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AN INTELLIGENT HOME ENERGY MANAGEMENT (IHEM) BASED ON STATE OF CHARGE OF BATTERY IN HOUSEHOLD LOADS ON RENEWABLE ENERGY SYSTEM.

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ABSTRACT

This work proposed the switching control strategy for household appliances in a rural area that based their storage on the battery for three days. The system is to track the state of charge (SOC) of the battery to balance with the demand from the output appliances. The existing controller or regulator tries to off all the appliances when the SOC is reaching a certain level. However, to avoid a total blackout and to avoid at least an appliance to be working. Thus, we try to design an intelligent discrete-time controller and optimize the controller parameter for the set point control followed the base rule. The system performance result shows that proposed switch control strategies work within a certain limit and avoid total discharge of the battery.

Keywords: *Alternative energy, Battery, Controller, Intelligent, and SOC.*

1. INTRODUCTION

Renewable energy such as solar and wind energy in their production depends on the amount of sunshine and speed of the wind in a particular area. Thus, the only way to store and mitigate this issue is to provide storage that will be able to store the energy for later use. The storage can come in the form of a battery or hybrid electrical vehicle. Because of the sensitivity of the battery, mostly they are operating under severe conditions in term of charge and discharging and most under deep discharge, which surely affect their lifetime [1] [2]. Then to balance the amount of energy at a particular time and, due to network capacity constraints, location, the other way apart from storage is by shaping the energy consumption at the sink end. Most of the household contains hundreds of electric appliances, while few of them are usable at a particular time [3]. Therefore, we need an intelligent control system that identifies device status and able to switch OFF or ON depend on the importance of the appliances at a particular time. Many of the researchers are being worked on the system in which individual appliances will be equipped with a smart meter and the control will base on the characteristic load profile. However, for identification and control of a single smart meter can measure the amount of power consumption of particular time.

Unlike in the grid where two-way information flow between electricity providers and consumers in smart grid, where many forms of energy management have been working on in order to save energy [4] [5]. The systematic practice in most common approach is demand response mechanism which encourages the end user to change their consuming pattern of normal consumption in order to respond to change in the time-dependent electricity price [6].

Because of the numerous advantages of most of the renewable energy sources, a great attention has been focused on them. The Apart from providing continuous energy whatever there are variations of load and other weather conditions but to generate different sources in an intelligent manner that allows satisfaction of the load demand and maintain the batteries charged in case of standalone systems. Electricity demand varies at different hours of the day. The variation is not predictable from hour to hour. But the essential thing is for the loads to meet the capacity of the supply [7], [8].

Various architectures of the hybrid energy system have been proposed with different power management controls (PMC). Some of them are based on logical states and others on intelligent algorithms [9]. The lathers are more interesting, especially for standalone application in a remote area or where there is no grid.

With a numerous number of researchers have been working on the power management control. Most of their work based on the grid in order to balance or control the power from generations or from the customer side to reduce the cost of electricity consumed. In power aspect and energy control the common among are smart grid that involve two-way infrastructure between demand and supply i.e. the consumer and grid as supply of the electricity. They're different ways of handling the demand side energy management problem like artificial intelligence (AI) techniques like artificial neural network (ANN) [10] [11], fuzzy logic control (FLC) [12] [13] [14], adaptive neural fuzzy inference system(ANFIS)[15] [16], multiagent system and heuristic optimization like genetic algorithm(GA) ,colony particle search optimization (PSO) and the rest [17]. But, will find out that most problems of renewable energy for Microgrid or standalone are based on storage [3]. Apart from the cost of the initial stage of the installation, the problem sometimes arises from the charging and discharging of the batteries due to lack of information about the state or amount of load needed on particular times of the state of the battery. To rescue this, we can come out with a system since a lot of work on display of the level of the battery, but the one that will automatically reschedule or shed the load in accordance with the level of the charge, time of the day and frequency of the load are needed. For example, in most of the developing country where there is a problem of electricity, the best is to encourage people into the use of renewable energy [18]. By doing so, there is no way they will run for storage due to the nature of the most of renewable energy that unstable or not available at all time i.e. intermittent nature [19].

Since we believed that discharging current always affect the state or performance of the battery [20]. To maintain the durability of the battery, i.e. provision of higher battery life [21], the rate and discharge current of the battery must be kept at the particular limit. To protect the battery from over-discharge, the voltages of a health battery gradually recover and rises towards the nominal voltage. Thus, to maintain this a device may be developed to prevent the battery from being over discharge. The recovery of the battery voltage after removal of the load can be monitored and used to estimate the SOC of the battery [22]. The SOC can measure the suitability of the battery to reflect the energy storage and energy supply at an instant.

The Current trend of the data network advanced metering and sensor infrastructure has enabled bi-directional communication between generation and demand side [23] [24], either wireless or close contact, the demand –side energy management has now attained an intelligent outlook in both smart grid and off-grid standalone framework. As part of the objective, this will allow intelligent control the customer (demand) load in order to reduce or minimize the cost of production or reduces the cost of replacing the battery prematurely due to misuse. In addition, to minimize the peak load demand and or peak load ratio.

Therefore, the purpose of this paper is to develop an intelligent algorithm for IHEM to control the power consumption in off-grid rural standalone that based their supply on the autonomy of the battery for days. For this study, then, a rule base algorithm is designed to control the loads automatically based on the charge on the batteries, time of the day, load current without affecting owner meaning the owner priority also need to be considered.

2. LOAD OPTIMIZATION

Energy optimization now becoming interesting and increasing focus among researchers as long as new intelligent infrastructures and devices are going to replace the traditional manual ones.

The performance of the battery affected negatively when discharged at a higher rate; so, a proper consideration for additional battery to support higher load requirement. With this, there is a higher lost meaning higher running efficiency of the system translated to higher system capacity. To correct this, we can employ a system optimization strategy.

2.1 Loads modeling

Let $x_i(t) \in \{0,1\}$ and $P_i(t) \in R^+$ be denoted ON/OFF binary of appliances i at time t, and its instantaneous power consumption respectively.

If p is to be represented by the number of appliances under test that feed on power from the inverter as in Table 1. Thus, vector representation of the appliances ON/OFF states at time t can be defined as

$$X(t) = \left[x_i(t) \ldots \ldots x_p(t)\right]^T \tag{1}$$

Now the average power consumption can be represented by $\overline{P_\iota}[l]$ from $P_i(t)$ for a period index *l* defined by

$$\overline{P_\iota}[l] = {\textstyle\sum_{t \in t_i}} P_i(t) x_i(t) \Big/ {\textstyle\sum_{t \in t_i}} x_i(t) \tag{2}$$

where $t_i = \{(l-1)\,T_{est} + T_{s,}\ (l-1)\,T_{est} + 2T_{s,}\ \ldots., l\,T_{est}\}$

A vector of an appliance's average active power consumption at period index *l, is* denoted by

$$\overline{P_\iota} = \left(\overline{P_\iota}[l], \ldots \ldots \ldots . . \overline{P_p}[l]\right). \tag{3}$$

We can assume that the active power consumption of appliance I is stationary if it converges the constant value $\overline{P_\iota}$ over a period (i.e., $\lim_{l \to \infty} \overline{P_\iota}[l] = \overline{P_\iota}$), otherwise, it is nonstationary.

To estimate the power consumption of individual appliances over a period within the limit of $SOC_{min} \leq SOC \leq SOC_{max}$ of the battery. The idea of load management employed is based on load balancing that satisfy the owner, and the system so as to maximize available energy from the batteries, while as in grid connection own they employed load shedding to manage the available generation [25]. Using Eq. 4, energy store is

$$E_b = C_b \times V_{t\,SOC.} \tag{4}$$

where E_b is the energy stored in watt-hours on battery, C_b is the capacity in amp-hours in the battery, and $V_{t\,SOC.}$ is the average voltage during discharge at a particular state of charge. Kilowatt-hours, multiply by 3600 equal into watt-hours.

2.2. Energy store in battery modeling

The energy storage capacity of the battery can be calculated using Eq. 5 according to [26]

$$E_b = d_o \left(\frac{E_{tot}}{9760}\right) \frac{1}{\eta_b} . \frac{1}{DoD_L} = d_o \frac{E_h}{V_b} \cdot \frac{1}{DoD_L} \tag{5}$$

Where d_o is the typical hours of energy autonomy, E_{tot} is the annual energy of the loads, η_b is the energy transformation efficiency, DoD_L is the maximum depth of discharge, and E_h is the average hourly energy of the load.

Thus, when the battery is in used the peak power percentage of the load that battery should cover can be represented known the capacity factor of the load and the power efficiency as Eq. 6.

$$P_{b-out} = \tau \frac{E_h}{CF_{load}} \cdot \frac{1}{\eta_p} \tag{6}$$

Where τ is the peak power percentage of the load the battery should cover , CF_{load} is the capacity factor and η_p is the power efficiency.

The power demand by the loads must balance with the power of the battery in order to have a good operating system i.e.

$$\overline{P_\iota}[l] \ \alpha\, P_b \ \text{ i.e. } \ \overline{P_\iota}[l] = P_b \tag{7}$$

Here, the aim of load management is to maximize available charges on the batteries, managing loads in priority –based ways as well as maintaining battery charge levels.

Those appliances that involve in the energy management due to the battery under three-day autonomy, their preferences due to the time of the day was shown in table 1 below and load profile for a day as in figure 1.

Table 1: Load consumption Characteristic

	LOADS

Component In Morning	Lighting	Radio	Lamp	DS - TV	Charging point	Fan			Total watt
Usage Time	5.30 – 6.30	6.00 -8.00	6.00 - 7.00	6.30- 7.00	6.00-7.00	4.00- 5.00			
Consumption	20	30	2.0	30.0	6.0	60			
Number	8	1	4	1	4	3			
Avg. Wattage	160	30	8	30	24	180			432
Priority	1	2	3	4	5				
Component in the Evening	TV	Charging point	Lab - Top	DS- TV	Lighting	Radio	Fan	Washing Machine	
Usage time	6.00- 10.00	6.00 - 10.00	8.00- 10.00	7.00- 9.00	7.00- 10.00	6.00- 8.00	7.00- 9.00	7.00-8.00	
Consumption	150.0	6.00	60.0	30	8.0	15	60	120	
Number	1	4	1	1	20	2	3	1	
Avg. Wattage	150	24	60	30	160	30	180	120	754
Priority	1	2	3	4	5	6	7	8	
Total wattage									1,186.00

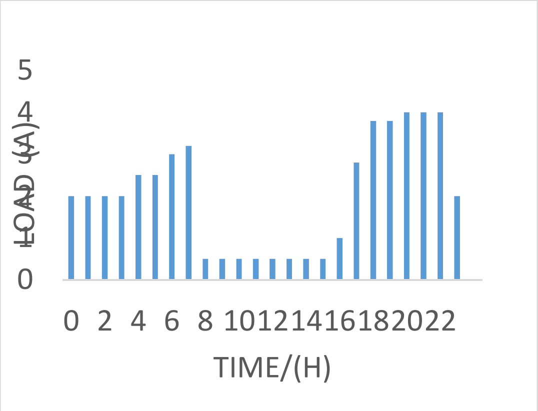

Fig. 1 The Daily Load Pattern of Residential on the test (Load profile)

Reduction of the consumption can be formulated as the optimization problem in the equation (8) below, which minimizes the sum of the squared errors in estimates of active power consumptions at period index *l, or* residual sum of squares (RSS).

$$\min RSS\ (\bar{P}_i) = \sum_{i=1}^{p}\left(\bar{P}_i\,[l] - \hat{\bar{P}}_i\,[l]\right)^2 \qquad (8)$$

Since we want the total consumption of the appliances to be balanced with the number of charges on the battery i.e. SOC conditions, the individual consumption of each appliance is not to be measured but total consumption. Thus $\bar{P}_i\,[l]$ can be stand as unknown. In order to correct that, the formula can be written in this form

$$\min MSE\ \left(y(t)\right) = E\left(y(t) - \hat{y}(t)\right)^2 \qquad (9)$$

Where $y(t)$ is repents total power consumption measured at the main electrical feed at time t and $\hat{y}(t)$ is the total consumption estimated by the sum of the estimated consumption of individual appliances. The optimization problem in Equation (9) can be solved by expressing $\hat{y}(t)$ with ON/OFF, state of individual appliances and their corresponding average power consumptions.

But, the instantaneous power consumption of appliance i, $P_i(t)$ can be described using $x_i(t)$ and $\bar{P}_i\,[K]$ such that

$$P_i(t) = (\bar{P}_i\,[K] + \varepsilon_{i1}\,(t)\,)x_i\,(t) + \varepsilon_{i0}\,(t)\left(1 - x_i\,(t)\right) \qquad (10)$$

where $\varepsilon_{i1}\,(t)$ is an error between the observed active power consumption and its expected value, and $\varepsilon_{i0}\,(t)$ is the appliance's power consumption when it is switched OFF (i.e. standby power for most remote control appliances) .

Known that $y(t) = \sum_i P_i\,(t)$ and the model in Equation (10), the total power consumption at K_{th} estimation period can be described as follows:

$$y(t) = \sum_{i=1}^{P}(\bar{P}_i\,[K] + \varepsilon_{i0}\,(t)\,)x_i\,(t) + \sum_{i=1}^{P}\varepsilon_{i0}\,(t) + \sum_{i=1}^{P}\varepsilon_{i1}\,(t)x_i\,(t)\ ) \qquad (11)$$

By the assumption that the standby power i.e. Vampire loads of each appliance is constant (i.e., $\varepsilon_{i0}\,(t) = \varepsilon_{i0}$ the Equation (11) can be simplified further. By assuming that the vampire loads are very small compared to the power consumption during their ON state (i.e., $\bar{P_\iota}\,[K] + \varepsilon_{i0}\,(t) \approx \bar{P_\iota}\,[K]$). Thus, after these assumptions the equation can be rewritten as the simple linear model as follows:

$$y(t) = \overline{P_k}\, x\,(t) + P_0 + e(t) \tag{12}$$

where $P_0 = \sum_i \varepsilon_{io}$ (i.e., the total vampire loads), $e(t) = \sum_i \varepsilon_{i0}\,(t) x_i\,(t)$ (i.e., the error of the linear model), and $\bar{P}_k = \left(\bar{P}_1[K], \ldots \ldots \ldots . \bar{P}_p\,[K]\right)$. By assumption that $\hat{y}(t) = \bar{P}_k\, x(t) + P_0$ in Equation (9) the optimization problem can rewrite by the following

$$\min_{\bar{P}_k P_0,} E\left(y(t) - (\bar{P}_k\, x(t) + P_0)\right)^2, \tag{13}$$

Or can be formulated as minimum error $e(t)$ of the total power load and the composite appliance power profiles $\bar{P}_k$ as shown in Eq. 14:

$$e(t) = \arg\min |\; y(t) - \textstyle\sum_{i=0}^{n} (\bar{P}_k\, x(t) + P_0)| \tag{14}$$

where it minimizes the expectation of e (t) with respect to ($\bar{P}_k$, P_0) given $y(t)$ and $x(t)$.

2.2 IHEM Controller

This controller consists of four inputs where monitors the consumption trend of the loads i.e. appliances in the home that attached to the inverter and another point where SOC of the charge of the battery are monitored. The central controller will then organize the two levels i.e. Consumption point and SOC point to check the appliance status based on the proposed rules below. The whole system consists of the solar panel, charge controller, battery, inverter, appliances and controller are shown in Figure 2.

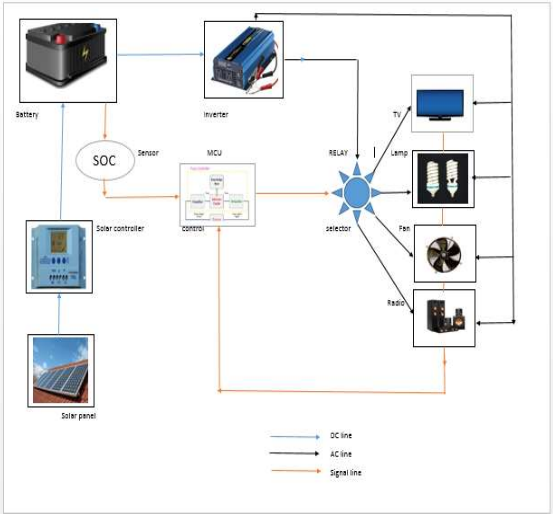

Figure 2: Pictorial representation of IHEM Flowchart

3. PROPOSED RULE BASE FOR IHEM SYSTEM

The following algorithm for IHEM system will allow the system to control the appliances by switching them in accordance with the SOC in order to reduce the energy consumption cost. The following steps can follow to implement this:

1) Read the power rating of all appliances (TL) has in table 1 and sense the state of the battery as in Fig. 2.
   Therefore, that Equation (4) will be proportional to Equation (9).
2) Identify system input and user input such as SOC of the battery in accordance to E_b in Equation (4), time of the day, load priority and user priority (i.e AP).
3) Sense the current on individual appliances to compare with the number of charges corresponding to energy to supply by a battery (E_b) on the battery in order to know the amount to shed or relay to switch off (when $x_i(t) = 0$) then $y(t)$ according to Equation (9) (i.e SOC α TL)
4) Determine new demand limits (i.e. NTL) by using Equation (10) by fulfilling the step 3.
5) Update priority of the appliances ON i.e. appliances with $x_i(t) = 1$.
6) If current demand $y(t)$ < New demand limit (i.e. CNL < NTL), then go to step 2.

7) If current demand $y(t)$ > New demand level (i.e. CNL > NTL, or NTL < CNL), the turn OFF the appliance according to the system priority preferences, time of the day, and owner priority and go to step 4.

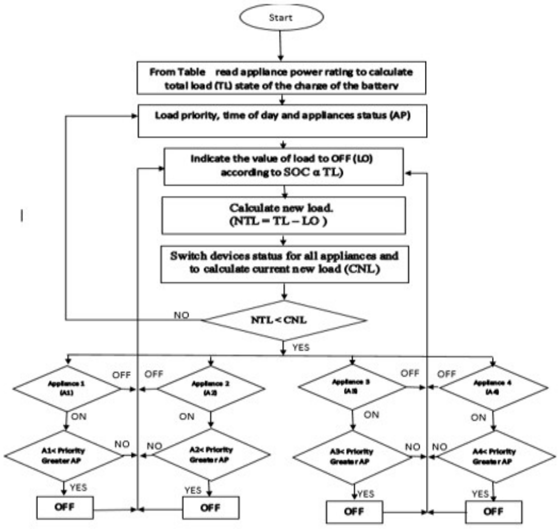

Figure 3: Flowchat of the schedule controller, considering Soc and load priority.

As reflected in figure 3, data are taken from all appliances, meaning the four appliances. The comparism between the appliance will then take according to their absorption with the total consumption weigh with the SOC of the battery as shown in the Figure 2. If the total electrical power consumption is greater than the state of charge (SOC) limit, the algorithm will turn OFF the lowest priority appliance starting with, and forces the loads to shift their operating time after.

4. DEVELOPMENT OF PROTOTYPE IHEM SYSTEM

The prototype of IHEM has been develooped to provide information about individual appliances and state of the battery in real time. The important componentt that have been considered in the IHEM system are the current measurement using current sensor from the sockets and SOC sensor on the battery. The input of the appliance i.e sucket not only measure the consumption but act as switches also to OF/ON the appliance from the central control for the select loads.

4.1 IHEM hardware

A prototype IHEM control has been developed as a standalone for off-grid system on autonomy. The system measures the power consumption by reading the current and voltage of connected electrical loads and control them (off / on) with electromechanical relay in the the output end after compared the loads with content on the battery using SOC sensor and application of the based –rules. The circuit of the IHEM is shown in Figure 4. The IHEM node is connected to home appliances at least four of them and i t is used for reading power consumption data of each appliance by means of current measurement IC and other side of to measure content of the battery. The decition on which appliance to swiches offor on based on the the rules and those measuement.

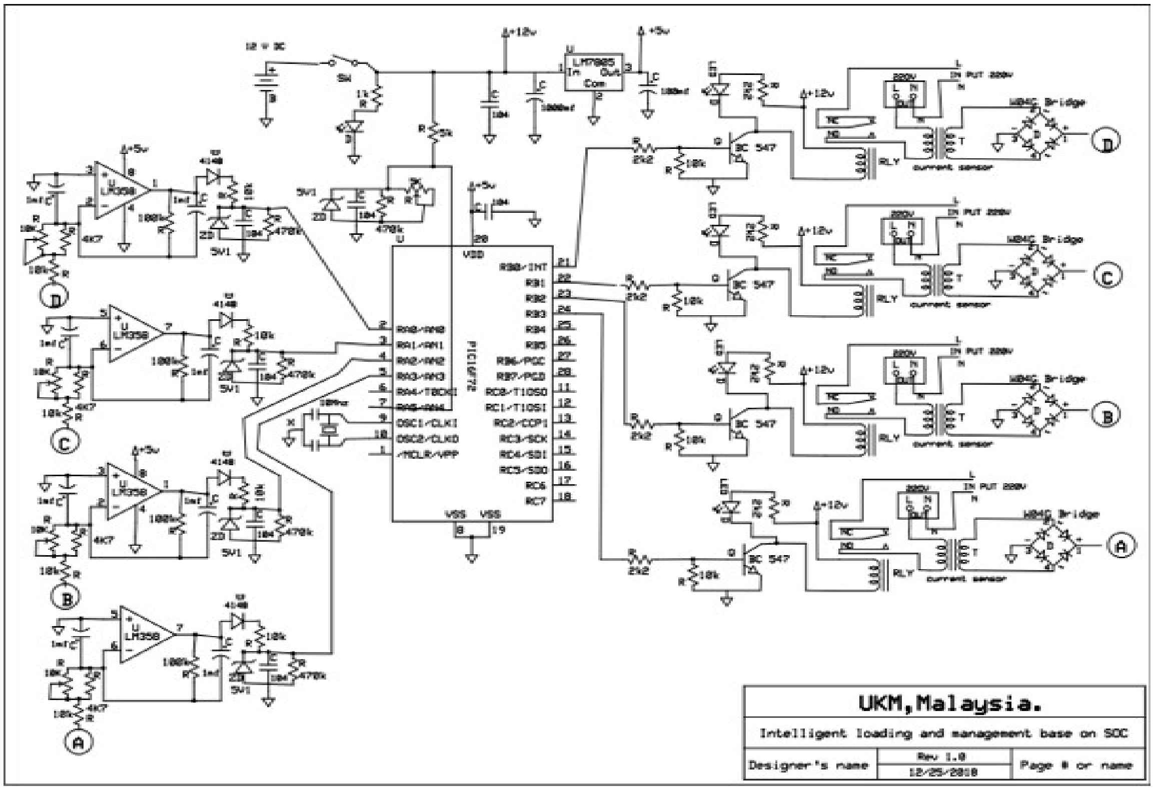

Figure 4: The circuit of the IHEMS System

Figure 5 shows the printed circuit board of the IHEM and prototype hardware of the IHEM system.

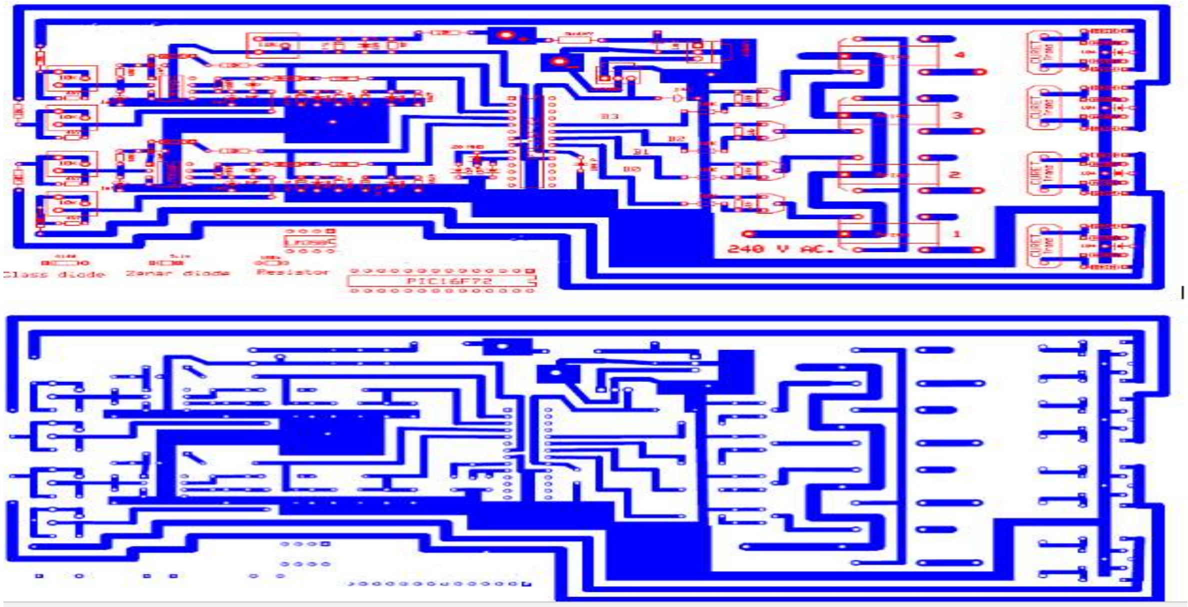

Figure 5 a: PCB layout of IHEM System

Figure 5b: Prototype hardware of IHEM

As shown in Figure 5, the transformer steps down the main voltage from 240 V AC to 12 V DC to provide voltage to the electromechanical relay, SRD-S-112D, the current sensor, LM 358 and LM 7885 for SOC sensor. And the central control IC (PIC 16F72) that coordinate the activity of the IHEM

5. SIMULATION RESULTS

The result obtained from two phases, i.e. measurements of the test performance with and without IHEM control based on the rules above. The voltage on the battery was being measured as in Figure 6, 7 and 8., to establish the voltage on the battery, state of the charge for three days along the battery based on the loads according to Equation (9) on the battery.

From the Figure 6 below, we can ascertain the movement of the voltage against the time of the day on the battery with loads, so that voltage falls as the day increases.

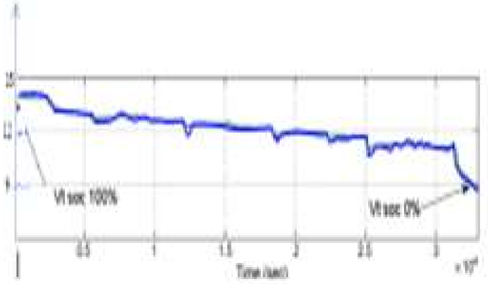

Figure 6: Voltages (V) against Time (Sec) for Period of three days without IHEM.

Without IHEM controller, voltage against time of the day was measurable and allow to fall as the loads on the battery increases. We notice that the battery goes to zero voltage as time moves on (see Figure 7). This danger to the wellness of the battery because there is no way the battery can get back to its initial voltage or state of the charge.

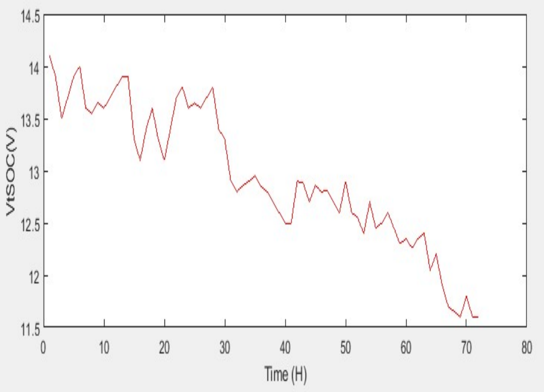

Figure 7: Voltages (V) against Time (H) for Period of three days with IHEM

By connecting IHEM comptroller, the measurement now carries on the time with loads on the battery, we find out that the controller does not allow the battery to drop into zero because its try cut off the appliaces that drawn current most than the content of the battery and safeguard the battery to fall to zero voltage, as in Figure 8.

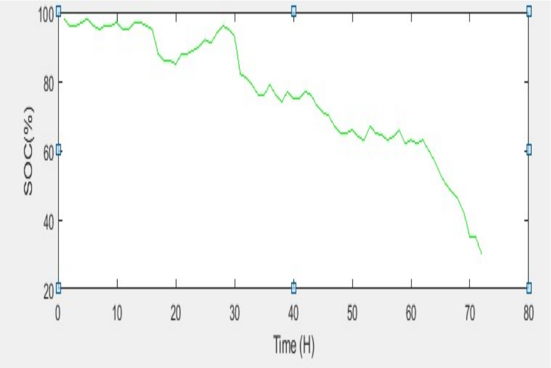

Figure 8: SOC (%) against Time (H) for Period of three days with IHEM

Observed the load profile when the controller is attached will notice that the profile is different from the figure 1 because all the vampire loads and unwanted loads are being cut off along with the usage according to the content of the t battery as shown in Figure 9.

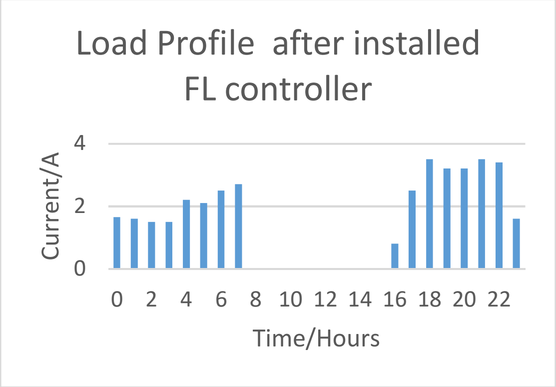

Figure 9: The Daily Load Pattern of Residential on the test (Load profile) after implementation.

6. CONCLUSION

This paper presented the control of the energy in the house using an inverter in remote area source energy from solar energy and the involvement of the smart home device. The proposed system will allow the loads to be on the battery in accordance with the charge or the capability of the battery in order to avoid running down the battery see Figure 8 and the result as in Figure 9. Also, to avoid premature running down of the battery to encourage and minimized the amount of the cost to establish the renewable energy. The proposed algorithm can manage the appliances and keep the total household power demand below an imposed demand limit of the battery as shown in Figure 2. The system can also take into account the load priority and owner priority in order. The priority based on the usage and the availability of the power base on SOC of the battery leading to a total load reduction so that there will be energy at all time and avoid deep discharging of the battery to improve battery life. Next work can tailor toward forecasting the status of the battery and likely appliances that will be used in future time. We hope the system can implement perfectly in the real home setting

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REFERENCES

[1] T. Guena and P. Leblanc, "How depth of discharge affects the cycle life of lithium-metal-polymer batteries," in *INTELEC, International Telecommunications Energy Conference (Proceedings)*, 2006.

[2] B. Zhao, X. Zhang, J. Chen, C. Wang, and L. Guo, "Operation optimization of standalone microgrids considering lifetime characteristics of battery energy storage system," *IEEE Trans. Sustain. Energy*, vol. 4, no. 4, pp. 934–943, 2013.

[3] M. A. Zehir and M. Bagriyanik, "Demand Side Management by controlling refrigerators and its effects on consumers," in *Energy Conversion and Management*, 2012, vol. 64, pp. 238–244.

[4] F.Katiraei, R. Iravani, N. Hatziargyriou, and A. Dimeas., "Micro-grids management," *IEEE Power Energy Mag.*, vol. 6, pp. 54 – 65, 2008.

[5] S. Aman, Y. Simmhan, and V. Prasanna, "Energy management systems: State of the art and emerging trends," *IEEE Commun. Mag.*, vol. 51, no. 1, pp. 114–119, 2013.

[6] S. Zhou, Z. Wu, J. Li, and X. Zhang, "Real-time Energy Control Approach for Smart Home Energy Management System," *Electr. Power Components Syst.*, vol. 42, no. 3–4,

pp. 315–326, Mar. 2014.

[7] K. Spees and L. B. Lave, "Demand Response and Electricity Market Efficiency," *Electr. J.*, vol. 20, no. 3, pp. 69–85, 2007.

[8] J. Torriti, M. Hassan, and Energy, M Leach ., "Demand response experience in Europe: Policies, programmes and implementation," *Energy*, 2010.

[9] M. S. Ahmed, A. Mohamed, H. Shareef, R. Z. Homod, and J. A. Ali, "Artificial neural network based controller for home energy management considering demand response events," in *2016 International Conference on Advances in Electrical, Electronic and Systems Engineering, ICAEES 2016*, 2017, pp. 506–509.

[10] D. C. Park, M. A. El-Sharkawi, R. J. Marks, L. E. Atlas, and M. J. Damborg, "Electric Load Forecasting Using An Artificial Neural Network," *IEEE Trans. Power Syst.*, 1991.

[11] M. N. Q. Macedo, J. J. M. Galo, L. A. L. De Almeida, and A. C. De, "Demand side management using artificial neural networks in a smart grid environment," *Renewable and Sustainable Energy Reviews*. 2015.

[12] D. K. Ranaweera, N. F. Hubele, and G. G. Karady, "Fuzzy logic for short term load forecasting," *Int. J. Electr. Power Energy Syst.*, 1996.

[13] G. Kyriakarakos, A. I. Dounis, K. G. Arvanitis, and G. Papadakis, "A fuzzy logic energy management system for polygeneration microgrids," *Renew. Energy*, 2012.

[14] H. He, R. Xiong, K. Zhao, and Z. Liu, "Energy management strategy research on a hybrid power system by hardware-in-loop experiments," *Appl. Energy*, 2013.

[15] L. C. Ying and M. C. Pan, "Using adaptive network based fuzzy inference system to forecast regional electricity loads," *Energy Convers. Manag.*, 2008.

[16] J. J. Cárdenas, L. Romeral, A. Garcia, and F. Andrade, "Load forecasting framework of electricity consumptions for an Intelligent Energy Management System in the user-side," *Expert Syst. Appl.*, 2012.

[17] G. Graditi, M. L. Di Silvestre, R. Gallea, and E. R. Sanseverino, "Heuristic-based shiftable loads optimal management in smart micro-grids," *IEEE Trans. Ind. Informatics*, 2015.

[18] G. Higgs, R. Berry, D. Kidner, and M. Langford, "Using IT approaches to promote public participation in renewable energy planning: Prospects and challenges," *Land use policy*, 2008.

[19] P. J. Hall and E. J. Bain, "Energy-storage technologies and electricity generation," *Energy Policy*, 2008.

[20] J. Kim and B. H. Cho, "State-of-charge estimation and state-of-health prediction of a Li-Ion degraded battery based on an EKF combined with a per-unit system," in *IEEE Transactions on Vehicular Technology*, 2011.

[21] P. Lombardi, M. Powalko, and K. Rudion, "Optimal operation of a virtual power plant," in *2009 IEEE Power and Energy Society General Meeting, PES '09*, 2009.

[22] P. Singh, R. Vinjamuri, X. Wang, and D. Reisner, "Design and implementation of a fuzzy logic-based state-of-charge meter for Li-ion batteries used in portable defibrillators," *J. Power Sources*, vol. 162, no. 2 SPEC. ISS., pp. 829–836, 2006.

[23] X. Fang, S. Misra, G. Xue, and D. Yang, "Smart grid - The new and improved power grid: A survey," *IEEE Communications Surveys and Tutorials*. 2012.

[24] M. Erol-Kantarci and H. T. Mouftah, "Energy-Efficient Information and Communication Infrastructures in the Smart Grid: A Survey on Interactions and Open Issues," *IEEE Commun. Surv. Tutorials*, 2015.

[25] P. P. Groumpos and G. Papegeorgiou, "An optimum load management strategy for stand-alone photovoltaic power systems," *Sol. Energy*, vol. 46, no. 2, pp. 121–128, 1991.

[26] Kazem, H. A., Khatib, T., & Sopian, K., "Sizing of a standalone photovoltaic/battery system at minimum cost for remote housing electrification in Sohar, Oman," *Energy Build.*, vol. 61, pp. 108–115, 2013.