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Load Side Management (LSM) for Solar PV household System

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Abstract:
Abstract—In this paper we present a model of Load side management (LSM) control for household appliances that energized through on grid PV system. The intention here is to reduce the dependency on the grid operator to supply excess power above usual when there is PV intermittency. The proposed model of LSM control introduced here is to compensate for the reduction of power generated by solar PV system from its rated capacity by reducing the power consumption of the variable heavy loads depending on the power availability from Solar PV. This strategy was recently introduced for air condition systems employing variable fan speed. It was proved that using variable fan speed can manage energy consumption from the PV source and optimize energy utilization. In the developed solution here, home heaters can be also managed as variable loads that adapt their consumption according to the energy available from the PV source. The model is based on using PWM (Pulse width Modulation) to control heating power. As a result, the heating time of the water to a certain temperature will be dependent on the energy availability. The developed algorithm uses measured values for available solar power and the heater thermal model in order to generate the suitable PWM signal that control the energy delivered from the PV source. The algorithm was tested using Matlab Simulink and the early results shows the validity of the proposed technique for Load side managements.

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INTRODUCTION

As the growing rise in the electric demand which lead to an increase in electricity cost, the residential sector is considered as the most electricity consuming sectors, which in some countries reach to 60% of itstotal consumption[1].Investment in constructing new traditional power plants associated with upgrading transmission and distribution network are recommended bygovernments in order to overcome the peak demand, despite the greenhouse-gas emissions. In fact, although the growing demand for energy lasts only for short periods it has a serious s financial impact.

On the other hand, the end users are always looking for effective solution to optimize the loads in economic way in order to contribute in limiting the raise in the electricity bill.

Consumers have many choices to reduce electricity cost if they can economically schedule their power consumption. Nowadays,Renewable energy has become attractive solutions of producing energy at low cost, including solar and wind sources,[2]PV technology has been widely spread, In the last few years owing to several advantages; availability of the solar resource, noiseless operation, low maintenance cost[3].In 2018 only, the total capacity has been grown by 24% with total capacity installed worldwide around 94 GW

[4].Recently, abounding growth in the integration of solar PVs into the distribution network,Load Side Management (LSM) with PV Solar mainly purposes to inspire a change in the use of electricity. Fortunately, that the peak time of the residential sector is mostly identical to the peak solar energy witch will contribute in utilizing of the solar PV power in distributed generation (DG)for homes in order to reduce the peak load thus, government can

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save through investing to meet this demand for short time.

LSM LITERATURE REVIEW

LSM of Solar PV technologyhas been studied in recent years towards utilizing ofall availablepower generated from the solar energyPV sources to be consumed fully by the consumer.The related studies mainly include issues of developing, modeling, simulation and optimization of LSM at each level. Various LSM techniques have been developed and simulated in order to guide consumers towards an economic choice [2,3,1, 5].
Comprehensives studieson LSM of rural area applications were conductedto manage power flows among different energy sources and energy storage, in order to maximize the benefit of the renewable energyresources due totechnical issues associated with grid expansion to the remote areasand the high cost required in [2,3,6,7,8,9].

On other hand, for the on RE (Renewable Energy) grid connected applications,many studies were introduced in order to get the benefit from the grid in selling the surplus energy and to charge the battery from the grid if needed. In [1]the author is proposing LSM strategy for a small scale applications to reduce electricity cost if the power consumption is scheduled economically.From the perspective of LSM PVsolar energy or Power supplied from the grid could be stored when the PV can generate surplus power or when the grid electricity is inexpensive.The stored energy might be managed for usage economically in future when the electricity price is high over peak load periods, or when the PV power is unavailable[1].

In respect of smart grid, LSM is playingan important function that allows customers to make informed decisions on minimizing the peak load demand, reducing their energy consumptionand reshape the load profile by generalizing day ahead Using load shifting that can be utilized by the central controller of the smart grid [10]

In[11]LSM strategy control is developed to satisfy costumer plan tasks in order to utilize the generated power from the PV system to improve the energy performance of the PV energy system and maximize utilization of the power using distribution generations.

In[12] the author introduced a LSM strategy for a PV rooftop installed in residential household, the applied LSM technique purposes to reduce electricity costs for the consumer and also power losses of the grid.An experimental of LSM technique was investigated of smart home in Turkey with renewable energy sources (solar PV and wind), storage systems and connection to the grid.

Balakrishnan Sivaneasana et al [13]proposeda novel LSM algorithm for managing solar PV intermittency in abuilding using demand response management technique. The proposed algorithm considers the building air conditioning and mechanical ventilation (ACMV) system, the developed solution will reduce the load demand of the ACMV system in such a way to be equal to the drop of solar generation by controlling the speed of the fan. Three different scenarios were investigated and the results showed that the proposed DRM algorithm can provide a costeffective solution to solar intermittency issues compared to utilizing large energy storage system or complicated solar forecasting system.

In thiswork, a model of LSM control for household appliances was investigated to supply surplus power over usual when there is PV intermittency. The proposed model is based on controlling the power consumption of heavy loads (if applicable) in association with power shortage from PV array. The deviation from therated capacity of a given PV array is the control argument. This strategy was applied here on HouseWater heaters as a heavy load so that when there is power shortage fromthe PV, then the water heater power consumption will be varied in order to compensate this power shortage with certain constrains.These constrains are proposed by the algorithm and approved by the customer.

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The algorithm aims at satisfying the customer regarding his needs of this load while keeping the electricity bill cost at acceptable range.The paper is organized as follows. Section 2LSM literature review, Section3 is about theproposed LSM strategy, in Section 4 the LSM model, in Section5 results and discussion. Finally, in section 6 the conclusion.

PROPOSED LSM STRATEGY

The objective of this LSM model for household appliances to propose an effective solution to reducethe consumer bill electricity by minimizing supplying excess power above usual when there is PV intermittency. The proposed model of LSM control is to compensate for the reduction of power generated by solar PV system from its rated capacity by reducing the power consumption of the variable heavy loads depending on the power availability from Solar PV. For example, water heater is a heavy load that can work as a variable power consumption load. The heating time will be of course affected. Thus, the developed solution will depend on managingboth heating time and the heater power while considering the dropin PV energy generation. If the PV power generated is still declining and reaching of the power limit which is defined previously by the consumer then the rest of loads will be gradually disconnected accordingly as consumer preferences. This strategy will ensure that the amount of power supplied by the grid to the household will remain the same (as before the drop of solar generation).

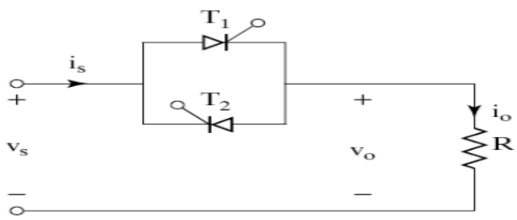
The proposed system for controlling power delivered to the water heater is based on using PWM (Pulse width Modulation). The basic principle of AC voltage control technique is explained with reference to a single-phase full wave ac voltage controller circuit shown in Fig.1The thyristor switches T1 and T2 are turned on by applying appropriate gate trigger pulses to connect the input ac supply to the load for ‘n’ number of input cycles during the time interval t_{on}. The thyristor switches T1 and T2 are turned off by blocking the gate trigger pulses for ‘m’ number of input cycles during the time interval t_{off}. The ac controller ON time t_{on} usually consists of an integral number of input cycles. For a sine wave input supply voltage,

$$Vs = VmSin(wt) = \sqrt{2}VsSin(wt) \qquad (1)$$

If the input ac supply is connected to load for ‘n’ number of input cycles and disconnected for ‘m’ number of input cycles, then $t_{ON} = n\times T$, $t_{OFF} = m\times T$ (2)

Then $P_{load} = P_{fullload}(T_{ON} /T_{ON} +T_{OFF})$ (3)

Where $V = V^2_m/2R_{heater}$ (4)



R_{heater} is the heater equivalent resistance in □.

Fig1: Single phase full wave AC voltage controller circuit [14]

When applying this principle to the water heater that if the PV power generated is dropped, the power consumed of the heater will be reduced. The advantage is that we do not need excess power from the grid while increasing the heating time .It is to be noted here, that the alternative solution is to completely switch off the heater power. The developed algorithm uses measured values for available PV power and the heater thermal model in order to generate the suitable PWM signal.

Fig.2 shows the proposed model of LSM system to compensate for the reduction of power generated by solar PVsystem from its rated capacity by reducing the power consumption of the variable heavy loads depending on the power availability from Solar PV. The power available from the PV system is measured (P_{PV}) and compared with the total power needed (P_{load}) to find the difference that has to be supplied from the grid (P_{grid}). The customer satisfaction and priority scenario will be also considered by the algorithm in order to find the suitable scheme of loads profiles.

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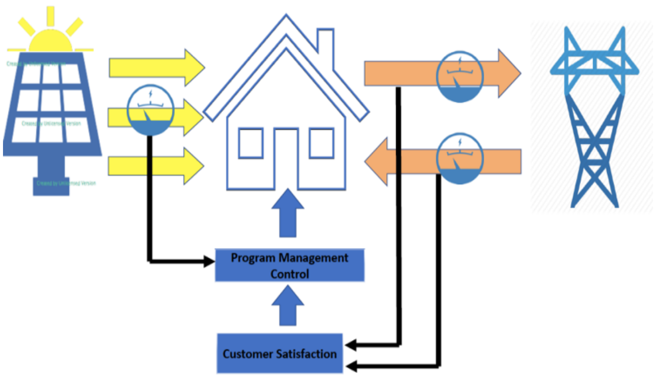
Fig.2 LSM System



I. LSM Model

The LSM model has been developed using Matlab Simulink that designed for a household PV grid connected systemsize 12 KW.Following is the description on the model aspects:

i. Power meters

The cornerstone of this model is the power meters which reading the power delivered to the household from the PV system(P_{PV}) and also another bidirectional meter to read the amount of import and export power from the network (P_{grid}) in order to be compared with the power threshold(P_{th}) which defined previously from the customer if the power loads ((P_{loads}))reaching higher thanthe identified value.

ii. Load classification

In this LSM strategy, appliances loads are classified as:

1.heavy controllable loads: define as loads which have highrating power capacityand its consumption could be reduced by controlling delivered power for example, the fan speed of air conditioner, the temperature of refrigerant, heating time of the Water heater…in table 1 shows the measured factors that affect the loads performance.

2.On/Off loads: defined as loads witch can't predictits operation, due to dependency on user behavior such as lights,TV,Kattel, ..ext.

Table1: heavy controllable loads which its consumption could be controlled.[11]

Appliance	Measured factor 1	Measured factor 2
Water heater	Temperature	NA
Washing machine	Temperature	Spin revolutions
Dishwasher	Washing parameter	NA
Oven	Temperature	Cooking time
Refrigerator	Temperature	Not used
Freezer	Temperature	Not used
Air conditioning	Temperature	Cooling time

Power Management Control (PMC)

The strategy of this control is to read the power supplied from the solar PV system (P_{PV}) and compare it with the power suppling from the grid (Pgrid) in order to be compared with the power threshold (Pth) that defined previously from the customer as the following equation PV - Pgrid≤ Pth . (5) if the power loads (Ploads) become higher than (Pth) thus, the developed solution will increase the heating time of the heater by reducing the load demand of the heater equal to the drop of solar generation. If (PPV) is still continues drop and reaches (Pth) then the rest of the on-off loads will be gradually disconnected accordingly as consumer preferences.

To verify the strategy, two scenarios were investigated, The First Scenario is the LSM model was simulated with no management on the variable load i.e. all loads are utilizing the power delivered from the PV system that scheduled in advance as consumer preference. If the power drop of solar generation (Pv) ≤ Pth thus, loads will be disconnected gradually as scheduled in advance.The Second Scenario is the LSM model was simulated by applying the Power Management control to reduce intermittency on the loads.

II. Results and Discussion

i. Scenario1

In this scenario performance of the model was evaluated without proposing variable load control. Result shows in Fig 3 that multiple intermittency occurs due to the constraints (Pth) identified by the consumer.As more constrains is applied to suppling power from the grid, the loads intermittency will increase.

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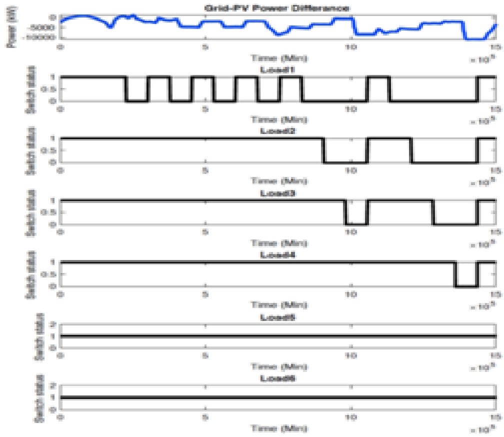

ii. Scenario2

In this scenario, performance of themodel was evaluated with applying the PWM on the heater water control, its power consumption is reduced by changing the firing angel of the PWM on the heater as thedrop of the power generated by the PV system.If the PV power defect is still continuous the other loads will be disconnected respectively as costumer preference.various firing angel ofPWM on the heater applied in the model to check the validity of this model as showed in Fig4,5,6,7 respectively.

In this scenario 2.1, in the Fig.4, we applied fire angle "45°" to the PWM of the heater, the power consumpotion is reduced from its rated capacity 3Kw to 2.4kW due this constrain, as seen less loads is disconnected compare to the previous scenario1.

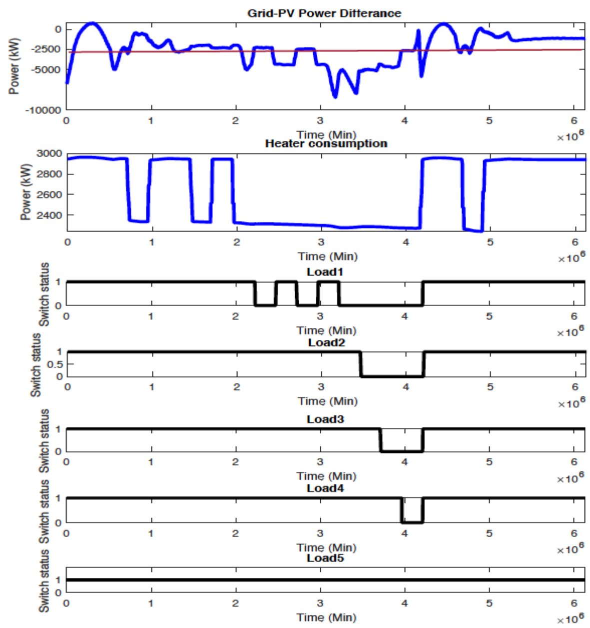

Fig.4 heater power consumption at fire angle is 45° scenario2.1

For the scenario 2.2, we increased the fire angle to be "70°",the rated capacity will be dropped to 1KW that means the heating time of the water heater will be longer but the intermittency of the loads will reduced as shownin the Fig.5.

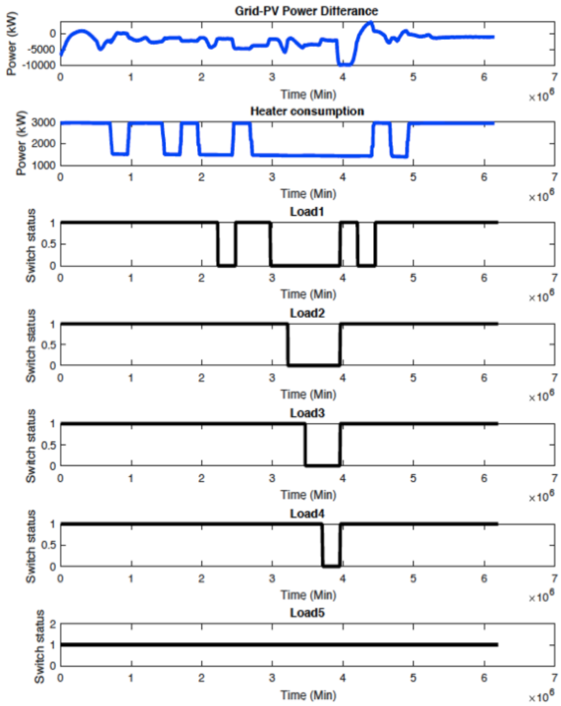

Fig.5 heater power consumption at fire angle is 70° scenario2.2

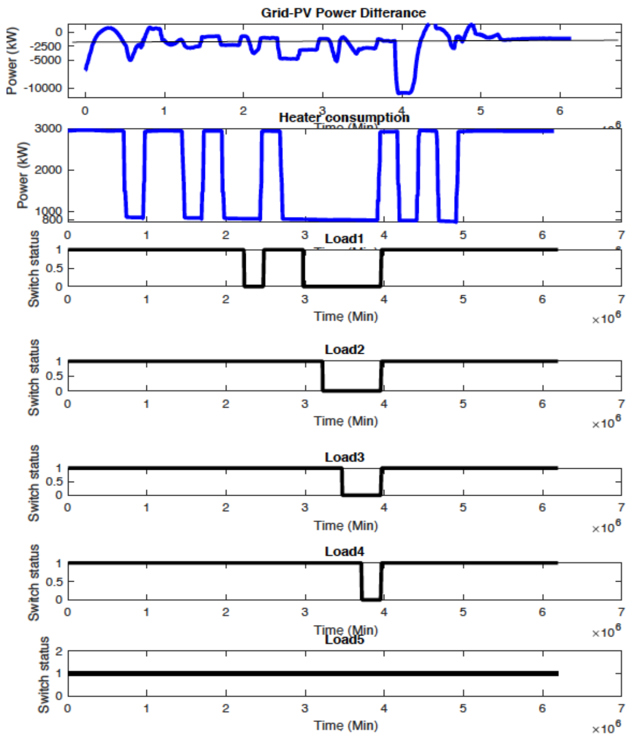

Fig.6 heater power consumption at fire angle is 90° scenario2.3

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In this scenario2.3, the fire angle is changed to be “90 ° ” the power heater consumption slightly decreased from the previous scenario to be 0.8KW that means the heating time will be longer but the intermittency of the loads will reduce as showninFig.6

In this scenario2.4 as the fire angle become“120°”(Fig.7) the power delivered is very small and in this case the heating will be inefficient because of the thermal dissipation .

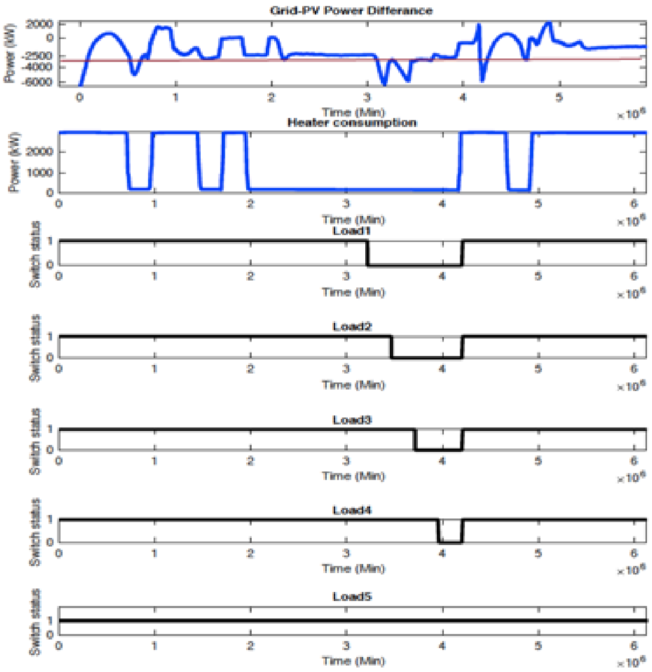

Fig.7 heater power consumption at fire angle is 120° scenario2.4

III. CONCLUSION

Load side management is an effective solution to optimize the loads in economic way in order to contribute in limiting the raise in the electricity bill.The proposed strategy of LSM helps the consumer in getting the payback in less time due to reducing power supplied from the grid. The performance is compared when using LSM with onlyOn/Off and LSM based on variable power control.The result shows different intermittency occurs on the loads due to the constraints requested by the consumer.As the proposed strategy of LSM applied as in the second scenario, the model is to compensate for the reduction of power generated by solar PV system from its rated capacity by reducing the power consumption of the Water heater depending on the power availability from Solar PV. Various firing angles of PWM applied on the Water heater. It was found that at 120° the delivered power is inefficient.

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