Optimal Allocation of Energy Storage Systems in Connected Microgrid to Minimize the Energy Cost

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Abstract— **Nowadays, finding the optimum locations of energy storage systems (ESS) and distributed energy resources (DER) in a microgrid is very controversial. In this paper, a novel method based on harmony search algorithm (HSA) is proposed to find the optimum locations of ESSs in a specified microgrid. The microgrid has renewable energy resources, and it is connected to the main network. This method will minimize the amount of purchased energy from the main network. Finally, the proposed method will be tested on 37-bus IEEE standard network which has 4 ESSs and capability of using renewable energy resources.**

***Index Terms*—Energy storage system, microgrid, optimal allocation, harmony search algorithm.**

I. Introduction

The power network operators face with new issues such as major load changes and geographical expansion of network. On the other hand, environmental and economical issues relating to the electricity market grow every day. These make the role of renewable energy more important in distribution level. Microgrid can be defined based on these factors. Therefore, it is set of loads, micro sources, and energy storages, which can work as a separated and controllable system [1].

Advantages of microgrid usage can be divided into two major categories:

i. The technical advantages
ii. The economical advantages

A brief review of technical advantages could be as follow:

i. In some cases transmission expansion are difficult due to the technical and economical problems, microgrid can be used to meet load growth [2].
ii. Distributed Generation (DG) sources and their power electronic converters can be used to control the active and reactive power, voltage drop regulating, imbalanced correcting, and other power quality issues in distribution network [3].
iii. If a microgrid can continue its operation independent of network, both the network reliability and power generation quality increase [4].

Moreover, the economical advantages could be summarized as follow:

i. Since energy resources are close to the consumers in the microgrids, transmission lines and losses costs decrease.
ii. As mentioned, DGs improve power quality in the microgrids. Therefore, the loss of cost in some industrial or commercial centers can decrease.

Despite advantages, microgrids face with limitations and problems; the most important of them are as follow:

i. Plug and Play DGs
ii. Islanding detection of microgrid
iii. Difficulty in voltage and frequency control [5]
iv. Appropriate load sharing
v. Stability in function
vi. Robustness of control system
vii. Resynchronization after reconnecting to the network
viii. Microgrid Protection

In this paper, the concept of microgrid is associated with the concept of electricity market. In other words, the assumed microgrid consists of several DGs and loads. As it is clear, the production of the DGs cannot be predicted. In this paper, wind turbines and solar energy are used as energy resources in the microgrid. Due to the asymmetric and unpredictable generation of these resources, energy storage should be used in the microgrid.

In this paper, it is supposed that at first, the microgrid feeds its loads by using of DGs and energy storage systems (ESS) which are placed in it; then, if they cannot provide enough power for feeding the loads of microgrid, energy will be purchased from network in order to feed the loads. Consequently, the main purpose of this paper is finding the optimum location of energy storage in microgrid with considering network topology and allocation of DGs to minimize the purchased energy from network. Harmony search algorithm is used to achieve this purpose.

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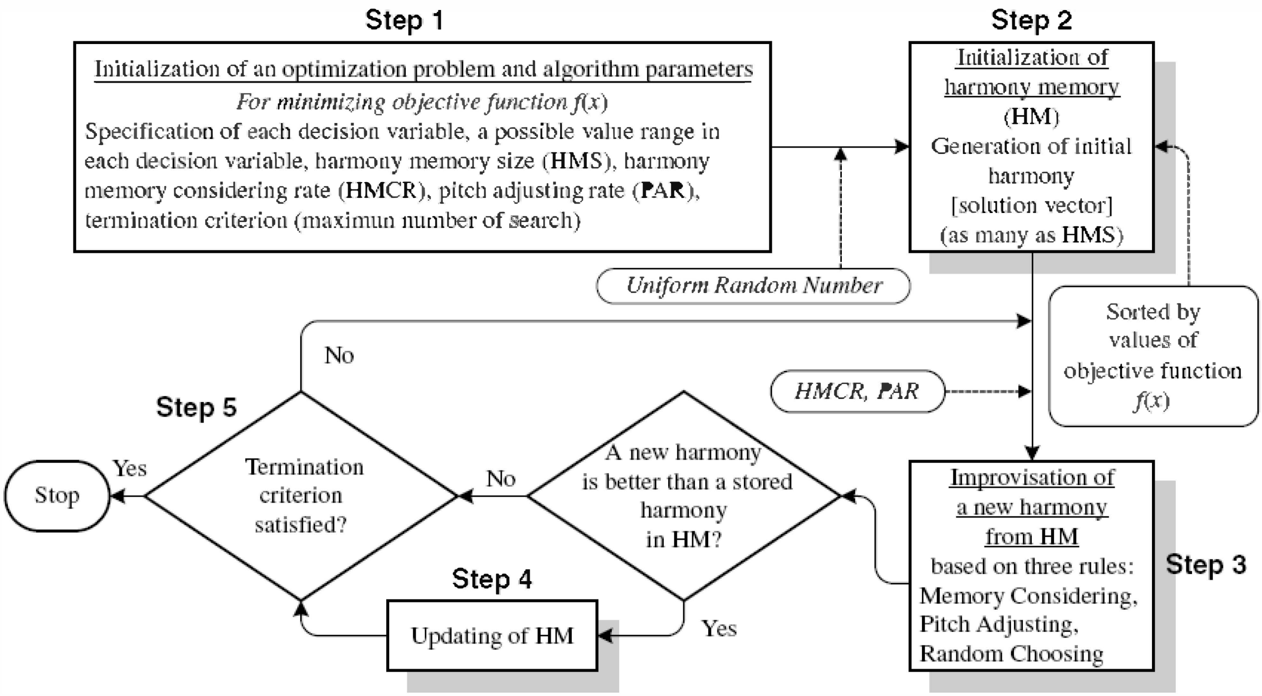

Fig. 1. The optimization procedure of a harmony search algorithm [6]

II. HARMONY SEARCH ALGORITHM

In 2001, Zong Woo Geem presented a meta-heuristic method which was named Harmony Search Algorithm (HSA) whose outline has been derived from the natural behavior of musicians in making the best harmony.

At first, musicians play music randomly with using musical instruments. These harmonies are stored within the musicians' memories. Then, the musicians play new music with using the harmonies which have been played and stored in their memories. The new music has been modified in comparison with the last one.

When musicians improvise one pitch, usually they follow any one of three rules: (i) playing anyone pitch from their memories, (ii) playing an adjacent pitch of one pitch from their memories, and (iii) playing totally random pitch from the possible sound range. Fig. 1 shows the optimization procedure of a harmony search algorithm [6].

III. THE PROPOSED METHOD

The main purpose of this paper is finding the optimum locations of ESS so that the energy which is exchanged between microgrid and network would be minimum.

At first, the characteristics of the microgrid such as lines profile, loads consumption in 24 hours period of time, loads location, locations of Distributed Energy Resources (DER) consisting of wind turbines (WT) and solar energy in this paper, energy generated by DERs in 24 hours period of time base on previous studies, and types of buses of the microgrid (Slack, PQ, PV) are stored in related matrixes.

In this paper, it is assumed that the planning is a one-hour plan and the amount of energy generation and energy consumption are constant during this period of time. In order that the period of time decreases in the plan, more details are required. Total energy generated by DERs and total loads consumption are calculated for every hour. If the sum of energy generated by DERs at one hour and the energy stored in the ESSs during previous hours is more than loads consumption and line losses(this assumption is named condition I), the additional amount of energy should be stored in ESSs. In this paper, batteries are used as ESSs, and it is assumed that the additional energy is stored equally in all batteries.

If the condition I is not true, obviously, the stored energy in ESSs should be used to feed loads of the microgrid and the extra energy which is required for feeding the loads should be purchased from the main network. In this condition, the ESSs discharge and the amount of their stored energy is reduced. The described process is shown below.

$$\begin{cases} DER_{(t)} + ESS_{(t-1)} > Loss_{(t)} + Load_{(t)} \;\rightarrow\; Batteries\ charge \\ DER_{(t)} + ESS_{(t-1)} < Loss_{(t)} + Load_{(t)} \;\rightarrow\; Batteries\ discharge \end{cases}$$

Where t and $Loss_{(t)}$ are the study hour and the line losses at the study hour, respectively.

In this paper, it is assumed that the microgrid is connected to the main network with Bus 1. Thus, the active and reactive powers which are injected from this bus to the microgrid are used for understanding what amount of energy have been purchased from main network.

During above steps, line losses should be considered. In other words, In the case of ignoring these losses and considering only loads consumption in the calculation of load flows, energy should be purchased from main network even if the total amount of energy generated by DERs and stored in ESSs are more than loads consumption. Because the capacity of ESSs is variable, if it changes, it changes the loads of the microgrid, so it can change the line losses; thus, a repetitive method is used to consider line losses, and if it is possible, these losses will be compensated by DERs and ESSs located in the microgrid.

IV. SIMULATION

The proposed method in this paper is tested on 37- bus IEEE standard network which fig. 2 shows [7]. Fig. 3 and Fig. 4 show the characteristics of energy generated by wind turbines located in the microgrid. Fig. 5 shows the energy generated by the PV [8]. Location of wind turbines and PV are indicated in Table I. Generally, two wind turbines and one PV are used in this microgrid.

The wind turbines production data are obtained from wind data in a windy region in Australia in 2005. These data are one month wind data of that region, showing energy generation on an hourly basis. In this paper, the average of generated energy in each hour of first 10 days are assigned to wind turbine connected to Bus 2 (WT1), and the average of generated energy in each hour of second 10 days are assigned to wind turbine connected to Bus 5 (WT2).

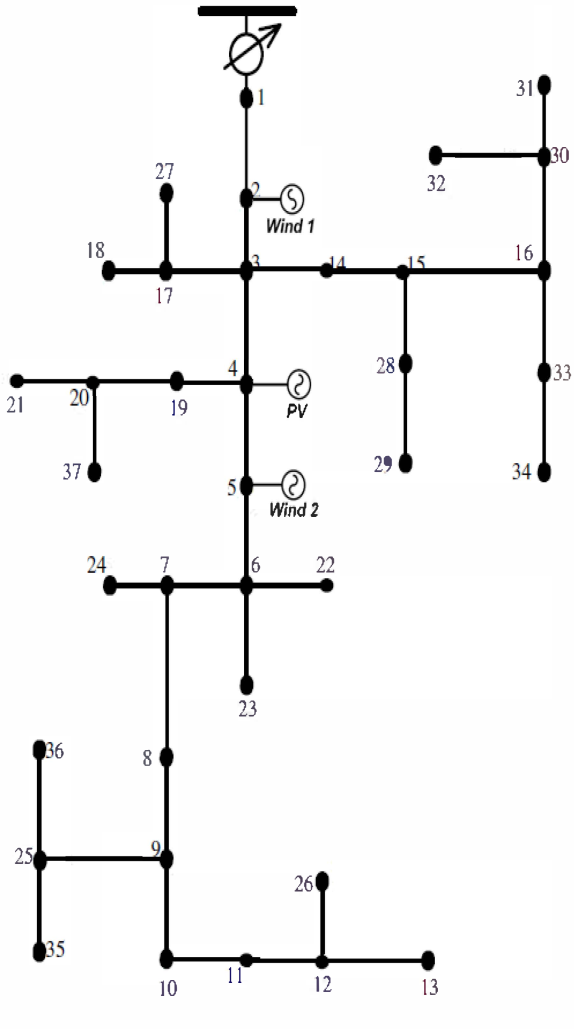

Fig. 2. The structure of microgrid

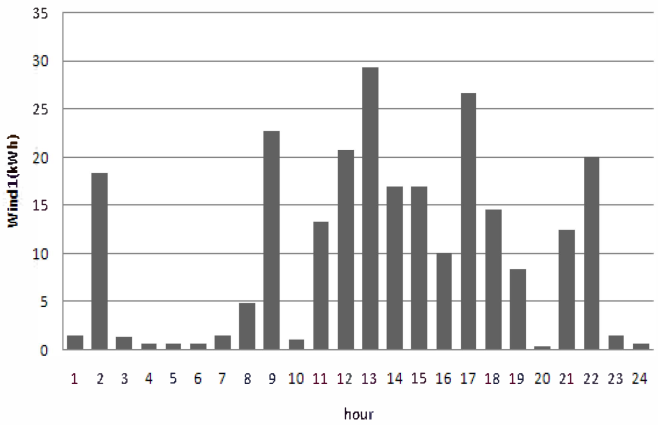

Fig. 3. Characteristic of energy generated by wind turbine connected to Bus 2

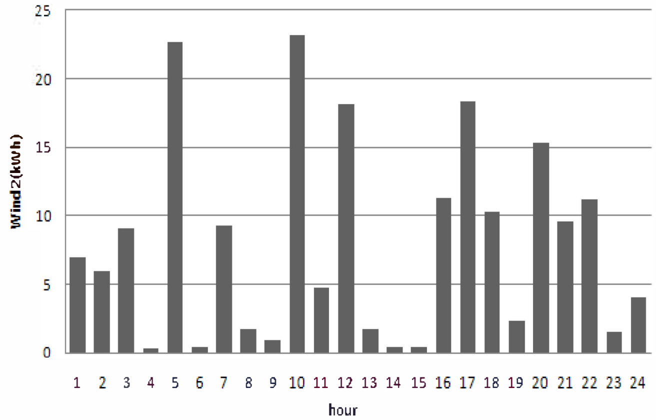

Fig. 4. Characteristic of energy generated by wind turbine connected to Bus 5

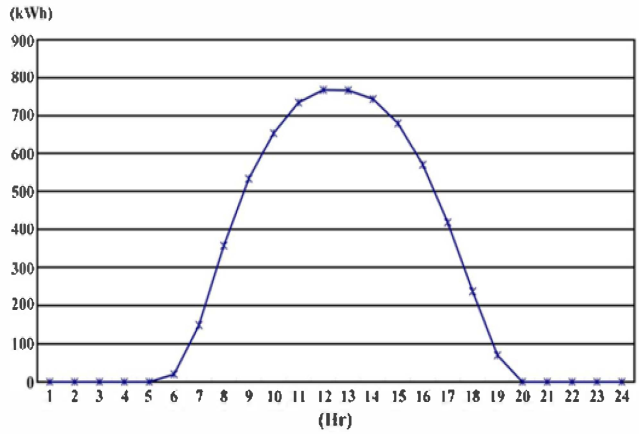

Fig. 5. Characteristic of energy generated by PV connected to Bus 4

The characteristics of Loads consumption are shown in Fig. 6 [9]. These loads are distributed over microgrid. Also, loads location is indicated in Table II.

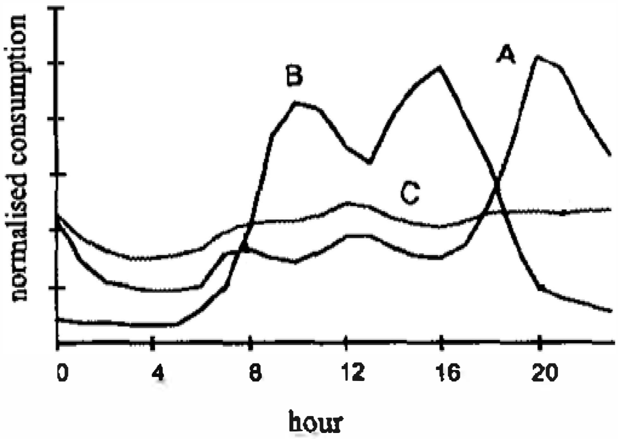

Fig. 6. Characteristics of loads consumption

In this paper, it is supposed to find optimum location for 4 ESSs. Using HSA method, Bus 2, 4, 10 and 16 have been selected to minimize the energy purchased from the main network, so the amount of energy purchased from the main network is equal to 181.0139 kWh for a day, but in the absence of ESSs, energy purchased rises to 227.795 kWh daily, which shows the importance of using ESSs in microgrids. The decreasing trend of the objective function is illustrated in Fig. 7 for 1000 iterations.

V. Conclusion

In this paper, HSA is used to find the optimum locations of ESSs in the microgrid. Allocation is done in a way that the purchased energy from the main network is minimized. As mentioned, using this method for finding the optimum locations of ESSs leads to less amount of energy which should be purchased from the main network, so the cost of microgrid decreases.

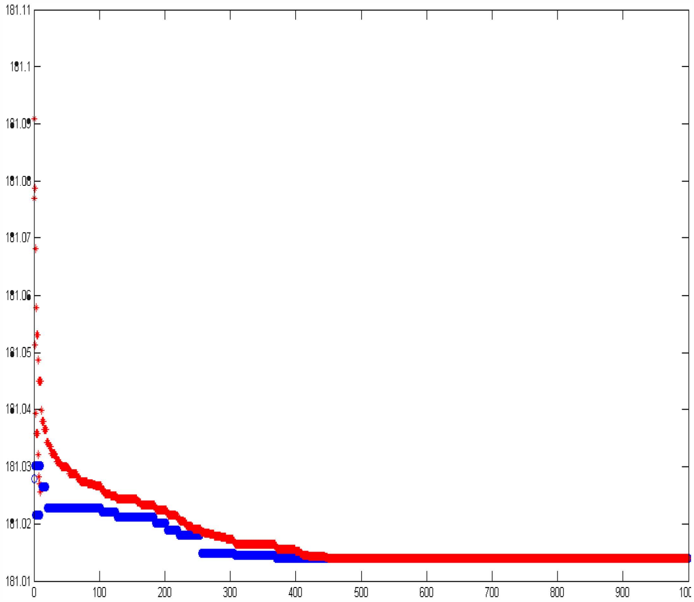

Fig. 7. The trend of objective function

TABLE I
LOCATION OF THE WIND TURBINES AND THE PV IN THE MICROGRID

Type of Renewable Energy Resource	Bus number
WT	2-5
PV	4

TABLE II
LOCATION AND TYPE OF LOADS IN THE MICROGRID

Type of load	Bus number
A	2-7-12-17-22-27-32-37
B	1-3-5-6-9-10-11-13-15-16-19-20-21-23-25-26-29-30-31-33-35-36
C	4-8-14-18-24-28-34

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