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Hybrid System Strategy for Demand Side Management of Residential Loads

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ABSTRACT: As of today, one of the major trends in energy conservation is Demand Side Management. It is the technological evolution of the smart grid, to apprise the consumers about their power consumption, to make judicious decisions so as to improve the timing and quantity of electricity usage. This management, if implemented, has an immediate effect, which is shown by a decrease in the operational costs and greenhouse emissions of the plants. However, this mechanism in today's energy sectors - especially residential - is not profoundly implemented. Therefore, algorithms or methods are required which can help a consumer understand usage and exercise energy conservation. The technique proposed herein, helps the consumer to take the necessary steps in order to achieve Demand Side Management for a Time-of-Day Tariff arrangement. Consisting mainly of an Embedded System interfaced to an Energy Meter and secondary power source (Battery), the energy and power readings are measured and run through the algorithm.

KEYWORDS: Demand side management, Time of Day tariff, Hybrid Power Source, Energy management.

ABBREVIATIONS: DSM – Demand Side Management; TOD - Time Of Day tariff; DC – Direct Current; AC – Alternate Current; SOC – State Of Charge; ISR – Interrupt Service Routine.

I.INTRODUCTION

Recently, Demand side management (DSM) has been the trend when discussing for an efficient solution in the energy management [1] problem. It has now blended with smart grid technology, forming an essential part of it. In want of better methods to control energy usage, Demand side management was established during the Energy crisis of the 1970's as a concept accepted by many so as to avoid depletion of energy resources. In the Electrical Sector, Demand-side management [2] has been traditionally viewed as a means of reducing maximum or peak electricity demand so that the utilities can delay building further capacity. In fact, by reducing the overall demand on the electricity network, DSM has various beneficial effects, including mitigating electrical system emergencies, alleviating the number of blackouts and increasing system reliability, reduced dependency on expensive imports of fuel, reduced energy prices, and reduced harmful emissions to the environment. Also, DSM has a major role to play in deferring high investments in generation, transmission and distribution networks [3]. Thus, DSM applied to electricity systems provides significant economic, reliability and environmental benefits. In practice, this is generally achieved by the modification of consumer's demand of electricity through various methods such as financial incentives and consumer education [4]. The load profile dated 1st December, 2015 in Fig-1 distinctly shows the variation in demand through the hours of the day for the Karnataka State region. These variations are subjective to the average high and average low energy usages of all the consumers. The main goal of DSM, here, is to encourage the consumers to use less energy during peak hours or to move the time of energy use to the off-peak hour's viz. night. This gave rise to a new tariff scheme called Time of Day (TOD) tariff, where the tariff rates for energy usage varies depending on the hour of the day, so that electrical energy cost for off-peak hours is low and the vice versa. To reach the objective of energy conservation, DSM uses many techniques [5] - peak clipping, valley filling, load shifting, flexible load curve, strategic conservation and strategic load growth. In the load curve of Fig-1, two peaks (crests) of approximately 8000MW and 7000MW are observed at 8 AM and 7 PM respectively. Similarly, valleys (troughs) are observed at 12AM, 4AM and 4PM lying between 5000 and 6000 MW. Reduction of the power demands at 8AM and 7PM and promotion of the demands at 12AM, 4AM and 4PM - peak clipping and valley filling respectively- forms the foundation for DSM. Practically, the peaks and valleys can't be clipped and filled easily, leading to a new strategy of load shifting – to shift the loads running at peak times to off-peak times. In order to achieve this optimization of the load curve, load reduction techniques are incorporated at the consumer's premises; this forms into another concept called strategic conservation.

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Strategic load growth is another optimization strategy of DSM that is applied on the daily response when introducing large demands. Another method used is the flexible load shape which involves identification of consumers having flexible load capabilities who are willing to accept constraints on energy usage during critical periods in exchange for incentives.

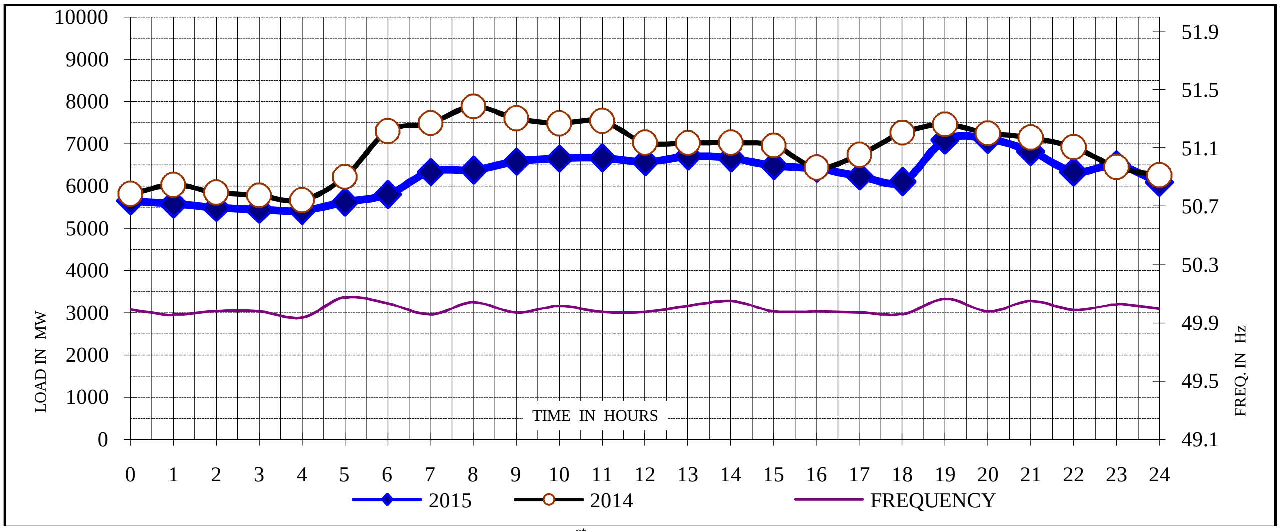

Fig - 1: The load curve as on 1st December 2015 for the Karnataka region.

II.HYBRID POWER SOURCE

Hybrid power [6] is one of the latest advancements in ways energy can be consumed. It involves combinations between two or more technologies to produce, store and supply power. As in this paper, the hybrid system (secondary source) as shown in Fig-2, works along with the power grid mains (primary source) for efficient energy usage. They have the capability to work with the main supply in unison to satisfy the load or even supply the demand by alternatively working with the main supply. The way [7] the primary and secondary sources supply the load is usually controlled based on conditions such as level of demand to be supplied, constraints on energy consumption and storage capacity of the battery. These conditions are analysed to form the algorithm which governs the charge controller to achieve the synchronization with the main primary source with accurate charge and discharge times.

This paper, adopts the system in Fig-2 into the proposed strategy so as to observe DSM. A battery with agreeable capacity (depends on load) is used as the secondary power source and is connected in parallel to the power mains. A charge controller is used to control, through pulses or signals, the battery by monitoring its State of Charge (SOC) or level of charge. The controller also can open or break significant parts of the circuit for monitoring and controlling the status of the control circuit breakers CX and CY. When the battery is to be charged, the controller provides pulses to the solid state components of the power rectifier allowing AC power to be converted into pulsating DC. The pulsating DC is then filtered using a filter (usually capacitive) to remove the AC component to obtain nearly pure DC power. During this complete charging process, the controller keeps the control circuit breaker CX closed and the control circuit breaker CY open to allow the DC power to be stored in the battery. This process continues until the SOC (which lies between 0 and 100% or 0 and 1) reaches 1, indicating full charge of the battery. The controller now opens circuit breaker CX. When the time comes for the battery to be discharged, the controller keeps CX open but closes CY and simultaneously provides pulses to the solid state components of the inverter. This results in the DC power stored in the battery to be converted into AC power. The AC power obtained has a lot of harmonic components present and hence has to be filtered through a low pass harmonic filter to obtain nearly accurate AC Power which is supplied to the load. If the SOC is low after the discharging cycle, the controller closes CX with CY remaining open, and provides pulses to the rectifier, repeating the charging cycle. This way, the battery acts as a secondary power source by trying, along with the primary source, to satisfy the demand and attain DSM. The time of charge, discharge, status of circuit breakers, and the SOC of the battery are all controlled by the algorithm in the controller. This algorithm

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is nothing but the proposed or devised strategy discussed in further sections. The circuit breakers A and B along with additional switchgear provide protection to the battery and power mains during faults in the system.

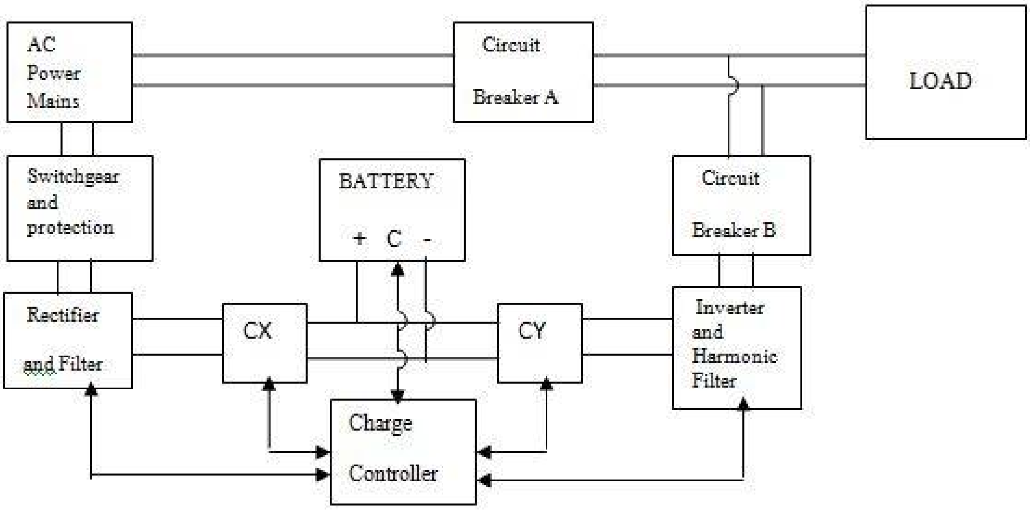

Fig-2: The Block diagram of a Hybrid power source used in the strategy.

III.DEVISED STRATEGY

This strategy or method is developed mainly for curbing residential demands [8] during peak times and improving demands during off-peak times of a single consumer. It utilizes a day-ahead concept of DSM with load shifting and peak clipping as the two main techniques for energy management. The main aim of this method can be to shift loads to off-peak periods, reducing demand during peak periods, maximize savings in terms of energy and electricity bills, or to an extent, to reduce the power distributed by the utilities. The goal of the algorithm [9], by running it in all houses in the area, is to also bring the load profile of the area to the desired load profile which is set by the utilities based on capital costs, running costs, costs of generation, transmission and distribution, etc. Fig-3 shows the proposed architecture for the demand side management algorithm. According to the proposed architecture, the energy meter, like in every consumer's premises, is connected in parallel (1) to the power mains to measure the energy readings. It also involves centrally an embedded system interfaced (2) to the energy meter which can take in the readings of the energy meter and produce results based on the devised algorithm. The Battery acting as a Hybrid power source as shown in the previous sections, forms an integral part of the system and is connected in parallel (3) to the AC power mains. Also, in this arrangement, the embedded system acts as the charge controller for the secondary power source (Hybrid). Therefore, it is a single computing device, that handles both the DSM devised algorithm and the control pulses (4) to the secondary power source system. The architecture is technically an open loop system. However, it becomes a closed loop through human intervention in the form of the consumer making changes to his pattern of energy consumption, according to the analysed information conveyed.

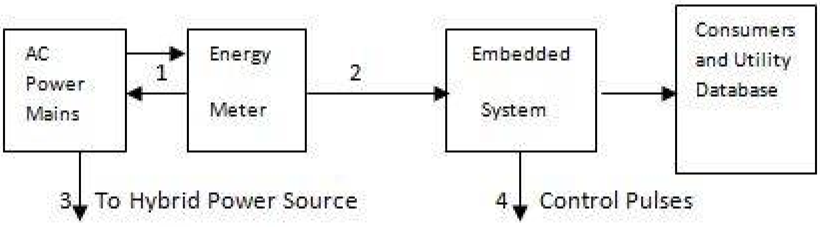

Fig-3: The proposed architecture for the DSM strategy.

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A few assumptions as shown below have to be made for effective working of the algorithm.

Assumptions:

1. Time of day tariff scheme is already being used in the metering system.
2. The time of day tariff rate values for the day ahead is already declared to the consumer.
3. The pulses from the Energy meter are equivalent to 1 Watt.
   i.e., One pulse reading = 1 Watt-hour consumed.
4. The power consumption pattern (demand profile) of the consumer remains nearly the same for the next day of energy usage.

A. ENERGY METER PULSE COUNTING.

As known, the energy meter returns an output which is the pulse equivalent of the energy consumed. The pulse width T_{high}- ON period, varies depending on the meter. Some pulse output meters allow T_{high} to be set. Hence T_{high} remains constant during operation, which is taken here as 500 milliseconds. The time between the pulses, $T_{Low,}$ is what indicates the power measured by the meter. Hence, even the load (demand power) consuming energy can be determined using $T_{Low.}$ If the electricity meter does not have pulse output connections or the connections are not accessible due to restrictions imposed by the utility company, then these meters have an optical pulse output LED. In such cases an optical sensor is used to interface with the meter. In such cases, to detect the pulses from the LED a light sensor is used. A single read or count of a pulse indicates energy consumption of 1Watt-hour. For example, if 1000 pulses are read, the energy consumed is 1000*1=1000 watt-hour or 1 Kilo watt-hour (KWh).

B. ROLE OF EMBEDDED SYSTEM.

Any embedded system (Arduino) can be interfaced with the energy meter. The Arduino is always updated with the TOD tariff ratings T (h) of the day. Also, the Arduino initializes two variables U_p (zero) and U_v (a predetermined maximum value) with predetermined values. This allows it to make the necessary calculations to run the algorithm for that day. The energy meter produces pulses which are read by the Arduino continuously with the help of interrupts. The pulses are fed to an interrupt (pin 3 or interrupt 1) that the Arduino uses. The Arduino is made to wait for the falling edge of an energy meter pulse, after which it responds by directing the flow to an interrupt service routine (ISR). Before jumping to the ISR, the Arduino also records the time‘t’ of the day. Once into the ISR, a counter called ‘PulseCount’ is incremented by 1, indicating a pulse read. The PulseCount holds the value of the elapsed energy consumption. The corresponding pulse time ‘t_p’, which is also read when the pulse appears at the interrupt pin, holds the value of the power consumed. The energy consumption is therefore calculated using-

$$Energy\ E\ = \frac{PulseCount}{1000} \ldots in \ldots KWh$$

Similarly the power of the load that draws the current is also calculated using-

$$\text{Power } P\ = \frac{3600}{Pulse\ time\ tp\ in\ milliseconds} \ldots in \ldots KW$$

Here, t_p is the total pulse time, which is the addition of T_{high} and T_{Low}. Since T_{High} is always constant, the power P varies due to changes in the off-period $T_{Low.}$ Now the power and energy values are updated and stored. The elapsed energy consumption is a single value and hence can be stored in a single variable. However, the calculated power is stored in an array P[i], where ‘i’ is the number of pulse readings. Now that the inputs from the energy meter are read, converted and stored as energy and power parameters, the Arduino has to implement a DSM strategy to realize the periods of peak and low consumptions. It does so by taking in a new parameter called Usage U_n. This U_n is used to store the value of the mathematical multiplication between the calculated power P and the tariff rating T (h) for the current hour h.

$$Usage\ Un = P \times T(h)$$

By multiplying Power P, which reflects the power consumption profile of the consumer, and the tariff T(h), which reflects the power consumption profile of the region supplied by the utility, we get Usage $U_{n,}$ which is the resultant containing the characteristics of both the consumer demand and regional demand. This U_n can be, hence, used to comparatively obtain the high and low periods. This is performed by U_n is comparing with the U_p and U_v values. Here, U_p and U_v are the variables used to store the usage values for peak and valley of the consumer profile respectively.

- If U_n is greater than U_p, then hour of highest (peak) energy consumption is at the current time t and current hour h (Peak time) and U_p=U_n.
- If U_n is lesser than U_v, then hour of lowest (valley) energy consumption is at the current time t and current hour h (Peak time) and U_v=U_n.

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This gives us the peak and valley consumption values which are, for a single pulse reading, inaccurate. The Arduino now comes to the end of the Interrupt service routine, and becomes ready to wait for another pulse reading. This procedure continues and repetitively calculates and updates its energy, power and usage values, with increasing accuracy of results with time. In a span of few hours the peak and valley periods of the user can easily be determined with high accuracy. The results are now ready to be communicated to the consumer for completing the DSM loop. This method is limited to finding the lowest period and the highest period. In different words, when the load profile has two or more peak valleys, it considers the highest peak and the lowest valley, neglecting the other less pronounced peaks and valleys. However, this can be overcome by also storing U_{p-1}, U_{p-2}….. and U_{v-1}, U_{v-2}…..and so on, allowing for the details of the less pronounced peaks and valleys accessible.

C. ROLE OF HYBRID POWER SOURCE.

While the embedded system's main purpose is to perform deductions for load shifting, the Hybrid power source serves an equally important purpose of peak clipping. As stated before, the charge controller serves as the heart of the hybrid power source system. However, the advantage of having the embedded system is that it can perform two functions – calculations of energy and power for the main part of the algorithm and production of control signals for the hybrid power source. In other words, it also acts as the charge controller improving the simplicity of the system. The control of this system also forms a part of the algorithm running in the Arduino. It is known that the Arduino has stored in it, the time of Day tariff rates T(h) for the happening day. This tariff rate values are usually stored in an array. This helps the Arduino to determine the time periods when the tariff rate is low (T(low)) and high (T(high)). When the tariff rate is T(low), the Arduino sends status control signals to the control circuit breakers so as to keep CX closed and CY opened. Simultaneously the required pulses are sent to the power rectifier. This causes charging of the battery. This charging process continues until the battery reaches an SOC of 1, or the battery is demanded to be discharged by the consumer. The discharge process is initiated by the Arduino by sending status signals to the control circuit breakers so as to close CY and open CX. Also the pulses are fed into the inverter to activate discharge mechanism. The time of discharge of the battery can be decided through two ways. First one, is to allow the battery to be discharged when the tariff rate is T (high). This results in effective peak clipping. The second method is to allow the consumer to decide on the time of discharge. This provides the consumer total control over the discharge mechanism of the hybrid power source system. This option can be presented to the consumer to choose his preferred method of discharge. The battery stops discharging when the stipulated period of discharge is over, or if SOC of Battery becomes very low (tends to zero). Due to this the Arduino again activates charging mechanism when the tariff rate is T (low). This repetitive process, on addition to the main algorithm, helps it by making peak clipping feasible.

IV.ALGORITHM

The algorithm given below includes the complete mechanism required to drive the DSM strategy in the Arduino. The battery is arranged to be discharged at the peak demand period.

Step 1: Start

Step 2: Read and store the time of day Tariff rating values in an array T[h], where h is the hour of the day. Record the current time t of the day. Initialize the variables U_p as 0 and U_v as the maximum usage value (Any large value).

Step 3: Wait for a new pulse (Falling edge) from the pulse output of the Energy meter. Record the current hour 'h' of the day and the pulse time 't' (T_{High} and T_{Low}).

Step 4: If tariff rating value T[h] for the current hour h is the lowest T[low] and SOC of battery is substantially low, charge the Battery (through the charge controller) by making CX = 1 (closed) , CY = 0 (open) and providing pulses for the power rectifier.

Step 5: Increment a counter 'PulseCount' by 1.

Step 6: Using the counter, the elapsed energy consumption is calculated using,

$$Energy\ E\ = \frac{PulseCount}{1000} \ldots in \ldots KWh$$

Step 7: From the energy consumed and pulse time t, the power of the load connected is calculated using,

$$Power\ P\ = \frac{3600}{Pulse\ time\ tp\ in\ milliseconds} \ldots in \ldots KW$$

Where, $t_p = T_{High} + T_{Low}$.

Step 8: Update and store the power P[i] and energy E values from the calculated ones, where 'i' is the number of pulse readings.

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Step 9: Multiply the power P with the Tariff rating value T[h] for the current hour h and store it in an array Usage U_n.

$$Usage\ Un = P \times T[h]$$

Step 10: The usage U_n is compared with U_p and U_v. If Usage U_n is greater than the previous pulse reading result U_p which is the last highest value of Usage U recorded, then hour of highest energy consumption is current hour h (Peak time) and U_p=U_n.

$$\mathrm{Up} = \begin{cases} Un, & Un > Up \\ Up, & Un < Up \end{cases}$$

Else continue to step 11.

Step 11: If Usage U_n is lesser than the previous pulse reading result U_v which is the last lowest value of Usage U recorded, then hour of lowest energy consumption is current hour h(Valley time) and U_v=U_n.

$$\mathrm{Uv} = \begin{cases} Un, & Un < Uv \\ Uv, & Un > Up \end{cases}$$

Step 12: The time of highest energy consumption and time of lowest energy consumption is sent to the consumer.

Step 13: Recommend the user to use energy more during Valley time and less during peak time to implement energy and money saving. If it is not feasible for the consumer to consume less energy during the peak time, discharge the stored energy from the Battery during peak time by making CY = 1 (closed), CX = 0 (open) and providing pulses for the inverter.

Step 14: Go to step 3.

V.RESULTS AND DISCUSSION

The proposed strategy was simulated using MATLAB, Arduino IDE and MATLAB Simulink to obtain the required results. The system was tested for the pulses, which were the equivalent of the load profile shown in Fig-4. A typical TOD tariff rate typical of any urban, residential scheme is inputted into the simulation as shown in the Table 1.

Table 1: The Time of Day tariff rates used in the simulation.

Tariff T(h)	Hour timings h
2 INR	$0 < h < 6$
4 INR	$10 < h < 14$
6 INR	$6 < h < 10\ and\ 14 < h < 18$
8 INR	$18 < h < 24$

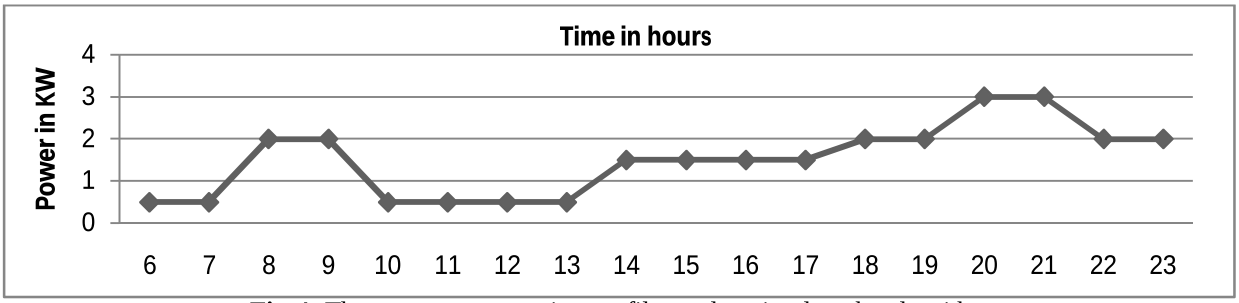

Fig-4: The power consumption profile used to simulate the algorithm.

The results obtained from MATLAB and Arduino IDE were recorded and tabulated as in Table 2. It can be observed that there are two regions of low power consumption (0.5KW) – 6AM to 7AM and 10AM to 1PM. But the algorithm has chosen only the latter as the lowest valley. This is because the tariff ratings during the former period (6AM to 7AM) are higher than that of the latter period (10AM to 1PM). Thus, the former results in a higher Usage U value (3) than that of the latter (2), indicating that the latter period is the best time to perform valley filling.

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Table 2: The results obtained by the execution of the devised strategy.

Period	Power consumption(KW)	Timings	Usage U	Tariff rating (INR)	Battery status
Highest Peak	**3**	**8PM-9PM**	**24**	**8**	**Discharging**
Lowest valley	**0.5**	**10AM-1PM**	**2**	**4**	**Charging**

From the results, the consumer is recommended to use more energy during the determined Lowest Valley and reduce or shift the load operating at Highest Peak. The Hybrid system was simulated using MATLAB as shown in Fig-5. The load was assumed to be completely resistive and equal to the demand (3KW) at the highest peak. The battery supplies to the load at a voltage of 100 Volts.

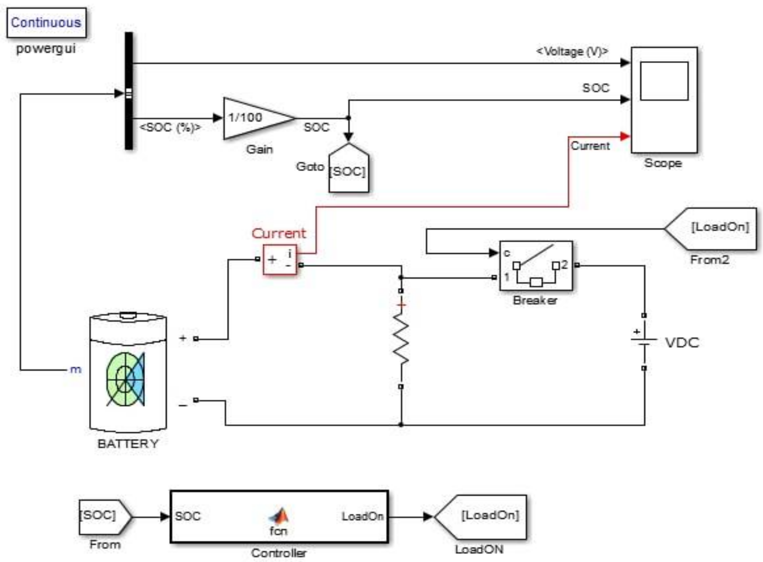

Fig-5: The simulation of the hybrid power source using MATLAB Simulink.

The consumer is helped by the Hybrid power source present in the system, by charging its battery during the lowest valley (**10AM-1PM**) and consequently discharging it during the highest peak (**8PM-9PM)**. The results of the simulation are shown in the form of the charge and discharge curves (SOC) of the battery in Fig-6 and Fig-7.

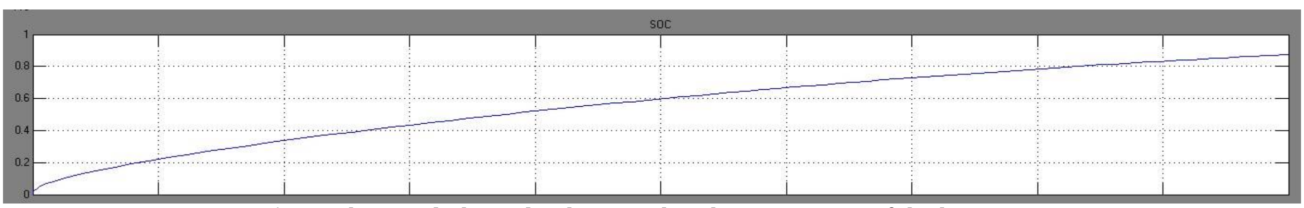

Fig-6: The simulink results showing the Charging Curve of the battery.

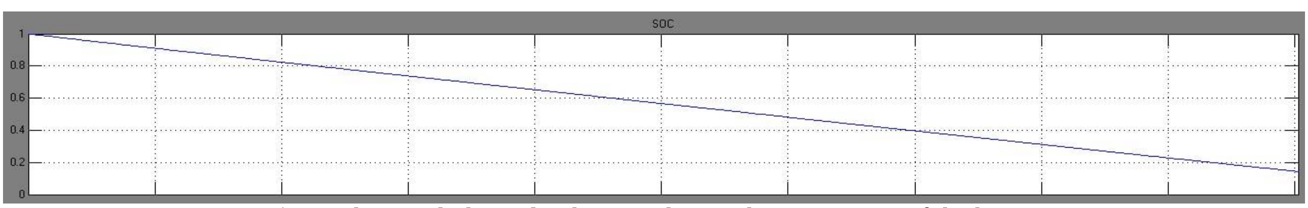

Fig-7: The simulink results showing the Discharging Curve of the battery.

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The degree to which the battery can satisfy the load at peak hours depends on its current capacity. Since resistive load is used (Power factor = 1), for the given peak, total current drawn is,

$$Current = \frac{3000}{100*1} = 30\ Amps.$$

Since peak period is for one hour between 8PM-9PM, a current carrying capacity of 30 Ampere-hour or more allows the battery to work independently, without main power supply. In such simulation conditions, the battery sufficiently supplied the required 30 Amps for the period of one hour. If battery of current capacity less than 30 Ah is considered, the battery has to work together with the main power supply to satisfy the load. By introducing a battery of 10Ah, the battery supplied for one-third (1/3 or 10A) of the load current leaving the remaining two-thirds (2/3 or 20A) for the main power to satisfy.

VI.CONCLUSION

The demand side management strategy that has been presented in the paper is devised mainly to tackle the energy management issues posed in the residential sector. It can be employed to any house of the present time. The proposed mechanism is a novel technique based on the essential DSM concepts of load shifting and peak clipping and works by informing the consumer and aiding him in making precise decisions for achieving demand side management. The effects of this can be effective shifting of loads, peak clipping, valley filling, reduced electricity bills, etc. The day-ahead system adopted can be further improved by making the strategy cognitive. In other words, instead of using a day-ahead concept, the algorithm can be configured to take into account the results of previous days for comparative study, evaluation and analysis to make the results more precise and accurate in operation. The Hybrid system can also be modified to accommodate renewable energy sources instead of a battery, to further improve energy efficiency.

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BIOGRAPHY

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