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Intelligent Residential Energy Management System

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Abstract

Energy crisis is one of the critical problems faced by the world and the energy demand is increasing day by day. Energy Management performed efficiently is one of the possible solutions to address this global problem. An Intelligent Residential Energy Management System (IREMS) that effectively switches the loads between the battery and renewable energy source using smart tools like Support Vector Machine (SVM) is proposed in this paper. The power generated from the renewable energy source used, i.e., solar is stored in a battery and is used to power up the appliances, thus reducing the power consumption from the grid. Depending on the availability of grid and charge in the battery, the IREMS system intelligently decides the switching of the loads between the battery and the grid. IREMS algorithm is validated on a domestic setup having different types of loads in hardware. IREMS is housed in a LPC6148 microcontroller and subsequent room controllers that execute the decisions as communicated by the IREMS are also developed.

Keywords: *Residential Energy Management System, Support Vector Machine, renewable energy source, load profile, energy savings.*

Article History

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1. Introduction

Households are potential candidates of overall energy consumption where significant energy savings are plausible. Though 80% of the world's population have access to electricity, the amount of usage varies with different countries. According to World Energy Council [1], US and Canada top the list of 16 significant developing and developed countries whereas India and Nigeria are placed in the least position. There are numerous factors that drive these differences starting from the home lighting till the type of appliances used in the house. In India, 80% of the population enjoy electricity and the average household size is 5 per house, whereas in US or in Canada the average household size is 2 or 3 per house. This reflects the urbanization of the people in developed countries [2]. This scenario puts forth a scope for a suitable Energy Management System (EMS) that can effectively distribute the electricity depending upon the requirement and thereby optimize the electricity usage worldwide. EMSs for domestic scenario [3], [4] are used for managing and monitoring the electrical consumption of the home appliances with the local renewable generation and for displaying the energy savings at regular intervals of time [5]. A microcontroller-based EMS discussed in [6] sheds the loads based on fixed priority when the energy consumption crosses a threshold level. An Energy Sniffer developed in [8] uses fixed energy profile databases to perform energy management. Remote switching of the electrical appliances based on its location, serial number updated in the local and cloud databases enabled the user manually controls the appliances in his home. Algorithm for smart home was developed using recurrent Neural networks in [9] that tracks the change in the human behaviour in using his domestic appliances. A wireless enabled electricity manager at home generate the load profile for an appliance or a home giving an option for the user to set his monthly energy consumption bill and thereby controls his appliances accordingly [7], [10], [11]. Hardware demonstration of Home EMS for Demand Response applications developed in [12], [13] had the ability to perform energy management as a response to the utility signals. Loads are curtailed based on an energy consumption limit fixed based on the local generation, load patterns, electricity price etc as determined using

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genetic algorithm in [14]. Smart metering and Power line communications were used to monitor to the local renewable generation and thereby energy management is performed in [15] and [16]. Load shedding based on price signals and demand response signals was performed as a part of energy management in [17] and [18] respectively. Load shedding or curtailing of loads creates an uncomfortable situation for the domestic consumer which is unravelled by performing effective switchover of loads to a local storage renewably energized using a generalized intelligent algorithm in this work.

2. Automated IREMS

A one BHK house is considered for this study and the layout is shown in Fig.1. The house consists of an Intelligent Residential Energy Management System (IREMS) installed in the living room of the house. This has two inputs: (i) from the Grid connection of the house and (ii) from the battery storage, charged by the solar panels installed at the roof top of the house. There are separate Room Controllers (RC) mounted on each room. The controlling of appliances in the living room is taken care by the IREMS thereby need for another RC is eliminated. All the loads in the house are connected using relay switches through the controllers to effectively perform the load control. Battery has a built-in Battery Management System (BMS) that is responsible for the battery overload and under-discharge protection.

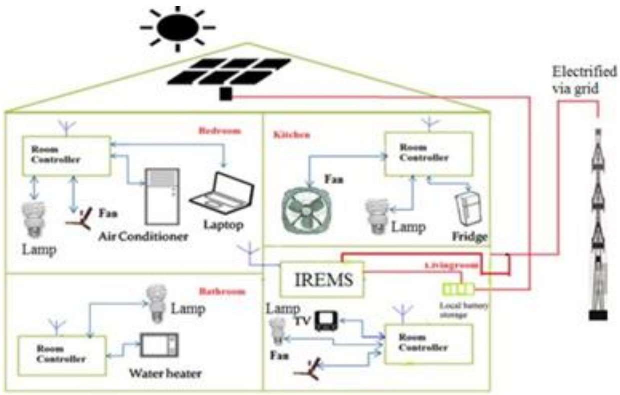

Figure 1 : Domestic Layout

The front view of an IREMS is shown in Fig.2 which consists of four panels: (i) Display to show messages to the user (ii) Grid or Solar availability indicator (iii) Power usage from the grid and the charge usage from the battery and (iv) Battery State of Charge (SOC). These illustrations are to make the consumer, aware of his energy usage in turn his savings due to solar installation in his premises and also to reduce his energy consumption.

In regular time intervals, IREMS monitors the status of the house and the decision is communicated to respective RCs which in turn performs the action thereby energy management is automated in the domestic premises. When the households are energized through IREMS globally, the overall throughput in the context of energy savings can be highly appreciated. The status parameters of any domestic consumer installed with rooftop solar panels are identified as (i) Grid Availability (ii) Time of Day (iii) SOC of battery and (iv) type of loads. Status values such 1, 0 or -1 are assigned for these status parameters to make it a generalized algorithm that reduces the memory storage in the target platform.

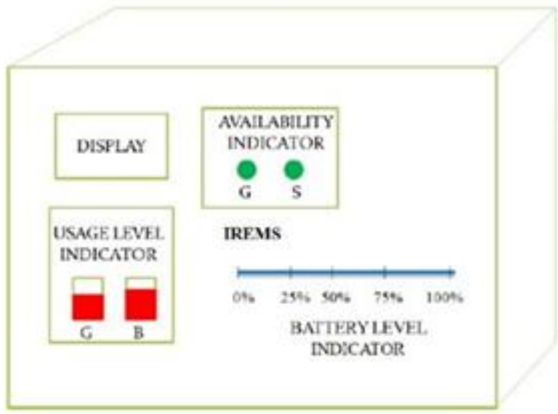

Figure 2: IREMS

The type of load and its power consumption are tabulated in Table I. Decision from IREMS are identified as (i) Maintain status quo (ii) Redirect to Grid (iii) Redirect to Battery (iv) Message the user. For eg., loads that can be energized by the battery are suggested by the IREMS to be redirected to the battery based on its SOC, possibility of charging depending upon the time of day. If battery SOC is very low, then the loads are to be serviced by the grid. If both the power sources are unavailable then a message is displayed to the consumer.

Table 1: Types of loads

Type of load	Power Consumption (W)
Light Loads (LL)	0 – 150
Medium Loads (ML)	150 – 350
More Medium Loads (MML)	350 – 650
Heavy Loads (HL)	650 -1000

Automation in turn the decision making should be human-like that are strengthened by experiential learning and logical reasoning. Dataset is generated by varying the values for the chosen status parameters and corresponding decisions are assigned for each occurrence. Models are created and simulated using machine learning algorithms such as Support Vector Machine (SVM) and Artificial Neural Network (ANN). Simulation is done in the MATLAB environment. The results proved that SVM gives better results in terms of classification accuracy when compared with ANN as shown in Table II. Fivefold cross validation is performed such that five datasets are

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created by distributing the decisions and its corresponding status. Classification accuracy is the accuracy obtained in classifying the unknown test data. Though the model CDA_B is better among the other models when trained with ANN, it is able to classify all the unknown patterns correctly when modelled with SVM algorithm. Since, this is a multiclass classification problem, Radial Basis Function (RBF) kernel is used to perform non-linear classification.

Table 2: Comparison of ANN and SVM results

Model	ANN Accuracy	SVM Accuracy
ABC_D	73.68%	78.94%
BCD_A	55.55%	55.55%
CDA_B	83.33%	100%
DAB_C	73.68%	100%

3. Hardware Validation

The chosen SVM model that realizes the concept of IREMS is validated in hardware using the LPC2148 as the controller that acts as the target platform. Fig.3 shows the schematic of the complete system in hardware.

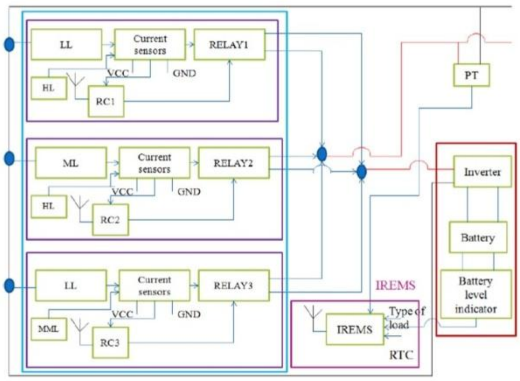

Figure 3 : Schematic for hardware validation of IREMS

IREMS and the RCs are realized using the LPC2148 ARM controller. Every controller is enabled with a Zigbee communication module to enable bidirectional communication between the controllers. IREMS needs to frame the 4 different status parameters. A battery level indicator shown in Fig.3 determines the SOC of the battery and communicates it to the IREMS. A Real Time Clock (RTC) is used to determine the Time of Day with which load switchover between battery and grid is determined. A potential transducer (PT) is connected to the grid to determine its availability. All the loads in different rooms are connected through the RCs as shown in Fig.4 which sense the load current in turn determines the type of load that are switched ON in that room. This information is transmitted to the IREMS through the wireless communication module.

Once the status parameters are formed, the decision of redirecting the load to grid or to battery is suggested by the IREMS using the SVM classifier model. This is transmitted back to the RCs which energizes the relays (R1, R2, R3 etc) pertaining to the corresponding loads thereby executing the instruction given by the IREMS. This process repeats at regular intervals of time. A single load integrated with the grid and battery through IREMS is shown in Fig.5. The RCs are duplicated for different rooms with the loads and communication modules connected to it.

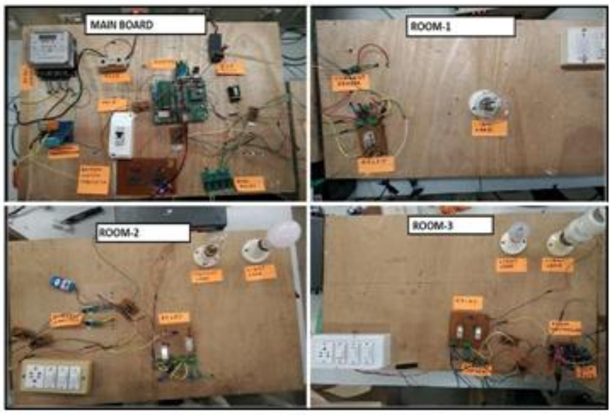

Figure 6 : Labor tory level setup for hardware validation of IREMS

The laboratory level hardware setup is shown in Fig.6. Loads include 2 CFL lamp as light loads, 1 fan as medium load, 1 TV as more medium load, Fridge and Mixie as heavy loads with a total power of 310W is considered for the hardware validation. Table.3 shows the considered size of the loads to validate the IREMS algorithm. Here 6 loads are considered under different types of loads, i.e., a 5 W CFL lamp is considered as a light load, a 40 W incandescent lamp is considered as a 60 W fan, a medium load, a 60 W incandescent lamp is considered as a 150 W TV, a more medium load and 100 W incandescent lamps are considered as 1200 W fridge and 750 W mixie which are heavy loads.

Table 3: Reduced Loads used in the demonstration

Household controllable loads	Loads used in the demonstration
CFL Lamp 20 W	CFL Lamp 20 W
Fan 60 W	Incandescent Lamp 40 W
TV 150 W	Incandescent Lamp 60 W
Fridge 1200 W	Incandescent Lamp 100 W
Mixie 750 W	Incandescent Lamp 100 W

The laboratory IREMS based on the status parameters suggested the decision which is transmitted to the RCs wherein the appropriate actions are taken in the respective loads. This is again updated during the next time interval in order to predict the next decision. The energy savings per day obtained with the household controllable loads when IREMS is installed in the

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domestic premises is calculated on a timely basis and is shown in Fig.7. The appliances turned ON as shown in Table 4 is assumed based on the peak hour usage. Also, the usage of fridge is throughout the day whereas the mixie usage is considered to be a maximum of 10 min per 2 h interval.

When IREMS is installed, the light loads such as light, fan and TV are energized by the local storage assumed that there is adequate charge in the battery. The assumptions may vary depending on the usage and the number of persons in the house. The results of the comparison are a rough estimate inferring that there can be changes with respect to the individual domestic profile, to insist the fact that usage of IREMS leads to significant reduction of energy usage from the grid.

Table 4: Reduced Loads used in the demonstration

Time	Appliances Turned ON
06:00 pm – 08:00 pm	1 fridge, 4 lights, 1 TV, 3 fans, 1 mixie
08:00 pm – 10:00 am	1 fridge, 2 fans
10:00 pm – 12:00 midnight	1 fridge, 2 fans
12:00 midnight – 02:00 am	1 fridge, 2 fans
02:00 am – 04:00 am	1 fridge, 2 fans
04:00 am – 06:00 am	1 fridge, 2 fans
06:00 am – 08:00 am	4 lights, 3 fans, 1 fridge
08:00 am – 10:00 am	1 mixie, 3 fans, 1 fridge
10:00 am – 12:00 noon	1 fridge, 2 fans
12:00 noon – 02:00 pm	1 fridge, 2 fans
02:00 pm – 04:00 pm	1 fridge, 3 fans, 1 TV
04:00 pm – 06:00 pm	1 fridge, 2 fans, 1 TV, 2 lights

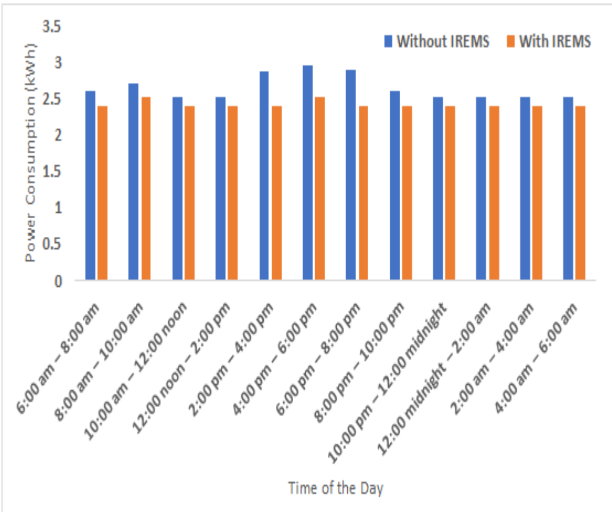

Figure 7 : Comparaison of grid energy consumption with and without IREMS

Fig.8 shows % energy savings per day in a 2-hr time interval. It is evident that 5 % energy savings is possible throughout the day whereas an average of 16.3 % energy saving is possible for a period of 6 hours. It is evident that 2.63 kWh of energy is saved by the IREMS over a day for the considered load profile. The overall energy consumption by the domestic consumer per month is observed to be reduced considerably. When IREMS is installed in every domestic premises, a substantial reduction in the global energy consumption can be accomplished.

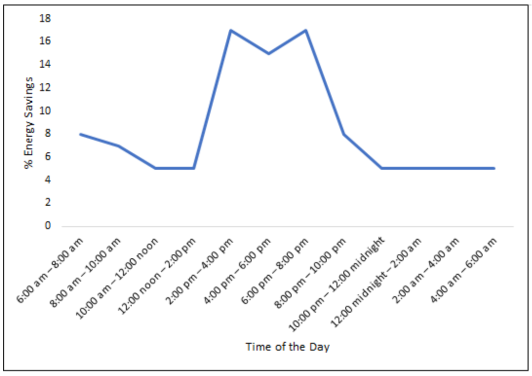

Figure 8 : EnergySavings (%) over a day

4. Conclusion

A laboratory model setup is established to validate the operation of IREMS that effectively performs switchover between the local storage and the grid in order to service the loads. A load profile for a domestic premise is considered and the energy savings by the IREMS is calculated which turned out to be significant. IREMS is generalized i.e., it works irrespective of the nature of the loads as it handles the status of the loads in the home thereby the storage is also greatly reduced. IREMS suggests the switchover decisions using SVM classifier which always gives a unique solution for the input data. Further, IREMS can be tested for real field implementation so that it becomes a complete product.

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