Design and Implementation of a Load Scheduling Embedded System for Off grid Solar Power Systems

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Abstract— **Power drives most activities in health centers and homes. However, its availability and high cost make it an expensive commodity. Off grid power systems like PV-battery setups are more sensitive to fluctuations in the generation and load. Power generation in such systems is also intermittent due to dynamic weather changes and other natural factors which require inevitable use of batteries. Batteries are the most expensive part of off-grid solutions and their use has to be optimized. Furthermore, these systems, like any other power source, have maximum capacities beyond which they should not operate. If these limitations are not well observed, usage of the available power cannot be maximized and the power equipment may be damaged. In this regard, this paper proposes an embedded system solution that schedules appliances to run when there is available power from solar panels. The appliances are connected to the smart scheduler through a dedicated smart plug that powers the appliance depending on the conditions set by the smart scheduler. This solution not only ensures that loads are served at the earliest possible availability, but also avoids blackouts in the system. Furthermore, smart utilization of the resources minimizes the battery need and hence, the investment costs.**

Keywords—load scheduling; off grid systems; photovoltaic systems; smart plug; smart scheduler; load control

NOMENCLATURE

$\boldsymbol{P_{available}}$	Constant Considerable power to serve the loads
$\boldsymbol{t_{min}}$	Earliest time of day for obtaining $\boldsymbol{P_{available}}$
$\boldsymbol{t_{max}}$	Latest time of day for obtaining $\boldsymbol{P_{available}}$
$\boldsymbol{P_{load}}$	Power demand for any load
$\boldsymbol{d_{load}}$	Running duration for each load
$\boldsymbol{SL_{max}}$	Max. number of loads that can be served by $\boldsymbol{P_{available}}$
$\boldsymbol{t_{i,start}}$	Start time for ith scheduled load
$\boldsymbol{t_{i,finish}}$	Finish time for the ith scheduled load
$\boldsymbol{P_{used}}$	Total Power being consumed by each scheduled load
$\boldsymbol{List_{arr}}$	Array list of all finish times $\boldsymbol{t_{i,finish}}$
$\boldsymbol{t_c}$	Time when smart scheduler receives a request
$\boldsymbol{Id_{load}}$	Identifier for the incoming load

I. INTRODUCTION

Electricity (or electrification) plays a key role in boosting the country's economy. In Africa, the electrification rate is slowly growing and most regions are still far off the grid. This is attributed to the geographical size and infrastructural challenges in these regions [1]. Consequently, they rely on kerosene, batteries, candles and wood for their energy. Diesel generators are also commonly used in commercial centers and factories. However, these hydro-carbon sources get depleted and are harmful to humans. This makes the implementation of renewable energy off grid systems in such regions an alternative worth considering[2]. The operation and maintenance costs of a renewable energy based off grid system, especially solar, are lower due to the availability of the resource. The system also generates clean energy which is important in environmental conservation and control of the carbon content in the atmosphere [3].

With the steady drop in the prices of Solar PV, installation of an off grid solar system has become cheaper than ever. The remote regions in Africa are seizing the opportunity and several health centers and public institutions are creating their own off grid systems in order to offer more services to the community[4]. However, there is still hesitation in the use of Solar PV due to the high upfront cost of batteries that store excess energy for use at times of less or no generation from PV. The cost of operation and maintenance of the batteries is also quite high in terms of management. In [5], the optimal conditions for maximizing the battery life cycle in a photovoltaic system are discussed. One of the conditions is maintaining a good Battery Array to Load ratio (A: L) to ensure that the batteries are not over loaded. However, such a solution requires large number of batteries, hence large investment costs. The charge and discharge times of the batteries also have to be observed. When these conditions are not observed, PV systems become costly in terms of maintenance.

The challenges raised call for the need to reduce on the number of batteries required to run the Solar PV off grid system and also maintain the batteries at optimal conditions in order to minimize the cost of running an off grid solar PV system.

Demand side management became more feasible with the tremendous opportunities that ICT brings in the energy sector. A lot of work has been done in this field with major focus on reducing the peak load on smart grids. Most of the work suggests algorithms [6] and models that can be implemented to minimize the cost of energy and also cut the peak load on the grid. However, they all point at managing terminals that are connected to the grid. The utilization of solar power in off grid PV systems is barely considered in their models. The work in [7] discusses various load scheduling models and ranks them according to the percentage of the peak load they shave off the grid. This is important when choosing the scheduling model to implement.

In [8], several models are created to show how various classes of home appliances consume power. The work in [9] considers the off grid systems in demand side management by proposing systems that incorporate distributed energy resources

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in the peak load control and management of the grid. However, this does not focus on the maximization of power usage of the energy generated by the local energy resource but rather determine when to switch to the grid or remain on the local energy source, and also calculate the power to feed the grid. In [10], an embedded system is implemented to perform load scheduling of home appliances basing on the pricing information of energy from the grid. This also focuses on minimizing energy costs and cutting the peak load. The system collects power usage plans from the user and price of power from utility to create a scheduling model for the home appliances. The research in [11] presents an implementation of a smart plug that automatically collects appliance's power consumption information and also switches the appliances. Control of power wastage through power consumed by appliances while in standby mode is implemented in that research using embedded systems. This also aims at cutting demand and the cost of power.

Generally, most previous work aims at managing the grid, but not much has been done to manage and optimize the usage of power generated by off grid systems. The work in [12] presents a smart metering system using Bluetooth as the communication medium. This is also pertinent in this research, especially when it comes to the interconnection of the scheduler to the loads. The smart scheduling approach of this paper has been proposed in [13] and implemented in [14] using computer systems. However, given the energy requirements and required expertise to run the system, that implementation may not be feasible in such communities. Therefore an embedded system based approach has been assumed to maximize the usage of power generated by an off-grid PV system and improving its reliability. This aims at minimizing the need for back up batteries since most loads run at a time when the PV array generates enough power. At times of less or no power, the system maintains the optimal conditions for the batteries to avoid being drained by the loads. Moreover, it avoids overloading the system and consequent brownouts/blackouts. This system has a major benefit of maximizing the use of power generated by the PV system since it ensures that the loads run during the time of maximum generation. This solves the challenge of power wastage, hence reducing the break-even timeframe.

This paper is divided into four sections. Section II discusses the proposed load scheduling algorithm for a PV off grid system. Section III details the design and implementation of the proposed embedded system. The conclusion and future work are discussed in Section IV.

II. PROPOSED LOAD SCHEDULING ALGORITHM

The challenges being addressed in this paper are under utilization of the generated power and overloading the PV system. To put this into perspective, the daily PV power generation is studied. The total power generated by a PV system depends on the area and yield of the PV module, and the average solar radiation on the PV panel at any given time. This is represented by (1).

$$P_t = A \times k \times R_t \tag{1}$$

where P_t is the power generated by the PV module at time t, A is the area of the PV module and R_t is the solar radiation at t. k is a constant that caters for the energy losses due to temperature. Ideally, the power generation of a PV module throughout the day varies as shown by the dotted line in Fig.1.

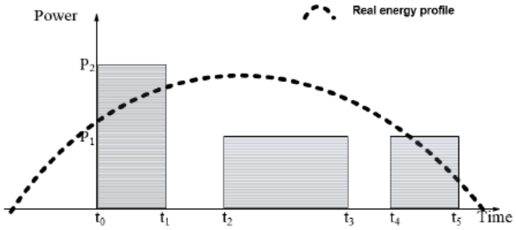

Figure 1: Overloading and underutilization of PV systems

The loads running from t_0 to t_1 and t_4 to t_5 are overloading the system whereas power is being wasted between t_1 and t_4 since the demand is less than the available power. To solve these two challenges, an appropriate load scheduling algorithm has to be implemented to ensure that there is always a balance between the power generated and the available demand. This algorithm can be created based on four different possibilities. The first possibility is the loads having the same power demand and run for the same duration. The second case is where the loads have the same power demand but run for different durations. The loads may also have different power demands but run for the same duration, or they may have different power demands and run for different durations. The fourth possibility is the most practical since it considers the diversity in power demand and operation of the loads.

A. *Same Power Demand, Same Running Duration Algorithm*

This algorithm implements the first scenario discussed in the previous section. This is the least probable and simplest scenario. However, since the major focus of this paper is embedded system development, this scenario is selected for implementation but should other algorithms be developed, they can easily be implemented in the embedded system presented here.

To model this algorithm, a constant considerable amount of power for scheduling, $P_{available}$ and the minimum and maximum time of day, t_{min} and t_{max}, respectively, when this power can be generated are assumed. The scheduled loads are stored in an array and each incoming load is added to the schedule array with respect to the indices of the currently served loads in the array. For any incoming load, its start and finish time can be modeled as stated in (2) and (3).

$$t_{i,start} = t_{(i\%SL_{max})} + \frac{i \times d_{load}}{SL_{max}} \tag{2}$$

$$t_{i,finish} = t_{(i\%SL_{max})} + \left(\left\lfloor\frac{i}{SL_{max}}\right\rfloor + 1\right) \times d_{load} \tag{3}$$

The start time of the i^{th} load, $t_{i,start}$, is determined by adding the finish time of the load that is in position $i\%SL_{max}$ of the array to the product of $\frac{i}{SL_{max}}$ and load running duration, d_{load}. The load finish time, $t_{i,finish}$, on the other hand is the sum of the finish time of the load at the same position and the running duration d_{load} multiplied by $\left[\frac{i}{SL_{max}}\right] + 1$. Whether the load is waiting or running, the user can cancel the operation at his/her discretion. In this case, the load is removed from the array and the wait time for the waiting loads have to be adjusted accordingly.

III. DESIGN AND IMPLEMENTATION OF THE SMART SCHEDULING SYSTEM

This section discusses the whole process of the proposed smart scheduling system design and implementation. The last subsection summarizes the experiments done with the implemented system and results obtained.

A. *System Requirements*

The system has a smart scheduler that schedules all appliances based on their power rating and priority using a scheduling algorithm mentioned. The connection between the smart scheduler and appliances is through a network of smart plugs onto which each appliance is plugged. Each appliance connects to a specific smart plug that has been specially programmed for it. The smart plug contains power consumption and run duration information for that appliance which it transmits to the smart scheduler while sending a schedule request. The smart plug controls the connection of the appliance to the smart scheduler and the power source. It communicates with the smart scheduler that determines the time when to switch the appliance on or off. Communication between these two devices can be of any technology while Bluetooth is used for this particular implementation. The conceptual diagram is shown in Figure 2.

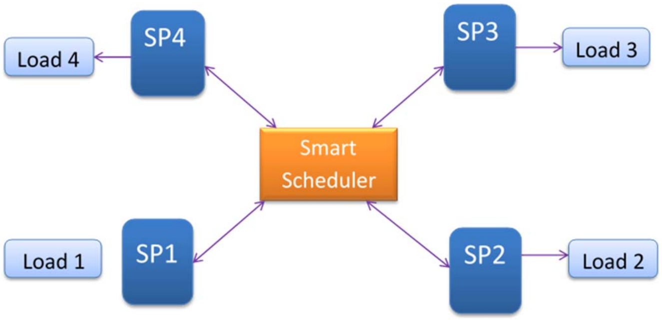

Figure 2: Conceptual Diagram for the proposed Scheduling Embedded System

B. *System Design*

As already mentioned, the system is a network of smart plugs and a central smart scheduler, with Bluetooth as the medium of communication. A PIC16F887 microcontroller is being used as the control unit in both the smart plug and smart scheduler. A HC-06 Bluetooth module manages the communication and a 16 x2 LCD is used to display the feedback information. The smart plug has got extra features that enable it to control the load and also give feedback to the user. The extra features are the relay, tricolor LED and the socket. The micro controller of the smart plug triggers the relay to switch the load depending on the commands received from the smart scheduler. The tricolor LED shows the state of the plugged load. The Green color of the LED implies that the Load is being served by the smart scheduler, yellow represent the waiting state, whereas the red shows power availability in the socket. Needless to say, the socket on the smart plug is where the load is plugged. The high level architecture of smart scheduler and smart plug are shown in Figure 3.

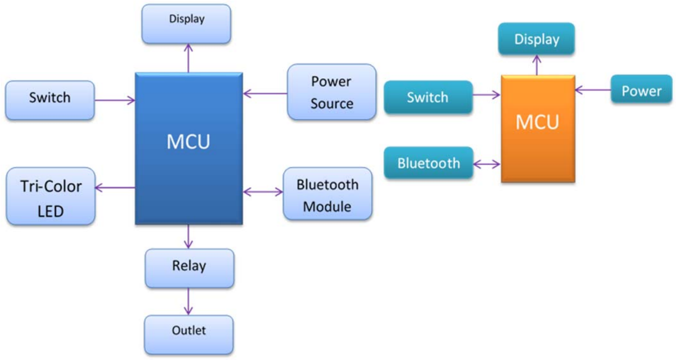

Figure 3: Smart Plug (Left) and Smart Scheduler (Right) High Level Architecture

C. *Operation of the Smart Plug*

All appliances have smart plugs to which they are connected. Once plugged, the smart plug sends the ID of the connected appliance to the smart scheduler so that the appliance can be added to the schedule. This request to the smart scheduler can only be made when the button on the smart plug is pushed ON by the operator. The smart scheduler then responds with the time the appliance has to wait until it gets powered. On plugging the appliance, the tricolor LED lights red. When the button is pushed the smart plug sends the schedule request to the smart scheduler which responds with the time this particular load has to wait before it is served. At this point, the LED lights yellow. The wait time is displayed and counted down from the LCD until the start time for the appliance to run is reached. It is then that the smart plug immediately triggers the relay to power the appliance. At this moment, the tricolor LED lights green. The appliance then runs for its time slot and switched OFF thereafter. The user may as well decide to stop the appliance before its time slot expires. This is done by simply pushing the button the second time. When the button is pushed, a cancel schedule request is sent to the smart scheduler which removes the appliance from the schedule list and the appliance is turned off. The flowcharts in Figure 4 summarize the operation of the smart plug.

D. *Operation of the Smart scheduler*

The only work of the smart scheduler is to run a load scheduling algorithm that ensures that at any instant, the available power and demand are balanced. In this case, the algorithm discussed in section II is implemented. Once the smart scheduler is powered, it gets $P_{available}, t_{min}, t_{max}$ for the day, P_{load} and d_{load}, and starts waiting for schedule requests from the smart plugs. On receiving the request, P_{used} is calculated and the available power is determined by getting the difference between $P_{available}$ and P_{used}. If the available power is enough to serve the load, it is powered instantly. Otherwise, it is scheduled to wait for a finite time. In cases where if a load is scheduled shall run beyond t_{max}, the schedule request is dropped. The same applies to schedule requests whose power demands are higher than $P_{available}$. The smart scheduler maintains an array of finish times , $t_{i,finish}$ for both running and waiting loads. The array is refreshed every second to ensure that $t_{i,finish}$ that expires is removed from the array. The flow charts in Figure 5, 6 and 7 summarize the algorithm.

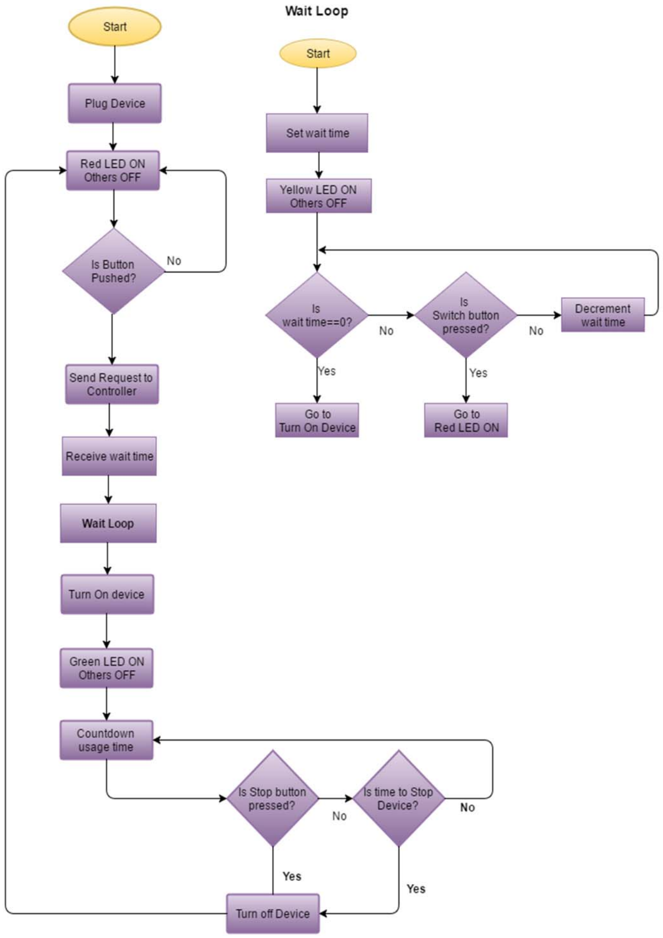

Figure 4: Flowchart showing the operation of the Smart Plug

E. System Implementation

The implementation was done on a Lab X1 Programmer kit using MikroC. Table 1 lists the components that were used to implement both the smart plug and smart scheduler. Figure 8 shows the lab setup of the smart plug. When a button is pushed, a request is sent to the smart scheduler through the Bluetooth module. The smart scheduler responds with the time the smart plug should wait before it switches ON the load. This wait time is counted down from the LCD. Once the time is up, the load is turned ON and the usage time counter is started. The load runs for a specific duration, as instructed by the smart scheduler and is then switched OFF once the appointed usage time expires.

TABLE I: LIST OF SYSTEM COMPONENTS

Component	Type
Micro Controller	PIC16F887
Bluetooth Modules	HC-05 and HC-06
LCD	16x2
4 Relay Module	SRD-05VDC-SL-C
PIC Lab Kit	X1
LEDs	Red, Yellow and Blue

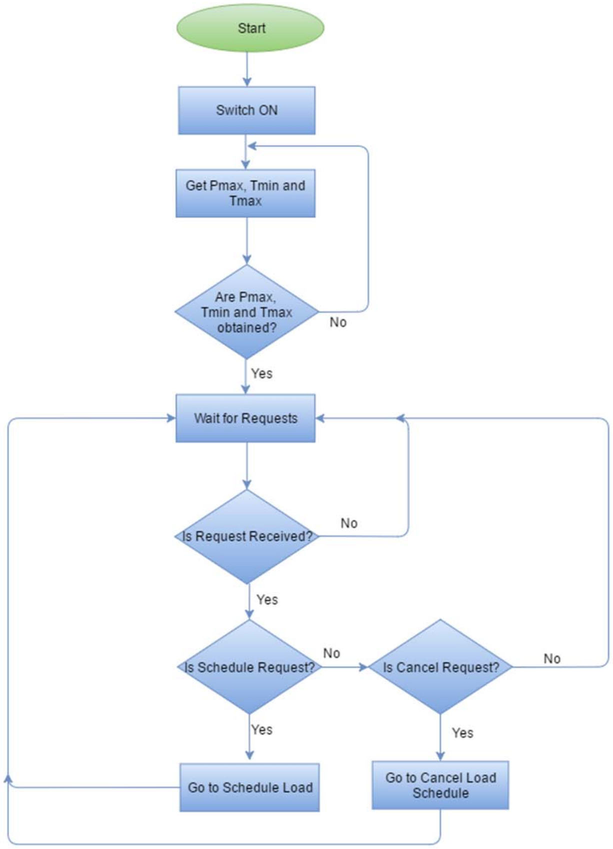

Figure 5: Flow chart showing the operation of the smart scheduler

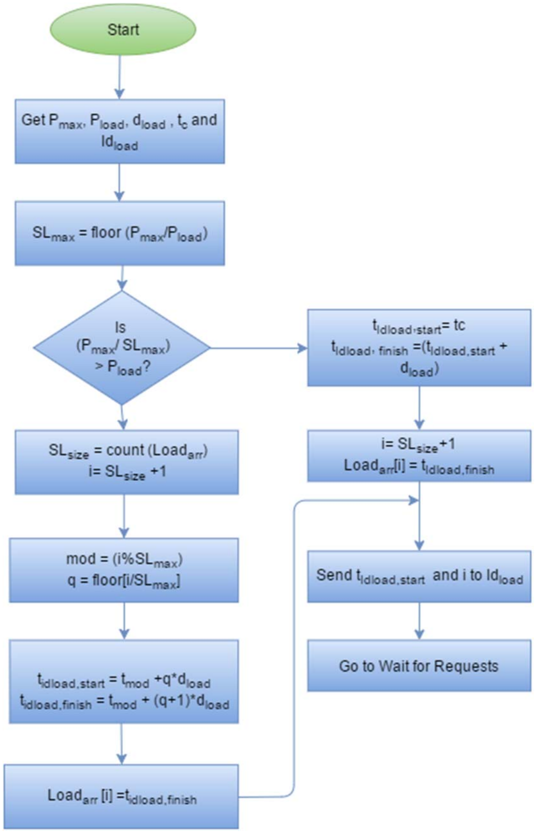

Figure 6: Flowchart for scheduling a load

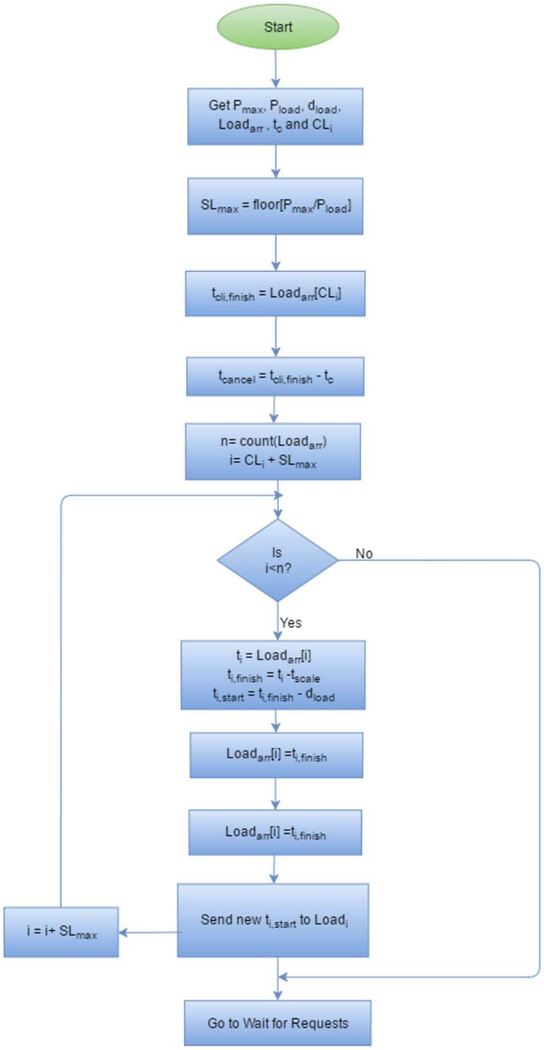

Figure 7: Flowchart for cancelling a scheduled load

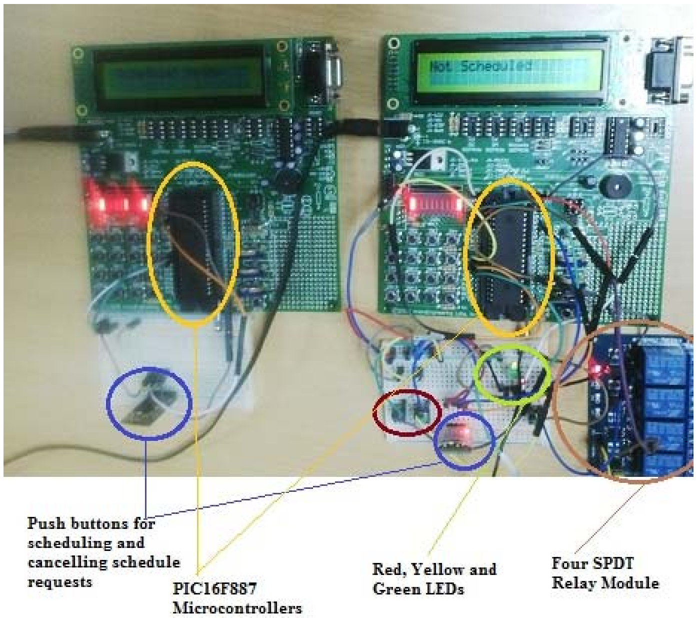

Figure 8: Smart Scheduler (Left) and Smart Plug (Right) in their default states

F. *Experiment and Results*

The load scheduling embedded system prototype was successfully developed and tested in the laboratory. In the experiment, LEDs were connected to the Relays of different smart plugs and schedule requests sent to the smart scheduler. The smart scheduler sent back different wait times to each smart plug. The smart plugs counted down the wait time and turned ON their respective LED when the wait time had elapsed. All the LEDs kept lighting for the same duration and were automatically turned OFF by their respective smart plug when the running duration had elapsed.

IV. CONCLUSION AND FUTURE WORK

This paper discusses the design and implementation of a load scheduling embedded system for off grid solar systems. This implementation is necessary in the management of a PV system as it maximizes the use of power being generated. It also minimizes the size of the storage system required to save the excess power, since the loads are scheduled at the time of generation. Hence the installation cost is greatly reduced. Moreover, the solution minimizes wastage of power generated since it ensures consumption of most amounts during generation.

As future work, the feature for collecting data about the frequency of loads on the schedule list and generated power shall be added. This shall enable the system to make more intelligent decisions like prioritizing loads and reporting performance of the PV system. As illustrated in Figure 9, load 1 is first scheduled and runs for its time slot. Then it requests for schedule again at the same time with load 6. So the smart scheduler gives load 6 higher priority over load 1 because the latter has run once more than its counterpart.

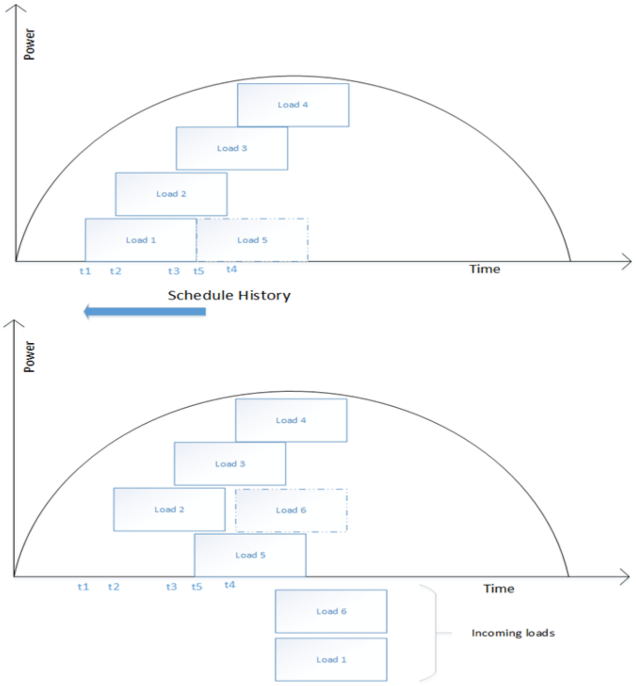

Figure 9: Prioritizationof Loads based on Service History

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