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A NOVEL APPROACH OF INTELLIGENT LOAD SCHEDULING IN SMART GRID ENVIRONMENT

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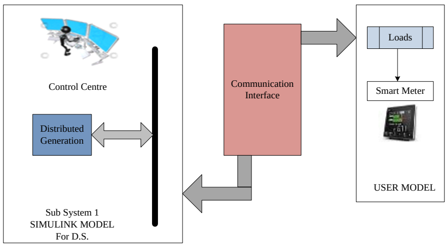
Graphical abstract



Abstract

The deployment of smart meters in distribution systems provides an excellent pathway for load monitoring in the future smart grid paradigm. The proposed methodology involves a novel idea of power distribution optimization from the substation level. This paper elaborates a model by identifying the dynamic intelligent load scheduling problem and the approach is simple with less complexity thereby reducing the power outage time at the end users. This solution can be easily applicable to power distribution network using smart grid concepts and develops a load scheduling architecture. The problem efficiency is explained clearly which enhances the idea when the consumption among users is centrally available and it is easy to generate bills without errors. The main focus of this paper is modelling the loads in consumer side targeting an optimal scheduling .The proposed system is implemented in a realistic scenario and the obtained results exhibits effectiveness of the model.

Keywords: Smart grid, Smart meters, Load scheduling, demand, Consumers

1.0 INTRODUCTION

Current electric power systems are in urgent need of modernization in order to address many of the pressing issues that are faced in the world today. These issues include global warming, depletion of fossil fuels with an increasing, reliable electric supply. Major factors like rapid increase in carbon emissions and increasing world population are also the main concern in this regard. The enormous power demand has triggered the government sector and energy utilities to move on to the use of renewable energy integration with the distribution system [1].

The need to improve efficiency and flexibility of the distribution system is very much required. The Smart grid technology has been the main area of focus for research in order to tackle the issues of electric power supply and utilization. Hence, dynamic modelling of smart grids at the distribution and consumer level is required. Among the major problems faced by power plant operators is the distribution of power to clients whose demands vary seasonally or daily. Further, in nations with a wide East West spread, the demands may have a temporal content wherein the diurnal variation has to be catered by appropriate switching of loads.

Significant energy saving opportunities arises due to effective load balancing and load scheduling. The analysis of parameters like voltage, current, power trends are very important in overall scheme of reducing energy costs. The main focus is reducing overall energy bill by moving into the way of balancing three phase distribution system. The approach is analysed with the scheduling operation of loads to reduce energy demand. Immediate energy savings in addition to reduction of energy cost can be created through proper load scheduling by intelligent techniques using smart grid concepts [2]. This is a major way to balance load management which can minimize the demand. In developing countries, the current power scenario is that the power demand is multifold greater than the power generated. Load scheduling is being followed to answer this problem, which means power outage considered for certain sections of the city. The proposed model focussed from a sub-station level, how the power scheduling can be effected without posing many grievances to the end-users. Utilization of smart meters and smart devices at various stages of transmission and at the end-user premises helps to achieve the goal along with other sub-advantages.

In the world of power management, there is a critical issue of distributing available power to many loads. The demand and supply mismatch indeed leads to more ineffective load scheduling. The dispatch of power from generation to distribution utilities is a dynamic process. Thereby proper power management of the scheduled power should be managed more effectively. Based on this scenario, there should be a need of a new technique which enables optimal load scheduling within the distribution system. The other important elements in this paper are analysed to minimize the quantum of loads executed during power outage time and for aiming for cost savings.

The authors in paper [3] explain the loads scheduling in a smart home with the integration of renewable energy sources are proposed. As in this model, the scheduling at the home level obtaining an optimal solution by developing different load schedules with different electricity cost [3]. In paper [4] the authors have developed an optimal distributed load scheduling algorithm that maximizes the social welfare of the power system. The model has involved game theory approach using smart grid concepts in order to maximize the profit. The approach developed in [5] exhibits the idea of user friendly and privacy maintained load scheduling among the users with the scheduling of the domestic appliances at the user level installing a smart meters at home. Load scheduling for demand side management in smart grid have been formulated as an optimization problem and solved by linear programming techniques in many research approaches [6-8].

The authors in [9] developed a load scheduling protocol for demand side management in smart grid which explores the limitation of allowable power loads. In paper [10] algorithm approach of the power scheduler was developed for a residential demand side management. In [11] proposed a new supervisory control schemes in the distribution feeder is exhibited. This controller located at the substation level controls local regulating devices based on the changes in the system conditions. The paper [12] proposes casual load scheduling with time varying prices using stochastic dynamic programming. The authors in [13] formulated a load scheduling problem as a stochastic optimization problem assuming cost of electricity is random and is available only in real time.

Although the above mentioned works have explained with different ideas, these methods include complex mathematical analysis, slow in response. Hence, in this paper authors made an attempt to overcome above said drawbacks, developed a new algorithm which having the features of easy implementation, simple in design, faster in response and does not involve complex mathematical computations. The paper exhibits a valuable study that can suggest useful information for the power sectors, energy utilities and readers towards load scheduling. The devised mythology is acceptable for addressing the limitations of presented literature and gaps introduced by the authors. The main aim of this paper is to focus on the idea of replacing power outage with selective phase outage in order to find power theft identification and transmission losses. The work also initiates power utilization curves available for customer centrally so that the information relevant is exhibited using further prediction techniques.

Thereby the main target of this proposed work is to solve the issues of load scheduling from the substation level without involving many computational techniques. A simple method is proposed which tackles the issues of

i. Power outage can be replaced with selective phase outage
ii. Power utilization curves available per customer centrally so that the information relevant for further prediction techniques can be done
iii. From the distribution centres, transmission losses in the distribution lines and transformers and aid corrective actions can be done. Power theft bypassing energy meters can be identified.

The rest of the paper is organized as follows. Section 2 contains the description of the proposed methodology and its respective technique involved to solve the existing problem. In section 3 and 4 algorithm and the results of the techniques are illustrated with the simulation. Finally the conclusions are given in section 5.

2.0 METHODOLOGY

This paper proposes a new methodology of intelligent load scheduling using smart meters fixed in the distribution side in order to reduce power outage time of the end customers. This model involves smart grid concepts with the communication capabilities at the user premises with the power distribution centres and also the need of smart power consuming devices. To understand the proposed method, the developed model is analysed in two categories. 1. Distribution, 2. Consumer side, with smart meters fixed at the customer side and a supervisory control unit installed at distribution centres/substations. In addition, this paper focuses from a substation level also how the power scheduling can be employed without posing any grievances to the end users.

In this work the three phase distribution for domestic customers are categorized into following three types such as Essential Lighting load, Heavy load, and Non-essential loads. The lighting load is considered to have maximum availability to the end-user. Figure 1 depicts the overall design of the proposed model exhibiting a new idea of installing the smart meters at the distribution and the consumer side to have a central control. The phase and the category is stored in the smart energy meter (SEM-1) installed at the consumer premises.

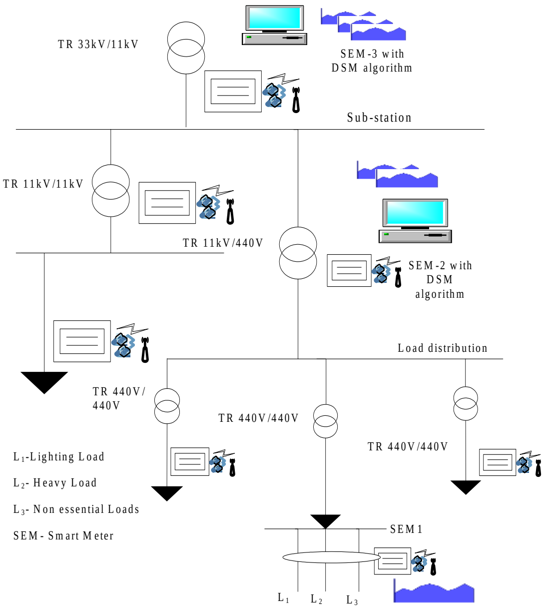


Figure 1 Proposed overall Design

In this paper as an overall design, the three categories of load are well distributed across the phases to accomplish a well-balanced load. The smart meter (SEM-1) installed at the customer premise constitute the following capabilities. It exhibits communication to the supervisory computers/meters at the distribution and substation level. The communication can be established with the present available technology or using enhancing technology like PLCC (Power Line Carrier Communication), HART (Highway Addressable Remote Transducer protocol) [14]. It makes and breaks single or all phases based on the command received from the substation. It stores the energy utilization and the power factor of the consumer over a period of time and provides time averaged data to the supervisory control at the substation level.

The supervisory control (SEM- 2/3) as in Figure 1 installed at the distribution centres/substations is expected to be followed by the list of capabilities. It binds the communication to the consumer smart meters (SEM-1) and to the immediate substations wherein the communication technology would remain same throughout the distribution grid. It sends the signals to the individual consumer premises on the make-break details of specific phases. Thereby it stores the aggregate energy utilization to the specific distribution area. In Figure 2 explains the simple structure of communication interface between the distributed systems to the user interface. The forecast of load demand are based on the current load curves. Further with this arrangement wherein the smart meters in the grid, have obvious advantages by exploiting the communication and data storage technologies. The power utilized by the customer at different time slot can be recorded at SEM-1. The time based averaging shall be performed at this stage and made available for the central supervisory communication meters for load forecasting.

Methods like baseline energy use and analytic hierarchy process are being used to determine the load curves. The baseline model is a prerequisite one in prediction for the need of energy savings for a successful energy management program. These models are created mainly by regressing the energy consumption with respect to the weather and other independent variables [15]. There are several methods to establish the baseline model, such as statistical regression models, computer simulation and other models [16]. The information obtained from measuring the energy performance of a building for a minimum of 12 months will thereby create a baseline for the total energy consumption. This creates a starting point for the improvement of energy efficiency goals and for evaluating future performances. Saaty (1980) developed the Analytical Hierarchy Process (AHP). The AHP methodology compares criteria, or alternatives with respect to a criterion, in a natural, pair wise mode. To do so, the AHP uses a fundamental scale of absolute numbers that has been proven in practice and validated by physical and decision problem experiments [17].

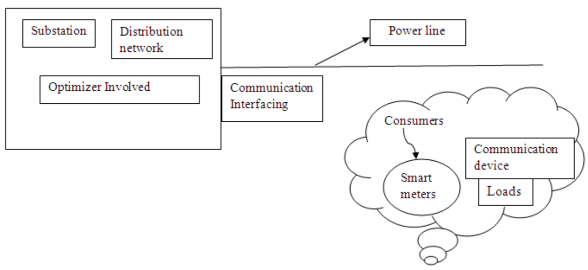


Figure 2 Communication interface between distribution side and user

AHP is a process involved a hierarchical representation with includes judgments and measurements as integrated solution within. The process involves linear algebra for computation which differs from other conventional decision analysis. It involves a numerical approach in a hierarchical fashion by the process of decision making. It is a three step process involving identifying, organizing decision objectives, criteria in a hierarchy fashion [18].

In this proposed new model, the same metering system shall also be installed on the intermediate distribution centres. By this the load consumed at the distribution centre can be compared against the vector sum of the load of the consumers. This helps us to determine the transmission losses in the distribution lines and transformers and aid corrective actions. Also, power theft bypassing energy meters can also be identified. Hence, corrective actions could be taken with centrally available information. Precisely, when the energy consumption per consumer is available centrally, it would be simpler to generate bills and hence avoids human efforts and mistakes. Based on the present conditions of the connected loads to the grid, the new proposed model can be developed as in algorithmic approach which runs dynamically calculating the demand on the distribution side network and shifts the surplus power from the surplus area to the inadequate area. By using the load balancing technique, the power being transmitted can be improved by proper scheduling of load with flattening of loads and by supplying the base lighting load constantly.

3.0 ALGORITHM OVERVIEW

The proposed algorithm model is developed by implementing the following steps. The design in the proposed one exhibits them by installing smart meters in the consumer side in a smart grid environment. The scope of Demand side management study can be understood and can be followed with the forthcoming analysis. The work design is split into two modules of the distribution centre analysis and the consumer side with this simple approach. A dedicated code for the proposed algorithm is coded in C++ programming and tested. Further, the proposed approach model is built in a MATLAB/SIMULINK. This model will enhance the future aspect of intelligent load scheduling in a smart grid approach for the future era of modern grids.

When a load scheduling is needed due to power shortage, the supervisory control runs the algorithm based on the following information and keeps the outage to minimum, these steps involved in the basic level approach for this method in a round fashion is presented below.

1. Calculate the essential lighting load needed per consumer from the load patterns.
2. Identifying the phases (L_1, L_2, L_3) they are distributed from the information available in the individual consumer meters where L_1, L_2, L_3 are the lighting, heavy and non-essential loads respectively.
3. If the minimum lighting load can be made available with the available source of power. It intimates the individual consumer meters to break the other two phases namely the heavy load, other non-essential.
4. The customer meter can also further receive the details of how long this state would prevail and intimate to the consumer through a user interface.

The consumer premises should be wired based on the upper ceiling of Kw rating for the lighting essential load phase. By this, the consumers no need to face complete power outage for longer time. This proposal also replaces need for uninterrupted power supply used by the consumer. The advantage of such a replacement is the reduced power utilization of the UPS battery. It reduces energy losses in battery storage and AC-DC-AC conversion and mainly results in reduced cost and maintenance to the consumer. Further, with this arrangement wherein smart meters are employed in the grid, there are other obvious advantages by exploiting the communication and data storage technologies. The power utilized by the customer at different time-slot, climate, can be recorded at the SEM-1. The time based averaging shall be performed at the different stages and can be made available for the central supervisory communication meters for load forecasting. The algorithm works with the concept of scheduling the power to the consumers considering the user priority. The loads can be resistive or inductive loads and be operated from timely depending upon the consumer needs. The usage of real power and reactive power vary depending upon the power quality. In the case of inductive loads at homes like refrigerators, there is more of reactive power to the source with a variation in phase and the power factor changes the power quality. In order for the need of improving them, certain consumers are cut off from the source which affects the power quality. This is done by an optimization algorithm then runs dynamically collecting data from the network, exhibiting a check to find which consumer affects the quality and terminates from supplying. Consider two networks for the study as $area_1$ and $area_2$ respectively. Here for the model considering domestic consumers. The loads considered as the input power to the network is P_{i1}, P_{i2}.

The list of variables implemented for the design which considers the concept of scheduling the power to the consumers based upon the consumer priority and quality of power management.

P_i – Input power to the network
P_{i1}, P_{i2} – Input power to network $area_1$ and $area_2$
P_{l1}, P_{l2} – Power required for Lighting Loads for $area_1$ and $area_2$
P_{h1}, P_{h2} – Power required for Heavy Loads in $area_1$ and $area_2$
P_{o1}, P_{o2} – Power required for non-essential Loads in $area_1$ and $area_2$.
P_{t11}, P_{t22} – Surplus power in the $area_1$ and $area_2$
P_{d1}, P_{d2} – Power demand of both the areas considered
P_d – Total demand of Power in network.

The lighting load power P_{l1}, P_{l2} for the two areas is calculated. The input on/off matrices is segregated into three matrices and checked for loop condition in the programming to calculate the total power consumed by Lighting loads, Heavy loads and non-essential loads separately. The Objective Function developed for the proposed model with necessary constraints are;

J = minimize (Power demand –Power Schedule) (1)

Where the power demand in (1) is calculated using the amount of demand for the total time by the individual loads

$$P_d = \sum_{t=1}^{L} (K_t * Totaltimeofpowerrequired)$$

K_t=Power rating of the first load among the predetermined loads considered.

$$Power\ scheduled = \sum_{t=0}^{T} \sum_{t=1}^{t} (k_t * S_w(i)(t))$$

Where $S_{w\ (i)\ (t)}$ is the optimal switching status of the loads among the lighting, heavy and the other non-essential loads. Switching status of the loads can take either zero or one.

$$S_{W(i)(t)} = \begin{cases} 0, \\ 1, \end{cases}$$

Indicates the state of on and off condition of loads over a time t (2)

The necessary constraints in (2) are satisfied then each input in the matrices is checked for zero or one. From the demand side, P_{d1}, P_{d2}, P_d is the values obtained from the above conditions. In the model subset models are created. Further the conditions of P_i>P_d is done.

The constraints involved is that the power allowance constraints for the loads is that at instant time the scheduled power should not exceed to the total power allowance over a time period.

$$\sum_{t=0}^{T} \sum_{t=1}^{t} (k_t * S_{w(i)(t)}) \le Power\ allowance$$

The other constraints involved is the total ON time i.e., $h_1 \le H_1$ where H_1 is the total time and h_1 is the sum of the switching status of the loads over a time period.

3.1 Algorithm : Intelligent Load Scheduling

Step1: The condition Input Power ≥ Total demand of power is top module , which is evaluated with two prior conditions.

Step2: If the condition is satisfied, the simple algorithm runs in the considered area network by identifying the phases which are distributed and collected from the smart meters installed in the networks.

Step 3: The above step is carried out by calculating with breaking the R, Y, B phases. For instance, the condition of P_{h1},P_{o1} = 0 is satisfied there is break in the phases Y, B.

Calculating P_{l1}. The surplus power is also calculated by P_{t1}=P_{L01}-P_{L1}. Finally P_{t11}=P_{t1}. Further if the condition is invalid the need to break the other phases B, R is done.

Calculation of lighting load, and surplus power is done and iteration is continued

Step 4: The minimum lighting power load for consumers are provided with available source of power if $P_{in} \geq P_D$ is not satisfied. This intimated the users to break the other two phases accordingly.

The flowchart in the Figure 3 clearly depicts the model design in the two level modules. In the setup the parameter explanation of each variable in both the networks are clearly explained. This method does not involve any complex mathematical optimization. The pseudo code explains the ideology of the entire set up for this intelligent load scheduling.

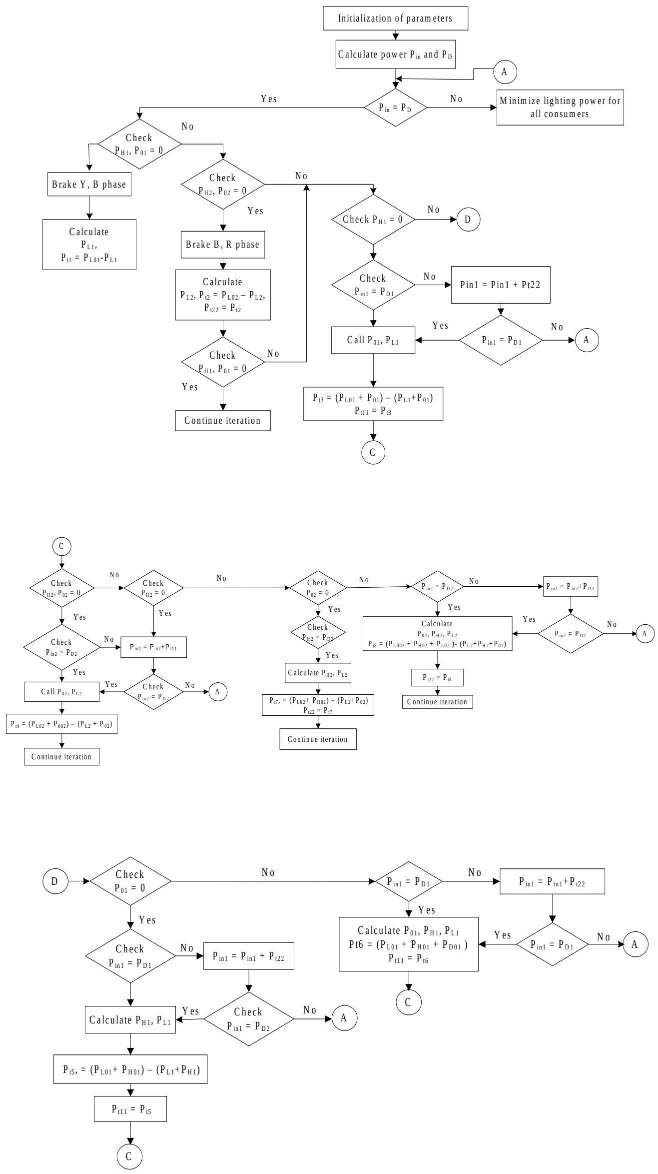


Figure 3 Flow chart of proposed methodology

4.0 RESULTS AND DISCUSSIONS

In order to demonstrate the effectiveness of the proposed system simulations are performed by considering the various loads like lighting load, heavy load and non-essential load. The proposed algorithm is implemented with smart meters in a smart grid environment invokes a better way of intelligent load scheduling. The proposed algorithm code is developed using C++ to verify the performance of the system. Further, the design considered in the network is built using MATLAB/SIMULINK to carry out the system performance. Simulations are carried out using 2.4 GHz INTEL i3 processor personal computer with 2.0 GB RAM. The complete schematic of MATLAB/SIMULINK model for the system under study is shown in Figure 4. The developed system comprises of three phase source with input voltage of 11kV and it is fed to the three phase transformer, and then supplied to various loads through circuit breakers. System is designed in such a way that the power can be fed to three different types of loads which considered in the network. In this work, novel approach for intelligent load scheduling using smart meters is employed to reduce power outages. The simulation model is developed to observe the variation of power flow with respect to time when there is a change in load network occurs. Perhaps the voltage and current waveforms shows the voltage stabilization can be maintained by cutting down the additional loads. The simulated results were presented in the following section. The further practical output is a considered case and the results are obtained on programming analysis.

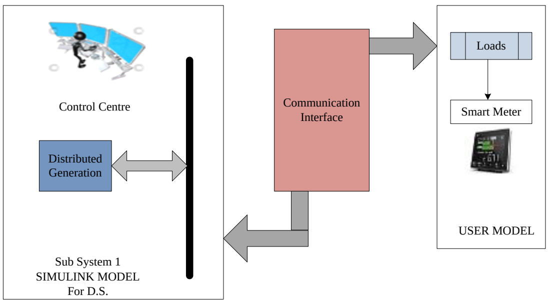


Figure 4 Block diagram of developed SIMULINK model

The performance of the proposed system analysed by considering five different areas which comprises of various loads such as lighting load, heavy load and non-essential load.The five areas are supplied by three phase distribution system. The total load of $area_1$, $area_2$, $area_3$, $area_4$ and $area_5$ are 5979 W, 6656W, 8895W, 10800W and 6616W respectively. The MATLAB code was written in such a way that to get best combination of on/off conditions of loads to minimize the load demand. This switching status can able to decide the consumer to operate the system particularly at the instant of time, based on this the remaining other two loads will work. The developed simulated model is executed by considering the switching instants obtained from the programming analysis, the total output reduction and related waveforms were presented. For verification of this proposed system total input power to both the networks is considered as 40 kW.

Total demand obtained after implementing DR algorithm and total saving of power is done. In normal scenario the total consumption was noted by 38946 W, by implementing the DR algorithm in the proposed developed model it has been reduced to 38353 W. So it clearly indicates saving of 593W in the total network shows better operating condition of the system without effecting power outages to consumer.

Figure 5 shows consumption of load for different areas with consumption of power for the case considered for analysis of the designed system in the smart grid environment. Figure 5 indicating the different load for all five areas.

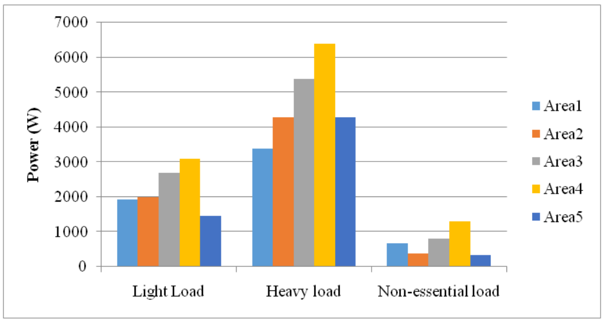


Figure 5 Actual demand for different areas

For verification; the designed system is simulated and results are presented below. Simulation results indicate that the distribution of load among different categories appliances and this will work on the basis of switching instants generated from the algorithm. The simulations has been performed by considering the constraints such as no power outages to the consumer, reliable of power, and three categories of loads distributed well across phases to accomplish a balance load in the entire network. The simulated results presented in Figures 6, 7 and 8 indicate the distribution of load among the appliances. Figure 6 shows the consumption of active and reactive power for lighting load of area 1. The total maximum load of 38353W considered to analyze the system performance simulations are carried out for same interval of time for the three different loads. For the verification of heavy loads three phase induction machines were considered for a domestic purpose. Figure 7(a) and (b) exhibits the stator current and stator voltage respectively. Figure 8(a) and (b) shows current and voltage waveforms of non-essential loads for which considered in the simulations. From the Figure 6, Figure 7 and from Figure 8 it can be deduced that the proposed method closely follows the desired power output according to the system switching instants and three different categories of loads were scheduled to minimize the load demand. In addition, the designed system is well balanced in case of load changes. This method demonstrates superior performance at all types of loads with high accuracy. It can be concluded that saving power of 593W is obtained by implementation of proposed method. The system is balanced in case of load changes in the network and further observed the target of managing the utilization of power without shedding power and power factor. The developed system can be extended to the n numbers of areas and scheduling can be done in effectively on programming analysis.

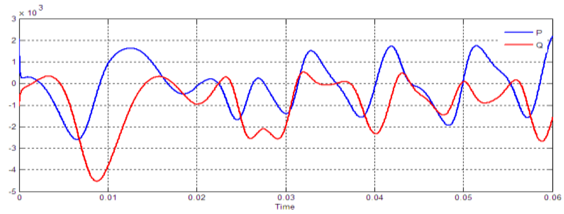


Figure 6 Active and reactive power of machine

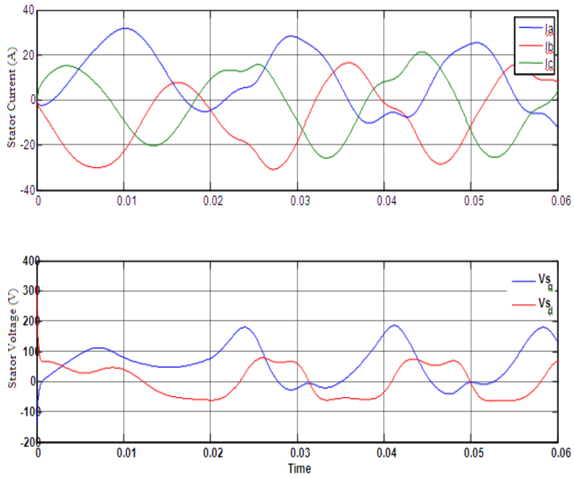


Figure 7 (a) Stator current (b) stator voltage

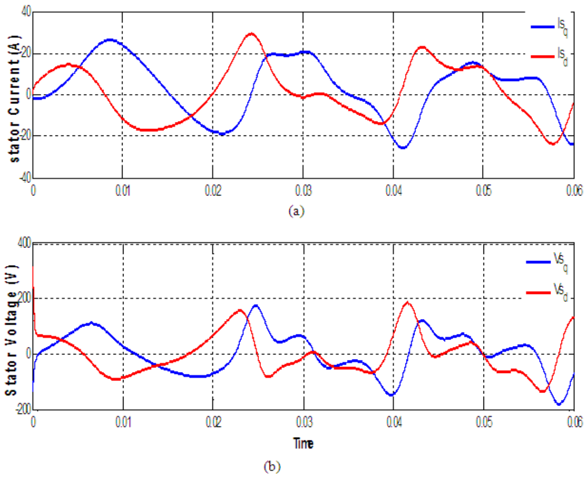


Figure 8 (a) Stator current (b) Stator voltage

Further, to validate the effectiveness of the proposed method it is tested by considering the air conditioning system in a single house of area 1. The house is consists of three air conditioning units. In the normal scenario the air conditioning system consumes a load of 4500W in a particular hour. It has been presented in Figure 9(a). After implementing the proposed algorithm the peak load is reduced to 1500W in the same one hour and the consumer able to utilize the system without any interpretation. The proposed system is able to schedule the load in such a way that the air conditioning unit receives equal amount of load with minimum peak load and designed system having the capable to flattening the load demand and it is presented in Figure 9(b). Further, the proposed method offers various advantages such as easy implementation, simple in design, faster in response and does not involve complex mathematical computations. Trial and error method and complex iterative computations are not present.

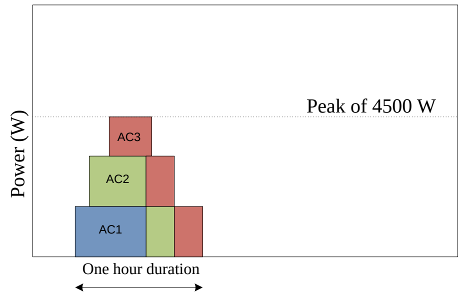


Figure 9 (a) Consumption of load without scheduling

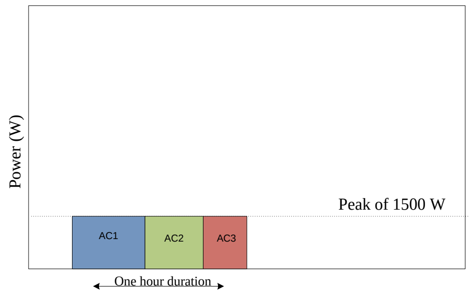


Figure 9 (b) Consumption of with scheduling

The system requires input parameters of voltage, current and provides the power consumption effectively. In addition this method can be further extending to identify transmission losses, power theft, and accumulation of load curve at each consumer level and take corrective/predictive actions.

5.0 CONCLUSION

In this paper a new intelligent load scheduling methodology is proposed using smart grid concepts. This proposed idea with sample results and modelling set up replaces need for uninterrupted power supply used by the consumer. Methodically, this approach include smart grid concepts of smart meters with communication capabilities at the customer premises , power distribution centres, smart power consuming devices and communication concepts. . This optimized method improves the quality of power transmitted, by eliminating the consumer wherein affects the power quality by more of reactive power. Mainly the target of power utilization is managed which is a crucial aspect worldwide with the reduction of energy losses .Utilization of the proposed technology can be further extended to identify transmission losses, power theft, and accumulation of load curve at each consumer level and take predictive actions .The proposed technique is a prerequisite step up which can be extended to future smart grid set ups .This presented technology can also be implemented using a proper communication networking systems in the future era of electrical grids.

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