Research Article

ABC Research House

Asia Pac. j. energy environ.

AN INNOVATIVE ARCHITECTURE FOR THE DISTRIBUTION FRAMEWORK OF SMART GRID WITH RENEWABLE SOURCES AND POWER STORAGE

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Abstract

Smart grid is a new highly integrated power grid which refers to the next generation power grid, with advanced features and two-way flow of electricity and communication. The smart grid is expected to provide real-time information and near instantaneous balance between supply side and demand side. It combines with the advanced information and communication technology such as Wireless Fidelity (Wi-Fi). Wi-Fi is a wireless network technology that allows smart meters and other electronic devices to communicate over a wireless medium. In this paper, we have introduced and modeled a new architecture for a community smart grid, where an information center is established as the controller of the community power grid. Based on this new approach, the potential impact of smart battery, smart metering and renewable energy sources have been studied. Then, we provided an optimal approach for power allocation in the new architecture, which can reduce the power taken from the regular utility even in situations of overloading, and reduce the line loss of power scheduling. Finally, we proposed a methodology to analyze the daily load profile for residential clients with renewable energy resources.

Key words

Smart grid, distribution framework, load profile, renewable energy, Battery storage

2/22/2017 **Source of Support:** None , **No Conflict of Interest:** Declared

INTRODUCTION

The development of smart grid has been widely promoted by governments and utilities in recent years, with the purpose to optimize the usage of energy resources. Dynamic smart devices like smart meters are being deployed in many European countries, like UK, Germany, France, Italy, which represents the first step towards the development of innovative smart grid. Smart grid is referred to the next generation power grid. Those features include demand side management, fault alarm and advanced metering system. We assume a local community smart grid of a limited number of residences with renewable energy sources (wind and solar), battery storage, and smart meters equipped with wireless interfaces compliant with the IEEE 802.11 standards. The core goal of this research work is to explore the availability and application of renewable energy resources with traditional power supply.

Figure-1 shows the traditional power distribution system, addressing domestic customers that consume electrical power, supplied by the utility. The conventional power distribution scheme, terminal users can use energy as they require meeting their household applications. In each house, there is an electrical energy meter to record the consumed energy in KWh and convey back the collected data to utilities. The electricity supply company report back the monthly energy consumption bills to the domestic consumers. After that, the energy consumers pay for the energy consumption. In general, there are three categories of electrical load depending on daily load cycle, maximum, minimum and average. Maximum of a utility consumer is the greatest demand during a given period in a day.

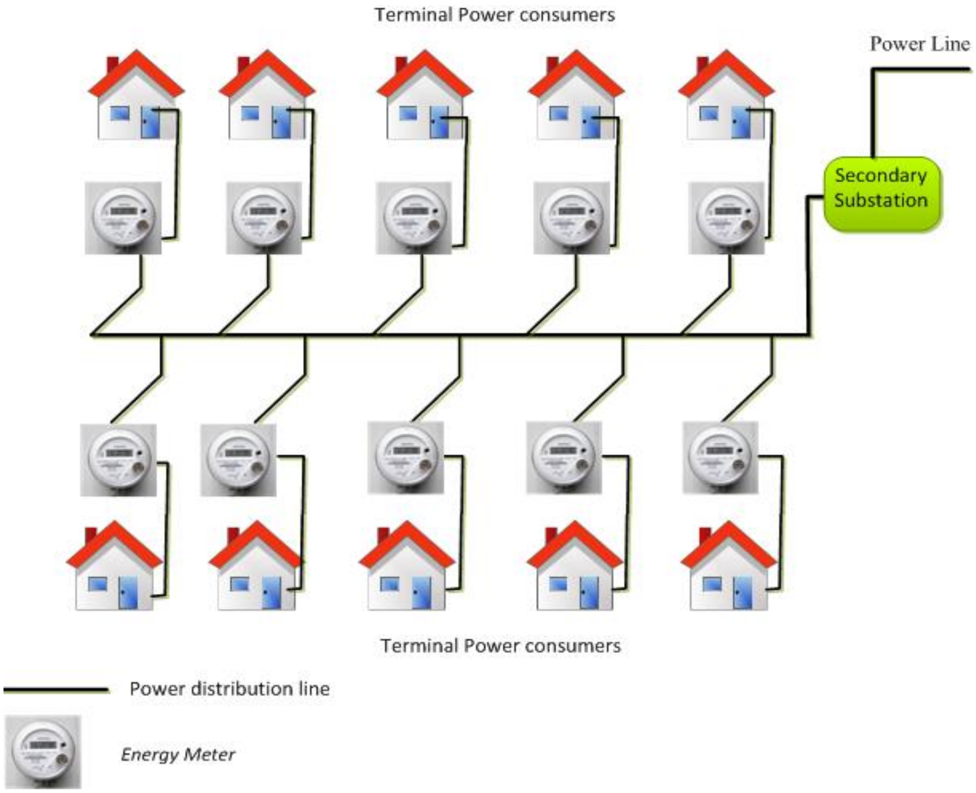

Figure 1: Conventional power distribution system for domestic users.

It varies time to time. The maximum of all the needs that have occurred during a particular period is the maximum load. Maximum is generally less than the connected load because all the consumers do not switch on their connected load to the system at a time. The knowledge of maximum is very important as it helps in determining the installed capacity of the user's home. The average demands have occurred in a given period during a day or month or year.

Daily average demand is the ratio of total number of power units consumed by the users in a day to the total hours (24hrs) in a day. Minimum load of a utility consumer is the lowest demand during a given period in a day. At the power supply level electricity is not just transported from utilities to consumers but also can be delivered from end users to utilities via distribution feeder lines. The information of consumer's is collected and integrated via information and communication technologies to analyze the behavior and preferences of the power consumed by end users in daily life (The US National Institute of Standards and Technology, 2012).

MODELING OF POWER CONSUMPTION

The smart grid (SG) concept aims to achieve a sophisticated system by integrating an information and communication technology infrastructure to the existing power system infrastructure and the new distributed generation system, in order to fully exploit the use of renewable energy systems and to maximize energy efficiency of the whole local community power grid. From a slightly different perspective, a "smart grid" can be considered as a data communication network that achieves, with the support of specific energy management hardware devices, flexible, seamless inter-operation abilities among different advanced components of the system for efficient utilization of the energy. SG end-to-end architectures basically comprise of three main layers: the SG application layer, the power layer, and the communication layer (Gungor and Lambert, 2006). Many consumers and household begin to install small-scale renewable energy systems such as photovoltaic and wind turbines (Figure 2). These systems are standalone systems, which enable customer to generate part of their energy consumption. In case of grid connection mode, the consumer may take extra power from the utility to meet their power demand.

This integration of distributed energy systems (DES) into the electricity grid will be the future smart grid (Bouhafs etal, 2012). To manage and control these new applications and systems, a reliable communication network is needed due to serve this purpose. Wi-Fi standards are the candidate wireless technology in our proposed scheme. Communication system considered as a fundamental infrastructure that allows monitoring the operation, transfer both measured information and control signal among our proposed self-sustainable smart grid system and the central control unit. Power Data Aggregator and Management (PDAM) center is the controller of our smart grid community. We propose a hybrid solar-wind system for domestic application.

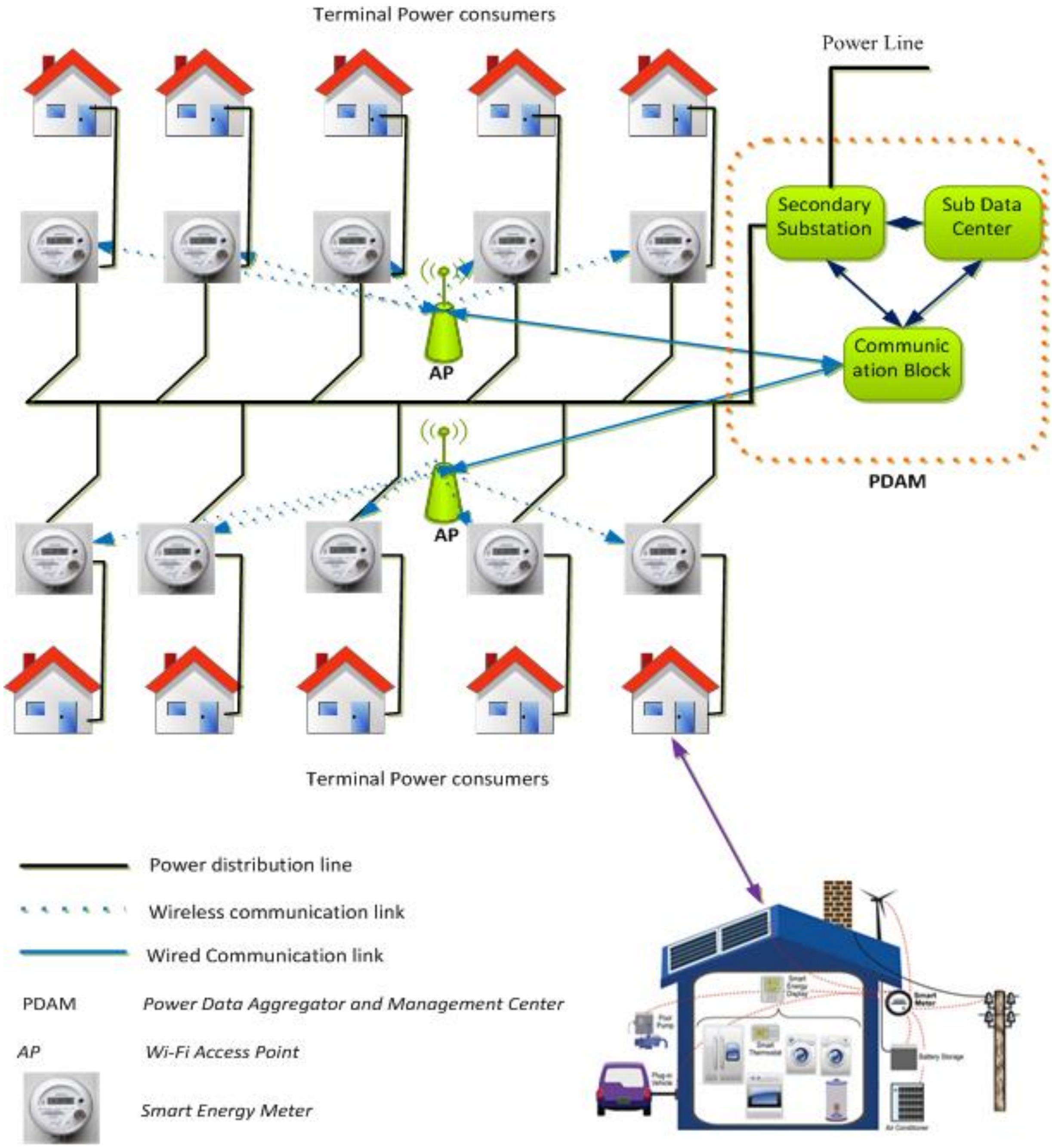

Figure 2: Two-way flow of power distribution network.

In this scenario, all users home has wind and solar power generator a smart battery, equipped with a smart meter to facilitate the smart home applications using communication network (Wi-Fi standards) to monitor the power generation and consumption behaviour according to the user's home appliances in our local community smart grid. Sub-data center is an important part of the PDAM by cooperating, sharing and updating smart meters data via wireless links.

Renewable Energy Resources in the Smart Grid

Energy demand is increasing dramatically day by day in the world and renewable energy resources are the significant substitute source of energy (T.C. Enerji, Piyasası Denetleme Kurulu). New alternative energy resources have been also utilized to minimize the energy deficit. Alternative energy is generally defined as energy that comes from natural resources and replenished on a human time scale such as solar, wind, biomass, tide, wave power and geothermal (Energy Information and Administration, 2009).

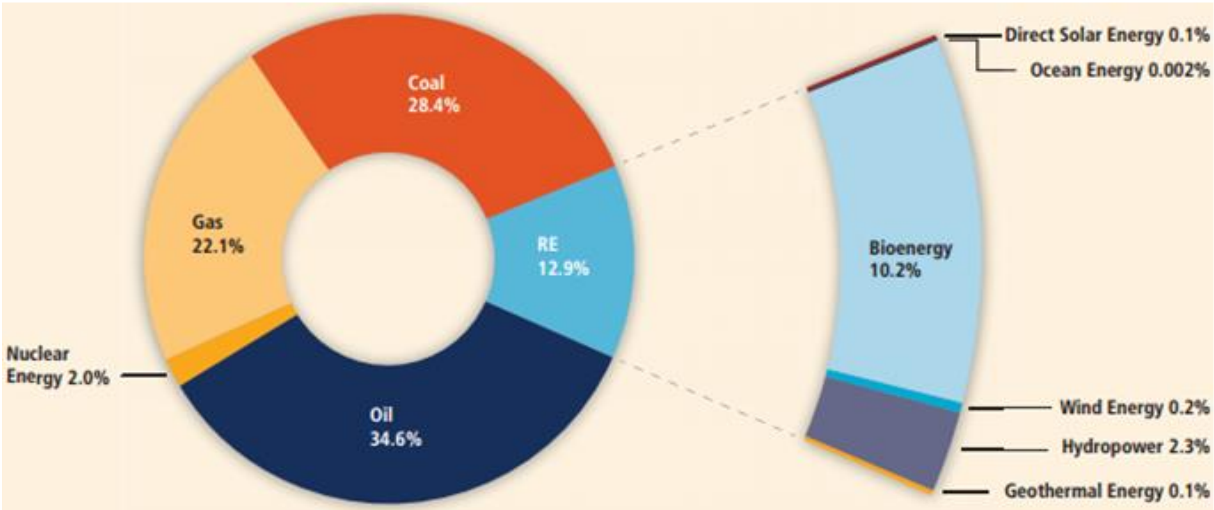

Figure 3: Shares of energy sources in total global primary energy supply (Bain, 2007) (Bain, 2011)

Solar Power Allocation

The solar power is the conversion of sunlight into electricity, proportional to the corresponding solar irradiance can use to generate electricity. Solar power can be harvested to generate electricity by the means of photovoltaic systems. Sun beam is absorbed with photovoltaic (PV) material and electrons are emitted from the atoms that are bounded. This release activates a current. Photovoltaic (PV) is known as the process between beam absorbed and the electricity induced. With a common principle and individual components, solar power is converted into the electric power. Solar batteries are produced by waffling p-n semiconductors. Under beam, electron flow and current occurs. In closed-loop, PV current passes through the external load. While in open-loop, the current completes the circuit through the p-n diode structure. On the flat roofs, the photovoltaic modules will be frequently allocated in arrays in the optimized tilted position towards the sun (Walker, 2001).

Wind Power Allocation

Wind turbines are used to convert the wind pressure into electric energy. Electric generator inside the turbine converts the mechanical force into the electric energy. Wind turbine first converts the kinetic energy to mechanical energy and then converts it to the electricity (Consultation on future network technologies research and innovation in horizon 2020, 2012).

Energy Calculation

Two categories of power generation (i.e. solar and wind) are mutually complemented at the same time with regard to various features during energy collection. Though solar power generation doesn't commit for reliable supply although it has low operation and maintenance cost while the wind power production have a high capacity, yet low reliability. The hybrid generation system can effectively improve the solar and wind power generation when a single output impact on power stability and dependability.

- Need of speed in calculating wind power :

$$\boldsymbol{Power} = \frac{1}{2}\rho A V^3$$

Where ρ = air density,

A = Swept area (A- πr^3),

V = Velocity, $\pi = 3.1416$

$$\boldsymbol{Watts} = \frac{1}{2}\left(\frac{kg}{m^3}\right) x(m^2\ ) x \left(\frac{m}{s^2}\right)^3$$

Where approximately $1.2\frac{kg}{m^2}$at standard ambient temperature and pressure.

- Mathematically wind energy is directly proportional to speed to the power of three.

- Little change in speed effects winds power considerably even for the small amount of time (The smart grid: An introduction, 2011).

The hourly energy generated (*E*, kWh) from the PV system is calculated using the equation given below.

$$E = A \eta_m P_f \eta_{pc} I$$

Where A is the solar array area in m^2,
E *is* the hourly based energy generation in kWh,
η_m is the reference module efficiency (0.111),
P_f is the packing factor (0.9),
η_{pc} is the power conditioning efficiency (0.86),
I is the hourly basis insulation (kWh/m^2).

Today's best PV systems can achieve an overall efficiency of about 12% (Bellarmine and Joe, 1996) (Traca etal, 1983). However, it may be mentioned that technological breakthrough may change the scenario (Bergey, 1993).

Solar Panel &Wind Turbine Sizing

For the module efficiency, the solar panel produced the best efficiency of 21% in commercial products in the current. To demonstrate our proposed scenario 1.5 kW solar panel is our planned consideration. Specifically for this project work, the average wind speed is nearly 4.2 m/sat at 10 m, and the wind power per unit area is approximately 30 W/M^2. Compared with sampled qualitative magnitude estimation of the wind resource, it is clear that without the height restriction, a better evaluation of the wind resource can be completed in a higher place. Subsequently, near the large commercial wind turbines, small scale turbines are also available for residential scale use installed on a roof. These residential wind turbines produce a rate outputs of 2 – 10 kW and they are usually approximately 2.1 – 7.6 min diameter. Finally, 1.8 kW wind turbine as a rated capacity to implement our proposed research (Katti and Khedkar, 2007).

Figure 4: Example of hybrid power system used in solar and wind mill

Energy Storage

The energy storage system can be adapted energy production and energy consumption. Battery storage is one type of various storage methods commonly used for direct current (DC) electric power networks, but its disadvantage is involved in its expenditure regarding high maintenance and limited life spans. With advance and novel technologies, the liquid metal (NaS) battery is currently applied with cheap implementation for large-scale storage, particularly used in Japan and United States (Ibrahim etal, 2008). To achieve the electricity storage efficiently, some electrical devices are employed to convert electric power from one form to another. Since the solar panels and batteries are operating on direct current (DC), DC-DC converters are used for regulating voltage. As the wind turbines are operating on alternating current (AC), AC-DC converters can be employed for the conversion process. Also the load is operated on AC; inverters are broadly used to supply AC power from batteries (Demirta, 2008).

Smart Metering System

The metering unit represents the interface between the grid and the end user; hence it is the foremost element of the current evolution toward full integration between smart homes and smart grid. Conventional energy meters only measure the energy, consumed by the domestic users following numerous drawbacks and the impossibility of implementing any automatic action useful for improving efficiency. In the 1990s, utilities began addressing these problems by introducing automated meter reading, with the ability of unidirectional communications of the energy consumption to a central unit by means of power-lines or wireless communications, yielding significant reductions in billing costs and improvements inaccuracy.

Smart meters have nice features of hardware (HW)/software (SW) capabilities to run transmission control protocol (TCP)/internet protocol (IP) suite and applications on top of TCP. A smart meter is a digital, advanced device with high accuracy, control, and configuration functionality with better theft-detection ability. With these communication capabilities, a communication path between the electrical utility and the consumer is created to exchange information for billing and monitoring purposes.

Figure 5: Smart Meter

Advance Metering Infrastructure (AMI) represents a full exploitation of meters' capabilities, allowing full automation of the billing process and adding flexibility to time-of use billing. AMI meters maintain continuous display the energy consumption behaviors of the terminal users. To monitor and manage the electricity utilization, SM can join the Wi-Fi network and remain control via central co-ordinator (Kok etal, 2011).

Performance Evaluation

Figure 6 shows the average hourly basis energy use for residential users from Monday to Sunday (7 days in a week).

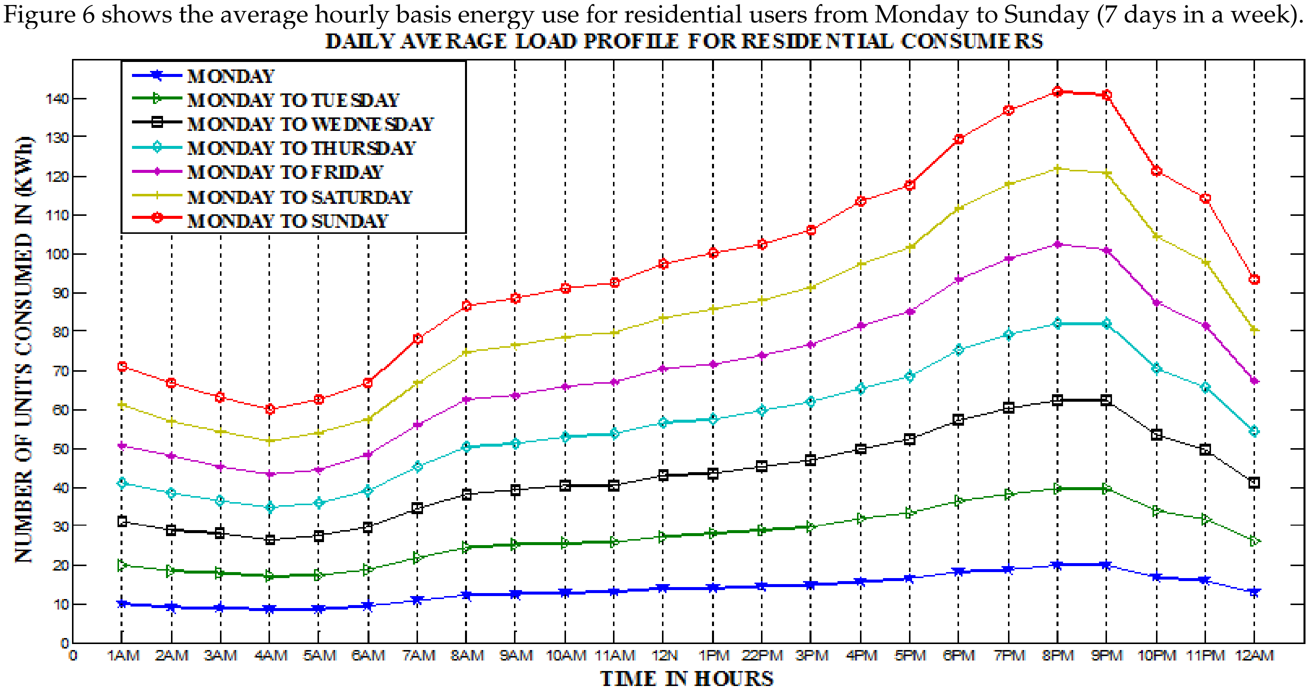

Figure 6: Hourly basis daily average load profile for residential consumers.

The hourly change in electrical demand provides a snapshot of what may be expected the distributed generation equipment through a daily period. By using the considered utility residential load profile data, the data are analyzed for each hour of the day across all days in the week.

The hourly data, which spans all hours of the week, represents the range of change in electrical use for each hour of the day throughout the week. From the above figure it is clear that the number of units consumed by the terminal customer increasing day after day. For example, on Monday the maximum energy consumption is near about 20 KWh but average is 12 KWh and minimum is 10 KWh.

On the other side, from Monday to Sunday energy intake is the sum of seven days where 140 KWh is the greatest energy utilization and about 100 KWh is the average and 70 KWh is the minimum. It is most important to reduce the energy taken from the regular utility company to shape our community power grid smarter and less expensive. In our propose scheme smart grid framework we have implemented and utilized the renewable energy sources (solar & wind) in the regular power grid.

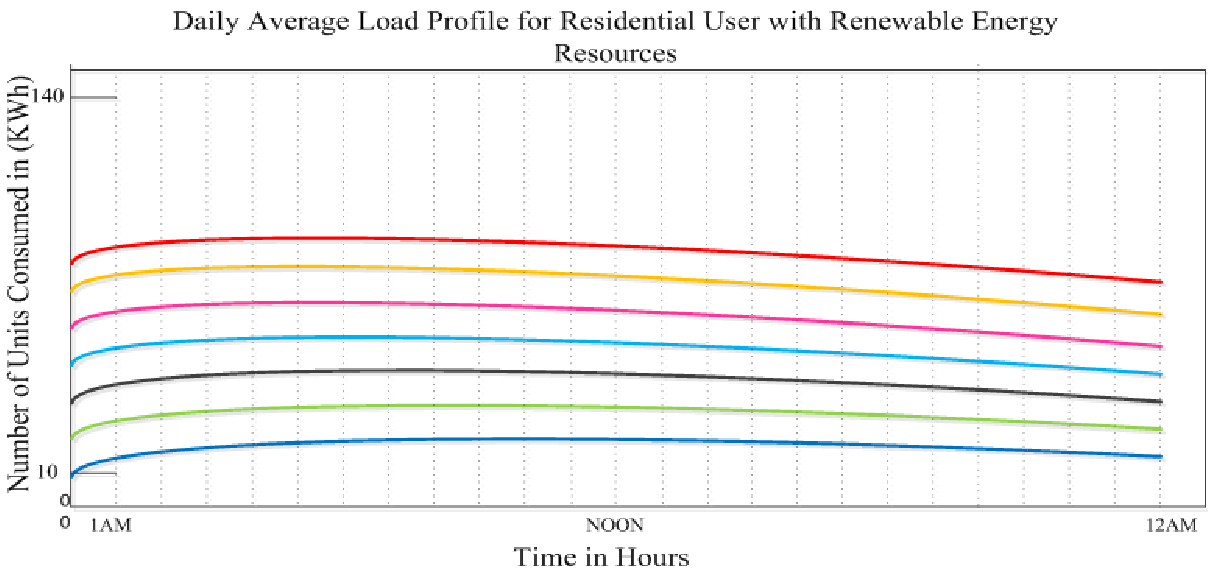

Figure 7: Daily average load profile for residential user with renewable energy resources.

Figure 7, shows the utilization and application of renewable sources (solar & wind). Using conventional power distribution system we have to pay for the energy taken from the utility for the total number of units consumed by the terminal users. However, by applying solar and wind dynamo we can generate extra energy in our own premises and can store in a smart battery. Using solar and wind dynamo it is clear that the minimization is possible to take energy from the regular power supply company. When the battery storage is running out then the extra power will be taken from the neighbour of the community or from the power supplier. In this case we have to pay for a limited number of units as an extra cost. Applying this strategy we can save power and money for the entire day as well as for the full week. If we continue this technique it is more convenient to use for the month as well as for the year around.

CONCLUSION

This study was focused on the smart grid powered by wind and solar energies. Pertaining to the load profile, e.g. the residence type and the number of users, a more comprehensive load and consumption profile was focused and established two proposed scenarios for a local community smart grid.

Smart grid conclude a foundational wireless technology that will provide considerable changes to the existing power grid, consumer lives, the quality of power delivery, and conventional energy resources. Traditional energy sources produce energy with high environmental damage, as opposed to renewable energy sources (solar, wind, waves, and biomass), which do not present this problem, but have remarkable different dynamic characteristics than traditional ones. An integration of these into the existing energy grid is necessary and involves new technologies such as Wi-Fi. The information flow is an important concept to define these technologies. On the other hand, advanced technologies and applications offered by smart grid will shave the energy consumption behaviours of consumers, and hence, a considerable reduction in energy consumption will be achieved. The integration of Wi-Fi technologies into the existing grid has been accelerated with the smart grid standardization and it will be the future power grid.

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