Empirical Validation of Fuzzy Logic Based Predictive Load Scheduling in Mimic Home Energy Management System

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Abstract

Load scheduling plays a vital role in the home energy management systems. The main objective of this load scheduling is to balance the power demand and supply power without degrading the performance of the loads and consumers tolerance. Though many research works concentrate on load scheduling, very few works concentrated on real time scenario. On the other hand, research work concentrated on optimal load scheduling through fuzzy logic requires incorporation of fuzzy based system in either simulated or real-time home energy management system. Hence, the proposal aims to schedule the loads in a simulated home energy management system through fuzzy logic controller using MATLAB Simscape with required subsystems. The proposed simulated environment considers four different resistive loads. Intelligent scheduling is aimed to achieve efficient load scheduling. A fuzzy controller has three inputs namely integrated source, state of charge of battery, and power demand whereas probability of scheduling is considered as output. The efficiency of the proposed fuzzy-based load scheduling scheme is evaluated under various load conditions for different sub-systems with varying input power. The results exhibit the efficacy of the proposed scheme.

Keywords: Home energy management system, Load scheduling, Smart grid, Fuzzy logic, Demand side management

1 Introduction

Smart grid is the synergetic solution for the challenges in a traditional grid like one-way distribution, centralized generation, manual monitoring, etc. [1-2]. Smart grid incorporates two-way distribution, distributed generation, self-monitoring, two-way communication, etc. [3]. Smart grid includes smart infra-structures and communication protocols that facilitate sophisticated principles and operation from generation to utilization stage. Further, smart grid uses renewable energy sources for distributed generation and reduces the cost of energy usage by smart pricing techniques through Demand Side Management (DSM) [4-6]. DSM, an approach in Home Energy Management System (HEMS) plays a significant role to reduce energy usage through load scheduling by shifting the energy usage from peak hour to off-peak hour thereby flattening the load curve.

Load scheduling is achieved through traditional optimization, soft computing techniques, evolutionary algorithms etc. [7-9]. Mixed-integer linear programming-based model for shiftable loads is done by considering the Time of Use rate [10]. Scheduling problems with various soft computing techniques such as Fuzzy Logic, Artificial Neural Network, and Evolutionary Computation are discussed in [11]. By using the Particle Swarm Optimization algorithm, the load scheduling is achieved with residential/ commercial /industrial loads, and hour-wise scheduling is achieved [12].

Encouraging the consumers to utilize less power consumption during peak hours through the fuzzy logic controller for HVAC loads is elucidated in [13]. In [14] the real-time problems faced at the time of executing DSM using load shifting in the HEMS are debated. For effective DSM in a smart grid, HEMS combined with renewable energy sources for achieving energy saving and minimization of its cost is discussed in [15]. The challenges faced issues and probable solutions in DSM are enlightened [16]. Realizing load priority technique and prediction of threshold power are discussed [17]. The energy management system including load and battery management is implemented by using a fuzzy logic controller and the load forecasting model is developed [18-20]. The reduction in the cost for PV-connected grid system when compared to the system without a fuzzy logic controller is presented [21].

From all the above works, it is clear that the majority of the works lacks considering real time load demand and setting up of HEMS. Moreover, the existing works validated the output either for specific inputs or for modeling. Hence, either simulation or real time based HEMS set up to validate fuzzy based system is mandate. To evade this issue, mimic HEMS is simulated using MATLAB and Simscape to observe dynamic load conditions in real time.

2 Related Work

Load scheduling in HEMS using fuzzy logic is proposed when the power supply is less than the power demand. Intelligent scheduling is implemented with three inputs and single output [22]. 3*3*3=27 rules are framed as Fuzzy Rule

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Base (FRB) with IF THEN statement in the Mamdani- fuzzy logic controller. To comprehend the implementation logic of framed rules, few rules are high-lighted in Table 1.

In this work, loads are classified into three different categories namely base loads, shiftable loads and non-shiftable loads. Base loads are the permanent least loads. The operating time of shiftable loads can be changed whereas non-shiftable loads do not allow. The proposed fuzzy logic controller efficiently manages load scheduling. However, the work deficit in addressing the efficiency of the fuzzy based system in real-time/simulated HEMS. To achieve this, the proposed fuzzy based scheduling is validated in simulation. The contributions of the proposal are highlighted below.

(i). The simulation of HEMS with dynamic loads to mimic real time scenario.

(ii). Validation of the proposed fuzzy logic based intelligent scheduling system for dynamic environment.

Table 1. Fuzzy rule base

Rule No	İntegrated source	Battery SoC	Power demand	Probability of scheduling
01	Minimum	Charging	Minimum	Little Medium
02	Minimum	Charging	Normal	Medium
03	Minimum	Charging	Peak	High
..	..	..	..	..
..	..	..	..	..
25	Excess	Discharging	Minimum	Little Medium
26	Excess	Discharging	Normal	Low
27	Excess	Discharging	Peak	Little Low

3 Proposed System

The proposed fuzzy logic based Mimic HEMS (M-HEMS) consist of integrated energy sources namely solar and battery SoC as inputs and the probability of scheduling of electrical loads as output. The power produced from the photo voltaic panel and the battery during discharging state is considered as supply power. As the state of battery is determined using state of charge, it is considered as one of the inputs to the proposed HEMS. Power demand is deliberated from the loads. Based on the supply and demand, the fuzzy logic controller is invoked to switch on/off electrical loads i.e. load scheduling. If the power supply is more than power demand, there is no need of scheduling other-wise the loads ought to be scheduled based on FRB. The block diagram of M-HEMS is shown in Figure 1.

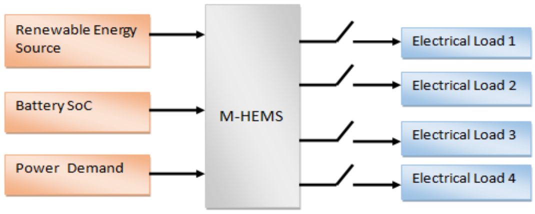

Figure 1. Block diagram of M-HEMS

To validate the proposed fuzzy-based scheme, PV source, battery and electrical loads need to be either modeled or designed. As modeling gives a definite recommendation for action in a particular condition whereas simulation allows users to determine how a system responds to different inputs for better understanding. Hence, the proposal simulates the M-HEMS to analyze the dynamic behavior of the supply power or loads to mimic a scaled-down version of the real-time scenario. The flowchart for the proposed system is shown in Figure 2.

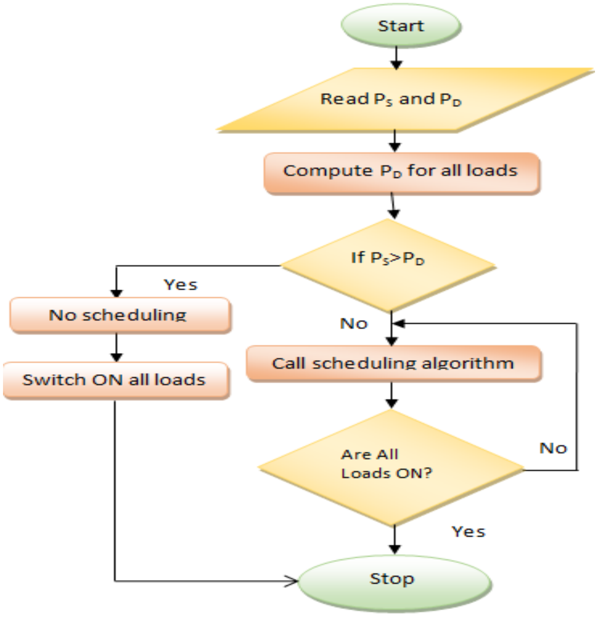

Figure 2. Flowchart for the proposed system

Initially, the total power supply P_S (Integrated source and Battery SoC) is calculated and is compared with the demand power PD (for all type of loads). If power supply is greater than the demand power, then there is no need for scheduling the appliances or vice versa.

4 Implementation

Fuzzy logic-based Mimic HEMS (M-HEMS) is implemented using MATLAB version 2018-b along with the Simscape setting in the Simulink model. The main advantage of the Simscape is that dynamic variation of the load is done at the time of running the model itself without interrupting the simulation.

Scheduling is achieved as per the rules framed based on fuzzy model for change in PV panel output, battery SoC and power demand and the impact of these parameters on load scheduling is observed. For better clarification, the load categories and the input and output term sets for fuzzy scheme are given in appendices A and B respectively. Figure 3 shows flow chart of simulated fuzzy logic control for M-HEMS.

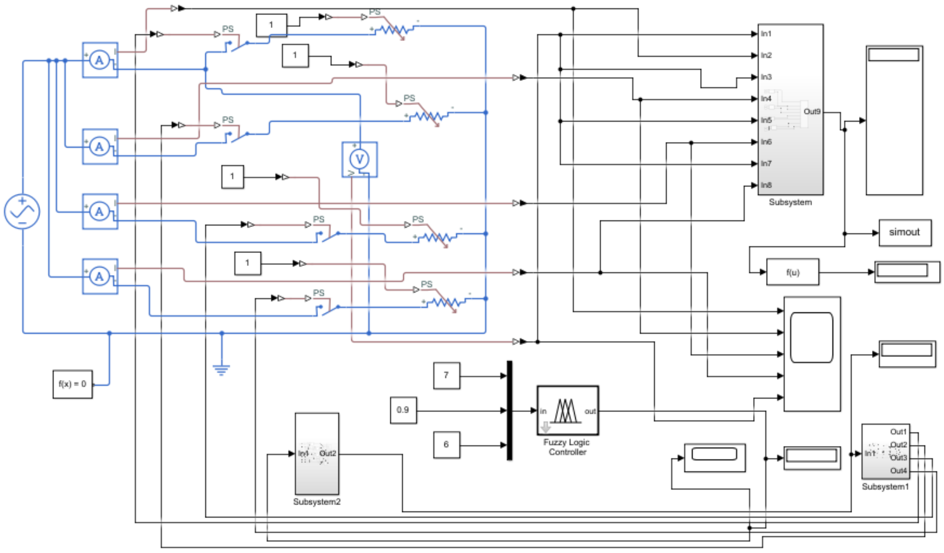

Figure 3. Simulation of fuzzy logic control for M-HEMS

In this, M-HEMS has three subsystems namely real and reactive power estimation, scheduling level detection and output indicator subsystem for load scheduling with four electrical loads. In order to measure voltage and current for each load, totally five sensors are utilized of which one as voltage sensor and four as current sensors since loads are connected in parallel. Based on these sensed values, power consumed by the loads is obtained.

The supply power using PV and battery SoC is also computed. Whenever, the power demand exceeds supply power, proposed intelligent Mamdani fuzzy logic controller is invoked. The fuzzy logic controller comprise 3 input blocks namely integrated source, battery SoC and power demand to predict the probability of load scheduling. 27 rules are framed as FRB and probability of load scheduling is estimated using the inference.

Defuzzification is achieved using centroid method. For better visualization of the proposed scheme, each subsystem is presented from Figure 4 to Figure 6 respectively. The first subsystem for measuring real and reactive power estimation subsystem is shown in Figure 4.

For all four loads, the voltage and current are sensed and the corresponding power is computed.

The scheduling level detection subsystem depicted in Figure 5 is to identify the need and probability of load scheduling as little low, low, little medium, medium and high respectively. The output of the fuzzy logic controller acts as input to this system and executes scheduling under different supply power and load conditions. The output indicator subsystem is illustrated in Figure 6. The input to this subsystem is the output of scheduling level detection subsystem. From the output of this subsystem, the number of loads to be switched on/off is found out. If the output indicator subsystem is 1, then the probability of scheduling is little Low. For this condition, no need for scheduling and hence, all the four loads can be ON. Similarly, if output indicates 2, then scheduling is Low and hence, one load must be switched off. In this fashion, as the output block point increases gradually from 3 to 5, the number of loads to be switched off is increased which clearly depicts the efficiency of the proposed load scheduling. The results obtained through experimentation are discussed in subsequent section.

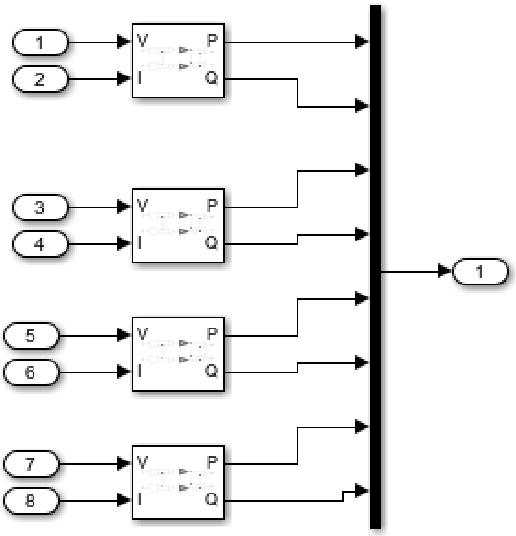

Figure 4. Power calculation subsystem

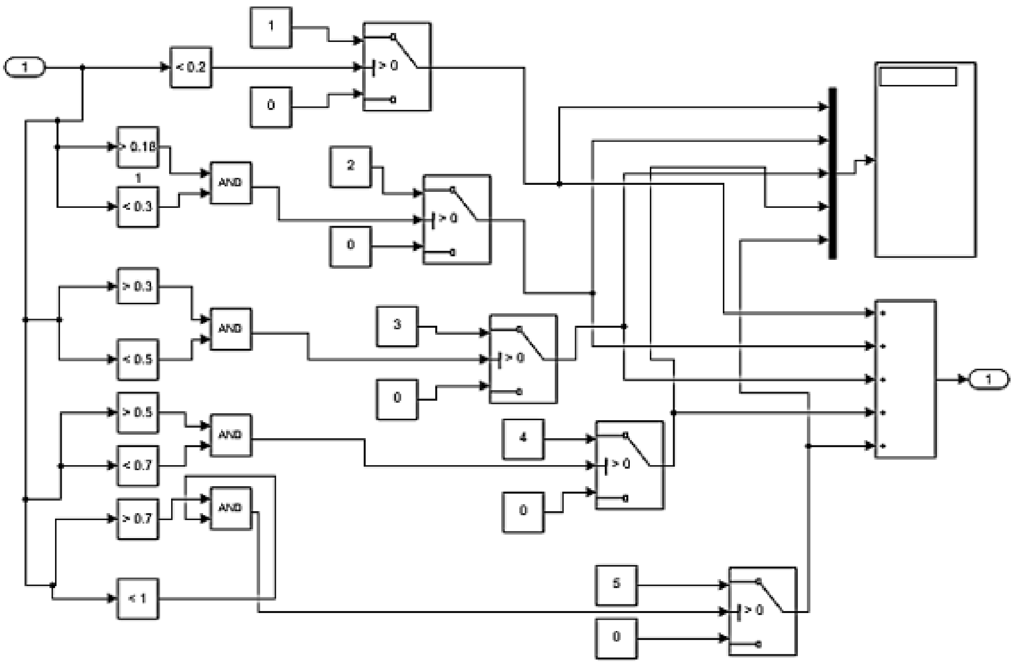

Figure 5. Scheduling level detection subsystem

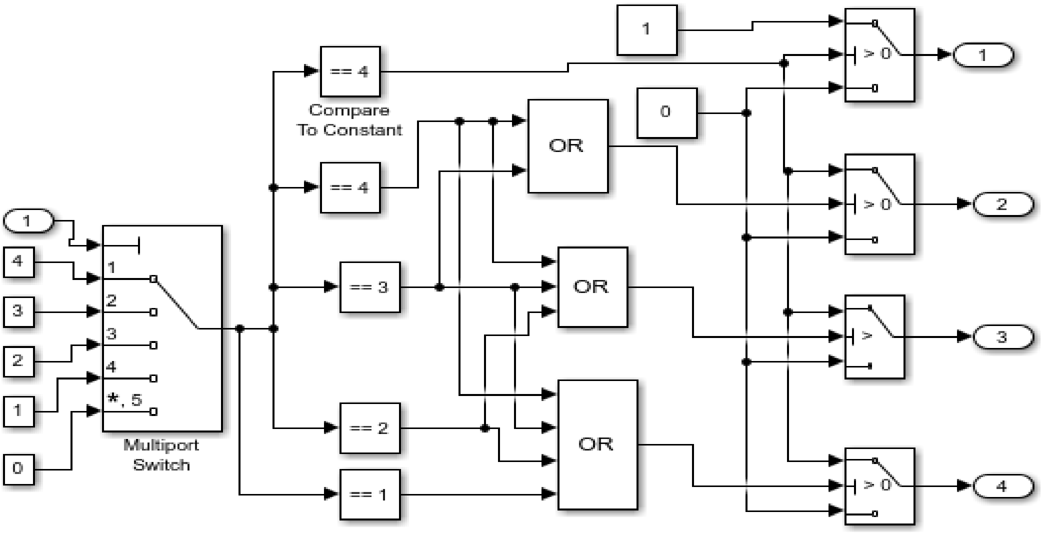

Figure 6. Output indicator subsystem

5 Results and Discussion

For load scheduling, four variable loads each having a maximum power of 7 kW are considered and the total maximum power consumption of the connected load is arrived as 28 kW. Based on the load conditions and the available power, the number of loads to be switched OFF exhibited in Simulink is portrayed in Table 2.

Figure 7 to Figure 11 shows the load conditions for different levels of scheduling. Each graph has five quadrants numbered from left to right of which four quadrants correspond to load currents where as fifth quadrant is the voltage waveform.

Table 2. Load condition

Display	Load condition	Scheduling
1	All 4 loads ON	Little Low (LL)
2	3 loads ON	Low (L)
3	2 loads ON	Little Medium (LM)
4	1 load ON	Medium (M)
5	All loads OFF	High (H)

From Figure 7, it is inferred that for PV input (P_{PV}) of 7kW, Battery SoC (P_{SoC}) of 1.6kW and the Power Demand (PD) of 7 kW, the Probability of Scheduling (POS) indicates no need for scheduling. Thus, it is evident that when PV input is in minimum range and battery SoC is in the mode of discharging with minimum demand, then the probability of scheduling is Little Low. For the second scenario portrayed in Figure 8, 12kW, 1.6kW and 15kW are considered as PV input, Battery SoC and Power demand respectively to predict the load scheduling.The results exhibit the probability of scheduling as Low which is evident through zero current in first quadrant in Figure 8. Similarly, the supply power and load demand are varied and respective probability of scheduling is presented from Figure 9 to Figure 11. The results substantiate that increase in demand proportionally influences shutting down of the loads which in turn proves the efficacy of the proposed scheme.

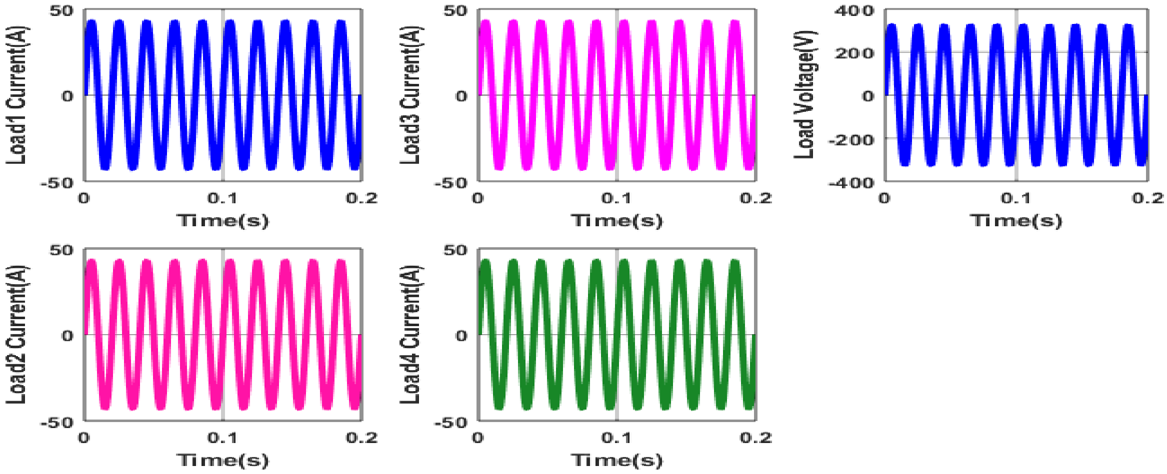

Figure 7. All 4 loads ON (PPV-7kW, PSoC-1.6kW, PD-7kW and POS-LL)

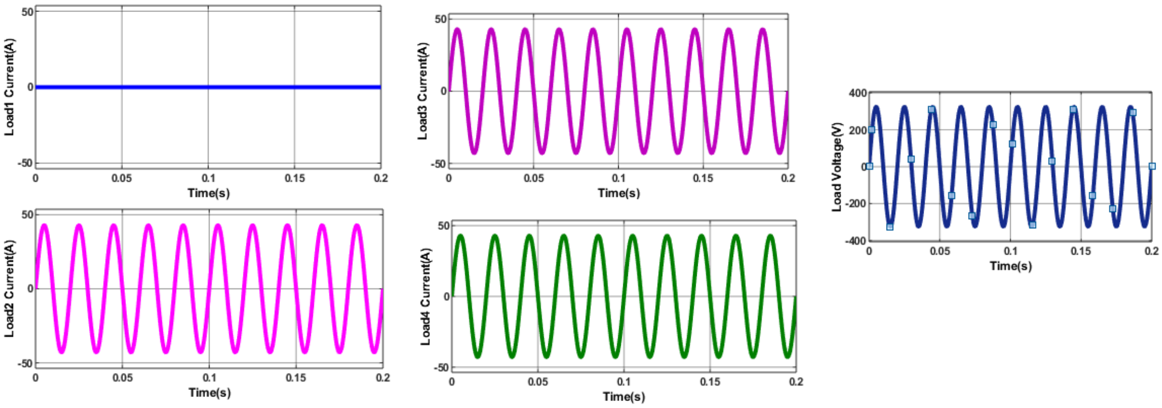

Figure 8. Three loads ON (PPV-12kW, PSoC-1.6kW, PD- 15kW and POS- L)

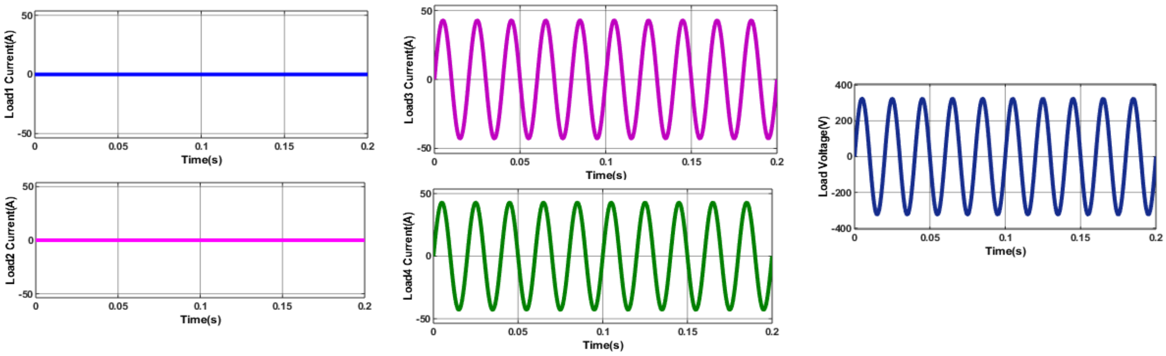

Figure 9. Two loads ON (P_{PV}-7kW, P_{SoC}-0.5kW, PD- 6kW and POS- LM)

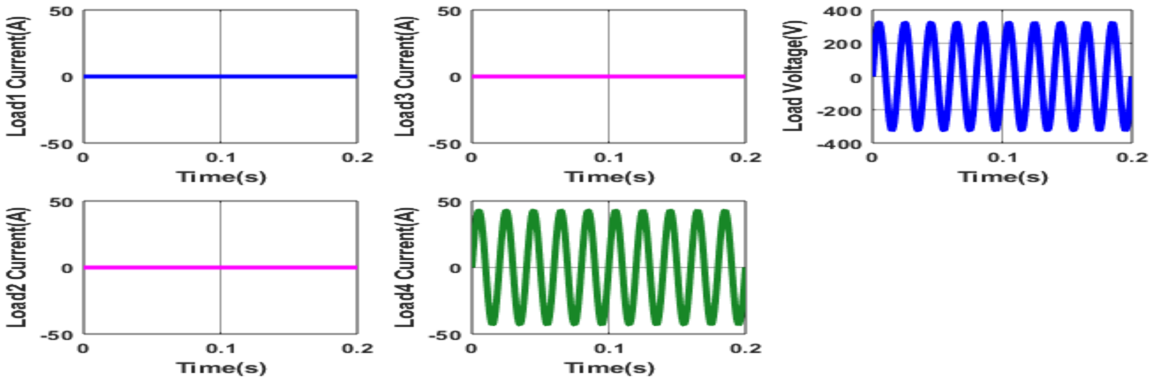

Figure 10. One load ON (P_{PV}-7kW, P_{SoC}-1kW, PD- 25kW and POS- M)

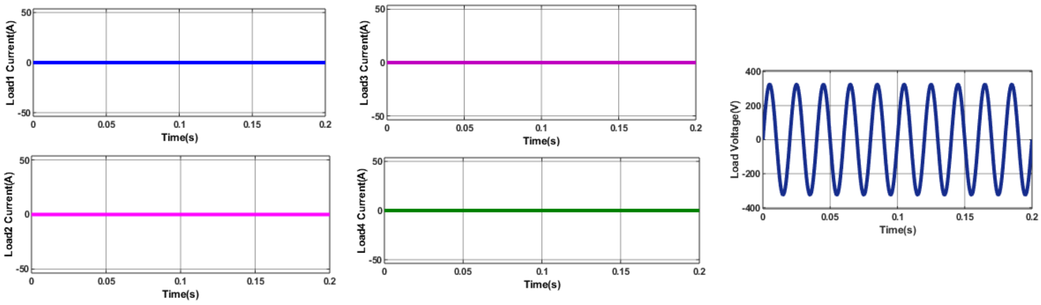

Figure 11. All 4 loads OFF (P_{PV}-7kW, P_{SoC}-0.5kW, PD- 25kW and POS-H)

Further the performance of proposed M-HEMS and SHEMS [17] is compared and the results are depicted from Figure 12 to Figure 15. where '0' corresponds to **OFF** and '1' to **ON.** Here, M-HEMS consider priority based scheduling by ranking the criticality of the load with 10% increase in load. Among the four loads, the order of preference is assumed as L1, L4, L3 and L2. Under such circumstance, the experimental results are compared for both methods with variable supply power (P_S) from solar (P_{PV}) and battery (P_{SoC}) by keeping conventional power source (P_{EB}) as constant as illustrated in equation 1.

$$x\,P_S = x\,(P_{PV} + P_{SoC}) + P_{EB}\,, \tag{1}$$

where x is the % of available power supply which should be distributed to all the loads.

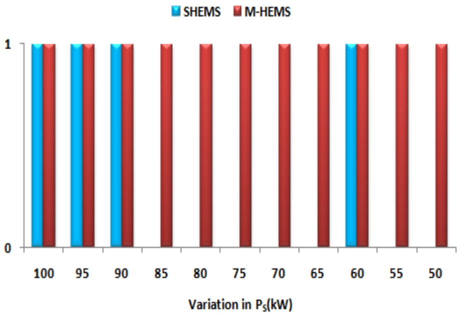

Figure 12. Scheduling for Load 1

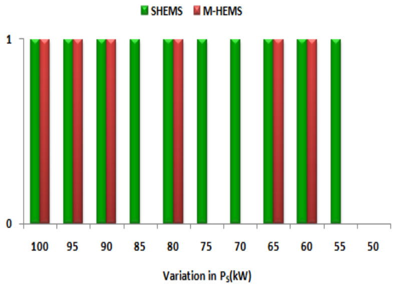

Figure 13. Scheduling for Load 2

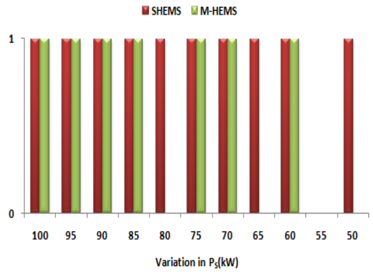

Figure 14. Scheduling for Load 3

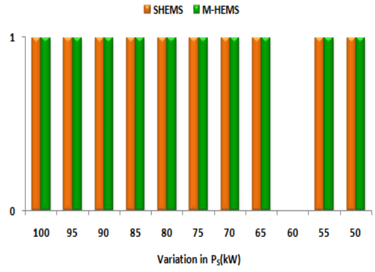

Figure 15. Scheduling for Load 4

From Figure 12 to Figure 15, it is apparent that SHEMS remains in **OFF** state for many of the circumstances of change in power supply. This is because, SHEMS considers crisp values where as fuzzy set is considered in M-HEMS. Hence, the performance of M-HEMS is overwhelming since it can prioritize the loads based on criticality which is not evident in SHEMS.

6 Conclusion

Load scheduling in Demand side Management is one of the promising techniques to attain peak shaving. Hence, efficient load scheduling is mandate to achieve optimal energy management system. Fuzzy logic based Mimic home energy management system is proposed by considering PV input, Battery SoC and power demand as inputs to predict probability of scheduling. Based on the available supply power and demand, need for scheduling is decided. The proposal is implemented using MATLAB-Simulink to mimic the real time home energy management system. Simscape is applied to examine the performance of proposed fuzzy scheme under dynamic load conditions. The results demonstrate the effectiveness of the scheduling scheme in prediction of loads to be switched ON/OFF. Hence, it is apparent that the proposed scheduling is appropriate for real time applications. In addition, the performance comparison is made with SHEMS and the results demonstrate the superiority of the proposal through prioritizing the scheduling. Further, the model can be enhanced for integrated renewable energy sources and battery SoC with hybrid soft computing techniques. In addition, the power quality issues due to load and input power imbalance will be the future scope.

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Appendix A

Appliance type	Name of the appliance	Power rating (kW)
Base load appliances	Cooker hub	3–4
	Cooker oven	4-5
	Microwave	1.7-2.5
	Laptop	0.1-0.2
	Desktop	0.3–0.5
	Vacuum Cleaner	1.2-2
	Electric Car	3.5-5
Deferrable appliances	Dish washer	1.5–2
	Washing machine	1.5-2
	Spin dryer	2.5-3.5
Non-deferrable appliances	Interior lighting	0.84–1
	Refrigerator	0.3-0.5

Appendix B

Input parameters	Term sets	Limits (kW)
PV Output	Minimum	{0;5;10}
	Satisfaction	{8;13;18}
	Excess	{16;21;26}
Battery SoC	Charging	{0;0.4;0.8}
	Saturation	{0.6;1.0;1.4}
	Discharging	{1.2;1.6;2}
Demand	Minimum	{0;6;12}
	Normal	{8;14;20}
	Peak	{16;22;28}
Output parameter	Term sets	Limits (kW)
Probability of scheduling	Little Low	{0;0.1;0.2}
	Low	{0.18;0.27;0.35}
	Little Medium	{0.3;0.45;0.55}
	Medium	{0.5;0.625;0.73}
	High	{0.7;0.85;1}

Biographies

Nirmala Jegadeesan obtained her B.E. in Electrical and Electronics Engineering from Kamaraj University, India in 1994 and M.Tech. in Power Systems from SASTRA Deemed University, India in 2006. She is doing her Ph. D in Smart Grid at SASTRA Deemed University, India. Her areas of interest include Smart Grids, Internet of Things, Machine Learning and Power systems. She is currently working as Assistant Professor in SASTRA Deemed to be University, Thanjavur, India.

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