Optimal power scheduling of an off-grid renewable hybrid system used for heating and lighting in a typical residential house

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***Abstract*— In Turkey, there is a significant increase in demand for electricity due to population and economic growth taken place in recent years. This is a major economic factor affecting electricity price on market as well as other factors such as an increase in oil and natural gas prices. To be more specific around 50% of electricity is generated by natural gas generators and 95% of natural gas is imported from other countries. However, Turkey has considerable amount of wind and solar energy potentials to generate electricity through wind turbines and photo-voltaic arrays either on-grid or off-grid. An off-grid hybrid system is more attractive in rural areas where access to grid is limited or unavailable. This study focuses on a power scheduling in a simple renewable hybrid system in order to minimize the operational unit cost using the binary-coded genetic algorithm instead of using mixed integer linear programming. The preliminary results indicated that the binary-coded genetic algorithm produced encouraging and meaningful outcomes to minimize operational unit cost in a typical renewable microgrid photo-voltaic/wind hybrid system.**

Keywords*— *Genetic algorithms; Microgrid renewable systems; Optimal power schedulin; Cost reduction.

I. Introduction

Turkey's electricity demand constantly increases every year due to its fast economic growth and industrialization. In fact high demand for electricity influences on electricity price on market as well as other factors such as an increase in oil and natural gas (NG) prices. Unlike many countries, almost 50% of electricity in Turkey is mainly generated by NG combined power plant and 95% of NG is imported from other countries. However, Turkey has rich potential for generating electricity from renewable energy sources such as wind and solar energy sources through wind turbines and photo-voltaic (PV) arrays either on-grid or off-grid. Although wide-range of Turkey's population has access to electricity there are some regions where electricity access to grid is unavailable. In order to generate electricity in these regions a typical off-grid/stand-alone PV/Wind based hybrid system is attractive. A typical isolated hybrid system consists of small wind turbines, number of photo-voltaic panels, backup generators, a number of storage batteries and controllable and uncontrollable electrical loads [1]. It is obvious that operation of this type of hybrid system is assumed to be feeding electrical load constantly and the cost of electricity per kWh should be low as much as possible [2], [3]. This inevitably requires optimal power scheduling to obtain least operational cost because the whole system has several constraints [4], [5]. As the load varies from time to time the daily load curve should be well-forecasted by means of deterministic and stochastic techniques. It is also important that to forecast wind speeds and insolation values in the installation area. Hence the possible wind and solar power can roughly be estimated and the rated power of a wind turbine and the number of PV panels can be determined. A major problem in power systems is to equilibrate generation and consumption as much as possible [6], [7]. This is much important to an off-grid power system such as cell-phone base stations, emergency units in hospitals, airplanes, spacecrafts etc.

This study deals with a power scheduling in a PV/Wind based renewable system using the binary-coded genetic algorithm (BCGA) in order to obtain the least cost of electricity for short term. Besides, it encourages people to make use of possible wind and solar potential from an environmental aspect.

II. System Description

The hybrid system consists of a wind turbine and 9 PV panels, 2 charge controllers and 3 batteries as shown in Fig. 1.

Figure 1. A typical residential house for lighting and heating.

The wind turbine with permanent magnet synchronous generator generates 500W peak power and its cut in and cut off speeds vary from 2 to 25 m/s. Each PV panel has 235W peak power, solar and wind charge controllers have maximum charging current of 20A and 10A respectively at 12 volt DC.

There are 3 batteries used to store surplus energy and each of them has the capacity of 2.4kWh. The hybrid system can online be monitored by measuring electricity generation and consumption.

III. Problem Formulation

The optimal power scheduling problem for the hybrid system described in previous section is formulated by taking account for following considerations. The wind turbine and the PV panels generate electricity in order to supply to the load. If the generated power is higher than consumed power the surplus energy is stored in batteries. As the electricity generation is less than the load the battery is fully discharged. Some of loads should be shed if generated and stored energies are insufficient. For proper management of the system optimal power scheduling problem with several constraints is solved by using the BCGA method. The load may be controlled and uncontrolled between the limits. Unit costs for wind (c_w), PV (c_s), load (c_l), battery storage discharge (c_d), battery storage charge (c_c), undelivered (c_u) and excess (c_e) energies are 0.1€/kWh, 0.1€/kWh, zero, 0.15€/kWh, 0.1€/kWh, 0.6€/kWh and zero respectively. Optimal power scheduling is implemented on the hybrid system for each hour of the day. Hence, the total unit cost minimization function F_c can be expressed as

$$F_c = Min(\sum_{k=1}^{24}[c_w P_w(k) + c_s P_s(k) - c_l P_l(k) + c_c P_c(k) - c_d P_d(k) + c_u P_u(k) - c_e P_e(k)]) \quad (1)$$

Subject to

1. $\sum_{k=1}^{24}\left(P_w(k) + P_s(k) + P_d(k) - P_c(k) - P_e(k) + P_u(k) - P_l(k)\right) = 0$
2. $P_{wmin} \leq P_w(k) \leq P_{wmax}$
3. $P_{smin} \leq P_s(k) \leq P_{smax}$
4. $P_c(k) \leq 400W$
5. $P_d(k) \leq 200W$
6. $P_d(k) - P_{st}(k-1) \leq 0$
7. $P_{st}(0) = 200W$

where P_w, P_s, P_l, P_c, P_d, P_u, P_e and P_{st} are wind power generated by a wind turbine, power generated by PV panels, power demand for loads, power charged in battery, power discharged from the battery, undelivered power, excess power and storage power respectively.

In each time interval, the batteries can only be charged up to 400Wh and discharged maximum by 200Wh. It is also emphasized that the batteries are totally charged with 200Wh in their initial states. The wind, solar and load profiles were obtained by hourly wind and insolation rate measurements and the power demand was estimated in a typical residential house located in rural areas where the hybrid system was installed. In power scheduling process energy generated by the wind turbine and PV panels were daily estimated average values in a year and maintained constant all the time intervals as shown in Figure 2.

Apart from hourly power scheduling, for five-minute or fifteen-minute power scheduling number of data for each profile may be extended by the Support Vector Machines (SVM) or similar regression method. In this case time interval is a 5 minutes or 15 minutes and this might help obtain a better cost minimization under the same conditions but computational time.

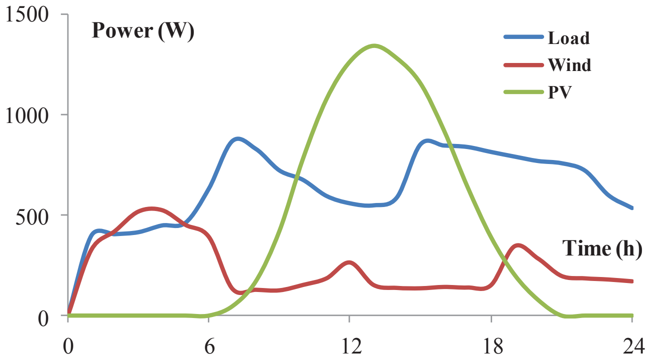

Figure 2. Variation of forecasted power generation and demand with time.

IV. Application of Genetic Algorithms Method

The BCGA software was developed in MATLAB environment to obtain the low-cost power scheduling for a typical residential house. In the design of the software power demand, charging and discharging powers were considered to be as variables. There were two types of load profiles: one covered all necessary electrical appliances, lighting, heating and cooling etc; the other consisted of some of necessary electrical appliances and lighting devices. Maximum of second load profile was 65% of peak power of the first load profile at each time interval hence its search space was determined between upper and lower limits of power demand. The excess and undelivered powers were calculated by taking account of the constraints given above.

The genetic process was initialized by the randomly generated binary population of 100 strings as shown in Figure 3. In order to obtain minimum operational cost power demand, charging and discharging powers were randomly generated within the search spaces determined by the constraints. Eq. (1) was used for the objective function and its reciprocal was expressed as the fitness function. The population consisted of 100 strings and each binary coded string was 24 bit length hence each variable had 8 bit length. Each string was converted to real numbers by the linear mapping to find its fitness through the fitness function given by (2). Thus, fitness for i^{th} population member can simply be calculated by

$$f_i = \frac{A}{F_{ci} + \varepsilon} \quad (2)$$

where A is an integer number for proper fitness scaling, F_{ci} is the i^{th} total cost and ε is the error margin used to avoid making the denominator zero.