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Mini Review

Random control of smart home energy management system equipped with solar battery and array using dynamic programming

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ABSTRACT:

Home Energy Management System (HEMS) is an efficient system represented in this article with Battery Energy Storage System (BESS) and optimal Photo Voltaic (PV) systems. In the proposal of HEMS, the charge / discharge regime, BESS capacity and power were determined suitably and desirable as design variables. BESS was used to save the energy in an affordable way during the peak hours of consumption. The proposal programming for determination of optimal operation strategy and BESS measurement represented as a Mixed Integer Non-Linear Programming (MINLP). In addition, the output power generated by the photovoltaic (PV) system was modeled as an indeterminate parameter and with a Probabilistic Distribution Function (PDF). The Monte Carlo Simulation (MCS) was used to deal with uncertainty. This simulation was accomplished using MATLAB 2015 software. The results confirmed that the introduction of HEMS can successfully minimize the annual electricity bills, and can also send energy to the network and spend on profits during high-cost hours.

Keywords:

Energy management, Photovoltaic systems, Distribution functions, Battery energy storage system.

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INTRODUCTION

One of the most principled methods for solving problems associated with energy-producing and consuming systems, which is dependent on non-renewable or renewable energy, is the use of management and control systems and strategies in buildings. Considering the dynamics of systems and mathematical modeling of the phenomena of mass and heat transfer, smart control systems and energy management systems, generally referred to as the Home Energy Management System (HEMS), can be used to achieve the objectives of energy management in buildings. Smart control systems prevent energy loss based on the energy production and consumption process in the past and recording the relevant data.

A HEMS is showed in Figure 1. The center includes a centralized control of the entire home by monitoring the features based on the communication networks. Power consumption data of home appliances including programmable and non-programmable devices at this time can also be provided by HEMS to deliver the optimal demand. Typically, the smart device uses HEMS, and home appliance timing can be run to respond to residential demand. An Electric Vehicle (EV) is a specific type of electric charge (Sun *et al*., 2016). This is not only a requirement to meet the environmental needs, but also to provide services for the environment. At present, the re-production of complexes in residential areas includes solar Photo Voltaic (PV) more than others. Home energy sources can be fully integrated into the HEMS management and operations and become smart home. Power storage devices play an important role in improving the quality of electricity and energy efficiency and maintaining the

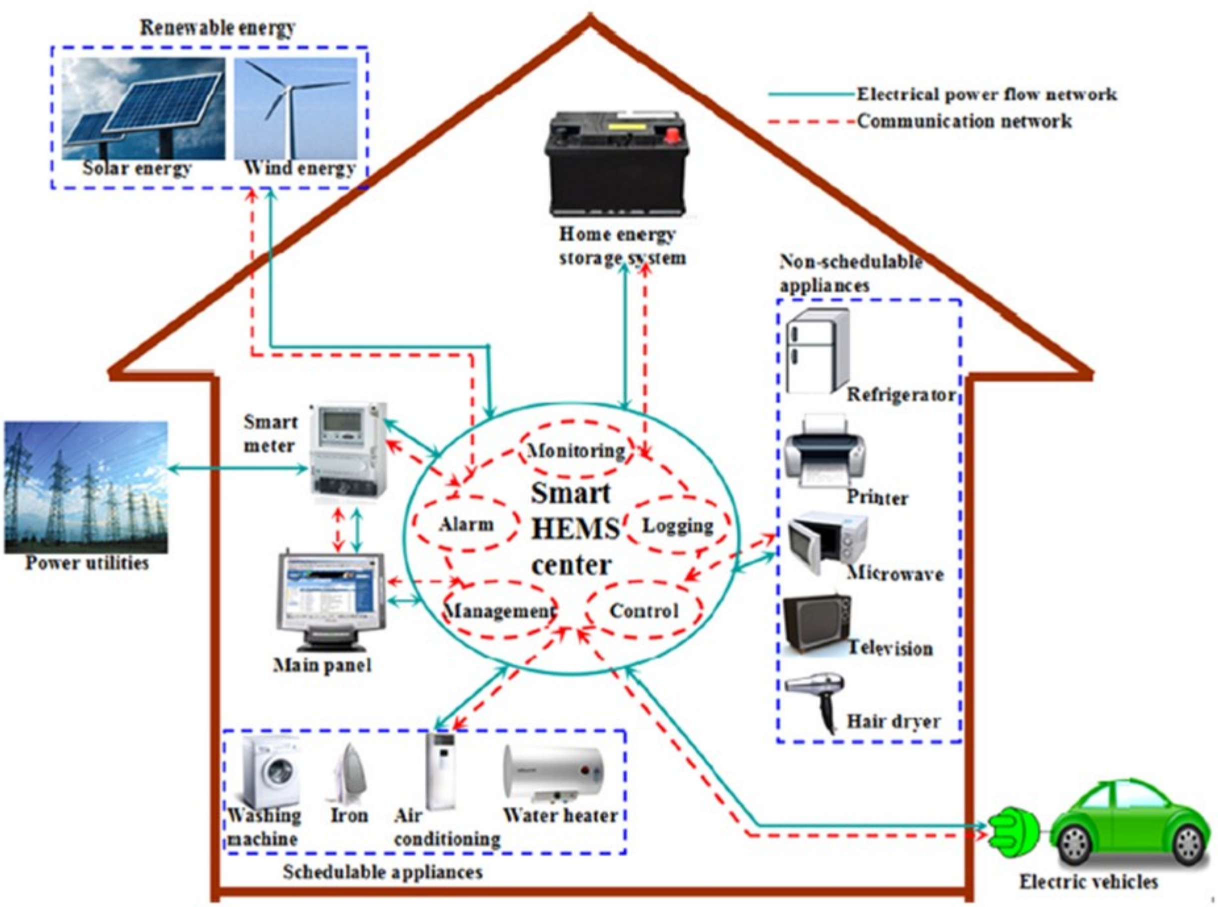

Figure 1. General architecture of a HEMS sample

reliability of the energy system, due to the natural interruption of solar energy (Mazen *et al*., 2013).

Considering the importance of HEMS, numerous techniques have been investigated and analyzed for optimizing energy at home. Ideal household appliance programming is one of the most commonly used ways to manage the energy consumed at home. The desirable programming can limit the general demand and control the devices' operation for a specific period decreasing the power costs and demands during the peak hours (Ahmed *et al*., 2017). The optimal programming of home appliances can be analyzed for different purposes, such as the common program between the home appliances and BESS, common optimal programming between electrical and thermal devices regarding the dynamic pricing for the device programming, programming of the home appliances in the real time of pricing and scheduling the real time of home appliances (AlSkaif *et al*., 2017).

Energy storage systems (such as BESS) and renewable energy sources (such as the PV system) are other options for home energy management. These solutions are widely used to control domestic energy consumption, such as the coordination of PV batteries in HEMS. In recent years, many technologies have been developed to improve the electricity efficiency and feeding (Shirazi *et al*., 2015). On the other hand, the demand for electricity has increased, so that even the peak of demand should be produced at least time and transferred with the minimal equipment. Because of the unstable demand, the network equipment needs have increased resulting in lower efficiency. Shifting the subscribers from fixed subscribers to active subscribers can be a solution to this problem within the production period (Habib *et al*., 2015).

Current energy demand and environmental crisis have prompted the rapid development of Electric Vehicles (EVs) and renewable energy, including Photo Voltaic (PV) solar energy and wind energy. With increased energy prices and the impact of greenhouse gases, high-efficiency electricity sources such as distributed generation sources will be more desirable. However, EVs charging activities and renewable energy production are always intermittent and volatile. If let it unchecked, a significant effect on the power grid may occur, including degradation of performance, overload, and especially when it is used in the large production unit (DG) and EVs. Implementing EVs and Renewable Energies is critical to ensuring the optimum use of electrical power for the operation of the smart grid (Lund *et al.*, 2015).

MATERIALS AND METHODS

The Home Energy Management System (HEMS) represents any control technique, method or strategy to increase energy efficiency and control. Due to the energy cost and constraints, HEMS is rising in modern societies, smart cities, and smart homes. HEMS can also be defined as any device or package that controlling and/or analyzing the energy consumed at home (Zhou *et al.*, 2016).

Considering the importance of HEMS, numerous techniques have been investigated and analyzed for optimizing energy at home. The desirable programming of home appliances is one of the most commonly used ways to manage the energy consumption. Optimum planning can limit overall demand and manage device operations for specific periods of time leading to the reduced power cost and demand during the peak hours (Ahmed *et al.*, 2017).

The program of response to demand can also be considered as one of the most efficient tools for HEMS. In the programs of response to demand, the devices' energy can be paused, adjusted and restricted in order for financial supports. These programs can manage the energy and decrease the power costs successfully (AlSkaif *et al.*, 2017). Several techniques exist to deal with demand response programs in HEMS, such as

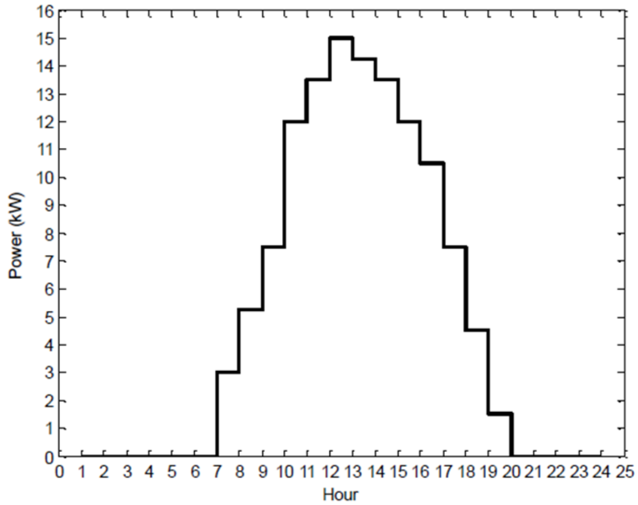

Figure 2. Specifications of electrical voltage during daylight hours

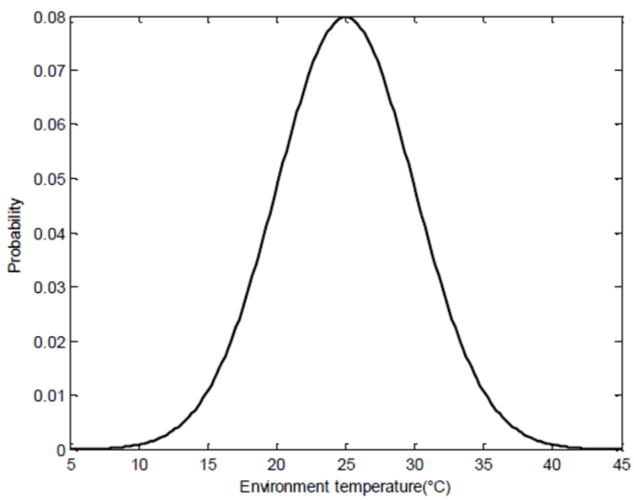

Figure 3. Environmental temperature modeling by Gaussian PDF with an average of 25 and a standard deviation of 5%

demand-party management for safe use of appliances, dynamic load management in smart home, regarding the operational preference of devices in HEMS, and the random method for smart demand response in micro-grid. Energy storage systems and renewable energy sources are other options for dealing with energy management at home. These solutions are widely used to control the energy consumption, such as the harmonization of PV batteries in HEMS, HEMS through energy savings, and HEMS non-linear prediction with PV-BESS. The use of an electric vehicle as an energy storage system is also discussed and addressed in HEMS (Yu *et al*., 2012).

RESULTS

Solar photovoltaic system

Photovoltaic systems, consisting of three parts of the solar panel, converter and battery, convert solar energy without any pollution to electricity. The conversion of solar energy into the electricity is performed by a panel of photovoltaic cells and change the generated electricity into the alternative current with the purpose of domestic consumption. Finally, the extra generated electricity in the system can be stored with the help of the battery. Wires, switches, and support structures can be named as the other components of the system (Hanif *et al.*, 2011).

The output power generated by the PV system usually increases during the middle of the day. A typical shape for the PV power at night is shown in Figure 2. The maximum power produced by this PV system is 15 kW at 12 O'clock. The output power of the PV system per hour is calculated by equation (1) where the temperature cell in relation (1) is given by equation (2). It is clear that the power output of a PV system per hour depends on the ambient temperature and solar radiation. Nevertheless, the ambient temperature and solar radiation are not constant, and are mainly shaped by probabilistic distribution functions such as Gaussian PDFs.

The normal PDF of Gaussian for ambient temperature and solar radiation is illustrated in figure 3, respectively.

$$P_{PV} = \left[P_{PV}^{STC} \times \frac{SR}{SR^{STC}} \times \left(1 - y \times \left(T_{Cell} - T_{Cell}^{STC}\right)\right)\right] \times N_{PV}^{S} \times N_{PV}^{P} \quad (1)$$

$$T_{Cell} = T_{ET} + \frac{SR}{SR^{STC}} \times (NOCT - 20) \quad (2)$$

About the Gaussian PDF model for both ambient temperature and solar radiation, it is concluded that the output power produced by the PV system in each hour (according to equation (1)) also follows the Gaussian PDF model. For example, the maximum

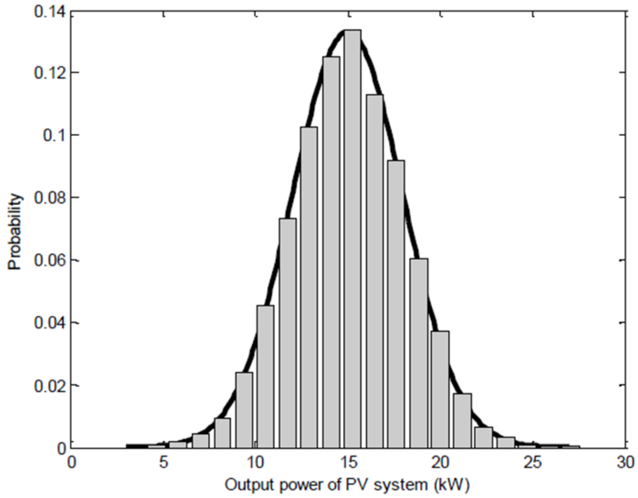

Figure 4. Output power of the PV system as a normal PDF and its equivalent discrete model

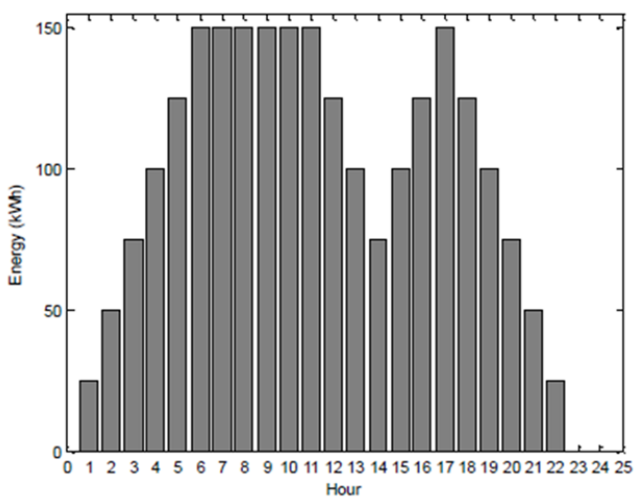

Figure 5. Energy situation in BESS during the day

power generated by the PV system in Figure 2 (15 kWh per hour at 12 O'clock) can be represented by Gaussian PDF with an average of 15 kW in Figure 4. In addition, continuous function model and its equivalent discrete model is shown in Figure 4.

The proposed goal of HEMS is to reduce the cost of energy for optimal BESS programming and optimize the use of the PV system. The cost of domestic energy during the day is expressed by equation 3. The daily cost of 365 (i.e. the number of days in a year) is multiplied by the equation 4 for explanation throughout the year and the annual cost calculation. The BESS investment cost is given by equation 5. Also, the cost of investment is projected over the life of the assets and converted to an annual cost equal to EB. Similarly, the annual cost of the PV system is expressed in Equation 6. Finally, the proposed HEMS objective function is given by equation 7.

$$C_d = \left[\sum_{t=1}^{T}\left([P_L^t + P_b^t - P_{PV}^t] \times C_p^t\right)\right] (\$\backslash \text{day}) \quad (3)$$

$$C_y = C_d \times 365\ (\$\backslash \text{year}) \quad (4)$$

$$C_B = [CE_B \times E_B^r \times CP_B \times P_B^r] \times E_B\ (\$\backslash \text{year}) \quad (5)$$

$$C_{PV} = [CP_{PV} \times P_{PV} \times] \times E_{PV}\ (\$\backslash \text{year}) \quad (6)$$

$$FC = \{C_y + C_B + C_{PV}\} (\$\backslash \text{year}) \quad (7)$$

The constraints are also given by equation 8 to equation 15. The constraint of equation 8 shows that BESS power is equal to the power of charge or discharge per hour. In this case, it is clear that BESS power is modeled as a negative charge in discharge mode. The constraints of equation 9 and equation 10 limit the strength and capacity of BESS, respectively. The efficiency of BESS is given by equation 11. The energy of BESS per hour is expressed by equation 12. The energy balance in the initial and final stages are given by equation 13. The restriction of equation 14 confirms the energy balance at home. The time horizon is defined by equation 15.

$$P_B^t = \begin{cases} Pc_b^t & \text{If BESS works on charging state} \\ -P_B^t & \text{If BESS works on discharging state} \end{cases} \quad (8)$$

$$P_B^t \leq P_B^r \quad (9)$$

$$E_B^t \leq E_B^r \quad (10)$$

$$\eta_B = \frac{Pd_B^t}{PC_B^t} \quad (11)$$

$$E_B^t = P_B^t \times t + E_B^{t-1} \quad (12)$$

$$E_B^0 = E_B^{T+1} \quad (13)$$

$$P_L^t + P_B^t - P_{PV}^t = P_{grid}^t \quad (14)$$

$$t = [1, 2, \ldots.., T] \quad (15)$$

Regarding the given modeling, proposed HEMS is expressed as MINLP. This problem was solved by the Advanced-Adaptive PSO (AAPSO). First, the primary population, including probable solutions to the problem, is generated randomly. Each row of the population is known as a particle that represents a possible solution to the problem. Then, each particle contains a set of

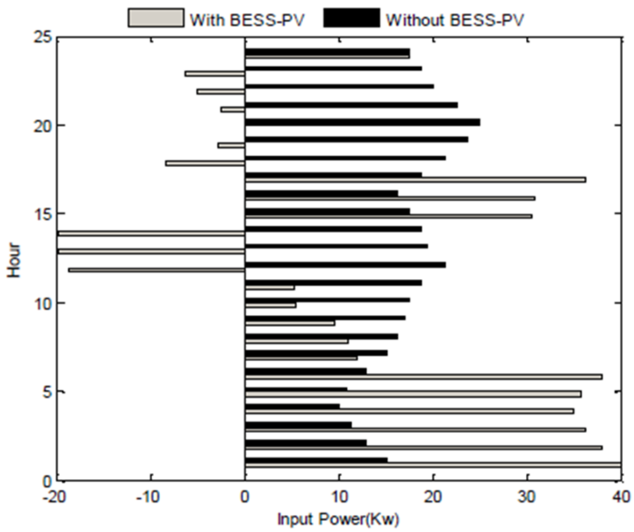

Figure 6. The input power to the home during the day

charging-discharge patterns for BESS. To start the optimization, a particle is selected in the population and the charge-discharge regime associated with the current particles is set to BESS. A sample Monte Carlo simulation is used to calculate the objective function (proportionality value) for the current particle. After calculating the objective function for current particles (for current particles using a sample-based Monte Carlo simulation), the algorithm goes to the two preceding steps (the selection of a particle in the population) and selects the next particles, and the target function is calculated for the next particles.

This method continues until the objective function is calculated for all particles in the population. Then the particle containing minimum fitness is selected as the best solution in the current repeat. Finally, the convergence of the AAPSO algorithm is investigated and the process is repeated until the convergent algorithm and the final solution are found.

DISCUSSION

The proposed method for simulating the optimum capacity and BESS charge / discharge regime was simulated and its results are shown in Table 1. Clearly, BESS is installed with the capacity of 150 kWh and power of 25 kW power. Also, the charge-drainage regime follows a rational process; where, BESS saves the energy during the low cost hours and drains it during the high cost and peak hours. In a few hours (7 to 11), BESS does not work. As illustrated in Table 2, such a good charging / discharging system significantly reduces the electricity bill for the home. Obviously, the installation of the BESS system and PV will decrease by 58.65% of annual electricity costs ($ / year).

Figure 5 illustrates the BESS energy during the day. Clearly, the maximum capacity of BESS is 150 kw/h and the saved energy could not be more than this amount. Also, energy increases within the charge hour, is fixed during the no operation, and as mentioned in table 3, decreases within the discharge hour. The initial and final energy are equal. These all confirm the accuracy of the proposal method.

In accordance with Figure 6, it is obvious for the both with and without BESS-PV cases, the home equipped with BESS-PV transfers the energy to grid during the peak hours and makes a profit. When the system is working completely at midday, the home also

Table 1. Proper capacity and BESS charge / discharge regime

Hour	1 to 6	7 to 11	12 to 14	15 to 17	18 to 23	24
Stat.	Charging	No operation	Discharging	Charging	Discharging	No operation
	Optimal BESS capacity				150 kW/h	
	Optimal BESS Power				25 kW/h	

Table 2. The effects of PV-BESS on HEMS

	Annual electricity bill ($/year)	Annuals PV cost ($/year)	Annuals BESS cost ($/year)	Total cost ($/year)
With BESS-PV	8899.6	1273.8	5358.1	**15532**
Without BESSPV	21522	-	-	**21522**

transfers the energy surplus to the power grid.

Molderink *et al*. (2010) represented a three-step procedure in their study in order to improve the domestic energy efficiency. They declared that the connection and disconnection of home appliances will lead to sustainable problems. Moreover, starting up of high-scale renewable resources requires new network management and design. Although distributed generations (DG) have a higher initial cost than the plants, they have a high potential allowing the distributed generation to meet all demand with the same reliability, but with less capacity range.

Molderink *et al*. (2009) in a study simulated the impact of smart grid technologies on the energy efficiency and finally, they determined a model and explained an advanced simulator for analyzing the impact of various combinations of micro-generators, energy buffers, appliances and control algorithms on indoor and large-scale energy efficiency. The simulator is easily accessible to new types of micro-generators, controllers, and other supported devices. The simulation of two studied simulators showed that the results are promising.

CONCLUSION

The home energy management system (HEMS) is an important part of smart grid enabling the domestic subscribers to perform the programs of responding to demands, independently. Given the increasing trend of electrical charges in distribution networks, the unrealized nature and cost of fossil fuels, environmental concerns and such problems, the use of hybrid systems is an efficient way to benefit from low cost and high reliability electrical energy. MATLAB 2018a has been used to simulate the genetic algorithm. An efficient HEMS was designed based on BESS and PV. The proposal HEMS was installed which uses BESS and PV. Optimum capacity and charge / discharge regime for BESS and uncertainty of the PV system have been identified. The problem was expressed as a random MINLP and solved with the AAPSO algorithm. The results showed that the installation of BESS and PV systems will reduce annual electricity by 27.8% annually. In the proposal method, the home sends the energy to the grid, during the high-cost hours and supplies it from the power grid within the low-cost hours. The home can also work in standalone mode. Such flexible conditions reduce the electricity bill significantly throughout the year. Additionally, the home can increase the profit by installing large-scale PV and BESS and sending more power to the upstream network. The results emphasize on the ability and efficiency of HEMS.

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