic system in the grids with dispersed generation and the wind generators that are integrated to this system. This could be a helpful tool to detect the faults at an early stage where the repairing of the machines is still possible and reasonable. Also it would help to differentiate the deviations and harmonic distortions in the grid from the faulty cases of the machines.

VIII. CONCLUSION

The new technology associated with smart grids & integration of dispersed generation, offers the opportunity to improve the quality and reliability as experience by the customers. However it also results in the increase of disturbance levels in several cases and thereby introduces a number of new challenges, which should not be used as arguments against the development of smart grids; rather we should develop appropriate monitoring & mitigation techniques [14] for power quality.

Irrespective of how the term smart grid is defined, one can safely state that electricity networks will face new challenges in the future, and that current and future challenges can be solved by a set of technologies that either exist today, or are being actively developed. If more and more dispersed generation is going to be installed all over the power networks like it seems to go then it is most important to find measures for power quality and security of supply.

In the situation where generation as well as consumption produces decrease of power quality in the grid, it is essential to analyze both generation and consumption in a very thorough way. If it proves to be necessary it might make sense to limit the usage of new plants and appliances or use some other methods to decrease their negative effect to power quality. Nevertheless, appropriate on-line diagnostics of dispersed generation units must be applied to guarantee sufficient power quality, supply reliability and overall safety of customers and different.

However they should attract attention to the importance of power quality for the successful and reliable operation of smart grids. New developments need new approaches and perspectives from all parties involved (network operators, equipment manufacturers, customers, regulators, standardization bodies, and researchers).

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The significance of the article is to evaluate and table the findings of my energy audit. It has been the responsibility of every electrical energy user to fix his PF nearer to unity. In the interest of those who are non technical, please be known that the PF in electrical terms is very much similar to blood pressure of a human being. Just as the deviation from the normal range is dangerous, so is the case of PF in the electrical system. A low PF or a Very high (leading) PF will cause heavy loss; in case of the human system it is the life loss.

To bring on table the energy scenario, let us consider the energy consumption pattern. While every urbanite blames the high power consumption by the agricultural sector for the huge power loss, it is more important to look at the facts and figures before we consider the main cause for power loss and the possible scope for savings. The fact that, the power consumed by industry sector, accounts for 50.7% against the 3.5% of agricultural sector has been neglected by and large but the fact is that the huge power loss exists in this sector is very much a fact. This is mainly due to the length of the transmission cable laid for the agricultural sector. If the industry sector is by & large educated the agricultural sector is largely uneducated. In both the cases we have the problem of power factor. The industry is not much concerned because the energy use pattern is unpredictable and or is advised by unskilled electrical contractors. The agriculturists are not to be blamed at all for the fact that they know not about Power Factor & its purpose, more important they get the power for free almost. Hence the point of concern is for those who wish to save on distribution loss either within or outside. The power factor parameter has been discussed widely by eminent technicians and everyone has a point to support their views.

Let me put my experience w.r.t. to the power factor, on the energy conservation/saving drive. It has been widely discussed that the improvement in power factor does not reduce active power or the units consumed. This statement is true at some point and false at the other. Let me discuss with few case studies, below. First, all the technocrats know the power is combination of Active power, Reactive power and Apparent power. And the Power Factor is related to all the three powers in the system. Secondly, what is it that constitutes the system? It is the device (motor, resistance heating coil or illuminating device etc.,) alone or it is in addition to the cable which interlinks the device and the power source, contactors, relays, measuring devices etc., and any other device which forms the part of the system as required on site. If you consider the power drawn by the device alone then the impact of power drawn by it certainly is independent of power factor. Is it just the device alone that constitutes the system? Can this device work without the other integral components? Certainly not, it is the cable conductor, contactors and all other devices that constitute the system which drives the key
device. Hence the total power drawn should be the power drawn by the complete system. Every piece of the system constitutes to active power drawn. In this context importance of the power factor is highly relevant and should be a key parameter when the power loss is accounted for.

Let us consider a case. The unit under discussion manufactures automobile components with good number of CNC machines and has a contract demand of 1300 KVA. The average power factor that was possible with APFC system was 0.87. The unit installed new APFC system and connected large sized capacitors and still the power factor showed no improvement (?). Our energy audit showed that the operating method of the unit was much below the manufacturers assumed loading on the machines. In fact the load on the motors was never felt by it because there was no major change in no-load and on-load power. The other findings were that the current in the cable was too high when compared to the active power. The table below gives the current drawn at different timings and the actual active power with power factor readings.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Cell details</th>
<th>Cable used Al in Sqmm</th>
<th>Resistance per KM</th>
<th>Time of Reading</th>
<th>KW</th>
<th>KVAR</th>
<th>KVA</th>
<th>PF</th>
<th>Voltage</th>
<th>Current</th>
<th>Voltage Harmonics</th>
<th>Current Harmonics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>400</td>
<td>0.086</td>
<td>12:00</td>
<td>38.82</td>
<td>78.82</td>
<td>88.00</td>
<td>0.45</td>
<td>414.00</td>
<td>115.00</td>
<td>0.80</td>
<td>2.70</td>
</tr>
<tr>
<td>2</td>
<td>UU</td>
<td></td>
<td></td>
<td>13:55</td>
<td>34.72</td>
<td>77.00</td>
<td>89.00</td>
<td>0.46</td>
<td>415.67</td>
<td>106.30</td>
<td>0.80</td>
<td>4.30</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>14:40</td>
<td>37.20</td>
<td>66.80</td>
<td>78.00</td>
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<td>418.00</td>
<td>105.70</td>
<td>1.60</td>
<td>5.80</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>36.91</td>
<td>67.54</td>
<td>78.00</td>
<td>0.48</td>
<td>415.67</td>
<td>106.30</td>
<td>1.03</td>
<td>4.27</td>
</tr>
</tbody>
</table>

* These readings are during lunch break, the machines are running idle.

The power factor improvement was taken up and the following readings were recorded. The pre & post power factor correction exercise showed that current in cable dropped substantially (as predicted), it was also found that the current harmonics increased five times.
The current reduction was also associated with the KWs (active power) reduction. The fact that the same job work was operated, before and after correction, a 10% plus, reduction in active power was seen. This was mainly attributed to the system loss. As it is seen from the table 1 above the cable resistance and the current flow in the cable was measured to arrive at the cable & accessories loss.

The loss due to accessories is reflecting beyond acceptance. However it is the reading on site and has to be accepted the way it occurs. The point of discussion is just that the impact of Power Factor on the working system as a whole. Extending the discussion further to the total energy consumption scenario the total energy savings by virtue of power factor consideration alone works out to be 5% of the total energy consumed in the industry sector and .35% in agricultural sector. The fact that the agricultural sector is spread over vast area the actual energy loss is much more than 0.35%. If we can generalize the energy loss in the agricultural sector is nearer if not less than industry sector.
Inference: it is to be considered by the large scale industries and the utilities and ascertain the actual loss rather than generalize the loss only on agricultural sector.

CONCLUSION

i. It is now very prominent that the improvement in the power factor helps reduce power consumption both in terms of units and the contract demand.

ii. The relation of power factor with active power drawn by the device should be extended to the system as whole and not the device alone.

iii. The current in the cable reduced inversely.

iv. The cable temperature was also less.

v. The loss due to drop in temperature will further add to our benefits.

vi. The voltage level across the terminals improved marginally.

vii. The impact of surge loads is not felt by the smaller motors/machines.

The other tangible benefits are:

i. Under the given cable size available on the site, more machines can be loaded, which implies reduced infrastructure cost.

ii. The power consumption is reduced by around 10% which otherwise would have been lost as $I^2R$ losses.

iii. The other benefits of PF correction will also prevail over the entire industrial establishment.

PRECAUTION

The point of concern or a critical factor is the RYB polarity that the industry has to follow. If the polarity is not followed then the result is that the PF would reduce and not increase in spite of any of the value connected in the network.

The sequencing of Capacitors is equally important when the connections are being made. The centre lead should always be connected to the Yellow phase when RYB polarity is maintained within the industry.

EXTENSION

The logic when extended to the utilities that are instrumental in power distribution will find that their losses can be substantially reduced. Considering the length of the distribution network the utility can achieve their distribution loss cutting in the first instance alone over 10%.

FURTHER STUDY

The impact of current harmonics on the system has now to be carried out in depth and rectification measures implemented accordingly.
Abstract - The concept of smart grid started with the idea of advanced metering infrastructure (AMI) and its initial goal was improving the demand side management, energy efficiency and developing a self healing electrical grid to improve the power system reliability. Smart grid also called as future grid or intelligent grid. It uses two way flow of electricity and information to create automated and distributed advanced energy delivery network. It changes the power flow and recovers the power delivery service. It is also two way cyber secure communication technologies and computational intelligence in an integrated fashion across electricity generation, transmission, substation, distribution and consumption to achieve a system sustainable. There are also ways to improve protection as well as security and privacy issues in the smart grid. Cyber security is critical issue due to increasing potential of cyber attacks. Organisations are working on the development of security and protection of smart grid. It is used to provide secure authentication and authorization and smartly protecting the grid is key feature in this paper.

I. INTRODUCTION

Smart grid is a method to decrease dependency on energy sources, reduce emission of global warming components and create a reliable sources of electricity. It is two way flow as grid as in smart grid, electricity can also be put back into grid by user. For example So, it is necessary to provide security and protection. Security means the cyber attacks and protection from transient. Internet based IPV4 and IPV6 developed many years will provide cost effective transport. One way is by SCADA i.e. Supervisory control and data acquisition solution. Which have various capabilities and securities and other one is transient environment of smart grid. The lighting will continue to produce direct and coupled transient that propagate in conductor until it grounded by surge devices. This paper shows the overall protection of smart grid.[1][6]

II. SMART GRID TECHNOLOGY

Smart grid can be regarded as an electric system that uses two way cyber secure communication technologies and large wind turbines and photovoltaic arrays. It will also require higher degrees of network which connected to new features. Cyber security is critical is critical issue it can lead to user errors, equipment failure and natural disaster. Its aim is to improving demand side management and energy efficiency and constructing self healing reliable grid protection. Reducing oil consumption, reducing greenhouse gas, accommodating[7] distributed power sources, automatic maintenance and operation and increasing consumer choice.
Many organisation uses the wind turbine and photovoltaic technology together as hybrid. Which utilized by individual organisation or residential consumer and connect to smart grid. As in fig(1).

Fig:1. Smart grid conceptual model.

1). Security Requirement and Solution.

Smart grid has structural security vulnerability in power transmission networks. The cascade based attack vulnerabilities in power grid have been founded. Attack way is from cyber which cause traditional topological metrics and other power operation failure. The US central intelligence agency says criminals have hacked into the computer system of utility companies, cutting the power to several internal cities [1]. Among various standards bodies the security of grid depend on authentication, authorization and privacy technology. Federal information processing standard (FIPS) approved, Advanced encryption standard (AES) and Triple data encryption algorithm (3DES) solution, offering strong security and high performance. Specific example given as National Institute of Standards and Technology [2] (NIST) which has number of programs has determined. 3DES solution become insures in 2030. AES preferred solution for new components. These technology are sort of management.

2). Smart Grid Transient Environment.

With numerous large and small wind turbines and photovoltaic solar arrays networked to the Smart Grid, significant amounts of conductors will be utilized to connect the network as in fig(2). It is planned that these conductors will have lower impedances, which will allow electricity to flow with lower losses. However, lower loss conductors will result in higher frequencies, such as those associated with electrical transients, to propagate further through the electrical distribution network. Lightning surges coupled onto electrical systems at the facility level shows surge currents can have varying amplitudes and durations. Calculations based on lightning rise times, break over voltages (dielectric withstand) of distribution equipment, and impedance of the earthing system show that lightning currents could exceed 120 kA fig(3)[4]. Most transients coupled on the electrical distribution system will have less energy content, but the magnitudes of lightning-induced transients will be sufficient to damage most electronic equipment. While switching transients are more common than lightning-induced transients, the data on switching transient is limited. The complexities of switching transients make predicting amplitude, frequency and duration difficult. Switching transients are determined by the characteristic parameters of the electrical system: inductance, capacitance, resistance, and conductance. In general, switching transients have a voltage that is less than two times the nominal system voltage, e.g. 480 V on a 240 V system. With more equipment located in the environment and connected to the SMART Grid, there is a greater chance that lightning-induced transients will be coupled onto the
SMART Grid. Equipment connected in close proximity of the induced transient has a higher probability of being subjected to higher amplitudes. In the SMART Grid, equipment that is normally connected deep inside a building or residence can now have direct exposure to the full energy capability of a lightning or switching transient.

![Smart Grid Diagram](image1)

**Fig. 2 Smart Grid**

![Lightning Induced Amplitudes](image2)

**Fig. 3. Lightning induced amplitudes.[3].**

a). Applying SPDs (surge protective device) to the Smart Grid.

Facilities that contribute to the supply of electricity to the Smart Grid have two service entrance locations: primary power source and alternate power source (Figure 4). Primary power is supplied from the utility. Alternate power is supplied from on-site resources (e.g., wind turbine, photovoltaic solar array, etc). Facilities with dual source power capabilities require an automatic transfer switch (ATS) device to ensure coordination of both sources. As shown in Figure 4, the system loads of the facility can be powered by the primary source (utility) or the alternate source (e.g., wind turbine, photovoltaic solar array, etc). The ATS also allows for the alternate power source to be networked into the SMART Grid. Providing surge protective devices (SPDs) has become a “best engineering practice” for protecting equipment and processes from transients. Intercepting transients at the incoming point of a facility has shown to be the best method of protection [4]. This requires the placement of SPDs at the electrical service entrance of a facility. Once the transient has been significantly reduced at the service entrance, additional protection is required at distribution panels and at the point of use [4]. Protecting equipment within a facility from transient conditions requires SPDs to be applied at the service entrance of the primary power and alternate power. To provide the best protection, SPDs should be placed as close to the service entrance as possible. In most cases, this requires the SPDs to be placed on the input of the service disconnect. SPDs intended to be installed upstream of the service disconnect are required to be classified as a Type 1 SPD [5]. To mitigate any remnant over voltage within the facility, a Type 2 SPD should be located on each subsequent distribution panel.

![Dual Source Facility with SPDs Installed](image3)

**Fig. 4. Illustration of Dual Source Facility with SPDs Installed**

III. PROBLEM DETECTION AND MITIGATION.
Many utility customers do not realize the limited information currently available to grid operators, especially at the distribution level. When a blackout occurs, for example, customer calls are mapped to define the geographic area affected. This, in turn, allows utility engineers to determine which lines, transformers and switches are likely involved, and what they must do to restore service. It is not rare, in fact, for a utility customer care representative to ask a caller to step outside to visually survey the extent of the power loss in their neighbourhood. It is a testament to the high levels of reliability enjoyed by electric utility customers that most have never experienced this; however, it is also evidence of an antiquated system. While SCADA and other energy management systems have long been used to monitor transmission systems, visibility into the distribution system has been limited. As the grid is increasingly asked to deliver the above four capabilities, however, dispatchers will require a real-time model of the distribution network capable of delivering three things: 1) real-time monitoring (of voltage, currents, critical infrastructure) and reaction (refining response to monitored events); 2) anticipation (or what some industry specialists call “fast look-ahead simulation”); and 3) isolation where failures do occur (to prevent cascades).

IV. CONCLUSION

The electrical grid is poised to transition from a system that was conceived more than 100 years ago, into a modern engineering marvel. The Smart Grid will revolutionize generation, distribution and utilization of electrical energy similar to how the Internet has revolutionized communications. Proponents of the Smart Grid tout that this complex network of fossil fuel and renewable energy sources will be capable of generating and distributing electricity at lower costs and lower levels of pollutants. In addition, the Smart Grid will reduce our dependency on foreign sources of fuel and be more reliable. To protect the Smart Grid, and all the advanced electronic devices that will be connected to it, high quality surge protective devices (SPDs) with proven performance, demonstrated safety, and unprecedented reliability are required. The SPD must be capable of connecting to service equipment to limit lightning induced transients from entering the facility or being coupled onto the Smart Grid. Additional SPDs will be required to limit any transient overvoltage that propagates into the facility. To achieve the vision put forth in this paper, there are many steps which need to be taken. Primary among them is the need for a cohesive set of requirements and standards for smart grid security. We urge the industry and other participants to continue the work that has begun under the direction of NIST to accomplish these foundational steps quickly.

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Application of Fuzzy Logic for Reduction of Current Harmonics in Single-Phase Grid–Connected Inverter

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Abstract— In the present era, distributed generation (DG) system uses current regulated PWM voltage-source inverters (VSI) for synchronizing the utility grid with DG source in order to meet the following objectives: 1) To ensure grid stability 2) active and reactive power control through voltage and frequency control 3) power quality improvement (i.e. harmonic elimination) etc. In this paper, fuzzy with hysteresis controller is applied to enhance the power quality by diminishing current error at higher bandwidth. The studied system is modeled and simulated in the MATLAB/Simulink environment.

Keywords— Distributed generation (DG), Fuzzy logic controller, Hysteresis current controller, Point of common coupling (PCC), utility grid, Power quality

I. NOMENCLATURE

\[ V_s \] grid voltage
\[ I_s \] grid current
\[ I_{ref} \] reference current
\[ E \] current error
\[ V_{dc} \] dc-link voltage
\[ f_s \] switching frequency
\[ L_f \] line inductance
\[ V_m \] maximum voltage amplitude
\[ I_m \] maximum current amplitude
\[ \theta_v \] voltage phase angle
\[ \theta_i \] current phase angle

II. INTRODUCTION

Distributed generation systems and their interconnection should meet certain requirements and specifications when interconnecting with existing electric power systems (EPS) [1]. For an inverter-based distributed generator, the power quality largely depends on the inverter controller’s performance. Pulse width modulation (PWM) is the most popular control technique for grid-connected inverters. As compared with the open loop voltage PWM converters, the current-controlled PWM has several advantages such as fast dynamic response, inherent over-current protection, good dc-link utilization, peak current protection etc.

However, the converter performance is largely depends on the applied current control strategy. Very extensive research work has been done besides current control techniques and is available in the literature. [2]. The common strategies of current controllers can be classified as ramp comparator, hysteresis controller, and predictive controller amongst which the hysteresis controllers are widely used because of their inherent simplicity and fast dynamic response [3]. The main objectives of the control of grid connected PWM-VSI is to 1) ensure grid stability 2) active and reactive power control through voltage and frequency control 3) power quality improvement (i.e. harmonic elimination) etc. The advantage of fuzzy control is that it is based on a linguistic description and does not require any mathematical model of the system. The Fuzzy set theory can be used to model the natural uncertainties of plant and control variables. The studied system is modeled and simulated in the MATLAB/Simulink environment.

The paper is organized as follows—Single-phase grid connected VSI is described in Section III. Analysis of hysteresis and hysteresis with fuzzy current controller is explained in the section IV. Section V, dedicated to results and discussion, followed by conclusion in Section V.

III. SINGLE PHASE GRID–CONNECTED VSI

![Figure 1. Single phase inverter connected to utility grid](image)

The single-phase grid connected inverter shown in Fig.1 Which is composed of a dc voltage source (\( V_{dc} \)), four switches (\( S_1-S_4 \)), a filter inductor (\( L_f \)) and utility grid (\( V_g \)). In inverter-based DG, the produced voltage from inverter must be higher than the \( V_g \) in order to assure power flow to grid. Since \( V_g \) is uncontrollable, the only way of controlling the operation of the system is by controlling the current that is following into the grid.

IV. ANALYSIS OF FUZZY WITH HYSTERESIS CURRENT CONTROLLER

A. Hysteresis band current controller.

In spite of several advantages, some drawbacks of conventional type of hysteresis controller are limit cycle oscillations, overshoot in current error, sub-harmonic generation in the current and uneven switching [4]. In case of hysteresis controller as shown in fig.2 the error is directly fed to the hysteresis band.
As given by equation (1) the reference line current of the grid connected inverter is referred to as $i_{ref}$ and difference between $i_o$ and $i_{ref}$ is referred to as error ($e$). The hysteresis band current controller assigns the switching pattern of grid connected inverter.

$$e = i_o - i_{ref}$$  \hspace{1cm} (1) 

The switching logic is formulated as follows:

If $e > HB$ then switch $S_1$ and $S_4$ is on

If $e < -HB$ switch $S_2$ and $S_3$ is on

The average load power is computed as:

$$P_L = \frac{1}{n} \sum_{j=1}^{n} v_j (j) i_j (j)$$  \hspace{1cm} (2) 

Using Torrey and Al-Zalmel\[6\] methodology, the reference source current is computed as:

$$i_{ref} = k v_g$$  \hspace{1cm} (3) 

Where $k$ is the scaling factor and computed as

$$k = \frac{2P_s}{V_m^2}$$  \hspace{1cm} (4) 

The switching frequency of the system can be calculated as

$$V_{dc} = L_s \frac{di_o}{dt} + V_g$$  \hspace{1cm} (5) 

From equation (1)

$$i_s = i_{ref} + e$$  \hspace{1cm} (6) 

By rearranging equation (5 and 6) we can calculate

$$T_{ON} = \frac{2L_s HB}{V_{dc} - V_g}$$  \hspace{1cm} (7) 

And

$$T_{OFF} = \frac{2L_s HB}{V_{dc} + V_g}$$  \hspace{1cm} (8) 

$$\frac{1}{f_s} = T_s = T_{ON} + T_{OFF}$$  \hspace{1cm} (9) 

$$f_s = \frac{(V_{dc}^2 - V_g^2)}{4V_{dc}L_s HB}$$  \hspace{1cm} (10) 

Hence, the switching frequency varies with the dc voltage, grid voltage, load inductance and the hysteresis band [7].

**B. The fuzzy with hysteresis current controller**

The main drawback of hysteresis current controller is uneven switching frequency which causes acoustic noise and difficulty in designing input filters during load changes. The switching frequency can be reduced by reducing the band width of the hysteresis band but at the same time the current error will increase which produce more distortion in the output current. To eliminate drawback upto certain extent fuzzy is used along with hysteresis current controller as shown in fig.3 [5].

The structure of fuzzy logic controller is given below in fig 4. Here the membership function is chosen as triangular as shown in fig 5. The input is taken as error ($e$) and the change in error ($\Delta e$). Total 49 rules are taken into account as given in table -1.

For example

If $e$ is negative small (NS) and $\Delta e$ is positive big (PB) Then output is positive medium (PM).

Table-1-Rule base for fuzzy controller
V. RESULTS & DISCUSSION

The section reveals the simulation results for fuzzy with hysteresis current control algorithm applied to single-phase mains connected inverter system. The studied model has been developed and simulated in the MATLAB/simulink environment. For simulation, the Dc-link voltage is taken 400V, and the grid voltage is 240V, the inductance of the line is 5mH and the utility grid frequency is 50Hz.

A. Simulation result steady state

Fig 7 shows that the proposed controller is able to control the active and reactive power independently.

B. Simulation result for transient state

1) Step change in load

To analyze the performance of the hysteresis and fuzzy with hysteresis controller the load is changed between the period 0.06 and 0.14 sec.

Fig 8 shows that the proposed controller is able to control the active and reactive power independently.

2) Change in hysteresis band width

In this case the hysteresis band width is changed at time \( t=0.1 \text{ sec} \) from \( \text{HB}=1 \) to \( \text{HB}=3 \).
As the band width of the hysteresis controller is increasing the switching frequency decreases but the current error increase so also the distortion in the grid current increases. In the proposed controller even if the band width increases the distortion in grid current and change in error is very less as shown in fig 10. It implies that the switching frequency can be decreased without hampering the power quality.

In studied current control scheme the inverter is also able to inject the current in phase with the grid voltage fig 11. (a) Shows that the current is in phase with the voltage even if the there is a phase change in the grid voltage at 0.1 sec. Fig 11. (b) Indicates the power factor of the grid current which is unity.

The THD of the proposed controller is considerably less 1.66% as shown in fig.13

3) Phase change in the grid voltage

Figure 10. Simulation result of grid current_error and switching frequency fuzzy with hysteresis controller.

Figure 11. Simulation result of (a) grid voltage and inverter current frequency (b) power factor

Figure 12. THD of grid current of fuzzy with hysteresis current controller

VI. CONCLUSIONS

The paper presents the control grid connected PWM VSI using fuzzy with hysteresis controller in the control loop. From the study we observed that, fuzzy with hysteresis current controller can able to enhance the power quality of the grid system as it is enable to reduce switching frequency even if the band width increased without any significant increase in the current error. As a result, the THD level of grid current is considerably reduced. More over, switching frequency of the inverter system has been reduced, hence switching losses are also reduced to certain extent.

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Synthesis and Applications of Conjugated polymers & it’s Supramolecular self assembly for Organic Photovoltaics

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Abstract: Two novel symmetrical acceptor-donor-acceptor organic dyes (S1-S2) containing 2,7-functionalized Fluorene (electron donor) cores connected with two anchoring cyanoacrylic acid (electron acceptor) termini via different numbers (2 or 3) of conjugated thiényl linkers were designed and synthesized. These H-Donor (proton donor) dyes (S1-S2) were complexed with a H-acceptor side-chain homopolymer carrying pyridyl pendants (with 1/2 molar ratio of H-donor/H-acceptor) to produce two novel hydrogen-bonded (H-bonded) polymer networks (PFNA/S1-S2). All the dyes, polymer are characterized by both 1H- and 13C- NMR spectroscopy. In addition the H-Bonded polymer networks were confirmed through FT-IR spectroscopy. There was an overlap of the emission spectra of proton accepting polymer PFNA and the absorption spectra of the proton donating dyes (S1-S2) thus the energy transfer from proton accepting polymer PFNA to proton donating dye has been expected. Furthermore the effects of the supramolecular architecture on optical, electrochemical, and organic photovoltaic (OPV) properties were investigated. Photophysical properties revealed that the absorption spectra of H-bonded polymer networks showed broader wavelength ranges and higher λmax values to appeal better light harvesting, though they showed blue shifts in their respective absorption maxima (λmax). The H-bonded polymer network PFNA/S2 containing S2 dye showed the better photovoltaic performance with a PCE value of 0.32%, than PFNA.

Keywords— H-bonded polymer network; rod-coil homopolymer; solar cell; self-assembly; supramolecular architecture.

Introduction

Conjugated oligomers and polymers are found to be advanced materials for the present study of solar cells. Oligomers have their unique advantage of their well defined chemical structure, specific electronic and optical properties. However, the material properties of oligomers are generally auxiliary to those of their polymeric analogues, which are responsible for the polymer properties, are lacking.1-2 Meijer and coworkers made use of a supramolecular H-bonded polymer containing oligo(phenylene vinyene) and ureido-pyrimidinone unit for the applications in OPV devices1. Afterwards, Lin et.al reported on supramolecular assemblies of H-bonded side-chain polymers which were prepared by complexation of solar cell dyes bearing carboxylic acids as protondonors (H-donors) with side-chain polymers bearing pyridyl pendants as proton-acceptors for the applications in OPVs.4

In general, different attempts of utilizing conjugated oligomers/polymers or both have been made to design electron donor-acceptor architectures to enhance the intramolecular charge transfer interactions from the electron donors to the electron acceptors and thus to increase the PCE values. In fact, different solar cell architectures have been developed, using different types of polymer backbones. However, the interests on oligomers with easy purification processes and lack of problems in molecular weight distributions etc. are generally auxiliary to their polymer analogues due to the better solvent processabilities and film morphologies in photovoltaic cells.3

Therefore, in order to get the advantages of both oligomeric and polymeric properties, an attractive approach of well-defined supramolecular architectures of π-conjugated oligomers with the processabilities of polymers could be an attractive approach in the field of organic photovoltaics. Thus, in this report, In order to get the advantage from physical properties of both small molecules and polymers in OPV devices, symmetrical Fluorene-based conjugated dyes containing Fluorene cores functionalized at 2,7-substituted positions linked to cyano-acrylic acid termini (as double H-donors) via π-conjugated oligo-thiophenes were synthesized, which were complexed with a side-chain homopolymer Poly[10-(6-(9,9-diethyl-7-(pyridin-4-yl)-9H-fluoren-2-yl)naphthalen-2-yl)oxy)decyl methacrylate] (PFNA), bearing pyridyl pendants (as H-acceptors). Then, double H-donors of dyes and H-acceptors of side-chain homopolymer PFNA can be self-assembled into H-bonded cross-linking polymers.

1. Synthesis

1.1 Synthesis of polymer and Dyes(S1,S2)

The H-Accepting polymer (PFNA) and dyes S1 and S2 were synthesized by simple step by step procedures as shown in scheme 1 and 2 and the detailed procedures are given as follows:

2. 7-Dibromo fluorene. (1) Fluorene (10 g, 60.21 mmol) was dissolved in 100 ml of dry dichloromethane and cooled under an ice bath, then bromine (7.71 ml, 150.52 mmol) was added dropwise over 30min. The reaction mixture was stirred at room temperature for overnight, and a saturated aqueous solution of sodium bisulfite was added to quench excess of bromine. The solution was extracted from dichloromethane
and washed with water and little brine. The organic layer was dried over magnesium sulfate, solvent was removed by rotavapor. The crude product was purified by recrystallization from hexane to yield white crystals (15.41g, 79%). $^1$H NMR CDCl$_3$, δ(ppm): 7.64(s, 2H), 7.58(d, $J$ = 8.0 Hz, 2H), 7.46(d, $J$ = 8.2 Hz, 2H), 3.85(s, 2H)

**Scheme 1**: Synthetic procedure for PFNA

2, 7-Dibromo-9, 9-diethylfluorene (2). A mixture of 2,7-dibromofluorene (10 g, 30.86 mmol) and potassium-tert-butoxide (10.37 g, 92.58 mmol) were stirred in 120 ml of dry THF under nitrogen for 1hr, then ethyl iodide (7.46 ml, 92.58 mmol) was added drop wise and stirred for additional 3hr. Excess of THF was removed by rota vapor, compound was extracted with dichloromethane and washed with water and a little brine. The organic layer was dried over magnesium sulfate. The solvent was removed by Rota vapor, and the crude product was purified by column chromatography using Silica. Hexane as an eluent to yield a white solid (10.7 g, 91.2%). $^1$H NMR (300 MHz, CDCl$_3$), δ(ppm): 7.52 (d, $J$ = 3.0 Hz 2H), 7.44 (d, $J$ = 12.0 Hz, 2H), 7.42 (s, 2H), 1.95 (q, $J$ = 7.2 Hz, 4H), 0.29 (t, $J$ = 7.5 Hz, 6H), 2-Bromo-9, 9-diethylfluoreneboronic acid (3). 5 g (13.15 mmol) of 2, 7-dibromo-9, 9-diethylfluorene was dissolved in 100 ml of dry THF and the solution was cooled to -78°C, under nitrogen atmosphere then 6.8 ml (17.10 mmol) of n-BuLi (2.5M solution in hexane) was added through a syringe and the reaction mixture was allowed to reach room temperature, then again cooled to -78°C and 12.13 ml (52.58mmol) of tri-isopropyl borate was added. The reaction mixture was stirred for additional 12 hr at room temperature then 50 ml of 2.0M HCL was added and stirred for another 2hr

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Excess THF was removed and the compound was extracted from dichloromethane, washed with water followed by a little brine. The organic phase was dried with anhydrous magnesium sulphate then the solvent was removed using rotavapor. The crude product was purified by column chromatography on silica using ethyl hexane: acetate (3:1) as eluent to yield a white solid (2.79 g, 61.5%). 1H NMR (300 MHz, DMSO-d$_6$), δ (ppm): 8.07 (s, 2H), 7.81 (s, 1H), 7.77 (s, 2H), 7.75 (s, 1H), 7.65 (d, J = 1.8 Hz, 1H), 7.51 (dd, J = 10.2 Hz, 1H), 1.98 (q, J = 7.8 Hz, 4H), 0.17 (t, J = 7.2 Hz, 6H).

4-iodopyridine (4). 4-Aminopyridine (7 g, 74.37 mmol) was dissolved in 100 ml of dry toluene and cooled to -10°C. To the resulting slurry powdered NaN$_3$ (6.67 g, 96.6 mmol) was added portion wise after each 1 min interval at such rate that no nitric oxide evolution could be detected. After 30 min the diazonium salt was filtered off. This salt was added portion wise to a solution of KI (30.86 g, 185.90 mmol) in 500 ml of an acetone: water (2:3) mixture. The reaction mixture was then decolorized by adding aqueous Na$_2$SO$_4$, then neutralized with saturated aqueous Na$_2$CO$_3$ and finally extracted with dichloromethane. The organic layer was dried over MgSO$_4$ and evaporated, and then the crude product was purified by column chromatography on Al$_2$O$_3$ using dichloromethane as eluent. To yield white crystal (10.3 g, 68%) 1H NMR (300 MHz, CDCl$_3$), δ (ppm): 8.27 (d, J = 6.3 Hz, 2H), 7.67 (d, J = 6.0 Hz, 2H).

2-bromo-9, 9-di-n-ethylfluorenone-7-pyridine (5): Mixture of compound 3 (2 g, 5.79 mmol), 4 (1.3 g, 6.37 mmol), K$_2$CO$_3$ (1.1 g, 7.55 mmol) were dissolved in 100 ml of toluene and ethanol (3:1) and degassed for 10 min, then Pd (PPh$_3$)$_4$ (100 mg, 8.69 × 10$^{-5}$ mmol) was added and then the resulting mixture was stirred under reflux for 4 hr. The solvents were removed under vacuum, extracted with dichloromethane and washed with water followed by a little brine. The organic phase was dried with anhydrous MgSO$_4$ and the solvent was removed under vacuum then the compound was purified by column chromatography on Al$_2$O$_3$ using 10:1 mixture of hexane and dichloromethane as eluent to yield low melting white solid (1.7 g, 76%). 1H NMR (300 MHz, CDCl$_3$), δ (ppm): 8.66 (d, J = 6.0 Hz, 2H), 7.78 (d, J = 9.0 Hz, 1H), 7.58 – 7.64 (m, 5H), 7.48 (dd, 2H), 2.04 (q, 4H), 0.35 (t, J = 6 Hz, 6H).

10-(6-bromonaphthalen-2-ylxoy) decanal-1-ol (6b) 6-Bromonaphthalene-2-ol (7g, 31.3 mmol), 10-bromo decanol (9.67g, 40.79 mmol), K$_2$CO$_3$ (13g, 94.14%), and a catalytic amount of KI was dissolved in 200 ml of dry acetone and stirred under reflux for 24hr. After cooling to room temperature, the potassium salt was filtered off. The solvent was removed by rotovap and then extracted with dichloromethane followed by brine wash. The organic solvent was dried over anhydrous MgSO$_4$ and was removed using rotovap. The crude product was purified by column chromatography on silica using mixture of hexane and dichloromethane (3:2) as an eluent, to get a light brown solid (11.2g, 94%). 1H NMR (300 MHz, CDCl$_3$), δ: 7.90 (s, 1H), 7.63 (d, J = 9Hz, 1H), 7.57 (d, J = 9Hz, 1H), 7.47 (d, J = 3Hz, 1H) 7.15 (d, J = 12Hz, 1H) 7.08 (s, 1H) 4.05 (t, J = 6Hz, 2H) 3.64 (t, J = 6Hz), 2H) 1.79 - 1.88 (m, 2H), 1.52 - 1.59 (m, 2H), 1.32 – 1.49 (m, 12H).

(10-(6-bromonaphthalen-2-ylxoy) decyloxy)(tert-butyl) dimethylsilane. (7b). Mixture of compound 6b (5g, 13.2 mmol), imidazole (1.16g, 17.15 mmol) were dissolved in 100 ml of dry dichloromethane, then degassed for 10 min. Tert-Butyl-chloro-dimethyl-silane (2.60, 17.15 mmol) was added at 0°C, then stirred overnight at room temperature under nitrogen atmosphere, then extracted with dichloromethane and washed with water. The organic solvent was dried over anhydrous MgSO$_4$ then the solvent was removed using rotavapor. The crude product was purified by column chromatography on silica using mixture of Hexane and dichloromethane (4:1) as eluent to get the product (5.53 g, 85%) 1H NMR (300 MHz, CDCl$_3$), δ: 7.89 (s, 1H), 7.64 (d, J = 9Hz, 1H) 7.58 (d, J = 6Hz, 1H), 7.48 (d, J = 15Hz, 1H), 7.16 (d, J = 15Hz, 1H), 7.07 (s, J = 1H), 4.64 (t, J = 6Hz, 2H), 3.62 (t, J = 7.5Hz, 2H), 1.79 – 1.84 (m, 2H), 1.45-1.53 (m, 6H), 1.29-1.32 (m, 8H), 0.90 (s, 9H), 0.01 (s, 6H).

Tert-butylidimethyl(10-(6-(4,4,5,5-tetramethyl-1,3,2-dioxaborol-2-yl)naphthalene-2-ylxox)decyloxy)silane (8b). 5 g of compound (7b) (10.13 mmol) was dissolved in 100 ml of dry THF and the solution was cooled down to -78°C under nitrogen atmosphere then 8.1 ml of n-BuLi (2.5M in Hexane, 20.26 mmol) was added. The solution was warmed up to room temperature, then cooled to -78°C. To this solution 5.51 ml (20.26 mmol) of 2-isoproxy-4, 4’, 5, 5-tetramethyl-[1, 3, 2] dioxaborolane was added and the resulting solution was stirred for overnight at room temperature. 50 ml of water was added and further stirred for 1hr. THF was removed by rotovap then extracted with dichloromethane and washed with water. The organic solvent was dried over anhydrous MgSO$_4$ and it was removed on rotavapor and the crude product was purified by column chromatography on silica using mixture of hexane and dichloromethane (4:1) as eluent to yield white solid (3.8 g, 70%). 1H NMR (300 MHz, CDCl$_3$), δ: 8.27 (s, 1H), 7.79 (d, J = 9Hz, 2H), 7.69 (d, J = 6Hz, 1H), 7.14 (d, J = 3Hz, 1H), 7.10 (s, 1H), 4.07 (t, J = 6.5Hz, 2H), 3.60 (t, J = 7.5Hz, 2H), 1.79-1.86 (m, 2H), 1.44-1.58 (m, 4H), 1.30-1.38 (m, 10H), 0.90 (s, 9H), 0.05 (s, 6H).

4-(7-(6-(10-(tert-butylidimethylsilyloxy) naphthalene-2-yl)-9, 9-diethyl-9H-fluoren-2-yl) pyridine (9b).

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Mixture of compound 5 (3 g, 7.93 mmol), 8 (4.7 g, 8.7 mmol) and K₂CO₃ (1.424g, 10.3 mmol) were dissolved in 120 ml of toluene: ethanol (3:1) and degassed for 10 min. To that 135 mg of Pd(PPh₃)₄ was added and the reaction mixture was stirred under reflux for 4 hrs. After cooled to room temperature the solvent was removed and extracted with dichloromethane and washed with water followed by a little brine. The organic phase was dried over anhydrous MgSO₄ and the solvent was removed using rotavapor. The crude product was purified by column chromatography on Al₂O₃ using mixture of hexane and dichloromethane (1:1) as eluent to yield low melting white solid (5.1 g, 91%) ¹H NMR (300 MHz, CDCl₃), δ: 8.68 (d, J = 6 Hz, 2H), 8.02 (s, 1H), 7.61 - 7.86 (m, 11H), 7.15 (d, J = 8.7 Hz, 2H), 4.08 (t, J = 6.6 Hz, 2H), 3.58 (t, J = 6.6 Hz, 2H), 2.06 - 2.17 (m, 4H), 1.80 - 1.87 (m, 2H), 1.40 - 1.49 (m, 2H), 1.22 - 1.36 (m, 12H), 0.86 (s, 9H), 0.41 (t, J = 3.6, 6H), 0.03 (s, 3H).

10-[6-(9,9-diethyl-7-(pyridine-4-yl)-9-fluoren-2-yl)naphtalen-2-yl)oxy]decyl methacrylate (11) Compound 10 (1.3 g, 2.37 mmol), 1,3dichloro1,1,3,3,tetrabutyldistannoxane dichlorol, 1, 3, 3, tetrabutyldistannoxane (131 mg, 0.23 mmol), 2,6-di-tert-butyl-4-methylphenol (52 mg, 0.23 mmol) were taken in a vacuum dessicator and dried by giving under vacuum-nitrogen alternatively. Then vinyl methacrylate (1.47 ml, 11.93 mmol) and 1.5 ml of dry THF were added. The resulting solution was stirred at 50° C for 48 hrs. The product was extracted with dichloromethane followed by washing with brine. The solvent was dried over anhydrous MgSO₄ and removed by rotavapor. The crude product was purified by column chromatography on Al₂O₃ using dichloromethane as eluent to yield white solid (1.3 g, 38%).¹H NMR (300 MHz, CDCl₃), δ: 8.68 (d, J = 5.7 Hz, 2H), 8.04 (s, 1H), 7.84 (d, J = 8.1 Hz, 1H), 7.79 - 7.81 (m, 4H), 7.73 (d, J = 1.5 Hz, 1H), 7.70 - 7.61 (m, 5H), 7.21 (d, J = 2.4 Hz, 1H), 7.18 (s, 1H), 4.11 (t, J = 6.3 Hz, 2H), 3.65 (t, J = 6.3 Hz, 2H), 2.11 - 2.19 (m, 4H), 1.87 (q, J = 6.3 Hz, 2H), 1.27 - 1.58 (m, 17H), 0.43 (t, J = 7.2 Hz, 3H).

10-,[6-(9,9-ethyl-7-(pyridine-4-yl)-9-fluoren-2-yl)naphtalen-2-yl)oxy]decyl methacrylate (11) Compound 10 (1.3 g, 2.37 mmol), 1,3dichloro1,1,3,3,tetrabutyldistannoxane dichlorol, 1, 3, 3, tetrabutyldistannoxane (131 mg, 0.23 mmol), 2,6-di-tet-butyl-4-methylphenol (52 mg, 0.23 mmol) were taken in a vacuum dessicator and dried by giving under vacuum-nitrogen alternatively. Then vinyl methacrylate (1.47 ml, 11.93 mmol) and 1.5 ml of dry THF were added. The resulting solution was stirred at 50° C for 48 hrs. The product was extracted with dichloromethane followed by washing with brine. The solvent was dried over anhydrous MgSO₄ and removed by rotavapor. The crude product was purified by column chromatography on Al₂O₃ using dichloromethane as eluent to yield white solid (1.3 g, 38%).¹H NMR (300 MHz, CDCl₃), δ: 8.68 (d, J = 5.7 Hz, 2H), 8.04 (s, 1H), 7.84 (d, J = 8.1 Hz, 1H), 7.79 - 7.81 (m, 4H), 7.73 (d, J = 1.5 Hz, 1H), 7.70 - 7.61 (m, 5H), 7.21 (d, J = 2.4 Hz, 1H), 7.18 (s, 1H), 4.11 (t, J = 6.3 Hz, 2H), 3.65 (t, J = 6.3 Hz, 2H), 2.11 - 2.19 (m, 4H), 1.87 (q, J = 6.3 Hz, 2H), 1.27 - 1.58 (m, 17H), 0.43 (t, J = 7.2 Hz, 3H).

1.2. Synthetic Procedures For S1 and S2 dyes

(2E,2′E)-3,3′-[5,5′-(9,9-Dihexyl-9H-fluoren-2,7-diyl)bis(2,2′-bithiophene-5,5′-diyl)]bis(2-cyanoacrylic acid) (S1): The dyes S1 and S2 were synthesized by the known literature procedure to yield dark brown solid (390 mg, 82.4%) ¹H NMR (300 MHz, DMSO-d₆), δ (ppm): 8.49 (s, 2H), 7.98 (d, J = 4.5 Hz, 2H), 7.87 - 7.81 (m, 4H), 7.70 (dd, J = 3.3 Hz, J = 9.9 Hz, 6 H), 7.62 (d, J = 3.9 Hz, 2H), 2.06 (m, 4H), 1.03 - 0.96 (m, 12H), 0.66 (t, J = 6.3 Hz, 6H), 0.51 (m, 4H). ¹³C NMR (75 MHz, DMSO-d₆), δ (ppm): 164.3, 152.3, 147.0, 146.6, 146.3, 142.3, 141.0, 134.6, 132.6, 129.1, 126.2, 125.6, 125.4, 121.5, 120.4, 117.3, 98.7, 55.8, 31.5, 29.5, 24.1, 22.6, 14.5, MS (FAB): m/z [M⁺] 853; calcld m/z [M⁺] 852.22. Anal. Calcd for C₄₉H₆₆N₂O₄S₆: C, 68.62; H, 5.49; N, 3.86.

S′,5′-[5,5′-(9,9-Dihexyl-9H-fluoren-2,7-diyl)-di-[2,2′,5′,2″-terthiophene-5″-(2-cyanoacrylic acid)] (S2): 1H NMR (300 MHz, DMSO-d₆), δ (ppm): 8.47 (s, 2H), 7.97 (d, J = 4.2 Hz, 2H), 7.83 - 7.76 (m, 4H), 7.63 - 7.58 (m, 8H), 7.49 (d, J = 3.6 Hz, 2H), 7.42 (d, J = 3.9 Hz, 2H), 2.06 (m, 4H), 1.00 - 0.95 (m, 12H), 0.65 (t, J = 6.3 Hz, 6H), 0.53 (m, 4H). ¹³C NMR (75 MHz, DMSO-d₆), δ (ppm): 164.3, 152.2, 146.9, 145.8, 144.6, 142.1, 140.7, 139.0, 135.1, 134.7, 134.2, 132.8, 128.9, 127.1, 126.1, 125.0, 121.3, 120.1, 117.2, 98.1, 55.1, 30.1, 29.1, 24.1, 22.1, 14.4, MS (FAB): m/z [M⁺] 1017; calcld m/z [M⁺] 1016.19. Anal. Calcd for C₄₉H₆₆N₂O₄S₆: C, 67.29; H, 4.76; N, 2.75. Found: C, 66.61; H, 5.02; N, 2.85.

1.3. Preparation of H-Bonded Polymer Networks (PFNA/S1-S2)

Proton acceptor polymer PFNA and proton donor dye (S1, S2) 1:2 molar ratio were dissolved in minimum amount of methylene chloride then sonicated for 5 min to make a clear solution. Then the solvent was evaporated under ambient temperature, and was followed by drying in a vacuum oven at 60 °C for several hours. The complexation of donor and acceptor through hydrogen bonding occurred during the solvent evaporation. Similar procedure was followed for the other H-bonded polymers PFNA/S2.

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2. Experimental

2.1 Materials
Chemicals and solvents were reagent grades and purchased from Aldrich, ACROS, TCI, Strem, Fluka, and Lancaster Chemical Co. THF and dichloromethane were distilled over sodium/benzophenone and calcium hydride respectively and freshly distilled before use. Tetra-n-butyl ammonium hexafluorophosphate (TBAPF$_6$) was recrystallized twice from absolute ethanol and further dried for two days under vacuum. N-bromosuccinimide was recrystallized from distilled water and dried under vacuum. The other chemicals were used without further purification. Chromatography was performed with Merck silica gel (mesh 70–230) and basic aluminum oxide, deactivated with water. The chemical structures for all products were confirmed by $^1$H NMR spectroscopy, mass spectra (FAB) and elemental analyses.

2.2. Measurements

$^1$H NMR spectra were recorded on a Varian unity 300 MHz spectrometer using d-DMSO as solvents. Elemental analyses were performed on a HERAEUS CHN-OS RAPID elemental analyzer. Fourier transform infrared (FT-IR) spectra were performed on a Nicolet 360 FT-IR spectrometer. Thermo gravimetric analyses (TGA) were conducted on a Du Pont Thermal Analyst 2100 system with a TGA 2950 thermo gravimetric analyzer at a heating rate of 20 °C/min under nitrogen. Gel permeation chromatography (GPC) analyses were conducted with a Water 1515 separations module using polystyrene as a standard and THF as an eluant. UV-visible absorption spectra were recorded in dilute THF solutions (10$^{-5}$ M) on a HP G1103A spectrophotometer. Thin films of UV-vis were spin-coated on quartz substrates from THF solutions with a concentration of 1 wt%. cyclic voltammetry (CV) measurements were performed using a BAS 100 electrochemical analyzer with a standard three-electrode electrochemical cell in a 0.1 M tetraethylammonium hexafluorophosphate (TBAPF$_6$) solution at room temperature with a scanning rate of 100 mV/s. During the CV measurements, the solutions were purged with nitrogen for 30s. In H-bonded cross-linking polymers, a carbon working electrode coated with a thin layer of H-bonded polymer, and for dyes in solution (DCM) a platinum wire as the counter electrode, and a silver wire as the quasi-reference electrode were used, and Ag/AgCl (3 M KCl) electrode was served as a reference electrode for all potentials quoted herein. The redox couple of ferrocene/ferrocnium ion (Fc/Fc$^+$) was used as an external standard. The corresponding highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) levels were calculated using $E_{ox/onset}$ and $E_{red/onset}$. The onset potentials were determined from the intersections of two tangents drawn at the rising currents and background currents of the cyclic voltammetry (CV) measurements.

2.3 Fabrication and Characterization of OPV Devices
Solar cells were fabricated on indium tin oxide (ITO)-coated glass substrates through a following procedure: The ITO coated glass substrate was first cleaned with a detergent and sonicated in an ultrasonic bath, and they were dried overnight in an oven. After this cleaning procedure, the substrates were subjected to UV ozone cleaning for 15 minutes. PEDOT: PSS (Baytron PH) was spin coated onto the substrates at 4000 rpm. The films were dried on a hotplate at 120 °C for 30 minutes. The samples were then transferred to the nitrogen filled glove box for the active layer deposition. A solution containing hydrogen bonded polymer networks (PFNA/Sx, where x vary from 1,2) and PCBM were prepared (2 wt%, 1:1 ) and were kept overnight digitally controlled hotplate at 60 °C for the uniform mixing. The solutions were used for the active layer deposition and were spin coated on the substrates at 1500 rpm for 60 sec. The films were allowed to dry in a covered Petri dish. No thermal annealing treatment was given to the active layers prior to the cathode deposition. Finally, a 20 nm Ca and 50 nm Al cathodes were deposited using a thermal evaporator at a base pressure of 1x10$^{-6}$ Torr. The device area was 0.1 cm$^2$. The devices were then transferred to the nitrogen filled glove box. The current-voltage characteristics of the devices were measured using HP
4156 semiconductor parameter analyzer. Air mass 1.5 Global (AM 1.5 G) solar simulator was used for the photo illumination of the devices.

2.4. Structural Characterization

H-acceptor side-chain homopolymer PFNA, dyes S1, S2 were satisfactorily characterized by $^1$H NMR, FAB, and elemental analyses. The weight average molecular weight ($M_w$) of H-acceptor polymer PFNA was determined by gel permeation chromatography (GPC) with THF as the eluting solvent and polystyrene as a standard. Figure 2 shows the structure of dyes S1, S2 and polymer PFNA. The number average molecular weight ($M_n$) and polydispersity index (PDI) of polymer PFNA were 12200 g/mol and 1.72, respectively. The decomposition temperatures ($T_d$) of H-bonded polymer networks PFNA/S1–S2 and H-acceptor polymer were shown in Figure 4. H-bonded cross-linking polymers (Figure 3) showed good thermal stabilities with decomposition temperatures of H-bonded polymer networks PFNA/S1 and PFNA/S2 are 382 and 374 °C, respectively which are adequate for their applications in polymer solar cells and other optoelectronic devices.

2.5. Result and Discussion

3.1. Optical Properties

UV-vis absorption spectra of H-acceptor polymer PFNA and H-donor dyes S1, S2 in DCM solutions ($10^{-3}$ M) are shown in Figure 5 and their data are listed in Table 1. H-acceptor polymer PFNA showed the maximum absorption wavelength of 360 nm with a bandgap of 2.95 eV, H-donor dyes S1, S2 showed the maximum absorption wavelengths 452 and 479 nm respectively and was attributed to the intramolecular charge transfer (ICT) from the donor Fluorene core to the cyanoacrylic acid termini. The increase in the absorption spectra from S1 to S2 and from PFNA/S1 to PFNA/S2 is attributed to the increase in conjugation with increase in a symmetric thiophene unit.
Table 1. Optical Properties of PFNA, S1, S2, PFNA/S1 and PFNA/S2

<table>
<thead>
<tr>
<th>Polymer</th>
<th>λ_{abs, film} (nm)</th>
<th>λ_{onset, film} (nm)</th>
<th>E_{g opt} (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFNA</td>
<td>360</td>
<td>420</td>
<td>2.95</td>
</tr>
<tr>
<td>S1</td>
<td>452</td>
<td>542</td>
<td>2.28</td>
</tr>
<tr>
<td>S2</td>
<td>479</td>
<td>580</td>
<td>2.13</td>
</tr>
<tr>
<td>PFNA/S2</td>
<td>465</td>
<td>686</td>
<td>1.80</td>
</tr>
<tr>
<td>PFNA/S1</td>
<td>431</td>
<td>661</td>
<td>1.87</td>
</tr>
</tbody>
</table>

*a In DCM dilute solutions.
*b Spin coated from DCM solutions.
*c The optical bandgaps were obtained from the equation E_{g opt, film} = 1240/λ_{onset, film}.

3.2. Electrochemical Properties

In order to go deep into the energy levels of H-bonded polymer network and charge injection processes of the H-bonded polymer networks in the BHJ solar cell devices, cyclic voltammetry (CV) measurements are employed. The cyclic voltammograms of polymers are illustrated in Figure 6 and the related data are summarized in Table 2. Cyclic voltammetry (CV) measurements were performed at a scanning rate of 100 mV/s in a solution of 0.1 M tetrabutylammonium hexafluorophosphate (Bu4NPF6) dissolved in acetonitrile at room temperature using a standard three-electrode electrochemical cell. A platinum disk working electrode, a Pt wire counter electrode, and an Ag/AgCl reference electrode were used. As shown in Table 2 the HOMO and LUMO for PFNA/S1 and PFNA/S2 were 5.25, 5.36 and 3.25, 3.45 respectively which is in the desirable range to be used in photovoltaic application. Furthermore the electrochemical band gap for PFNA/S1 and PFNA/S2 were 1.81 and 1.91 eV respectively which is in the acceptable range of error with respect to the optical band gap.

Table 2. Electrochemical Properties of H-bonded Polymer networks

<table>
<thead>
<tr>
<th>Polymer</th>
<th>E_{ox, onset} (V)</th>
<th>E_{red, onset} (V)</th>
<th>HOMO (eV)</th>
<th>LUMO (eV)</th>
<th>E_{g opt} (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFNA/S1</td>
<td>0.90</td>
<td>-0.91</td>
<td>5.25</td>
<td>3.25</td>
<td>1.81</td>
</tr>
<tr>
<td>PFNA/S2</td>
<td>1.01</td>
<td>-0.90</td>
<td>5.36</td>
<td>3.45</td>
<td>1.91</td>
</tr>
</tbody>
</table>

*a Onset oxidation and reduction potentials measured by cyclic voltammetry in solid films.
*b HOMO/LUMO = -(E_{onset} - 0.45) - 4.8 eV, where 0.45 V is the value for ferrocene vs. Ag/Ag+ and 4.8 eV is the energy level of ferrocene below the vacuum.

3.3. Photovoltaic Properties

In order to prove the potential application of the H-bonded polymer networks (PFNA/S1-S2) as electron donors in photovoltaic devices, we fabricated devices by spin-coating from 2 wt% dichlorobenzene solutions of polymer blends containing H-bonded polymer networks PFNA/S1-S2 (as electron donors) and PCBM (as an electron acceptor) in 1:1 weight ratio with a configuration of ITO/PEDOT:PSS/H-bonded polymer networks:PCBM (1:1 w/w)/Ca/Al (under AM 1.5 irradiation, 100 mW/cm²). Figure 7 shows the current density versus voltage (J-V) curves and the results are illustrated in Table 3. As shown in Table 3, the short circuit current density (Jsc), open circuit voltage (Voc), fill factor (FF), and PCE values of the OPV devices containing H-bonded polymer networks PFNA/S1-S2 were 1.76, 1.88 mA/cm², 0.55, 0.58 V, 27, 29 %, 0.26, 0.32%, respectively. The decrease in HOMO values of PFNA/S2 facilitated higher Voc value than that of PFNA/S1. The broader absorption spectra in PFNA/S2, harvested higher photocurrent and appealed a higher Jsc value of 1.88 mA/cm² than that of PFNA/S1.

Figure 6. Cyclic voltammograms of H-Bonded polymer network (PFNA/S1-S2) in solid films at a scan rate of 100 mV/s.

![Figure 6](image)

Figure 7. Current density-voltage curves of illuminated solar cells incorporating H-bonded polymer networks // PFNA/S1-S2 with PCBM in 1:1 (w/w) ratio under AM 1.5G, 100 mW/cm².

![Figure 7](image)
As a contributing parameter for the net PCE value, the fill factors of the OPV devices were low, which could be associated with the large series resistance of the devices. On the whole, the OPV device containing blended H-bonded polymer network PFNA/S1:PCBM resulted the better PCE value of 0.32% with $J_{sc} = 1.88 \text{ mA/cm}^2$, $V_{oc} = 0.58 \text{ V}$, and FF = 29%, which was mainly because of its broader absorption and better utilization of the solar spectrum. In general, the approach in self-assembly of H-donor dyes with H-acceptor polymers via hydrogen bonding was proven to enhance OPV properties by the unique non-covalent-bonded practical applications.

**Table 3. Photovoltaic Performance of PSC Devices** Based on H-Bonded Polymer Networks PFNA/S1-S2 Measured Under AM 1.5 Irradiation, 100 mW/cm²

<table>
<thead>
<tr>
<th>Polymer network</th>
<th>$V_{oc}$ (V)</th>
<th>$J_{sc}$ (mA/cm²)</th>
<th>FF (%)</th>
<th>PCE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFNA/S1</td>
<td>0.55</td>
<td>1.76</td>
<td>0.27</td>
<td>0.26</td>
</tr>
<tr>
<td>PFNA/S2</td>
<td>0.58</td>
<td>1.88</td>
<td>0.29</td>
<td>0.32</td>
</tr>
</tbody>
</table>

*PSC devices with the configuration of ITO/PEDOT:PSS/(PFNA/S1-S2):PCBM/Ca/Al where H-bonded polymer network:PCBM = 1:1 by weight.

### 4. Conclusion

To facilitate getting the physical properties of both small molecules and polymers in OPV devices, the concept of supramolecular architectures by complexation of H-donor dyes (S1-S2) with a side-chain H-acceptor homopolymer (PFNA) was applied to produce H-bonded cross-linking polymers. Photophysical properties revealed that the absorption spectra of H-bonded polymer networks showed broader wavelength ranges and higher $\lambda_{max}$ values to appeal better light harvesting, though they showed blue shifts in their respective absorption maxima ($\lambda_{max}$). The H-bonded polymer network PFNA/S2 containing S2 dye showed the better photovoltaic performance with a PCE value of 0.32%, than PFNA. Thus, the results by complexation of small molecules and polymers via H-bonding are very encouraging for the future research on donor-acceptor supramolecular architectures of oligomeric dyes H-bonded with processable π-conjugated polymers in organic solar cell applications. Thus the supramolecular architectures by the complexation of conjugated polymers with surface modified nanoparticles are in progress.

### 5. References


 Demand Response in Smart MicroGrids  

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**Abstract**—The mismatch between supply and demand in microgrids can be overcome by effectively utilizing distributed energy resources and/or encouraging demand side management. Demand response is one of the popular techniques to demand side management. In this paper an agent based architecture to simulate virtual markets enabling customers of the market to participate in demand response and trade power using intelligent trading strategy which makes the market more realistic and microgrids smarter is proposed. The proposed concept is verified on a system with two microgrids. The proposed MAS is developed using Java Application Development (JADE) framework.

**Index Terms**— Multi Agent Systems, Energy markets simulation, Smart grid, Demand response, Micro grids.

**I. INTRODUCTION**

Smart distribution grids can be realized with customer driven microgrids. A Microgrid is an aggregation of distributed energy resources (DERs) and loads. DERs include distributed generation (DG) and distributed storage (DS). Effective management of a microgrid is challenging with non-dispatchable sources like wind and photovoltaic [1-3]. In general microgrids are designed to operate in either grid connected or isolated modes. Also, these are provided with intelligence to island from main grid intentionally or in case of a fault. Apart from benefits obtained by integrating DERs into the distribution system, there are economic, commercial and technical challenges. Some of the technical challenges with respect to power management were addressed in the literature with viable options [4-5].

In the presence of non-dispatchable generation in microgrid, there is always an issue of supply-demand mismatch. One of the known solutions to such problem is to equip microgrids with backup power (diesel generators). The operating cost and environmental effects by such backup system are significantly high compared to green DERs and hence it is essential to embed certain intelligence to effectively utilize integrated distributed resources.

The gap between supply and demand can also be reduced by incorporating demand side management at the distribution end of the power system. Participation of consumers/customers in reducing the peak demand and shifting of the peak according to the generation will reduce the gap between demand and supply. One such mechanism is “demand response” in which, a customer can participate in load management voluntarily. Incorporating demand response (DR) in existing microgrid is a challenging issue as it involves smart communication, negotiation, and control. This paper presents an application of demand response in microgrids by implementing a virtual market enabling customers to participate in demand response. The customers with appliances/loads with low priority may participate in demand response by allowing the microgrid intelligent systems to operate their appliances when the cost of electricity is low. The main participants in residential sector include kettle, dishwasher, washing machine etc. The customer participating in demand response shall provide the utility/microgrid with information like starting, end and operating time. The microgrid intelligent system identifies situations where the cost of the power is low and starts operating the appliance continuously for the duration of operational time specified by customer.

The key intention of the proposed mechanism is to enable microgrids to participate in the simulated market and thereby effectively utilize the DERs. The developed intelligence routes the power from surplus locations to deficient. However the cost at which power will be traded is decided by pool members following an auction protocol.

In this paper multi agent system (MAS) is used to model market scenario with energy buyers and energy sellers. JADE (Java Application DEevelopment framework), is used to develop the proposed MAS architecture. The proposed architecture consists of several intelligent agents to make the developed market realistic and to incorporate demand response. Each customer in the market can participate in demand response by providing control over his/her equipment to developed intelligent system. Power trading by pool members using double auction protocol is discussed in section II. The developed intelligent system starts an instance of bilateral negotiation with energy sellers for each received demand response following the procedure along with architecture is given in section III. The implementation of the proposed architecture using JADE [7] on a test case with two microgrids forming pool is presented in Section IV.
II. AGENT BASED STRATEGY

A. Multi-Agent Systems

A multi-agent system is a system with two or more agents or intelligent agents. An agent is “a software or hardware entity that is placed in some environment and is able to autonomously react to the changes in that environment”. This nature of agent is called autonomy. An intelligent agent is an agent who exhibits pro-activity i.e. goal directed behavior and is able to interact with other intelligent agents and reactivity. The key features of agent technology are data and method encapsulations. MAS has been applied to wide range of engineering applications. The application of MAS is a construct robust, flexible and extensible systems or as a modeling approach.

B. Continuous Double Auction (CDA) Markets:

A CDA is a market place with agents selling goods called sellers and agents buying goods called buyers. The sellers and buyers in any CDA market trade single type of goods like energy or power. An “ask” is the price placed by a seller to sell one unit of the goods. A “bid” is the price placed by a buyer to purchase a unit of goods. At any time in the market, the current lowest “ask” is called an outstanding ask and is generally represented by \(oa\). Similarly, the current highest bid in the market is called an outstanding bid and is represented by \(ob\). A valid ask is lower than the present \(oa\) and ask not lower than \(oa\) is invalid ask. A valid bid is a bid higher than present \(ob\) and a bid not higher than \(ob\) is called invalid bid. CDA progresses in rounds and in each round invalid asks and bids are neglected by the market. In each round at most one unit of goods will be cleared and hence a CDA run will have multiple rounds and it terminates when all possible matches have made. A match will be made in the market when \(ob\) is higher than or equal to \(oa\) and match will be made between seller who submitted \(oa\) and the buyer submitted \(ob\). The match price is equal to the average of \(oa\) and \(ob\).

For each trader in the CDA market there is an acceptable price range. \(P_l\) is the lowest acceptable price in the market and \(P_H\) is the highest acceptable price in the market. In competitive grid connected energy markets this range will be termed as Grid buying price and Grid selling price.

The role of agents in agent based CDA markets is to represent their owners, who may be buyers or sellers. The agent can be an auctioneer, who conducts the auction. In practical, an agent in CDA market is a software intelligence that can be viewed as a delegate of his/her owner to achieve good profit.

C. Bidding Strategy:

Each trading agent in CDA follows a bidding strategy which allows him/her to squeeze maximum profit from the market. The bidding strategy followed by any trading agent merely requires two types of data, the global and local data. The global data includes acceptable market price range, present \(oa\) and \(ob\), winner of the last round, matching price history and supply to demand ratio. The local data includes expected profit margin, how many units of goods to trade, the forecast of future market and risk attitude. After perceiving this information, trading agents start placing their bids/asks. Depending on whether the previously placed bid/ask got accepted or not, each trading agent computes next bid/ask to be placed in the market.

In the agent based CDA market proposed here, trading agents follow the intelligent bidding strategy. This bidding strategy is derived from standard bidding strategy called “Zero-Intelligence-plus(ZIP)” strategy.

In a CDA market, profit motivated trading agents will initially quote at a prices which brings them maximum profit. If ‘\(p\)’ is the bid/ask price placed by a trading agent, then the price should always be better than or equal to a price called limit price (LM) of the trader. Placing asks lower than limit prices gives loss to the selling agents and placing bids more than limit price gives loss to buying agents. The relative difference between \(p\) and LM is called profit margin (PM). For selling agent increasing profit margin increases the ask value, whereas decreasing the profit margin reduces ask value. On the other hand, for a buying agent increasing profit margin decreases lower bid and decreasing profit margin results higher bid. The strategy followed by intelligent trading agents is similar to those of ZIP trading agents. However, the amount of increase/decrease in profit margin is different from ZIP strategy.

Qualitatively the intelligent strategy followed by trading agent is as follows:

a. An intelligent selling agent raises its profit margin whenever the last ask was accepted. On the other hand, a selling agent lowers profit margin if it is still active and the last ask was rejected.

b. An intelligent buying agent raises its profit margin whenever the last bid was accepted and is less than LM of the buying agent. On the other hand, a buying agent lowers profit margin if it is still active and the last bid was rejected.

The quantitative explanation of the intelligent trading strategy is similar to that of ZIP bidding strategy except the target price used in the bid/ask updating. The proposed intelligent strategy computes the target price \(T_i(t)\) as:

\[ T_i(t) = A_i(t) * S + B_i(t) * e(t) \]

\[ \text{.................(1)} \]

The \(A_i(t)\) , \(B_i(t)\) are the random values generated as mentioned above. \(S\) is standard target which is current \(oa\) for sellers and current \(ob\) for buyers. The \(e(t)\) in (1) is called eagerness and is calculated as the present ratio of supply to demand for seller agents and demand to supply for buyer agents.

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III. MICRO-GRID ARCHITECTURE
The proposed architecture to embed demand response into microgrid is shown in Fig.1. the architecture has agents called Global Intelligent Agent (GIA), Microgrid Intelligent Agent (MIA), Demand response agent (DRA), Load Agent (Lxy) and Generation Agent (Gxy). The agent GIA is further having agents named Recording Agent (RA) and Global Auctioneer Agent (GAA). The agent DRA is having two internal agents named Floating Buyer Management Agent (FBMA) and Bi-lateral Contract Management Agent (BCMA) to serve the loads participating in demand response. The agent MIA is also having two internal agents i.e. Priority Management Agent (PMA) and Local Auctioneer Agent (LAA). The detailed explanation of the agents in the architecture is given in the following sections.

A. Load and Generation Agents
The agents in the bottom level of the architecture are Lxy and Gxy which represents Load and Generation entities. The term ‘xy’ in ‘Lxy’ indicates load agent’s location and association. For example L_{12} indicates load number one of the second microgrid. Similarly Gxy indicates generation number ‘x’ of the microgrid ‘y’. The agents ‘Lxy’ and ‘Gxy’ have intelligence to bid in the auction conducted either by GAA or LAA. Upon requested by MIA, each load and generation agent collects owner choice and informs back to the MIA. Apart from collecting owner choice ‘Gxy’ has intelligence to sign bilateral contracts and to remind the owner regarding the signed contracts. Upon receiving the end of auction signal ‘Lxy’ and ‘Gxy’ will inform the owner regarding the set points for the next interval. The intelligence developed for Lxy and Gxy will allow these agents to participate in global market and local market simultaneously.

B. Microgrid Intelligent Agent
The next hierarchical agent in the architecture is MIA which is responsible for conducting auction among local agents by maintaining equal supply and demand in the local market. MIA makes local market cheaper and provides a privilege of ‘participation’ to high priority loads. The whole functioning of MIA is attended by Priority Maintenance Agent (PMA) and Local Auctioneer Agent (LAA). The PMA of each MIA is responsible for maintaining priorities of the loads having association with MIA. The PMA calculates priority index of each load agent by considering how frequently a load agent is participating in demand response and the share of the load agent in totally recorded demand response. PMA issues gate pass to high priority loads to enter local market. On the other hand, PMA verifies the type of generation of each generation agent willing to participate in the auction and allows low generation cost agents to enter local market. The LAA of each MIA is responsible for conducting auction among the traders who got gate pass to local market. Each trader in the local market follows the bidding strategy discussed before. Upon receiving bids from traders (load and generation agents), the LAA identifies the outstanding bid (ob) and outstanding ask (oa) in the market. LAA clears a portion of the market following the protocol mentioned in section II and subtracts an amount called ‘clearing size’ from current supply and demand in the local market. The clearing size is not a static value in the local market and it varies from round to round. The clearing size (CS) is the minimum among entitlements of the traders who submitted oa and ob. Upon finding the clearing size, LAA calculates the matching price by taking average of oa and ob.

C. Demand Response Agent
Next hierarchical agent in the architecture is Demand Response Agent (DRA) and its role is to receive and serve the demand response options by load agents. Like MIA, DRA also contains two internal agents viz. Floating Buyer Agent (FBMA) and Bi-lateral Contract Management Agent (BCMA) which will address the key roles of the DRA. Upon receiving demand response options from load agents, DRA communicates all demand response participations to BCMA of DRA. For each demand response option received, BCMA initiates bilateral negation with all the sellers irrespective of their current participation status. For doing bilateral negotiation BCMA creates a form called ‘bi-lateral contract form’. The bilateral contract form contains time intervals, price and participating load information. After receiving bi-lateral contract form, each seller agent leaves its signature against the favorable intervals in the willingness record of the bilateral contract and sends back to BCMA. BCMA collects all the signed bilateral contracts by seller agents and consolidates willingness records. While consolidating the willingness record, BCMA takes the following the steps into account.

a. Arrange all the contract forms in the order of arrival time.
b. Create an empty willingness record.
c. Allot the interval signed intervals
d. If more than one seller agent is willing to make the contract in same interval, then consider the number of other intervals they have signed and allot to the agent who has signed for less number of intervals.

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In Fig. 2(a), (b) and (c) a demand response with starting interval ‘5’ and dead line of 8 has been considered with operational time (OT) of 3. In order to serve such demand response option, BCMA creates a bi-lateral contract having willingness record with DS as 5 and DL as 8 and sends to all sellers (say G12, G22, and G32). The received bilateral contract forms signed by seller agents G12, G22 and G32 are shown at the left of Fig. 2(a), 2(b) and 2(c) respectively. It has been assumed that the signed contract sent by G12 has reached first.

In Fig. 2 (a) the interval ‘5’ is allotted to the seller agent G12. Fig.2 (b) shows updating consolidated willingness record with the willingness record sent by G22. G22 has signed in two intervals 7 and 8. Since 7 and 8 have not been allotted so far, G22 is allotted with the intervals 7 and 8. Fig. 2 (c) shows updating consolidated willingness record with the willingness record sent by G32. G32 has signed in interval 7. Since interval 7 has already been allotted to G22, BCMA verifies back and allots 7 to G32 because G32 has signed for less number of intervals and hence the consolidated willingness record becomes {5=G12, 6=null, 7=G32, 8=G22} as shown at the right of Fig. 2. (c).

Once consolidating the received contract forms is over, BCMA maps the consolidated willingness record to an array of ‘1’s and ‘0’s. While mapping consolidated willingness record, BCMA places ‘1’ if the interval is allotted otherwise places zero. The mapped on solidated willingness record is shown in Fig. 2 (d). Once the mapped willingness record is prepared, BCMA identifies the best set of intervals during which the load agent participating in demand response is to be served. In order to find best set of intervals, BCMA calculates sum of the mapped values of all possible combinations of intervals with each combination having intervals of OT. OT is the operation time specified by the load agent participating in demand response. Upon calculating all possible combinations, BCMA traces the combination for giving maximum value. This combination is the optimal duration to serve the load participating in demand response. If more than one such combinations results the same value then the combination which will be served first is to be considered. BCMA informs the result of negotiation to load agents participating in demand response, generation agents who have been given the chance of serving load and FBMA. FBMA examines the result communicated by BCMA and identifies the number of virtual buyers to be created. The virtual buyers are also called floating buyer agents (FBAs). FBMA creates FBA for each zero in the best set of intervals so as to continuously feed the load participating in demand response. The key role of a FBA is to purchase power from global market on behalf of load agent participating in demand response and after finishing the job assigned by FBMA these agents will terminate on their own.

D. Global Intelligent Agent:

The GIA in top level of the proposed architecture is responsible for initiating all local markets and conducting auction with global scope. The GIA also records the successful contracts and thereby informs corresponding traders. Like DRA of the top level architecture, GIA also contains two agents viz. Recording Agent (RA) and Global Auctioneer Agent (GAA). The key functions of the GIA mentioned are actually addressed by GAA and RA. The GAA of GIA conducts auction among the buyer agents willing to purchase power from global market and the seller agents willing to sell power in global market. The buyer agents may include FBAs and /or the load agents from the microgrids with deficit power generation. The GAA conducts auction following CDA protocol similar to LAA. Unlike LAA, the GAA clears the market with fixed clearing unit size. The clearing unit size is fixed for one CDA run and is equal to greatest common divisor of all the entitlements of the traders participating in auction. The clearing size will be fixed at the beginning of the first round and remains fixed for all the rounds. At the end of the auction GAA matches all unmatched traders to grid. The RA of GIA is instrumental in recoding all successful transactions among global members. RA is also responsible for sending auction close signal to all the traders participated in the global auction market.

IV. AN EXAMPLE

This section illustrates the working of the proposed architecture with the help of a case study. During each demand interval (15min duration), the first five minutes is
considered as auction period during which the auction (CDA) will be conducted among the agents willing to sell or purchase power in the next demand interval. Fig. 3 shows a system with two interconnected microgrids each having two distributed generators and two loads. Generation and load agents in each microgrid can participate simultaneously in both local and global markets. If excess power is available, then the intelligent agent of the corresponding microgrid initiates global market participation by allowing agents with high cost of generation to global market. MIA allows low priority load agents to enter global market if power deficit happens. For the case study shown in Fig. 3, a market price range of (GBP=9 cents/kWh, GSP=13.5 cents/kWh) is considered. Hence in each market (local or global) the bids/asks should be in this range. Table 1 and 2 show the global auction market prices and participation share of each trading agent without demand response on the previous day. The interval numbers in table 1 indicate the demand intervals starting from 6 am. The price history of the global market is an essential index for customers to start participating in demand response. It is also considered that L21 is having low priority loads of total capacity 30kW.

**Table 1. Global market share of generation agents and price**

<table>
<thead>
<tr>
<th>Interval</th>
<th>G11 (Price)</th>
<th>G21 (Price)</th>
<th>G12 (Price)</th>
<th>G22 (Price)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>(9, 9)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>50</td>
<td>(11.7)</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>50</td>
<td>(11.7)</td>
<td>30</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>40</td>
<td>(9, 9)</td>
<td>0</td>
</tr>
</tbody>
</table>

*Units for market share are in kW, Price in cents/kWh

**Table 2. Global market share of load agents**

<table>
<thead>
<tr>
<th>Interval</th>
<th>L11 (Price)</th>
<th>L21 (Price)</th>
<th>L12 (Price)</th>
<th>L22 (Price)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>(12.3)</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>(12.3)</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>(12.3)</td>
</tr>
</tbody>
</table>

*Units for market share are in kW, Price in cents/kWh

In the beginning of auction period of the interval ‘0’, the GAA of GIA issues “auction start” command to each MIA and FBMA of DRA. Upon receiving auction start signal from GIA, MIAs will request their load and generation agents to submit their bids/asks. While submitting the load requirement data L11 and L21 check the global history. Since the market is in initial stage and no demand response has recorded so far, the priorities of all load agents are same and hence any one of the load agents can be forwarded to global market.

Due to non availability of the power in local market from interval 1 to 3 on the previous day L21 was forwarded to global market and L21 purchased 30 kW of power from global market at a price 12.3 cents/kWh. Therefore, L21 chooses to participate in demand response and submits demand response option with DS=1, DL=7, OT=3 as (1, 7, 3). L11 (50kW), L21 (30kW, (1, 7, 3)), G11 (40kW) and G12 (30kW) of MG1 will submit the load requirement, demand response and generation availability information to intelligent agent (MIA). The PMA of MIA updates priority record to account new demand response participation and forwards.
demand response option to BCMA of DRA. However, the information provided by the agents in MG\textsubscript{1} may not be same as previous day. In such situation, MIA\textsubscript{1} will issues gate pass as per the updated history of the agents. Similarly L\textsubscript{i1}, L\textsubscript{i2}, G\textsubscript{i1}, and G\textsubscript{i2} submit requirement and availability of power to MIA\textsubscript{2}. Due to surplus power available MIA\textsubscript{2} forwards G\textsubscript{i2} to global market. MIA\textsubscript{1} and MIA\textsubscript{2} issue gate pass to highest priority loads and low cost generation agents. While giving gate passes MIA maintains supply to demand ratio as unity. LAA of the MIAs and GAA of GIA start conducting auction among the agents entered local and global auction markets respectively. On the other hand BCMA creates bilateral contract for the received demand response option and initiates negotiation with all generation agents. The bilateral contract form is having information size=30k, price= 11.25 cents/kWh, and willingness record with DS=1, DL=7. The price 11.25 is calculated by taking the average of GBP and GSP. As a reply to the bilateral contract form, each generator compares their price history for the previous day with the current price offered in the contract and sends willingness to BCMA. In the present case study G\textsubscript{11} sends \{4\}, G\textsubscript{12} sends \{6\}, G\textsubscript{21} send \{6, 7\} as their willingness. The BCMA consolidates the signed contract forms sent by generation agents by following the procedure given in section III as \{1=null, 2=null, 3=null, 4=G\textsubscript{11}, 5=null, 6=G\textsubscript{12}, 7=G\textsubscript{21}\}. The BCMA maps the consolidated willingness record and identifies the best set of intervals as \{4, 5, 6\}. The BCMA communicates this result to concerned agents and FBMA. FBMA creates a virtual buyer FBA to purchase power for interval 5 from global market in order to maintain continuity in serving the load. During the interval 4 the newly created FBA will participate in global auction and purchase power on behalf of L\textsubscript{21}. Upon successfully conducting and recording all successful matches, GIA and MIA terminates the auction by sending auction close signal to all participated agents. The FBAs participated in the global auction market will terminate from agent platform after receiving auction close from RA of the GIA. Fig. 4 shows the flow chart of the aforementioned mechanism.

The above MAS will be simulated using Java Application DEvelopment (JADE) framework.

V. FUTURE WORK.

In this work an agent based architecture for trading and power management in microgrids are presented. The proposed system uses continuous double auction algorithm for trading. Priority for customers participating in demand response at trading level is novel. The concept mentioned above has to be simulated with two microgrids system using JADE framework and can be extended for multiple microgrids.

VI. REFERENCES


Implementation of TOU for Smart Power Consumption

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1 PHD Scholar, JNTU, Kakinada, A.P.,
2 Asst Professor in EEE, GIET Gunupur Orissa,
3 Professor, JNTU, Hyderabad

**Abstract** - Smart grid encourages consumers to prefer suitable energy in co-operation with power grid at the most suitable time. The main aim of this is the load sharing by motivating consumers to operate only the most essential appliances at peak load periods and to transfer the operation of less needed appliances at off peak hours when tariff may be lower. A case study has been developed to provide information to enable the user Mr. Krishna Morthy who is a LT consumer. The results and analysis which have been presented in this has been generated by a real time data collected for Mogulthur, Andhra pradesh.

**I. INTRODUCTION**

The smart energy information management system developed with ability to record, store and process power consumption data of every major appliance in the domestic and industries. The power consumption data is accessible through the smart way like consumer energy portal, emails and on handheld devices. Consumers can track their power usage by device, room or appliance, which helps better regulate power consumption by analyzing minute wise, half-hourly, hourly, daily and monthly and smart appliances automatically response to increased demand in smart grid.

The case studies is developed for LT consumers, build complete power analytics, developed different types reports and save the power consumption amount by using power during off peak or mid peak. The TOU (Time of Use) Tariff is used reduce peak loads. The power analytics reports provide the deep insight into their consumption patterns like on peak, off peak, mid peak and cost per appliances.

**Appliances wise consumption for LT consumer** – The following case study has been developed to provide information to enable the user to act Mr. Krishna Morthy is a LT consumer and category is LT1-domestic. The below analysis provides deep insight for Mr. Krishna Morthy to take effective decisions

The consumers does not know about their Daily energy consumption, daily/hourly/half hourly/minute wise consumption, which appliances are causing more energy consumption

How they could manage their consumption better

The below reports clearly demonstrated the net savings by the use of TOU tariffs and the designed reports like cost by appliances.

**Appliances wise consumption for LT consumer** - In the LT consumers in Mogulthur circle we have consider Krishns Morthy with service no.000017 and physically the data is collected by appliances wise and analyzed the power consumption by appliance for Krishna Morthy and provided the deep insight on overall consumption.

Table Appliances wise consumption for LT consumers in month of September 2012

<table>
<thead>
<tr>
<th>Application ID</th>
<th>Billed units kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>cloth washer</td>
<td>9</td>
</tr>
<tr>
<td>dryer+iron</td>
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<tr>
<td>fans+cooler</td>
<td>40</td>
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<tr>
<td>Lights</td>
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<tr>
<td>Others</td>
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<td>Pump</td>
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<tr>
<td>Refrigeration</td>
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<tr>
<td>TV+ Computer</td>
<td>44</td>
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<tr>
<td>water heater</td>
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Proceedings of National Seminar on “Dispersed Generation & Smart Grid”

Table Appliances wise consumption for LT consumers in month of September 2012

<table>
<thead>
<tr>
<th>Application ID</th>
<th>Billed units kWh</th>
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<tbody>
<tr>
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<td>water heater</td>
<td>10</td>
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</table>

220

Cost Wise Consumption For LT consumer - In the LT consumer in Mogulturu circle we have consider KRISHNA MOORTY with service no. sc1020/21 and physically the data is collected appliances wise and analysed the power consumption cost by Appliances wise and analyzed the power consumption cost by appliance for KRISHNA MOORTY and provided deep insight on overall consumption

Table Appliances wise consumption for LT consumers in month of October 2012

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<tr>
<td>dryer+iron</td>
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<tr>
<td>fans+cooler</td>
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<tr>
<td>Lights</td>
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<tr>
<td>Others</td>
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<td>Pump</td>
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<td>Refrigeration</td>
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<td>TV+ Computer</td>
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<td>water heater</td>
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<td>208</td>
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</table>

Table Appliances wise consumption for LT consumers in month of November 2012

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<tr>
<td>fans+cooler</td>
<td>43</td>
</tr>
<tr>
<td>Lights</td>
<td>35</td>
</tr>
<tr>
<td>Others</td>
<td>23</td>
</tr>
<tr>
<td>Pump</td>
<td>9</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>19</td>
</tr>
<tr>
<td>TV+ Computer</td>
<td>47</td>
</tr>
<tr>
<td>water heater</td>
<td>12</td>
</tr>
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<td></td>
<td>208</td>
</tr>
</tbody>
</table>

Table cost wise consumption for LT consumer in the month of September 2012

<table>
<thead>
<tr>
<th>Appliance ID</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>clother washer</td>
<td>32.4</td>
</tr>
<tr>
<td>dryer+iron</td>
<td>39.6</td>
</tr>
<tr>
<td>fans+cooler</td>
<td>144</td>
</tr>
</tbody>
</table>

Table Appliances wise consumption for LT consumers in month of November 2012

<table>
<thead>
<tr>
<th>Appliance ID</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>lights</td>
<td>115.2</td>
</tr>
<tr>
<td>others</td>
<td>64.8</td>
</tr>
<tr>
<td>pump</td>
<td>43.2</td>
</tr>
<tr>
<td>refrigeration</td>
<td>54</td>
</tr>
<tr>
<td>TV+ Computer</td>
<td>158.4</td>
</tr>
<tr>
<td>water heater</td>
<td>32.4</td>
</tr>
<tr>
<td></td>
<td>684</td>
</tr>
</tbody>
</table>

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Figure cost wise consumption for LT consumer in the month of September 2012

Table cost wise consumption for LT consumer in the month of October 2012

**Appliance ID** | **Cost**
---|---
clother washer | 69
dryer+iron | 80.5
fans+cooler | 276
lights | 184
others | 115
pump | 97.75
refrigeration | 86.25
TV+ Computer | 299
water heater | 57.5

1265

Figure cost wise consumption for LT consumer in the month of October 2012

Table cost wise consumption for LT consumer in the month of November 2012

**Appliance ID** | **Cost**
clother washer | 40.25
dryer+iron | 74.75
fans+cooler | 247.25
lights | 201.25
others | 132.25
pump | 51.75
refrigeration | 109.25
TV+ Computer | 270.25
water heater | 61

Overall result | 1188

Figure cost wise consumption for LT consumer in the month of November 2012

**Appliance wise consumption for six months in kWh units for LT consumer** - The Krishna Moorty consumption pattern for six months by appliance wise and analyzed the month wise comparison

<table>
<thead>
<tr>
<th>Application ID</th>
<th>cloths washer billed units</th>
<th>Dryer + iron billed units</th>
<th>Fans + cooler billed units</th>
<th>lights billed units</th>
<th>others billed units</th>
<th>pump billed units</th>
<th>Refrigerator billed units</th>
<th>TV + computer billed units</th>
<th>water heater billed units</th>
<th>overall result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sep-12</td>
<td>9</td>
<td>11</td>
<td>40</td>
<td>32</td>
<td>18</td>
<td>12</td>
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<td>Oct-12</td>
<td>12</td>
<td>14</td>
<td>48</td>
<td>32</td>
<td>20</td>
<td>17</td>
<td>15</td>
<td>52</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Nov-12</td>
<td>7</td>
<td>13</td>
<td>43</td>
<td>35</td>
<td>23</td>
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<td>204</td>
<td>124</td>
<td>69</td>
<td>105</td>
<td>265</td>
<td>67</td>
<td></td>
</tr>
</tbody>
</table>

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Monthly peak wise consumption for LT consumer
The consumer can visualize every month power consumption sliced into the MID, PEAK, OFF PEAK and reduce the demand – supply mismatch. Krishna moorty Can login to consumer energy portal and he can do the different types of analysis.
Table monthly peak wise consumption LT consumer for six months

<table>
<thead>
<tr>
<th>peak category</th>
<th>Mid peak billed units KWH</th>
<th>Off peak billed units KWH</th>
<th>On peak billed units KWH</th>
<th>Overall result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sep-12</td>
<td>102</td>
<td>47</td>
<td>41</td>
<td>190</td>
</tr>
<tr>
<td>Oct-12</td>
<td>154</td>
<td>53</td>
<td>13</td>
<td>220</td>
</tr>
<tr>
<td>Nov-12</td>
<td>132</td>
<td>55</td>
<td>21</td>
<td>208</td>
</tr>
<tr>
<td>Overall result</td>
<td>725</td>
<td>327</td>
<td>165</td>
<td>1217</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peak category</th>
<th>billed units kwh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid peak</td>
<td>102</td>
</tr>
<tr>
<td>Off peak</td>
<td>47</td>
</tr>
<tr>
<td>On peak</td>
<td>41</td>
</tr>
<tr>
<td>Overall result</td>
<td>190</td>
</tr>
</tbody>
</table>

Figure monthly peak wise consumption LT consumer for six months
Table monthly peak wise consumption in the month of September 2012

Authors are solely responsible for Plagiarism Copy right reserved DGSG-2013@NIST[Type text]
figure monthly peak wise consumption in the month of September 2012
Table monthly peak wise consumption in the month of October 2012
Table monthly peak wise consumption in the month of November 2012

<table>
<thead>
<tr>
<th>Peak category</th>
<th>billed units (kwh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid peak</td>
<td>154</td>
</tr>
<tr>
<td>Off peak</td>
<td>53</td>
</tr>
<tr>
<td>On peak</td>
<td>13</td>
</tr>
<tr>
<td>Overall result</td>
<td>220</td>
</tr>
</tbody>
</table>

Figure monthly peak wise consumption in the month of November 2012

**Daily-Month peak wise consumption for LT consumer**

Daily data provides enough details for consumers to relate day-to-day activities to electricity usage. Examples include vacation days, holiday events, working days versus non-working days, extreme weather days versus mild days and so on. Only the days that are unusual stand out and those are the days the consumer care about.

Krishna moorty can log in to consumer’s energy portal and he can do the different types of analysis.

Table daily-month peak wise consumption in the month of September 2012

<table>
<thead>
<tr>
<th>Day</th>
<th>Mid peak billed units</th>
<th>Off peak billed units</th>
<th>On peak billed units</th>
<th>Overall result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>
Table Daily- month peak wise consumption in the month of October 2012

<table>
<thead>
<tr>
<th>Day</th>
<th>Mid peak billed units</th>
<th>Off peak billed units</th>
<th>On peak billed units</th>
<th>Overall result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
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</tr>
<tr>
<td>8</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

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### Hour wise consumption for LT customer

Hour wise consumption instantly knowing through consumer energy portal and also HAN automatically control the power consumption with help of smart appliances. The consumer can visualize the load pattern of the power consumption and take necessary action.

Krishna moorty can logon to consumer’s energy portal and he can do the different types of analysis.

<table>
<thead>
<tr>
<th>Hour</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<tr>
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<tr>
<td>11</td>
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<td>29</td>
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<td>6</td>
<td>2</td>
<td>1</td>
<td>9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Overall Result**: 122 55 31 208
Hourly-daily consumption in the month of nov.– 2012

TOU tariff calculation for LT consumer

Power companies to charge consumers different prices for electricity on the basis of the time of use the electricity used so that it will encourage consumers to shift some of their electricity uses to lower cost, non-peak hours. Many consumers can reduce their electricity bills. TOU tariff compare to regular Tariff and in the following table will provides the net savings to Krishna Moorthy.

<table>
<thead>
<tr>
<th></th>
<th>billed units</th>
<th>regular cost</th>
<th>TOU cost</th>
<th>net savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sep-12</td>
<td>190</td>
<td>684</td>
<td>674.38</td>
<td>9.62</td>
</tr>
<tr>
<td>Oct-12</td>
<td>220</td>
<td>1265</td>
<td>1275.39</td>
<td>11.15</td>
</tr>
<tr>
<td>Nov-12</td>
<td>208</td>
<td>1196</td>
<td>1175.31</td>
<td>20.69</td>
</tr>
<tr>
<td>Overall result</td>
<td>1217</td>
<td>5740</td>
<td>5618.84</td>
<td>142.7</td>
</tr>
</tbody>
</table>

and also reduce stress on the electricity generation and transmission infrastructure.

In the LT case study by seeing these reports he can able to shift the small amount of peak load into mid peak and half peak and directly reduce the electricity bill in the TOU Table TOU Tariff calculation monthly wise for LT consumer.
Figure TOU Tariff calculation monthly wise for LT consumer

Table TOU month wise consumption

<table>
<thead>
<tr>
<th>month</th>
<th>regular cost</th>
<th>TOU cost</th>
<th>net savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sep-12</td>
<td>684</td>
<td>674.38</td>
<td>9.62</td>
</tr>
<tr>
<td>Oct-12</td>
<td>1265</td>
<td>1253.85</td>
<td>11.15</td>
</tr>
<tr>
<td>Nov-12</td>
<td>1196</td>
<td>1175.31</td>
<td>20.69</td>
</tr>
<tr>
<td>Overall result</td>
<td>5740</td>
<td>5597.3</td>
<td>142.7</td>
</tr>
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</table>

Conclusion

It will reduce the demand supply mismatch, smart grids will be able to self heal, provide high reliability and power quality, be resistant to cyber attacks, operate with multi-directional power flow, increase equipment utilization, operate with lower cost and offer customers a variety of service choices. Smart appliances should be used in conjunction with smart grid for reducing the peak demand. Real time information feedback regarding peak load conditions sent to smart appliances at customer site. Reduced variability in consumption leads to lower breakdowns and lower operating costs. The different types TOU tariff can be designed by analyzing the different load patterns. Master data standardization can be developed for strong analysis.

REFERENCES

Voltage mode control for improving MPPT performance in PV system

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¹Dept. of Electrical Engg., National Institute of Technology Rourkela-769008, India
²Dept. of Electronics & Communication Engg., NIST Berhampur- 761008 India

Abstract

In photo voltaic power systems, both photovoltaic (PV) modules, switching mode converters and power conditioning systems present non linear and time variant characteristics, which results in difficult control problem. So the main theme of this paper is to review the different control techniques for maximum power point tracking (MPPT). These control techniques not only boost the low voltage but also convert the solar dc power into high quality ac power for driving autonomous loads without any filter. Pulse width modulation (PWM) used in these control strategies can reduce the switching loss, voltage and current stress of the switching devices. In this study dynamics of control techniques are also presented.

I. Introduction

The growing demand for energy, together with the increased price of oil products and the attention paid to environmental pollution, have progressively increased the interest in renewable energy sources. Many applications employing this technology have been developed, such as solar power generation, solar vehicle construction, battery charging, water pumping, satellite power systems, and so on. Nowadays, PV systems, which make the conversion of solar energy to electrical energy possible, have become widely diffused, both in grid connection and stand alone configurations. These are especially beneficial in remote areas that are isolated from the power distribution network.

Fig.1 Renewable Energy as share of total primary energy consumption

Among all the energy sources, renewable energy shares only 8% of the total energy consumption as shown in Fig.1, but solar energy is only 1% in 8% of renewable energy which shows the utilization is far low

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non-linear controllers are reviewed in this paper along with linear controllers.

III. Control overview in PV system

In this section control in both dc–dc converter and inverter has been described. Fig.2 shows the grid connected PV system. The PV system includes a PV array, boost converter, and inverter connected to grid. As the insolation and temperature is varying continuously during 24 hours time, the main objective in PV system is to track the maximum power for all insolation and temperature. The PV voltage $v_{pv}$ and the PV current $i_{pv}$ are taken in the MPPT block for picking the maximum power point voltage $v_{pv*}$ for calculating the maximum power from the instantaneous values of $v_{pv}$ and $i_{pv}$ at different insolation and temperature.

The algorithm used in MPPT for trapping the reference voltage $v_{pv*}$ is P&O or I&C or hill-climbing. Since the PV reference output voltage $v_{pv*}$ is very small, it is required to step-up the voltage, so the dc–dc converter used is boost converter with PWM technique in current control mode control.

The reference voltage $v_{pv*}$ obtained is given to PI controller to obtain the reference current command $i_{g*}$. Fig.2 shows the switching control both in dc–dc converter and inverter. The inductor current $i_L$ and the reference current command $i_{g*}$ is used to calculate the duty ratio $D$ in pulse width modulator as per the equations proposed in [7]. The driver signal obtained from PWM is used to drive the power MOSFET $S_0$ in boost converter.

Coming to the inverter case, the output in boost converter $v_{dc}$ is compared with our required reference dc voltage $v_{dc*}$ and fed to the PI controller, the output of PI controller is used to adjust the grid voltage $v_{g}$, to obtain the reference grid current $i_{g*}$. The grid current $i_{g}$ and the reference grid current $i_{g*}$ is used to calculate the control signal proposed in [8] for driving the four MOSFET switches $s_1,s_2,s_3,s_4$ in full bridge inverter. The PI controllers are considered by using the first order transfer function in which only one zero and one pole is considered.

Fig.2 Basic block diagram of single phase grid connected PV system

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In this control, the main observation that has to be considered is current $i_i$ is following the reference current $i_i^*$, PV voltage $v_{pv}$ is following the reference voltage $v_{pv}^*$ and grid current $i_g$ is following the reference grid current $i_g^*$ to shape the fundamental sinusoidal wave to avoid the harmonics generated on the grid side. The linear PI controllers are used for obtaining all the above references which controls the power switches (MOSFET) in the current or voltage mode control. But the response obtained with the linear PI controllers are not satisfactory which leads to the development of non-linear controllers. Three MPPT algorithms which are commonly used for tracking the reference voltage of PV array at maximum power are discussed to a brief extent along with flowcharts.

Perturb and observe (P&O) algorithm is dominantly used in practical PV systems for the MPPT control due to its simple implementation, high reliability and tracking efficiency. Fig.3 shows the flow chart of (P&O) algorithm. The present power $p(k)$ is calculated with the present values of PV voltage $V(k)$ and current $I(k)$, and is compared with the previous power $p(k-1)$. If the power increases, keep the next voltage change in the same direction as the previous change. Otherwise, change the voltage in the opposite direction as the previous one.

In hill climbing algorithm shown in Fig.4, instead of perturbing the voltage change, duty cycle perturbation is taken, and the remaining part of algorithm is taken same. Fig.4 Flow chart of Hill-climbing algorithm

The duty ratio in this case is defined for boost converter as

\[ D = \frac{V_{pv}^*}{V_{pv}} \]

where $V_{pv}^*$ is the MPPT output voltage and $V_{pv}$ is the solar panel voltage.

During rapidly changing irradiation and temperature, there is necessity to track the maximum power point, so Incremental conductance (I&C) algorithm is best suited. Fig.5 shows the flow chart of the incremental conductance algorithm which is based on the fact that the sum of instantaneous conductance $\frac{I}{V}$ and the incremental conductance $\left( \frac{\Delta I}{\Delta V} \right)$ is zero at the MPP, positive at the left of MPP, and negative on the right. The condition $\frac{\Delta I}{\Delta V} = -\frac{I}{V}$ is usually replaced by $\left( \frac{\Delta I}{\Delta V} + I \right) < \varepsilon$, where $\varepsilon$ is a small positive number.

![Fig.3 Flow chart of P&O algorithm](image)}
With this algorithm, at steady state the operating point may be located at a certain point in the interval BC or oscillating between the interval AB and CD as shown in Fig.6. If the step size $\Delta V_p = C$ is increased for rapid dynamic response to extract more energy under rapidly changing atmospheric (e.g. solar radiation and temperature) conditions, the tracking accuracy is decreased due to higher oscillation around the MPP and vice-versa. The perturbation step-size is automatically tuned according to the inherent PV array characteristics. If the operating point is far from MPP, the step size is increased to achieve fast dynamic response, whereas the operating point is near to the MPP, the step size becomes very small to reduce the steady state oscillation and improve energy converter efficiency of the PV power system. From Fig.6 is obtained based on the following equations:

$$\frac{dp}{dv} > 0, \text{left of MPP}$$
$$\frac{dp}{dv} = 0, \text{at MPP}$$
$$\frac{dp}{dv} < 0, \text{right of MPP}$$

From Fig.5, it can be seen that the perturbation step size should be positive (negative) to locate the MPP when operating on the left(right) of MPP, considering equation[1], it is evident that the $\frac{dp}{dv}$ is essentially suited for step size IV. Voltage mode control

Fig.7 shows the PV system with PWM boost converter in voltage mode control. Varying the duty cycle $D$ can control the DC output voltage of a converter. Voltage mode PWM
control mainly consists of three parts, namely output voltage error amplifier, a saw tooth generator and a PWM comparator. In voltage control mode also for tracking the MPPT, the above three algorithms can be used. In this method, error amplifier compares the output voltage of dc-dc boost converter with the MPPT reference voltage which generates the error voltage $v_e$ given by

$$v_e = \left[1 + \frac{Z_2}{Z_1}\right] v_{pv}^* - \frac{Z_2}{Z_1}v_A \quad (3)$$

The feedback dynamics is determined by the error amplifier consisting of $Z_1$ and $Z_2$. The output error voltage $v_e$ is compared with the saw tooth signal $v_{carrier}$ in the PWM comparator. The output of the comparator is the signal that drives the power switch S in boost converter. Based on the variation of duty ratio generated by PWM comparator, the power switch S is operated by calculating the duty ratio which is given by

$$D = \frac{v_e}{v_{carrier}} \quad (4)$$

The duration of the on-time is determined by the time between the reset of the saw tooth signal and the intersection of the error voltage with the positive going ramp signal.

When the output is lower than the nominal dc output value, a high error voltage is produced which increases the duty ratio causing the subsequent increase in output voltage in voltage mode control and if error voltage is reduced which causes the decrease in duty ratio such that the output voltage is decreased to balance the total output voltage to maintain constant.

The three algorithms Perturb & observe, hill climbing and incremental conductance algorithms used in the current and voltage control modes are tabulated according to the performance parameters in Table.1.

Table 1 Comparison of parameter performance of PV algorithm

<table>
<thead>
<tr>
<th>Algorithm/Parameter</th>
<th>Perturb &amp; Observe</th>
<th>Hill-Climbing</th>
<th>Incremental Conductance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependence</td>
<td>Voltage variation</td>
<td>Duty ratio variation</td>
<td>Conductance variation</td>
</tr>
<tr>
<td>Complexity</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Analog/Digital</td>
<td>Both</td>
<td>Both</td>
<td>Digital</td>
</tr>
<tr>
<td>Periodic tuning</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Sensed parameters</td>
<td>Voltage, current</td>
<td>Voltage, current</td>
<td>Voltage, current</td>
</tr>
<tr>
<td>Convergence speed</td>
<td>Relatively low</td>
<td>Relatively low</td>
<td>Relatively high</td>
</tr>
</tbody>
</table>
Results:

The boost converter output voltage is compared with the reference voltage in the error amplifier and the error voltage $V_e$ is noted, which again is compared with the carrier voltage of fixed frequency (20KHz) and fixed carrier voltage (15V) in the PWM comparator. The pulses obtained from the PWM comparator are used for switching power devices. The waveform results for different operating voltages have been shown in Fig. 8(a-i). In Fig.8(a,d,g), the output voltage $V_s$ time for $V_{in}=10V, 20V, 30V$ have been plotted, which resulted in output voltages of 25V, 45V and 72V respectively. Fig.8(b,e,h) shows the Error voltage $V_e$), carrier voltage($V_{carrier}$) Vs time which gives error voltages of 8.5V, 7.6V, 6.4V for $V_{in}=10V, 20V$ and 30V respectively. When error voltage is intersecting with the fixed carrier frequency, switching pulses are generated which gives switching pulses as shown in Fig.8(c,f,i). So the switching is very important to get the required output according to the load variations. Error amplifier and PWM comparators in which the first order pole and zero is used to obtain the error voltage and PWM switching pulse.
The above mentioned technique improve the maximum power point tracking. Voltage control mode discussed above tracks the maximum power by using the converters (boost converter and inverter). Different algorithms are proposed and voltage mode control along with error amplifier is also
explained for improving MPPT. Voltage control mode given better results compared to MPPT algorithms.

References:
Last Mile Connectivity to a Web of Things
An Energy Management Perspective

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Abstract—Today last mile data connectivity is very essential considering the growing data centric operations that we require to automate and optimize our daily activities. To minimize the non-renewable energy consumption as compared to renewable energy consumption at the last mile we need to be connected to the remote locations beyond the reach of prevailing data communication channels like fiber optic cables and coaxial cable as the add up to a massive cost overhead. We will study the possibilities of Power Line Communications and how it can be used to bridge the gap between remote network of intelligent devices which regulate and monitor the energy consumption. As the intelligent devices will be connected to a global database over the internet we will configure these Web Of Things over the internet.

I. INTRODUCTION

Power Line Communication (PLC) is a communication technology that enables sending data over existing power cables. This means that, with just power cables running to an electronic device (for example) one can both power it up and at the same time control/retrieve data from it in a half-duplex manner.

For the purpose of understanding, PLC can be broadly viewed as:

1. Narrowband PLC
2. Broadband PLC

Narrowband PLC works at lower frequencies (3-500 kHz), lower data rates (up to 100s of kbps), and has longer range (up to several kilometers), which can be extended using repeaters. Broadband PLC works at higher frequencies (1.8-250 MHz), high data rates (up to 100s of Mbps) and is used in shorter-range applications.

Recently, narrowband Power Line Communication has been receiving widespread attention due to its applications in the Smart Grid. Another application that narrowband PLC has been used in is smart energy generation, particularly in micro-inverters for solar panels.

Broadband PLC, in contrast, has mainly found acceptance as a last-mile solution for Internet distribution and home networking. With its high data rates and no additional wiring, broadband PLC is seen as an exciting and effective technology for multimedia distribution within homes. This optimism in the market is reflected by the recent acquisitions of Intellon by Atheros, Coppergate by Sigma, DS2 by Marvell, and Gigle by Broadcom, all in the Home Area Networking (HAN) segment.

There is another way to classify Power Line Communication and that is:

1. PLC over AC lines
2. PLC over DC lines

While most companies are currently geared towards providing AC-PLC solutions, PLC in DC lines also has applications. Two such applications are PLC over the DC-bus in distributed energy generation, and PLC in transportation (electronic controls in airplanes, automobiles and trains). This use reduces wiring complexity, weight, and ultimately cost of communications inside vehicles. However, in this article, we will be dealing mostly with narrowband PLC over AC lines.

The term Internet of Things (IoT), which is rapidly gaining ground in the scenario of modern wireless telecommunications, has recently become popular to emphasize the vision of a global infrastructure of networked physical objects. The basic idea of this concept is the pervasive presence around us of a variety of things or objects – such as Radio-Frequency identification (RFID) tags, sensors, actuators, mobile phones, etc. – which, through unique addressing schemes, are able to interact with each other and cooperate with their neighbors to reach common goals[1-2].

The IoT-idea is not new. However, it only recently became relevant to the practical world, mainly because of the progress made in hardware development in the last decade. The decline of size, cost and energy consumption, hardware dimensions that are closely
linked to each other, now allows the manufacturing of extremely small and inexpensive low-end computers.

Unquestionably, the main strength of the IoT idea is the high impact it will have on several aspects of everyday-life and behavior of potential users. From the point of view of a private user, the most obvious effects of the IoT introduction will be visible in both working and domestic fields. In this context, domestics, assisted living, e-health, enhanced learning are only a few examples of possible application scenarios in which the new paradigm will play a leading role in the near future.

Similarly, from the perspective of business users, the most apparent consequences will be equally visible in fields such as, automation and industrial manufacturing, logistics, business/process management, intelligent transportation of people and goods.

Internet of Things technology for smart grid is forming a tremendous smart network between people and equipment, by all kinds of information sensing equipment or distributed the recognition (RFID device, Infrared sensors, the global positioning system, laser scanning, etc.), which combined with

the existing network technology, database technology, middleware technology, etc. [3], the functions are as follows:

• Running status of the electrical equipment in power system. (Temperature, humidity, air pressure, etc.)
• Electrical parameters monitoring of all network nodes in power system;
• Main equipment health state in power system;
• Real-time tracking of operating personnel and repair personnel;
• Technical personnel’s management information;
• Environmental protection index and service condition of environmental protection equipment.

So, the real-time monitoring of key equipment operation status; the network interaction and the instant connection between users, between user and power system, the meta-analysis of data information, and the implementation of data real-time high-speed bidirectional transmission can improve reliability and availability of power system, which realize the optimization of operation and management. Thus, observability, controllability, self-recoverability for power system can be realized, for association between equipment, personnel management, and two-way exchange between personnel and equipment [4].

This paper analysis the application requirement of IoT at smart grid, combined with its fundamental function. On the base of that, the author initially puts forward the structure and function of IoT under the smart grid framework, and analysis the open issues.

II. POWER LINE COMMUNICATION
PLC is like any other communication technology whereby a sender modulates the data to be sent, injects it onto medium, and the receiver de-modulates the data to read it. The major difference is that PLC does not need extra cabling, it re-uses existing wiring. Considering the pervasiveness of power lines, this means with PLC, virtually all line- powered devices can be controlled or monitored.

When discussing communication technology, it is often useful to refer to the 7-layer OSI model. Some PLC chips can implement only the Physical Layer of the OSI model, while others integrate all seven layers. One could use a Digital Signal Processor (DSP) with a pure software realization of the MAC and an external PHY circuit, or an optimized System-on-Chip (SoC) solution, which includes the complete PLC – MAC and PHY.

Modulation Schemes used in PLC
A variety of modulation schemes can be used in PLC. Some of these are Orthogonal Frequency Division Multiplexing (OFDM), Binary Phase Shift Keying (BPSK), Frequency Shift Keying (FSK), Spread-FSK (S-FSK) and proprietary schemes too (for example Differential Code Shift Keying (DCSK) from Ytran). In the table below, BPSK, FSK, SFSK and OFDM are compared on the basis of two important criteria – bandwidth efficiency and complexity (cost).

OFDM in particular offers high data rates, but requires computational horsepower to churn out Fast Fourier Transforms (FFT) and Inverse-FFT (IFFT), as required by the scheme. On the other hand, BPSK, FSK are robust and simple but offer lower data rates. The current trend is to move towards OFDM with PSK modulation (G3 and probably P1901.2). Such heavy computation will require DSP capability, whereas FSK, PSK and SFSK can be accomplished by a microcontroller.

Various standards have been developed in order to ensure reliable communications and inter-operability, especially for the smart grid and home networking. Examples of such standards are:

These, along with the organizations that govern them like CENELEC, FCC, ARIB, Homeplug Power Alliance specify ranges for operation of PLC. If a worldwide standard for PLC were to be established, this would have a positive impact on adoption of PLC. So far, the G3-PLC standard is touted as the most robust scheme available, and the IEEE 1901.2 working group is committed to developing a universally acceptable standard.

Where:
CENELEC - European Committee for Electrotechnical Standardization.
ARIB – Association of Radio Industries & Businesses
EPRI – Electric Power Research Institute
FCC – Federal Communications Commission

Different regions of the world have different frequency bands allocated to narrowband PLC. The table below summarizes the different frequencies available for narrowband PLC communication in the respective region.

Applications of PLC

Earlier, we saw that PLC is widely used in the Smart Grid and in micro-inverters. As the market gets familiar with this technology, PLC should see wider adoption in other applications like lighting (e.g. traffic light control, LED dimming), industrial (e.g. UPS communicating to a network device, irrigation control), machine-to-machine (e.g. vending machines, a hotel’s reception-to-room communication), telemetry (e.g. offshore oil rigs), transport (e.g. Electronics in cars, trains and airplanes) and indeed, applications of PLC are only limited by one’s creativity. In this article, we will find out a little more about PLC in data distribution.

Last Mile Connectivity to Smart Grid using PLC

The ‘Smart Grid’ is essentially modernization of the transmission and distribution aspects of the electrical grid. This intelligent power distribution infrastructure enables two-way communication between the consumers and the utility. The consumers use home networks to communicate with their smart meter, which further communicates with the utility (Advanced Metering Infrastructure-AMI). The Smart Grid definition does not stop at energy utilization; supply of energy to the grid from Distributed Generation (DG) sources such as solar and wind fall into the same category. The DG system also includes Vehicle-to-Grid (V2G) - bi-directional sharing of electricity between Electric Vehicles (EVs) and Plug-in Electric Hybrid Vehicles (PHEVs) and the electric power grid. In this article, we will talk about AMI, Smart Appliances and V2G.

Advanced Metering Infrastructure:

The whole measurement and collection system that includes meters at the customer site, communication networks between the customer and a service provider, such as an electric, gas, or water utility, and data reception and management systems, that make the information available to the service provider, are referred to as AMI. The Smart Meters transmit the collected data through commonly available fixed networks such as Power Line Communications (PLC), Fixed Radio Frequency (RF) networks, and public networks (e.g. landline, cellular, paging) which is aggregated by a concentrator, sent to the utility and then to a Meter Data Management System for data storage, analysis and billing. Studies show that Narrowband PLC is best suited for AMI with over a 100 million NB-PLC devices installed to date.

Utilities are investing billions in AMI systems. PLC solution for data transmission needs no new infrastructure, unlike wireless, as it uses the existing power cables. Power line carrier systems have long been a favorite at many utilities because it allows them to reliably move data over an infrastructure that they control. Utilities may also use public cellular as the backhaul for the AMI data due to its footprint, zero implementation cost and low monthly fee. But on many occasions they may not be able to provide 100 percent coverage of a utility’s entire customer base.

Figure 2. TI Smart Meter with digital data interface

Figure 3. TI PLC Modulator interfaced with TI
Smart Mater to collect metering data over PLC

Alternatively, using wireless networks, RF solutions or PLC for data transmission will solve this issue. Rural utilities or the utilities located at challenging locations (for e.g. mountainous terrains) which are ill-served by wireless will have a difficulty communicating with the consumers. Additionally, wireless and RF solutions have reduced data rates in presence of interference like Bluetooth devices, cordless phones, concrete objects, hills and even trees. PLC can communicate to any location connected via the power line and has no line-of-sight requirement for data transmission. One of the most important considerations, due to the volume of network traffic inherent to the smart grid network, is congestion mitigation. As compared to wireless solutions based on ZigBee or Wi-Fi, PLC-based AMI have a proven track record of being better suited to avoid network congestion in emergency situations. Another oft cited requirement is that of redundancy in the communication channel – with the ubiquity of power lines, deploying a redundant channel becomes more economical.

III. WEB OF THINGS – THE INTERNET OF THINGS CONCEPT

The users of today’s networked world are swamped with information coming from a myriad of applications and services present on their devices, communication infrastructures, and on the Internet. In the near future, this information overload will be magnified many times when the Internet of Things (IoT) becomes a reality, i.e. objects, smart devices, services, sensors, and RFID’s can interact with the user and among themselves to provide services or information. Despite the simplicity of the operational principles of IoT technology, the design of a complete IoT system encompasses complex interactions not only between different layers of the open systems interconnection model, but it also involves several market, privacy, security, and business issues.

This heterogeneous landscape calls for a middleware platform which is able to consider all these complex variables in a flexible and modular way, which is able to provide a starting point for future upgrades and innovations, and which considerably reduces the implementation costs of IoT solutions.

Internet Of Things used towards last mile connectivity in Smart Grid Architecture

Electric power systems contain three major subsystems, power generation, power delivery, and power utilization. Recently, IoT have been widely recognized as a promising technology that can enhance all these three subsystems, making IoT a vital component of the next-generation electric power system, the smart grid. In this section, an overview of a few potential opportunities of applying IoT in smart grid is discussed.

A. Smart Grid

The term “smart grid” is somewhat qualitative since there are various proposed implementations that have varying levels of sophistication. However, standard among all implementations is the use of advanced sensor and communications technologies to enable better use of assets provide improved reliability and enable consumer access to a wider range of services. There are some defining features that exist in most smart grids

• A smart grid will provide an interface between consumer appliances and the traditional assets in a power system (generation, transmission and distribution),
• A smart grid will be at least semi-autonomous,
• A smart grid will optimize the assets of the power system,
• A smart grid will support better integration of distributed generation into the conventional centralized power system.

B. The application of IoT as a last mile connectivity solution in Smart Grid

As an Indispensable basic link of smart grid peripheral information perception, sensor network has broad application space in the power system, which will play an important role in grid construction, power system safety production management, operation and maintenance, information collection, safety monitoring, measurement and user interaction, etc., and improve Information perception depth and breadth and density in the smart grid.

Application requirements of IoT in smart grid is clear, the main scenarios are:

• In the power generation area, IoT can be used for unit monitoring, distributed power plant monitoring, plant area monitoring, pollutants and gas emissions monitoring, energy consumption monitoring, coal material monitoring, pumped storage power plant monitoring, wind power plant monitoring, power prediction, photovoltaic power plant monitoring, biomass electricity generation, energy storage monitoring, power connection, etc.
• IoT is also widely used for transmission line monitoring, tower protection, intelligent substation, distribution automation, condition monitoring, operation and equipment management, etc.
• IoT is mainly used for smart meter and senior measure, smart power consumption, multi-network convergence, electric vehicle and charging, energy
efficiency monitoring and management, power demand side management, etc.

This shows that, every link in generation, transmission, transformation, distribution, consumption in smart grid needs technical support of IoT. Most businesses of smart grid are associated with IoT.

C. Research in the Architecture of IoT at user side of smart grid using PLC as interface

The final goal to realize the integrated smart grid operation management system is constructing smart grid IoT systematic management system, while IoT system at user side is the key part of smart grid IoT operation management system, which can be divided into the following sections. The structure of IoT applied in smart grid

- Perception layer construction of IoT at user side of smart grid: The key to the IoT construction of distribution network and user network is the data acquisition and the safety monitoring during data acquisition.

- Network layer construction of IoT at user side of smart grid: When realizing real-time data acquisition to smart grid, it is noted that the way of data acquisition is diverse, such as carrier, fiber, radio, GPRS, etc.

- Management layer/ decision auxiliary layer construction of IoT at user side of smart grid: The management of IoT at user side of smart grid needs data curve, history curve, peak alarm, as well as automatic topology and information bidirectional treatment function from user side to distribution side.

Figure 4. IoT Node Based on ARM Microcontroller

IV. COMPATIBILITY ISSUES BETWEEN THE PLC AND THE IoT.

Although the enabling technologies described above make the IoT concept feasible, a large research effort is still required.

we summarize the open research issues in IoT research, the causes for which they are specially crucial for IoT scenarios and the sections when such issues will be discussed [9]. Besides, there are some technical issues for smart grid and the compatibility between IoT and smart grid.

- There is information islands exist in electric power corporations, which makes the information integration difficult. For example, many utilities have implemented separate systems such as a Trouble Call System (TCS), Supervisory Control And Data Acquisition (SCADA) System, Outage Management System (OMS), Asset Management System (AMS), Geographic Information System (GIS), just to name a few. In order to perform their designated tasks, often these systems require information that is resident in some other system and cannot be easily shared with the system that needs it.

- In order to access IoT to smart grid, needs to realize the communication protocol conversion of IoT heterogeneous system and the safety access of sensor nodes.

- The intellectualization of power system has not been complete, a lot of the in use device need to be upgraded, which need tremendous volume of works.

Figure 5. Testing IoT Node Performance in the Lab

- Because of the access of IoT, massive data processing and storage are needed. The computer data processing ability has to meet higher and stricter requirements, and the corresponding hardware costs of power system are also enormous.

Various applications would include remote monitoring, outage management (which includes fault detection of MV equipment), Demand Response (i.e. managing customer consumption of electricity in response to grid equipment), island detection (i.e. ensuring that local grids are not being powered by the DG system when there is no power present from the electric grid) and fraud/theft detection.
Smart Appliances:

A Home Area Network (HAN) is a communication-enabled home where all electrical appliances are connected in a mesh through Wireless, RF or PLC. Electrical appliances, today, are connected in a network with two-way communication enabled, with each other as well as the substation. These Smart Appliances allow automation and control from single or multiple access points.

Home appliances like washing machine, dryer, dishwasher, oven and stove, refrigerator, freezer, air conditioner and water heater, talk to the Smart Meter, (Refer to previous section for details) which gathers information of peak pricing hours from the utility through PLC. The appliances can then switch OFF/ON according to the price variations. This is a win-win situation for the consumer who saves on the electricity bill, and the utility, which can better manage peak demands. PLC also enables appliance monitoring and HVAC control – leading to further energy awareness and savings.

The sensors on the appliance side which are part of an IoT are connected to the Monitor via the Power Line. Any changes on the appliance end will be reflected on the LCD Display, which can be viewed and changed as required. Consumers will literally have control of their entire house at their fingertips.

PLC is a considerably more effective in home networks. HAN being realized by Wireless/Zigbee, will need new infrastructure to be installed. Moreover, penetrating physical barriers like walls within one floor, or reaching out to different floors is a challenge for Wireless. Wireless networks often face performance issues, like mentioned in the previous section, due to RF interference caused by devices like microwave oven, cordless phones or even Bluetooth devices at home. PLC on the other hand can reach out to every node connected via the power line. It converts virtually every socket in ones home into an access point, in many ways incorporating the best of wired and wireless communication.

Smart Power in Data Centers:

The Problem: With the rise of cloud computing and internet services, data centers and collocation facilities continue to show consistent double digit growth. Data center downtime is completely unacceptable due to loss of revenue and reputation that it causes. Such downtime is primarily caused by UPS battery failure, UPS overloading, and circuit breaker failure. Another critical concern for data centers is energy efficiency of devices because of rising unit electricity costs and additional cooling costs. Simultaneously, companies who outsource their computing requirements want access to all performance metrics of their systems including power at various levels. Adding communication between devices is a challenge, because wireless cannot work reliably in the data center environment while wired communication would exacerbate the problem of cable clutter.

V. CHALLENGES

PLC, of course has its challenges. Firstly, Power lines were not designed to carry data, and actually behave as low pass filters. Modeling the PL channel is difficult – it is a very harsh and noisy transmission medium, frequency-selective, time varying, and is impaired by colored background noise and impulsive noise. Thus maintaining signal integrity over power lines requires robust signaling techniques and hardware. Secondly, the structure of the grid differs across and within countries and the same applies for indoor wiring practices. There is no universal standard either for PLC or the grid; steps to ensure interoperability of devices need to be taken. Thirdly, questions are being raised today about the digital security of personal information that is sent over the power lines because these can be tapped into. Thus establishing privacy safeguards and equally important - convincing the public of these is another large-level issue that is being addressed. Lastly, PLC faces competition from other means of communication - both wired and wireless, and ultimately the choice of technology will be decided by a mix of cost, complexity, and feasibility. Today, the major competing technologies to narrowband PLC are Zigbee, Wi-Fi, GPRS and RS-232.

CONCLUSION

In the above article, we introduced Power Line Communication, as a data bridging technology between
the smart grid and the internet of things that collect information and help in implementation of the smart grid. The various types of PLC, modulation schemes, standards, and frequencies in use today were discussed. Finally, we presented the various applications of PLC – in energy generation, the smart grid, data-center power distribution networks, and, in LED lighting. Finally, the challenges of PLC were briefly emphasized. We also discussed how the Internet of things can be interlaced with the PLC and finally the Smart Grid. The challenges in the above approach were discussed.

REFERENCES


Appendix-A

Renewable Energy Certification (REC) Eligibility Criteria

Existing RE generators who have power purchase agreement (PPA) with the distribution licensees would not have the option of participating till the validity of their PPA. Hence, renewable energy producers who have opted for the preferential tariff agreement with the distribution licensees are NOT eligible for the REC route. As per the CERC guidelines, a generating company is eligible to apply for registration and issuance of RECs if it meets the following criteria:

1. It has obtained accreditation from the State Agency;

2. It sells the generated electricity either

   To the distribution licensee of the area in which the eligible entity is located, at a price not exceeding the pooled cost of power purchase of such distribution licensee or;
   To any other licensee or to an open access consumer at a mutually agreed price, or
   Through power exchange at a market determined price;

3. All REC based captive power producers shall be eligible for their entire energy generation including self consumption. Therefore, in the light of above discussion, a solar power producer really has two options for selling the produced power: Either through the preferential tariff agreement or through the REC mechanism that utilizes market forces and feeds the Renewable Purchase Obligations (RPOs).
Appendix-B

How to optimise building orientation?

Building orientation plays a major role in the building envelop heat gain. A proper building orientation of the building will reduce the solar heat gain to your building and will make good use of day light as well. Hence it is important to consider the building orientation as well as material selection for the building envelop to optimise the building energy consumption. Maximum heat gain in the building is from the south façade/windows, hence the designers can also consider the extended shading devices in order to reduce the heat gain.

The plate size of the building also affects the building heat gain. If there is a building having the square plate size, the envelope surface area (peripheral area) will be minimum and if the building is having a long rectangular plate size, the envelop area will be larger. The larger surface area will lead to the larger heat gain in the building and the smaller surface area will have the lower envelop heat gain. However the day lighting in a square building plate area will not be good as much of the floor area in a square building is far from the perimeter lighting. Hence the building plate size selection is a trade off between the envelop heat gain and the day-lighting accessibility.
The results indicate that rectangular shaped Building consumes more energy than the Square because of large area exposure to Heat. If we change the orientation of rectangular building and
put the smaller surface area towards south this reduces the energy consumption in the building 4062 mWh 3852 mWh.

There are few lessons we can conclude from this exercise is that the building envelop designing is a trade-off between the external heat in the building and the day-lighting requirements. An optimum solution for this is a site specific requirement. If the building is a data centre and you do not have too much of day lighting requirements, then go for a larger plat size and reduce the building envelop surface area and thereby reducing the overall envelop heat gain. However if the building is a commercial building, then the day-lighting requirement is a critical and you need to find out a trade-off solution for the optimum plate size of the building in order to reduce the building heat gain.
Appendix-C

How to structure a bankable solar PV project?

The increased interest in solar projects in recent years have raised the concerns of the investors towards the structuring a bankable solar project. On one side while there is a lack of clarity of cash flows in the REC route, the banks and financial institutions are reluctant in financing these projects and consider these projects as non-bankable. Some of the investors have gone highly aggressive in the reverse bidding and find it difficult to get the financed from the Banks. There is a need for the investors to understand that how the project structuring can be done in order to make it bankable project.

Structuring a project as a bankable project requires detailed consideration on the technical, legal and economic aspects of the project. Every bank and financial has its own set of criteria through which it assess the bankability of a project. However the basic requirement is that the project should have a stable and visible cash flow throughout the entire financing period of the project. The assessment by any banks or financial institution is done in typical four phases, which include the

a) Initial qualitative assessment, b) Assessment of cash flow models c) Quantitative risk assessment d) Assessment of financial structure.

The major aspect which any bank or financial institution assess for the bankability of a solar project is the local site conditions. The local site conditions are typically evaluated on the basis
of solar radiation available at the site and expected yield (Annual Energy Generation) which dictates the cash flow of the project. It is not only important to assess the energy yield for a single year, there is a requirement to have the energy yield assessment on long-term basis for which you are required to have the historical solar radiation data at least for 10 years for the site location. So that the trend can be forecasted to give the expected future energy generation for the banker. The data is not generally viable through the free data source. However some of the paid data sources such as 3tier or solar GIS provides this data on cost basis, which makes your detailed project report (DPR) as a bankable DPR. Following example show the historical data for some of the typical paid site done by us.

![Solar GIS hourly data chart](image)

In order to make the DPR bankable the financial institute also asks to conduct the energy yield assessment and electricity generation assessment at P50, P90 basis. Which gives reasonable comfort to the bank towards the expected generation from the solar plant. The typical P50 and P90 for the site can be depicted as follows.
Apart from generation the financial institutes also sees for technical assessment so that they can assure there is no nearby shading from nearby hills which may affect the generation. In fact your DPR should conduct detailed shadow analysis of the site including the inter row shadow which gives a high ranking in terms of technical assessment to the bank or financial institution.

While you are submitting your application in the bank, there is a need to provide the details about nearby infrastructure such as access roads, power evacuation, water availability etc.

Apart from technical aspects the bank-ability of solar project is heavily dependent on power purchase agreement. The PPA should be on long-term basis on a clarity of cash flow at least for the long tenure. The lender assess PPA and the party’s financial strength/pay ability, risk of the buyer. In this regard the PPAs with NVVN are considered bankable. The PPAs with state power utilities are also bankable, however some of the financial institutions have discomfort with
regards to balance sheet (negative) of the state power utilities which increases the off taker payment risk in the project.

Sometimes the PPA are signed with private parties as part of capital/ third part sale and the balance sheet of captive power buyer with third party becomes a critical factor in the bankability of the solar project. The technology selection and EPC also play an important role with the bankability of a solar project. For example if the modules and inverters are supplied from the reputed supplier. It is considered as a less risky proportion by the banker. If the EPC is not experienced or the structuring of EPC is not done through a single EPC contractor. It reduces the bankability of the project, hence de bundling of EPC contract is not advisable because banks find difficult to put a single point responsibility in terms of performance ratio guarantee in case of multiple/de bundled contractor.

Finally you should take care of permits, agreements, licences, land papers and other statutory clearances available so that there is no compliance risk seen by the lender. If you structure your project with all above aspects the project can be bankable, will achieve financial closure. Many times people approach bank first and then start accumulating this information, however if all this information is compiled in advance with bank/financial institution then it will not take much time in releasing your loan.
Appendix-D

Global Smart Grid Technologies and Growth Markets 2013-2020

October 30, 2013 · by firstgreenadmin · in Home, News.

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GTM Research forecasts the cumulative value of the smart grid market to surpass $400 billion by 2020, growing with an average compound annual growth rate of over 8%. This new report examines the global smart grid market from the perspective of growth and market share of technologies and services, featuring a top-down and bottom-up financial forecast along with highlights of regional trends, analysis and opportunity across the world’s established and emerging smart grid markets. By examining the major markets and technologies, the report identifies the biggest growth opportunities for the next 8 years and those markets which are most attractive to investors and utility vendors.
It examines the global smart grid market from a comparative perspective, looking at the expected growth rate of the individual regions as well as the cumulative global growth rates of discrete smart grid technologies. Then, each of the regions is examined in more detail, with comprehensive forecasting on each area for the period of 2013 to 2020, based on the key metrics of market segment value, percent share of the overall smart grid market, and compound average growth rate (CAGR).

<table>
<thead>
<tr>
<th>Smart Grid Market Segment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Metering Infrastructure (AMI)</td>
<td>Meter hardware, communications and networking, meter data management software</td>
</tr>
<tr>
<td>Smart Grid Data Analytics</td>
<td>Consumer analytics, grid operations analytics, enterprise analytics</td>
</tr>
<tr>
<td>Network Operations Software</td>
<td>Geographic information systems (GIS), outage management systems (OMS), demand management systems (DMS), Energy management systems (EMS), SCADA (T&amp;D)</td>
</tr>
<tr>
<td>Transmission Upgrades and Automation</td>
<td>Substation automation (communications, relays, SCADA and related sensors), wide area monitoring, flexible AC transmission systems (FACTS) and direct current transmission/HVDC rollouts</td>
</tr>
<tr>
<td>Smart Distribution</td>
<td>Switching, monitoring and control applications and power quality technologies and hardware (voltage regulators, tap changers, static compensators and capacitor switches, banks and controls)</td>
</tr>
<tr>
<td>Cybersecurity</td>
<td>Software, services and compliance processes and techniques</td>
</tr>
<tr>
<td>Services and Consulting</td>
<td>Project management, staff augmentation, management consulting</td>
</tr>
</tbody>
</table>
Appendix-E

Building Integrated Photo Voltaic (BIPV)

Building-integrated photovoltaic (BIPV) systems are photovoltaic (PV) solar energy systems that are specifically designed to blend in with the architecture of a building, combining the economic and sustainability benefits of distributed solar energy generation with the aesthetic appeal of a seamless integration into the overall building design.

BIPV system replaces the conventional building façade materials from different parts of the building’s exterior and significantly improves a building’s economic and ecological balance.

Different types of BIPV panels based on crystalline silicon and thin film technologies that can be incorporated in the buildings include:

1. Transparent PV panels
2. Flexible PV Panel
3. Opaque – Fixed PV panels

BIPV modules can be integrated into a building in different application types, e.g. in Building facades, canopies, pergola’s, roofing, skylights, railings, parking structures, fencing and others.
The feasibility of a BIPV system in a project will depend on various design considerations for e.g., areas available, type of PV module used- Crystalline or Thin film, Building orientation and anticipated energy production.

BIPV modules support structure is the building itself along with other conventional structural framing. It replace’s the conventional façade material like glazing/granite/marble and also provides onsite electricity which will reduce carbon intensive energy consumption, thereby reducing the net installation cost of the system. BIPV System also reduces thermal radiations into buildings and allows natural daylight pass through and further assists to improve sound and heat insulation of the building.

Onsite electricity generation maximizes the energy efficiency by eliminating the transmission losses that generally occur when electricity is supplied through the national grid.

The cost of a BIPV system is similar to a solar PV system, but by replacing the conventional structural glazing material from the building façade, the net installation cost decreases. Along with this benefit, accelerated depreciation and onsite electricity generation the payback period can be as low as 2 to 3 years and free onsite electricity is available through the life of the PV panels.

Many aesthetically elegant and well-integrated BIPV systems have been installed worldwide and have achieved a good market acceptance. Few project example photographs are as shown below.
BIPV system installed in a building envelope provides a highly visible public expression of the company’s environmental commitment and sustainability goals.

The adoption level of BIPV technology is gradually growing in India with increasing number of system awareness and showcase of developments by many solar market players.

With the conventional energy prices rising very fast, BIPV is a very cost effective solution for introduction of solar PV into building envelope and is one the crucial step in starting a Net Zero Energy building community.
Appendix-F

Grid integration of wind power; what can be learnt from Germany?

Germany has about 65 GW of installed capacity of which about 20 GW is contributed by wind power and balance is through Coal, Gas, Solar, Biomass and Hydro. Variability of wind power as always been a concern to the grid operators and Germany has successfully handled grid integration of wind through various approaches. The major initiative taken by Germany to handle such a large capacity was that they ensured balancing of power in order to absorb the fluctuations of wind power.

![Energy Sources Graph]

The transmission network in Germany is predominantly at 380KV level and there are four grid operators to handle the overall transmission system. Apart from transmission operators there are about 70 regional grid operators which operate at voltage level of 220KV, 110KV, and 20KV. The regional grid operators do not buy or sale powers rather they provide the wheeling facility for the electricity. German grid operators have very high capability of forecasting the electricity demand as well as generation and accordingly the balancing reserves are planned to fill the buffer. While the system has about 20GW of wind power there is large variation in wind power generation on regional basis which can go up to 1GW of variability.
The grid operators are very well equipped with forecasting the generation as well as demand and there are special electricity trading products available in real time so that the projected fluctuations can be deviated through price sensitive electricity trading products. This products include intraday trading and wind reserve which are applicable for two hour ahead production.

In some areas at some times the wind power is more than the grid capability and wind farms are subjected to shut down and stop producing electricity which
effects up to 10% of their revenues of wind power generators. German law provides compensation to wind power generators for not absorbing the electricity during such events. There are additional initiatives to absorb such high wind power, this initiatives include the construction of energy storage facilities in the form of MW class battery storage systems, 300 MW pump hydro systems as well as compressed air storage systems.

Apart from these initiatives Germany has also started adopting demand side management and load shifting options to handle the variability of the grid. Germany is also trying to implement the joint operation of various decentralized plants to handle the variability of wind power. For example wind power plants are being integrated with CHP, PV and Micro hydro as a joint operation plant which is controlled in combination from one central point. The country is also adopted smart grid solutions which include uses of plug in hybrid electrical vehicles, installing energy management systems in buildings advanced metering technologies and better communication system.
The systems of the four German interconnected companies with parts of Denmark, Luxembourg and Austria together form the German control bloc. The load frequency controller for the German control unit is located in Brauweiler (Amprion GmbH, Transmission System Operation). It controls the exchange of electrical energy vis-à-vis the UCTE system, including the CENTREL system (Poland, Slovakia, Czech Republic, Hungary). Within the German control bloc, each interconnected company controls the import/export with the neighboring systems for his own control zone. The surplus wind energy can fed to other zones through this interconnected German bloc.
While India is also facing the grid integration issues for wind power and there is need to learn from German experience and adopt the solutions in the form of better scheduling and forecasting, investment in balancing reserves, upgrading the transmission line for congestion management and use of storage facilities the integration of southern grid with NEW grid will also help in evacuating power from wind farms located in southern there is a need to introduce various demand side management (DSM measures) and innovative electricity trading to take benefit of real time demand variations. There is no single formula for grid integration, but it is need to take technical, policy and market mechanisms to handle large scale wind power in the Indian electricity system.