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Energy Optimization of Residential Energy Management in Micro Grid using Cyber Physical Controller

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ABSTRACT

The Rapid urbanization has created a serious shortage of power in the recent times. The people awareness and government regulations force the people to move towards the Renewable energy. The paper proposes a peer to peer energy sharing in a micro smart grid using a cyber physical system and optimization of energy in an individual home by using Non Intrusive Load Monitoring NILM technique. The consumer becomes prosumer in the microgrid in when they generate and consume energy to become an autonomous operation. The paper proposes a novel energy management system for coordinating the energy sharing in a distributed house hold prosumer. This enables an effective increase the utilization factor of the renewable energy system and reduction in decency of grid. The system is implemented in the real time and results are validated.

Key words: Microgrid, Cyber Physical System, Energy Management system

1.INTRODUCTION

The electric grid system in the system is undergoing major changes the unidirectional system is converted in to a bidirectional real time system where it can interact with its user and producer. This major change enables the user to produce, share and manage energy in the system. The recent advancement in communication system makes the consumer to a prosumer by giving control over the power. The smart meters and sensors provide the adequate information's to develop a self sustainable distributed energy infrastructure to manage the power generated and share the excess power in a grid. The increase in the introduction of renewable energy such as Solar PV, Wind energy and Storage system such as Battery (Lead acid, Lithium ion), Spinning Reserve increases the complexity in the system. The new communication system will provide the efficient methods to reduce the energy consumption pattern of the user based on the forecast of availability of the renewable system. The modern Communication technology enables the user to increase the utilization rate of the renewable system by managing the load and increase in communication between the prosumers to share the excess power to grid and receive the power during the demand without the depending on the traditional grid system. To make the system self sustain new forecast prediction mechanism, user load pattern and pricing policy need to be analysed [3,4]. The Load monitoring in each home and prioritization of loads in each home using Non-Linear Load Monitoring system (NILM) enables the energy optimization.

The Distributed system is divided as (I) Manual (ii) Semi-Automatic and (iii) Full Autonomous. The Full autonomous system is need of the hour to manage the system effectively and the decisions are taken based the predefined settings. The Energy Management System (EMS) will be responsible for monitoring and controlling of electrical appliances in the residential homes. The loads in the consumer homes are divided based on the consumer comfort as schedulable and non-schedulable. Various algorithms and models are proposed based on types of loads and requirements of demand response according to user priority.

2. SYSTEM DESIGN

Research work is in progress for building energy efficient home with energy management for the appliances. We propose a new energy management technique by dividing a Four layered management technique: Generation, Consumption, Storage and Sharing. All the home appliances such as AC, refrigerators, fans, light etc were considered in consumption part. The Renewable energy such as Solar PV panels, Wind energy, Fuel cell were taken in Generation part. The Lead Acid battery was considered during Energy Storage during excess energy production. The excess energy is allowed to share in the microgrid instead of using the energy generated in renewable is excess during the less demand period. The Smart Energy Monitor Unit (SEMU) measures the energy and consumption of all appliances in the home and transfers the total power value to the Smart Cyber Physical Controller (SCPC) using WIFI. The SCPC analyses the power value from the SEMU and reads the usage profile of each segmented appliances based on the priority levels. The structure of the system is given in Fig .1.

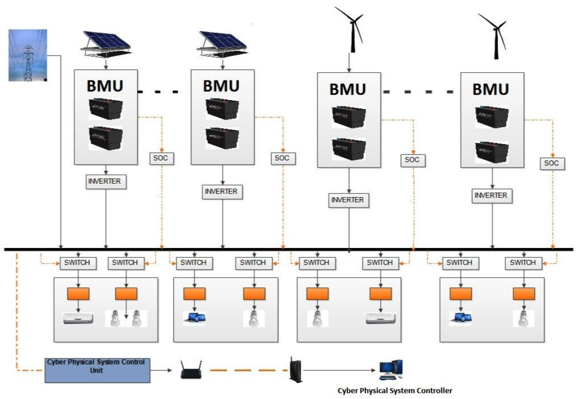

Figure 1: Block Diagram of Modern Microgrid System with Peer to Peer Sharing

Energy generation from the renewable system is monitored by the generation system, the energy generated by the solar and wind is monitored by the smart meters attached to the system and communicates the data to the SCPC system. The SCPC unit gathers the data and compares with the load profile data from the SEMU. The SCPC unit also forecast the load and generation based on weather conditions. The electricity pricing in India Currently follows Slab tariff method where price of electricity does not change with respect to time but the price of each unit changes with the Total usage. Table 1 Shows the Tariff structure of Tamil Nadu (India).

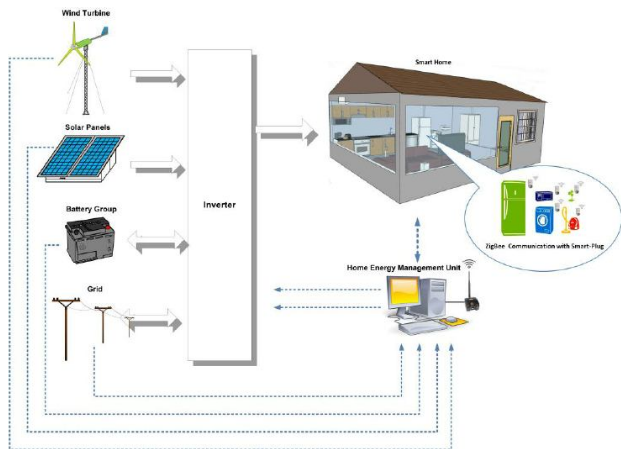

Figure 2: Block Diagram of Home Energy Management

The SMEU optimize the energy use such that the total energy utilized from the grid does not the slab (unit in KWH) since the whole price per KWH changes with respect to the Total consumption of the load. By analysing the user preference and loads usage the SMEU schedules the load during the availability of the renewable energy System (RES).

Table 1: Tariff structure by TNEB of Tamil Nadu (India)

lab-bimonthly	Fixed Charge	Unit Charge
up to 100 units	Nil	Nil
101-200	Rs. 20/service	0-100 – Nil 101-200 – Rs. 1.50
201-500	Rs. 30/service	0-100 –Nil 101-200 – Rs. 2.0 201-500 – Rs. 3.0
501 above	Rs. 50/service	0-100 –Nil 101-200 – Rs. 3.5 201-500 – Rs. 4.6 >501 –Rs. 6.60

SCPC keeps the user updated regarding the total usage of load, availability of RES, Battery State of Charge (SOC) and sharing of power with the neighbour during excess power and buying power from neighbour when needed.

3. SYSTEM COMPONENTS

3.1Smart Cyber Physical Controller (SCPC)

Cyber Physical system (CPS) is a medium that allows to control the applications based on the information

[1,2]. The system usually has processing modules for data collections such as sensors and actuators to perform actions based on the collected data. CPS has huge applications in Healthcare, vehicles and in smart city building. CPS is mostly used in industrial applications but the application of CPS between the human interactions gathers large applications on energy monitoring in residential and microgrids.

The proposed Smart Cyber Physical System (SCPS) is designed for making the current appliances in to smart appliance by scheduling them to use renewable energy more without disturbing the user comfort. The SCPS compares the generation and demand of loads and decides the solution based on the comfort setting by the user. Due to the controller the appliances are scheduled automatically based on the user preferences, slab rates in grid operator availability of energy from neighbor. The system aims in maximize the renewable energy utilization with optimal scheduling. The challenge of the system is to predict the availability of RES. The SMEU aims in minimizing the utilization of power from the grid operator during the non availability of RES. The scheduling unit disaggregate the total load in to load of each appliance so the appliance can be scheduled based on the priority setting in NILM.

3.2 Load Classification

The classifier system divides the whole appliances in to schedulable and non schedulable based on the user preference and power availability. The classifier makes sure that the scheduling doses not affect the user comfort. The scheduling is done that the time of operating is shifted and does not ban the usage of appliance. Load such as lighting will have no scheduling since they are with high priority where appliance like washing machine may be schedulable since they can be operated during the availability of RES [5,6,8]. The scheduling of appliances with high priority can be done only with user coordination. Each appliance working pattern and power usage is calculated before the classification and user preference is added to each appliance with priority and entropy value is added to rank the appliances. The appliance operating time is also calculated to make the scheduling more effective for e.g.: Normally the working time of Washing Machine can be calculated since they run on the same pattern according to the company specification on other side the water heater time cannot be predicted since the time depends on personal habit of the user.

The load scheduling starts scheduling by using the power balance equation when the generation is more and demand is less the system allows all the appliances to work. When the RES is lesser than the load the system first checks for the availability of RES from the neighbor. When neighbor RES is available the system starts utilizing the extra power from the neighbor and satisfies the load. When the neighbor power is not available the system starts scheduling system based on the priority. When the demand is much lesser than the generation and battery also fully charged the system flags the SCPC for sharing of power with the neighbor to generate more revenue.

4. EXPERIMENTAL SETUP

The real time prototype is being developed in the Hindustan university campus in Chennai, India which is funded by the MNRE, India [7]. The System is installed such a way that the there are four prosumer each having a capacity of 2KW,2KW, 1KW of solar PV each and one of the prosumers has 1KW of PMSG wind generator. Each system is connected with MPPT, Charge Controller and battery storage system. In this section simulation results are discussed by applying proposed model is discussed.

Figure 3: Solar Panel 5KW installed in the Campus and 1KW Wind Mill PMSG installed

A community of 4 homes is taken and power is generated by using installed solar and wind mills are added as primary sources for each home. Connection are made such that when the generation is excess in one home can be shared with other home to reduce the power purchased from the grid and to reduce the peaking in the grid. In this no power is sold to the utility and excess power is saved in the battery.

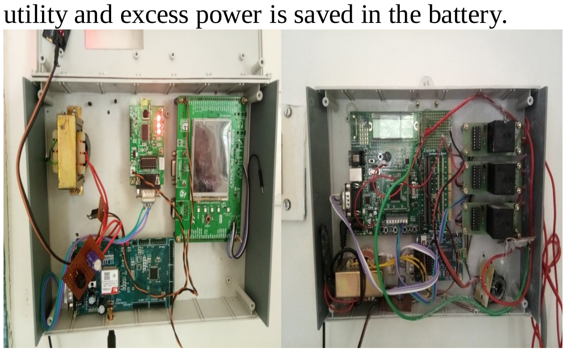

Figure 4: Master controller of EMS

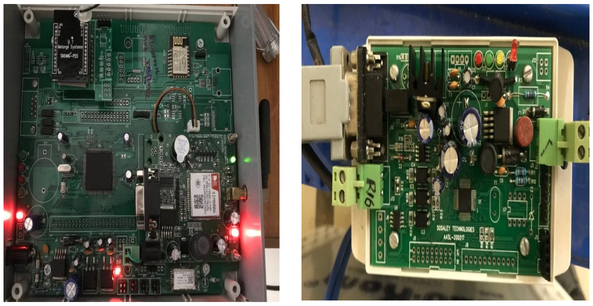

Figure 5: Battery Management system of EMS

The system further uses MIPS dsPIC30F at each Prosumer Node as Slave unit along with Lumisense IoT board to upload all the data such as Power consumed, Battery status, battery temperature, voltage, current and status of sharing to the master controller through cellular communication. Each IOT board is equipped with SIM900 GPRS modem to activate internet connection also equipped with a controller to process all input UART data to GPRS based online data. The data is collected from the Energy meter connected to each Prosumer Node. The System Uses Indigenous Made ICD Meters for Both AC and DC measuring applications. Which Enables us to get the real time data for Monitoring purpose. ICD make DC ENERGY METER (DEM 9004F) is used for measuring the solar panel output to the battery sours with the operating range of 0 – 800V DC and current range of 0 – 999.9 A.

Figure 6: Battery with BMS devices and Inverter system

The meter has PC Interface Optically isolated RS485 communication provided by the MODBUS – RTU which enables us to directly port the data in to system. Further Each Prosumer is connected with ICD SEM 9510 (Single Phase Energy Meter) meter with the Wide range of input voltage and Whole current operation (5A and 10A Ib with 600% operating range). It has Accuracy class 1.0 as per IS 13779, IEC 62053 and Accuracy class 0.5 as per IS14697, IEC 62053 operated meters). The Data Collection through Optical Port / IrDA with IEC 62056-21 protocol (standard) and Data Collection through Optical Port with DLMS (Optional) Isolated RS232 / RS485 with MODBUS RTU protocol [9]. Both AC and DC Meter connected in the system are directly capable of porting data to the system and all the data are processed and uploaded to the cloud each minute to get the Realtime scheduling of the system.

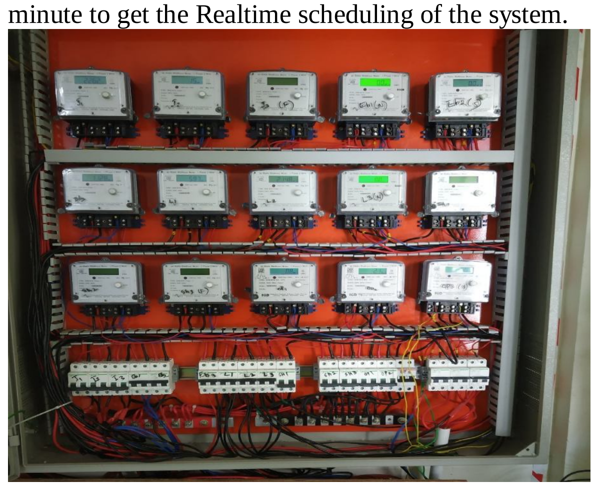

Figure 7: Master controller of EMS with MCB and BUSBAR AC for Sharing and Controlling

The system is totally controlled by the cyber physical master controller and all the decisions for scheduling is done based on the energy available in the storage system and based on the availability of the Renewable energy sources. The System is taken care to Reduce the system reliability for the Grid and improve the utilisation of the renewable energy to reduce the electricity bills and for quick recovery of the solar return.

5. RESULTS AND DISCUSSION

The proposed strategy has been tested experimentally using the Real –time EMS as discussed in chapter 5. The loads connected to different renewable energy sources. The objective is to maximise the utilization rate of solar and wind energy and minimise the dependence on utility grid.

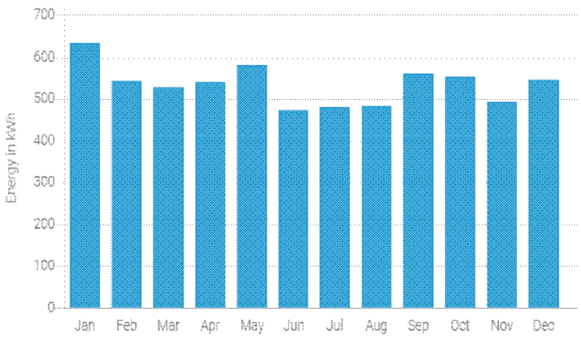

Figure 8: Annual Solar generation of a 2KW Solar plant

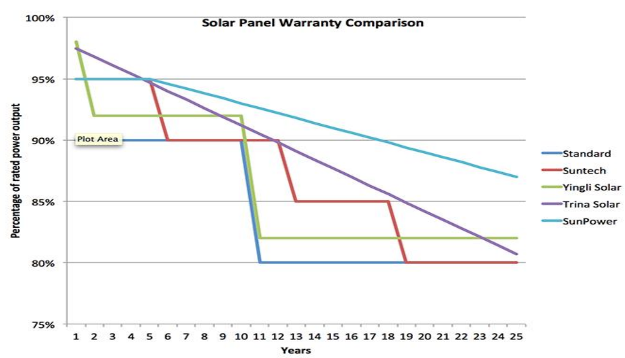

Figure 9: Warranty Period of Various Solar Panels

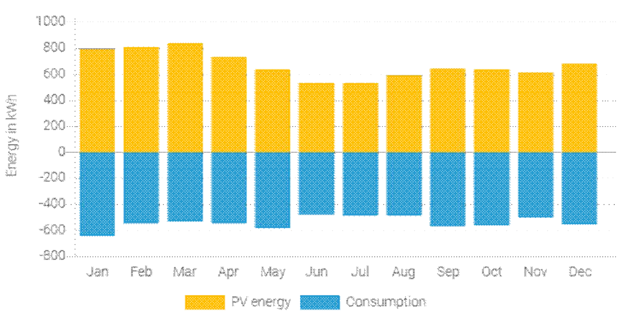

Figure 10: Solar generation and Consumption in prosumer

Fig.8-10 depicts the generation curve and load curve of three prosumers. As we are dealing with solar PV systems and the loads being class room loads of the University, the generation curve and load curve are more or less matching.Considering the scenario that 1kW source is not working, 2 kW is in working condition:

1 kW consumer FN load is shed (or in this case connected to utility grid), while AN load could be shared from 2 KW generation, (Since 2kW consumer AN have no load demand).

This sharing phenomenon saves 2.9 kWhr which amounts to Rs 23.2/half day. The same phenomenon could be carried out for other generation sources as well. The experimental set up for this project can facilitate sharing among all four generation sources and connected load. The experiment results show that the proposed EMS can increase the solar energy utilization rate and the payback period is reduced.

Table 2: Solar generation and payback period for different conditions

	Prosumer without RE	***Prosumer with RE***	***Prosumer with RE and Scheduling***	***Prosumer with RE and Scheduling and Sharing***
Total Solar Capacity	*0*	*2*	*2*	*2*
Total Load per Month (KWH)	*535.5*	*535.5*	*535.5*	*535.5*
Total Load Per year (KWH)	*6426*	*6426*	*6426*	*6426*
Total Solar production per year (KWH)	*0*	*3179*	*3179*	*3179*
Solar Fraction	*0*	*19.9*	*23*	*25*
payback period year	*0*	*9.3*	*8.2*	*7.5*
Co2 saving (kg/year)	*0*	*1701*	*1800*	*1900*
Grid Feed in %	*100*	*80.1*	*77*	*75*
Total Load covered by Solar	*0*	*1278.77*	*1477.98*	*1477.98*
Total Load Covered by Grid	*6426*	*5147.22*	*4947.02*	*4818.5*
Total Load Covered by Neighbour	*0*	*0*	*0*	*128.52*
Tariff (TNEB)/Month	*1981*	*920*	*860*	*830*
tariff (TNEB)/Year	*23772*	*11040*	*10320*	*9960*

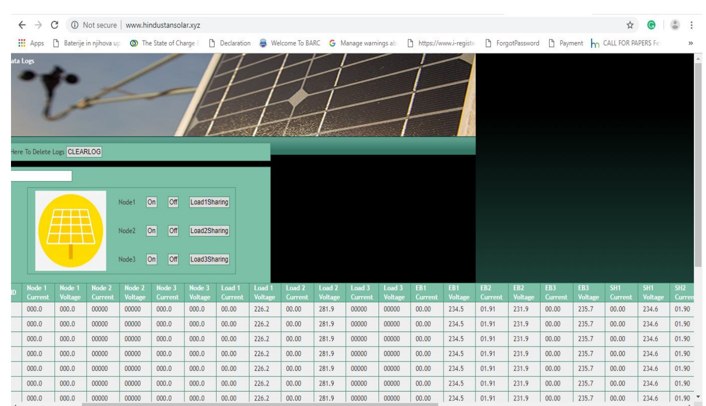

Figure 11: Realtime Solar and wind System Controlling and Monitoring Website Snapshot

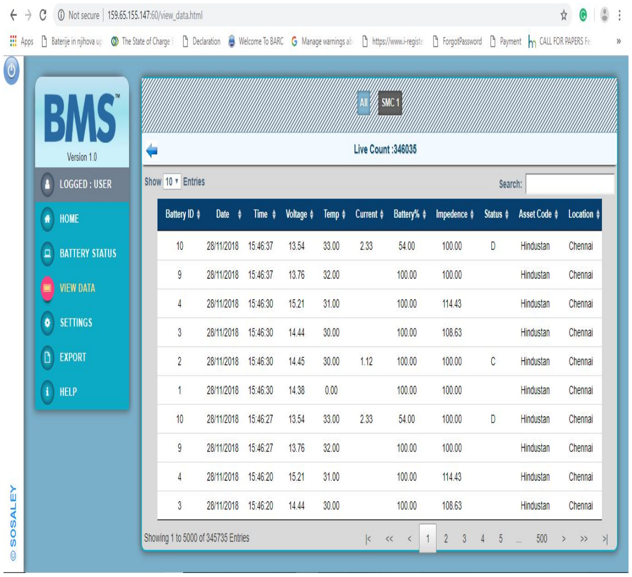

Figure 12: Real time Battery Monitoring System Website Snapshot

6. CONCLUSION

The proposed Cyber Physical based EMS improves the performance of the household prosumers and reduces the payback period of the solar panels installed. This improvement can be reflected in better load profile and improved usage of renewable energy sources. The collaborative behaviour such as load sharing and stored energy balance between distributed energy storage sources can be easily addressed by the given algorithm and a central EMS which is operated by a cyber physical controller. Cooperative operation between household prosumers is a feasible option in order to achieve independence from the utility grid while increasing the reliability and usage of local micro-grid. The cyber physical system enables to adapt the future energy systems to the new challenges, exhibiting adaptive performance such as flexibility, efficiency, sustainability, reliability, and security.

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