GA-BASED ENERGY MANAGEMENT OPTIMIZATION FOR GRID-CONNECTED PHOTOVOLTAIC SYSTEM WITHOUT BATTERY STORAGE

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Abstract

This paper presents genetic algorithm (GA) based optimization of energy management for grid connected photovoltaic (PV) systems without battery storage. The major objective of this work is to minimize energy cost by maximizing objective function of GA considering both energy consumption and generation. In objective function calculation, PV module output power obtained by model of PV modules and previous power recordings from the PV system were employed. In the system, some electrical appliances and lights are in the energy consumption side and photovoltaic energy source connected to the grid is in the energy generation side. A simulation study was implemented to obtain energy cost savings using GA optimization in a commercial building. Due to the cost of the batteries, PV system is implemented without battery storage. Therefore, by adapting fluctuating PV energy generation with the time-flexible loads, an effort was aimed to develop a smart-grid strategy.

Key words: *energy management, PV system, genetic algorithms, optimization, load scheduling*

1. INTRODUCTION

Energy management is a continuously raising issue due to the depletion of fossil fuels and energy problems in the world. Renewable energy integration using energy management strategies can contribute socio-economic development and economic growth of countries. Thus, reliance of the countries on imported fossil fuels can be reduced.

Because of the nonlinear nature of PV energy, the integration of renewable generation applications can be complicated. Depending not only on the geographical location and seasons, the output power is closely linked with hourly and daily weather variations. A number of researches have been carried out in recent years dealing with the issue of energy management. In several studies, operating and duration time of home appliances were shifted by load shifting and optimal scheduling methods. Chao et.al. (2010) addressed an energy management system by taking household profiles and energy consumption profiles of electrical appliances into account. An effective advice on their energy consumption was provided by enabling them to take focused and effective actions towards efficient energy use. Arabali et. al (2013) developed a smart-grid strategy to shift the load and match the renewable energy generation and cooling load. It was shown that, the methodology can be used to provide utility companies with an energy-management tool to optimally utilize the installed renewable energy sources and the storage system to meet the flexible loads of the residential/commercial/industrial feeders. The authors used GA-based optimization approach together with a two-point estimate method to minimize cost and increase efficiency.

Asare-Bediako et.al. (2012) analyzed a smart home energy management system implementation and its contribution to energy savings and efficiency enhancement for residential customers. The authors presented a general overview of energy efficiency measures focusing on residential loads and optimization of energy usage is investigated. Adika and Wang (2014) proposed a demand side energy management for a grid connected household with a locally generated photovoltaic energy. To ensure efficient household energy management, smart scheduling of electrical appliances was presented and no energy storage device was employed. The household here optimizes its energy use in order to reduce its energy bills. Mengi and Altas (2011) proposed a Fuzzy Decision Making based Smart Management System (SMS) considering both the environmental conditions and power demands by

loads. The authors used wind and PV panels as the main power sources and determine the switching sequences of the photovoltaic/wind system. In order to prevent power supply discontinuity to loads during the switching from one source to another, an algorithm is included in the SMS.

The objective of this study is to minimize energy cost by maximizing objective function of GA considering both energy consumption and generation. The developed GA-based algorithm is used to shift the loads to match the PV energy generation. A simulation study was implemented to obtain energy cost savings by adapting fluctuating PV generation with the time-flexible loads. This paper is organized as follows. Section 2 presents determination of PV power by employing model of PV modules. Section 3 addresses genetic algorithm based energy management optimization. In Section 4, simulation results from the employed GA-based algorithm are given. Finally the conclusions are presented in Section 5.

2. DETERMINATION OF PV POWER BY EMPLOYING MODEL OF PV MODULES

The proposed algorithm requires determination of current PV power output of PV system and recordings of PV power outputs for the previous three days. Recording data in Konya, Turkey is obtained from 6:00 to 18:00 and sampling points have been collected from the inverter in each 10 minutes throughout a day totaling 72 sampling points. Also, solar irradiance and cell temperature values were obtained by a silicon irradiance sensor with active temperature compensation. Its irradiance measurement error with temperature compensation is ±6%, and the temperature measurement accuracy at 25 ^{o}C is ±1.5 ^{o}C. Single-diode model of PV cells is used to determine output power of PV modules (Kulaksız and Akkaya 2012). The equivalent circuit of a PV cell is given in Fig. (1). The model parameters were obtained using the method described by Kulaksız (2013). Once the I-V characteristics of a single solar cell are determined, the model is expanded to determine the behavior of the PV array utilized in this study.

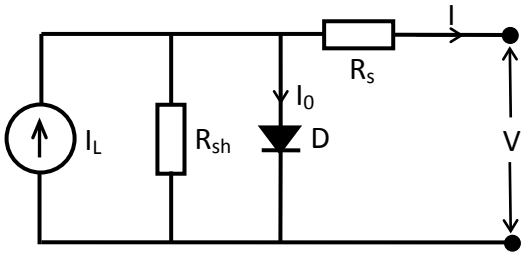


Figure 1. The equivalent circuit of a solar cell

The current-voltage characteristic of single cell described by the Shockley solar cell equation is given in Eq. (1) (Lorenzo 1995);

$$I = I_L - I_0\left[\exp\left(\frac{V + I.R_s}{n.V_{th}}\right) - 1\right] - \frac{V + I.R_s}{R_{sh}} \qquad (1)$$

where I is the output current, I_L is the generated current under a given insolation, I_0 is the diode reverse saturation current, n is the ideality factor for a p-n junction, R_s is the series loss resistance, and R_{sh} is the shunt loss resistance. V_{th} is known as the thermal voltage. For an individual cell it is calculated from;

$$V_{th} = k.T / q \qquad (2)$$

where k is the Boltzmann constant (1.3806 x 10^{-23} J/K), T is the cell temperature (in Kelvin) and q is the electron charge (1.6022 x 10^{-19} C).

The saturation current, I_0 of the solar array varies with temperature according to the following equation;

$$I_0 = I_r \left[\frac{T}{T_r}\right]^3 \exp\left[\frac{qE_{GO}}{n.k}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \qquad (3)$$

where T_r is the reference temperature, Ir is the saturation current at T_r, E_{GO} is the band-gap energy of the semiconductor used in the solar array. In Eq.(1), I_L is a function of incident solar radiation and cell temperature and is given by;

$$I_L = \left[I_{scr} + K_I(T - T_r)\right]\frac{G}{100} \qquad (4)$$

where I_{scr} is short circuit current at reference temperature T_r, K_I is the short circuit current temperature coefficient and G is the insolation in mW/cm^2. In this study, by sensing solar irradiance (G) and cell temperature (T), Eqs. (1)-(4) were used to calculate output power of PV array. Then, optimum operation timings of flexible loads were determined by GA. The system manages the switching of the loads with respect to varying environmental conditions to meet the PV generation fluctuations. The peak power of the on-grid PV system is 1000W. The connected load to the system is considered as 500 W maximum with three parts such that the base load of 300 W and two additional loads of 100 W each. The use of GA for energy management optimization is explained in Section 3.

3. GENETIC ALGORITHM-BASED ENERGY MANAGEMENT OPTIMIZATION

Genetic algorithms can be used to solve complex decision and optimization problems. By using multi-point search method, optimal utilization of electricity by appliances of the consumers was identified in a grid-connected PV system. The advantage of this method is that it takes account the electricity needs and also consumer comfort and convenience for the least change of the lifestyle of the consumers. Thus, during peak hours of load demand, when the solar irradiance is low, load shifting delays the non-critical loads to hours when the PV energy is in excess of the load.

In GA-based optimization of energy management, each individual in the population represents the feature subset, which must be solved for the optimization problem. Individuals in the GA are usually represented by n-bit binary vectors. Thus, the search space corresponds to an n-sized Boolean space. In each generation, the evaluation of an individual, i.e. output power for a given time of the day, requires calculation of the objective function. In this study, the objective function is determined by Eq. (5) ;

$$\text{Objective function} = P_{pvmodel} + (\text{Sum of PV powers in previous 3 days}) \times 20\% \qquad (5)$$

where $P_{pvmodel}$ is the power obtained from the PV model.

At first, the GA creates an initial population, calculates objective function for each chromosome, and evaluates that population. The population then grows with a large number of generations to search for the best input parameters. The GA continues to operate until a predefined number of generations are complete to generate the population with new numbers. The evaluation is done for each individual in the population (Kulaksız and Akkaya 2012). Thus, GA optimization provides an adaptive approach to determine optimum time of the day to supply flexible loads.

Genetic operators are performed on the selected individuals to generate successive generations, and the algorithm explores the space of candidate solutions. Applications of fitness-dependent selection and crossover and mutation genetic operators are repeated until a satisfactory solution is obtained (Yang and Honavar 1998).

4. SIMULATION RESULTS

The simulation study of the presented energy management algorithm is realized to testify effective utilization of installed PV energy sources to meet flexible loads. Photovoltaic power data from a 1 kW

PV system installed in Konya, Turkey was used in simulations. Different case studies for several days were carried out to investigate the energy efficiency of the system. The GA-based optimization was implemented in both sunny and cloudy days. Figs. 2 and 3 show the objective function vs. generation number for the GA optimization and variations of generated PV power, load power and power injected to the grid (grid power) respectively, implemented in 05.07.2014. Figs. 4 and 5 show the similar results obtained in 01.10.2014 and Figs. 6 and 7 show the results obtained in 01.02.2015. From these simulation results, it can be seen that by shifting the flexible loads, the energy user can maximize the amount of surplus energy injected into the grid. Thus, by enabling the participation of the customers in efficient electricity consumption besides energy generation, the savings in energy costs could be realized compared to the traditional users. From the simulation results, the grid power waveforms can give an idea about the size of storage batteries, in case of a PV system implementation using battery storage.

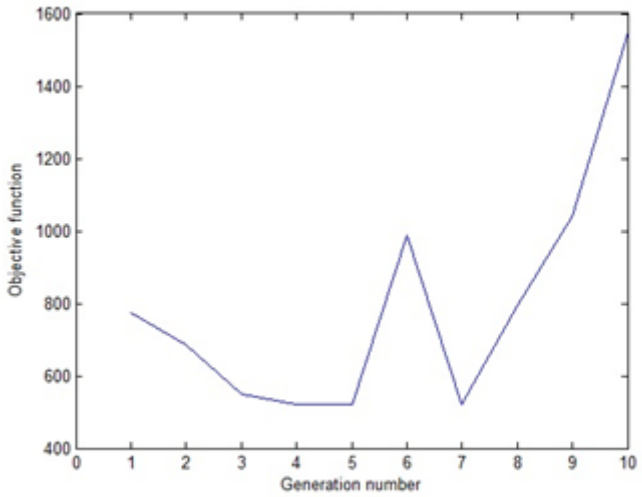


Figure 2. Objective function vs. generation number for the GA optimization implemented in 05.07.2014

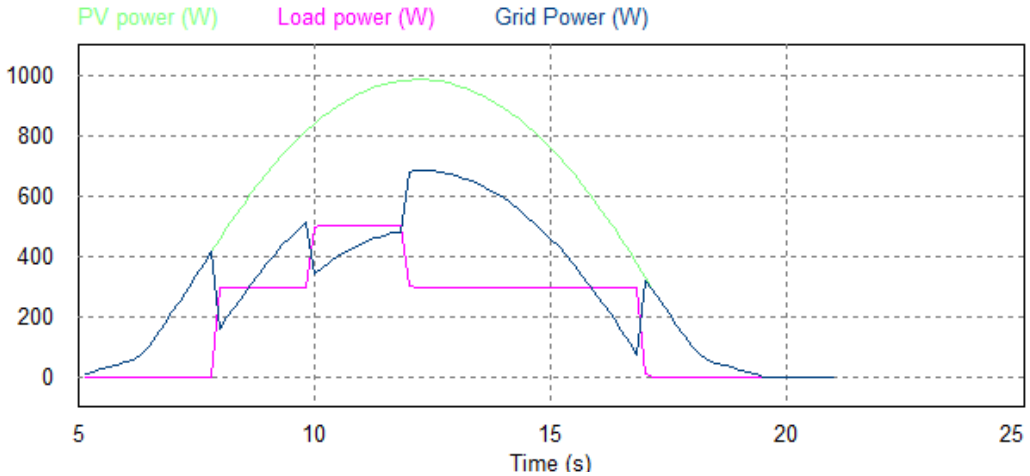


Figure 3. Variations of generated PV power, load power and grid power in 05.07.2014

The GA-based optimization algorithm was also observed for a cloudy day. Figs. 8 and 9 show the objective function vs. generation number for the GA optimization and variations of generated PV power, load power and grid power respectively, implemented in 03.02.2015. Since the PV output

power is affected by fluctuating weather conditions, the energy management of the system becomes very complex. By representing an intelligent exploitation of a random search, genetic algorithms are successfully used in energy management system to deal with the changes of the weather conditions. Employing also the recordings of the previous three days in objective function, the success of the results could be increased.

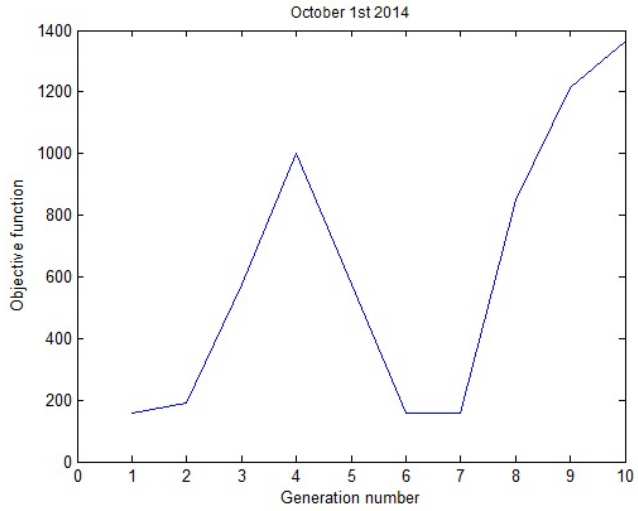


Figure 4. Objective function vs. generation number for the GA optimization implemented in 01.10.2014

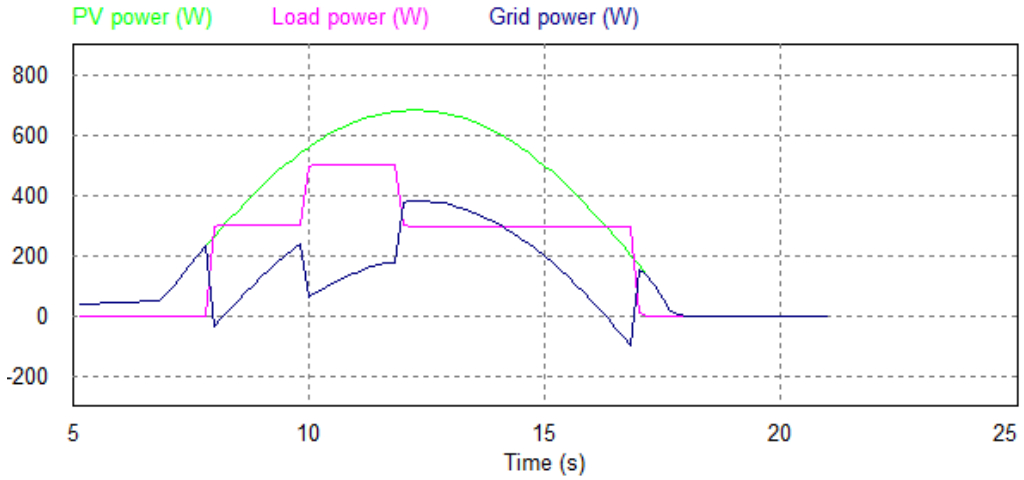


Figure 5. Variations of generated PV power, load power and grid power in 01.10.2014

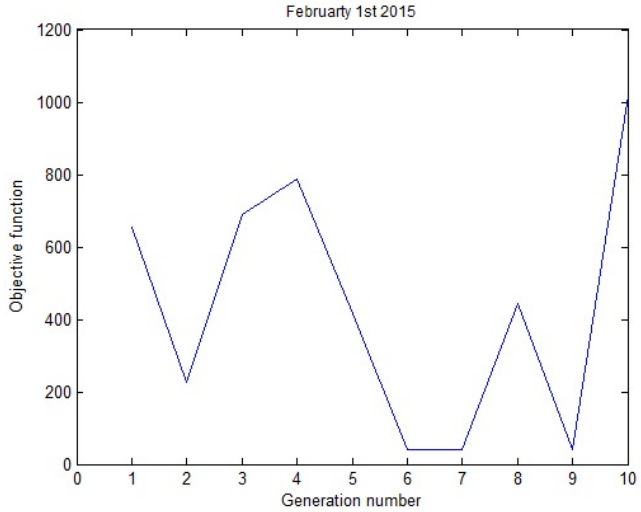


Figure 6. Objective function vs. generation number for the GA optimization implemented in 01.02.2015

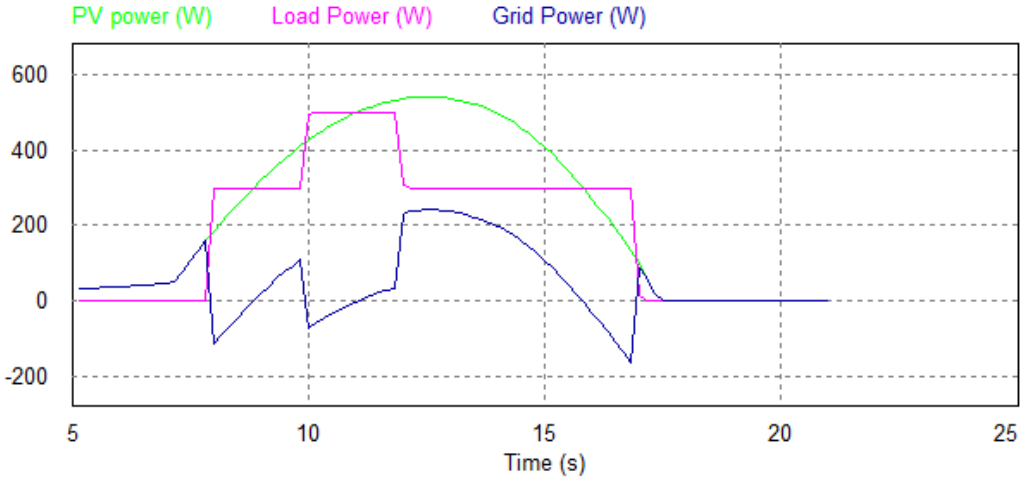


Figure 7. Variations of generated PV power, load power and grid power in 01.02.2015

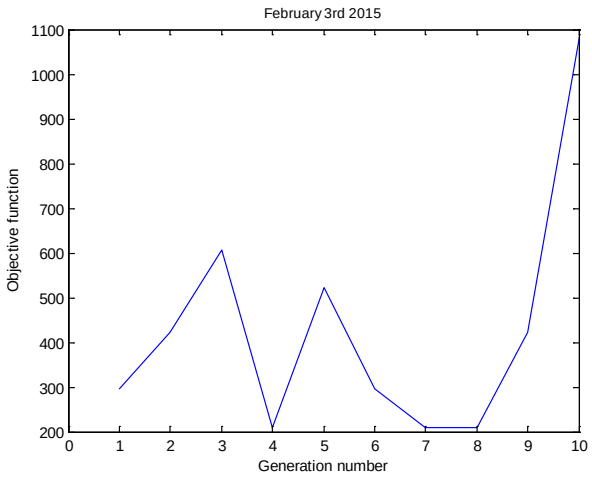


Figure 8. Objective function vs. generation number for the GA optimization implemented in 03.02.2015

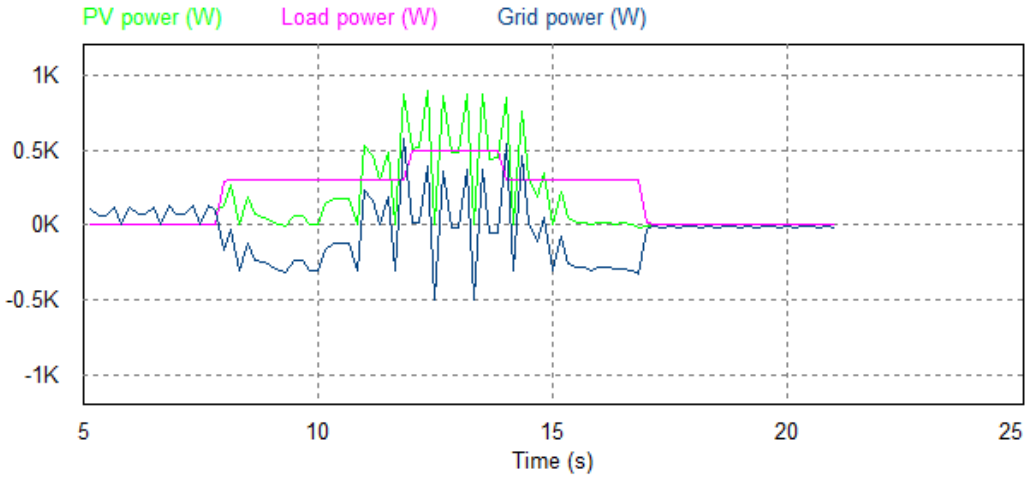


Figure 9. Variations of generated PV power, load power and grid power in 03.02.2015

5. CONCLUSION

In this study, by considering consumption and generation, it was aimed to implement energy management in order to reduce the energy cost. The results show that genetic algorithm based systems can be a good solution for complex problems in which a mathematical model is difficult to develop. The proposed energy-management strategy can provide optimal utilization of installed PV energy resources to meet the flexible loads of the consumers. Energy efficiency can be further increased by including storage batteries for storing energy when PV energy generation is more than required. Since the optimization option is influenced by the feed-in tariff, including this parameter in future studies can give improved energy efficiency. The current system was not practically implemented yet and by including the Zigbee-based control, it will perform many actions automatically for future domestic applications. It can also be extended to other areas of renewable energy systems and smart grid applications.

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