Abstract—Intensive efforts have been made recently in transforming the power grid into smart grid by means of incorporating extensive information and communication infrastructures. In this paper a versatile stochastic optimization approach has been proposed for smart grid, to suffice the residential customers in an efficient energy management comprising high penetration of renewable and distributed energy sources, market based online electricity pricing, large scale storage of energy and high quality demand side management, mitigating monetary expense. The terminology Boost converter used in this paper increases the throughput of solar panel voltage. Smart energy meter, an added advantage of the proposed system provides a two way communication between the utility board and residential unit. The simulation results indicate an appreciable tradeoff between storage capacity and cost saving. This proposed energy consumption scheduling algorithm ensures, generating scheduling solutions within 10 seconds for fast household appliance applications.

Keywords—Boost converter, energy storage, real time pricing, smart energy meter, smart grid, stochastic optimization.

I. INTRODUCTION

The electrical power grid is by nature a complex adaptive system and it regards with significant amount of uncertainties [1]. The existing grid faces some sensitive problems which are major factors of concern. They can be specifically mentioned as follows: 1) limited delivery system. 2) High cost of power outage and power quality interruption. 3) Inefficiency at managing peak load. 4) Increase in global warming and hazardous emissions. This negative impact of global warming and greenhouse effects is indeed a curse to the entire existence of life on earth. So for the sake of rescuing our earth it is mandatory to switch towards renewable energy sources. Since smart grid encapsulates this peculiar features of utilizing this renewable energy sources, smart grid integrate large amount of renewable generation in specific solar to meet our overwhelming electricity energy demands [2].

The smart grid inbuilt the following essential components in addition to the existing power grid.

1. Renewable energy generation: For the purpose of future energy sustainability and also with the aim of conserving conventional energy sources it is significant to adopt renewable energy sources. For the benefits of residential customers photo voltaic modules are used as renewable source which are being integrated in counterpart.

2. Energy storage: It is well known factor that tapping of renewable energy is intermittent by nature. The two major factors of concern in the field of energy generation are the abrupt increase in random power demand and uncertainty in supply of energy vested with it [3], [4]. Hence it is obvious that the storage of energy is indispensible to meet the unforeseen energy demands. Residential customers use battery as their means of temporary energy storage [5].

3. Demand side management: The energy demands of smart home system can be managed effectively by shifting energy consuming workload from peak hours to off peak hours for the sake of balancing the load and minimizing the monetary expense of the consumer [6]. There persist two types of energy demands namely elastic and inelastic. If the energy demands of customer satisfied within a certain time limit then they fall under the category elastic energy demand. On the other hand when appliances are to be powered as per the necessity then they can be stated as inelastic.

Smart grid introduces another worth mentioning feature say smart meter. Smart meter is a device that is connected to power distribution system which embeds a scheduling unit that helps in implementing shifting of workload [7], [9]. It also helps in receiving periodically the updated pricing information from various utility companies and the scheduling unit incorporated within it arranges the various household appliances for operation during different time intervals [10], [11].
II. SYSTEM ARCHITECTURE AND MODELS

Owing to uncertainties under the real time pricing environment this paper mainly focuses in minimizing the electricity expenses of customers through optimally scheduling the operation and energy consumption for each and every appliance. Figure 1 depicts the architecture of energy management system used in residence.

The following subsections are included in this model.

A. Utility control unit

The utility control unit performs the usage patterns and the other analytics associated with it. In this system, there persist a mutual usage data communication between the smart meter and the control unit. A cluster of meters is together assigned with a single control unit which helps in optimal utilization of the same.

B. Residential customer unit

The residential unit includes the below mentioned household appliances: air conditioner, washers, coolers, etc. The complete functionality of this residential unit is achieved by the inclusion of the following modules as shown in Fig.2.

1) Renewable energy generation: The resources are fast depleting with proportionate increase in energy demand, which ultimately results in providing a significant importance in the generation of renewable energy. Renewable energy source that is adopted in this paper is photovoltaic cells which promise a clean and cost effective factor that simultaneously turns out to be an opaque medium against harmful reactions to our ecosystem. PV cell uses the technique photoelectric effect which helps in converting the sunlight of certain wavelengths into direct current.

Generally a single PV cell cannot suffice the residential customer needs, so it is mandatory to connect them in series and parallel for the purpose of achieving the targeted voltage and current levels. As the PV cell generated voltage is intermittent by nature, the boost converters are included which aids in boosting the voltage, thus helps the PV cells in maintaining an ever sustainable voltage.
2) **Boost converters**: A boost converter or step up converter is basically a DC-to-DC power converter which functions with an aim of producing an output voltage greater than its input voltage. Power is a factor that must be conserved and hence as a result of these criteria, always output current is lower than the source current.

   ![Boost converter](image)

   **Fig. 3. Boost converter**

   The role of maximum power point converter is felt by the presence of boost converters which is ultimately merged with the output load of solar panel. The voltage from the solar panel is given to the controller which in turn generates the relevant PWM waves that is further fed back to the boost converter’s switch control input. The core functionality of boost converter is storing current in its boost inductor when the switch is closed or just delivering the currents from its inductor to the load when the switch opens and it is shown in Figure 3. The output of boost converter is fed to energy storage block.

3) **Energy storage**: There most frequently exists an energy mismatch between the PV profile system and the residential energy demand. To synchronize this mismatch the concept of energy storage is introduced, which is used to store the excessively generated electricity at daytime, which forms as a supplement form of power usage that can be released at night time to meet the residential customer needs. This phenomenon paves way for appreciable amount of reduction in tapping of electricity from grid.

   ![Energy storage](image)

   Overcharging and discharging will affect the operational life of a battery and hence it must be protected from these phenomena by incorporating a controller that helps in regulating the charging and discharging cycles [8].

4) **Inverters**: Generally battery produces the DC power, but the household appliances requires AC power for its operation, for that reason the inverter is used to convert this 12V DC into 230V AC household voltage. The voltages from these inverters are used by appliances through contactors.

**C. Real time pricing model**

   Real time pricing models (RTP) prices tends to be different for varying time intervals while they maintain a flat nature within each time interval [13]. As the energy consumption of the residential unit reaches a predetermined threshold, the inclining block rate (IBR) pricing model shows a steep increase in its price and shows a considerable rating in electricity price over rest of the time. This paper combines both the RTP and IBR pricing models which leads to the much ensuring model of current flat rate tariffs.

   The magnanimous feature of this model provides the recharging of the battery from the electric power grid at times of low electricity price and simultaneously discharging them during peak electricity pricing [12].

**III. THE PROPOSED SCHEDULING ALGORITHM FOR HOUSEHOLD APPLIANCES**

   The household appliances generally tap energy both from renewable energy sources and electric power grid. These renewable energy sources are intermittent by nature and the electric power grid may pose some uncertainties in operating its household appliances. The proposed stochastic scheduling algorithm helps to solve these menaces [14], [15]. Energy demand can be categorized into two as follows:

   **A. Inelastic energy demand**

   The appliances which are powered whenever needed are termed as power consumers which directly reflect the nature of inelastic energy demand. Appliance such as lights, fans and television can generally be incorporated in inelastic energy demand. Hence it is excluded from scheduling unit.

   **B. Elastic energy demand**

   The energy demands when met within a specified time limit, it ultimately leads to customer satisfaction. These appliances are nomenclature as elastic energy demands.
Appliances such as refrigerators, mixers, heaters, oven, etc can be shortlisted under elastic energy demand. Here scheduling unit takes its role in controlling thereby adjusting the operation times of these appliances and amount of their energy usage.

An energy demand queue is created to store these energy demands. The queue follows a First-in-First-Out (FIFO) policy. In general the highest priority is assigned to the appliance that is first placed in the queue. The scheduling unit presets a limit on total load demand for each and every household appliance based on updating pricing information from utility unit. So if the total load demand appliances exceed the specified threshold limit then the scheduling unit automatically turns off its lower priority appliance in the queue.

C. Control Objective

Objective points to minimize the expected cost related to electricity shown in (1).

\[
Z = \lim_{T \to \infty} \frac{1}{T} \sum_{t=0}^{T-1} E\{C(t) (A_{l}(t) + A_{b}(t))\} \quad (1)
\]

Where \(C(t)\) denotes the real time electricity pricing at the starting of each time slot send by utility unit to the smart meter , \(A_{l}(t)\) denotes the power drawn from grid and \(A_{b}(t)\) denotes the tapping of power from grid for battery recharging, employed at times of electricity price fluctuations.

IV. SMART METER

A smart meter is an energy meter that records utilization of electric energy in short intervals of time and sends the relevant details to the utility unit for scrutinizing and billing purpose, in predetermined time intervals. A two-way communication between meter and the central system is aided by smart meter. The Advanced Metering Infrastructure (AMI) is a technique incorporated by smart meter and this notable feature is absent in traditional AMR. This helps to reduce the monetary expense charged to customers in the real time pricing arena. The following worthy features are encapsulated in smart meter: eliminates the payment of bill in person at the EB office, provides consent for fetching details regarding updated pricing power utilization, accuracy of bill is verified, inclusion of multiple buildings to the wireless methodology does not alter the uniqueness of the network.

A. ZIGBEE

Zigbee is basically, a wireless communication technique that aids communication between meter and utility unit.

The Zigbee’s unlicensed operational frequency band is 2.4GHz which is typically a IEEE 802.15.4 standards which is subjected to specifications of physical radio, and it clearly illustrates the MAC and physical layers which are basically the protocol layers. Zigbee extends a bandwidth of 250Kbps that suffices the creation of home automation and AMI. Zigbee supports low powered short distance communication. This feature can be updated to long distance transmission by incorporating intermediate devices that aids in data transmission over long distances.

V. SIMULATION RESULTS AND DISCUSSIONS

In this simulation a PV panel, a battery, boost converter and other appliances are employed in a particular household which incurs a real time pricing. Fig.4 depicts the simulation result of this paper using MPLAB IDE and PROTEUS software.

Fig. 4. Simulated output of efficient energy management of residential customers using PROTEUS software.
The various subunits of this simulated output are as follows:

A. Voltage monitoring unit

In this simulation, solar panel is represented by a potentiometer and LCD displays the corresponding voltages with respect to the potentiometer position which is shown in Fig.4.

B. Boost converter

Based on the solar panel output voltage, a PWM wave is generated by the controller which is fed to the switch control input of the DC-DC boost converter. The PWM wave is displayed by using a digital oscilloscope, shown in Fig.5.

![Digital oscilloscope showing PWM wave](image)

C. Wireless communication unit

The virtual terminal displays the amount of voltage utilized by the household appliances. It also indicates whether the source of voltage is from electricity grid or solar panel, shown in Fig.6.

![Virtual Terminal showing voltage and status](image)

D. Contactor unit

The relay unit consists of two contactors namely A and B. If the solar panel voltage is less than 5V, then the contactor A is ON and thereby the household appliances draws voltage from electrical grid. On the otherhand the contactor B will be in its ON state when the solar panel voltage exceeds 10V and hence the energy from solar panel will be consumed by the consumers as the prime energy source, shown in Fig.4.

VI. Conclusion

The scheduling algorithm introduced in this paper provides an efficient energy management and household appliance scheduling based on real time pricing released by utility companies in predetermined time intervals. The methodology proposed in this paper is to store the excessively generated renewable energy for future use and thereby to charge the battery at times of low electricity price and simultaneously discharging them during peak pricing time to minimize the monetary expense. From the simulation results, it can be concluded that power scheduling approach using RTP combined with the IBR pricing model is a better way compared with the RTP alone pricing scheme. As a future vision of this paper super capacitors are used as energy storage that can charge faster than batteries, last longer and overcome physical toll that wears down the batteries in charging and discharging. This algorithm has the capability to schedule the solutions at a much faster rate which indeed is a boon to the residential customers and thereby favouring them to suffice their ever increasing thirst in energy needs and simultaneously proving to be economical.

REFERENCES


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