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A MODIFIED HONEY BEE MATING OPTIMIZATION ALGORITHM FOR MULTI-OBJECTIVE VOLTAGE CONTROL OF DISTRIBUTED HYBRID WIND AND PV SYSTEMS

[1]LIZHEN WU, [1]XIAOHONG HAO

[1] College of Electrical and Information Engineering of Lanzhou University of Technology, Lanzhou ,Gansu, 730050, China

E-mail: [1]wulzh@lut.cn , [2]wulzh111@yahoo.com.cn

ABSTRACT

Recently, Distribute Generation sources (DGs) connected to the distribution network has received increasing attention. The daily voltage control is one of the most important schemes in distribution networks, which can be affected by DGs. This paper presents a multi-objective Voltage optimizes control modeling, including objectives that are the total cost of power generated by Wind Farms (WFs) and Photovoltaic (PV) pants and the grid; the total electrical energy losses; the total emission and the voltage deviations of the bus. Moreover, a new optimization algorithm based on Modified Honey Bee Mating Optimization (MHBMO) algorithm is proposed to determine the best operating point for the active power generated by WFs and PVs, reactive power values of capacitors. In order to overcome the shortcomings of original HBMO algorithm, the mating process is improved. During the optimization process, the proposed algorithm finds a set of non-dominated (Pareto) optimal solutions which are stored in an external memory called repository. Also a fuzzy clustering technique is used to control the size of the repository within the limits. Finally, a typical IEEE 32-bus distribution test system is used to investigate the feasibility and effectiveness of the proposed method. Simulation results illustrate the correctness and adaptability of the proposed model and the MHBMO algorithm.

Keywords: *Multi-objective optimization, Modified Honey Bee Mating Optimization (MHBMO), Distribute Generation sources (DGs), Wind Farm (WF), Photovoltaic (PV), Voltage Control.*

1. INTRODUCTION

In recent years, the application of Renewable energy sources (RESs), such as wind, biomass, solar, hydro and etc. has become more widely spread mainly due to the needs for better reliability, higher power quality, more flexibility, less cost and smaller environmental pollutions. On the other hand, Distribute Generation sources (DGs), such as wind and PV (photovoltaics) are expected to play an important role in future electricity supply and low carbon economy[1-2]. However, high penetration of DGs into the grid environment will bring new challenges for the safe and efficient power system operation, especially on the distribution networks. Using RESs imposes a different set of operating factors on distribution network, such as reverse power flow, voltage rise, decreasing fault level and reduction of power losses, harmonic distortion and stability problems[3].

Since the X/R ratio of distribution lines is small and the configuration of distribution network is radial, the daily voltage control is one of the most important control schemes in distribution networks, which can be affected by DGs. The voltage control is defined as regulation of voltage over the feeders and reactive power (or power factor) at the substation bus[4-5]. The control is achieved by adjusting the Load Tap Changer transformers (LTCs), Voltage Regulators (VRs) and capacitor banks as control variables to minimize an objective function considering the constraints[6]. In this regard, various optimization techniques are implemented to the voltage control problem in distribution networks. In Ref. [7,8] the objective function is the optimization of voltage profile by using genetic algorithm (GA) to cope with the optimization problem, but the objective function are single objective. Nowadays, different multi-objective evolutionary approaches are also implemented to the daily voltage control problem.

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In Ref. [9-11] the objective function is the optimization of voltage profile by using a Particle Swarm Optimization (PSO) approach. In Ref. [12] dynamic ant colony search algorithms are used to the voltage control in radial distribution networks considering Distributed Generations. But they have not considered the impact of active power of DGs on the Volt/Var control problem.

In this paper, a new approach for daily voltage control in distribution networks considering DGs, such as Wind and solar Photovoltaic energy, also considering the active power as a control variable is presented. The objectives are the total cost of power generated by Wind Farms (WFs) and Photovoltaic (PV) pants and the grid; the total electrical energy losses; the total emission and the grid and the voltage deviations of the bus. Moreover, a new optimization algorithm based on improved HBMO algorithm has been put into use to solve the daily voltage control, which not only has a better response but also converges more quickly than ordinary evolutionary methods like genetic algorithm.

The original HBMO often converges to local optima[13]. In order to avoid this shortcoming, a new method is proposed to improve the mating processing. Therefore, the mating process is corrected so that to overcome the two main shortcomings which exist in the traditional HBMO. During the optimization process, the set of Pareto optimal solutions which are found by the algorithm would be stored in an external memory called repository. In addition, to find the 'best compromised' solution among the Pareto optimal solutions, a fuzzy-based mechanism is introduced and applied to the set Pareto solutions set. Finally, a typical IEEE 32-bus distribution test system is used to investigate the feasibility and effectiveness of the proposed method.

The paper is organized as follows: the model for the multi-objective voltage control is presented in Section 2. In Section 3, the basic mechanism of HBMO, improved HBMO is described. In Section 4.the feasibility of proposed approach is demonstrated and its performance is compared with other methods for IEEE 32-bus distribution test feeder. In Section 5 are the conclusions.

2. MODELING OF MULTI-OBJECTIVE VOLTAGE CONTROL IN HYBRID POWER SYSTEM

Different models of RES according to their operation technology and connection to the grid are as follows.

2.1 Wind Farms (WFs)

With the developments which has happened in the technology of the wind power generations in recent years, there has been an increasing interest to get use of the wind farms which are connected directly to the power system. This kind of RES is divided into two categories of fixed and variable speed. In the fixed speed type, the rotor of the squirrel cage induction generator is rotated by the propeller through gear box while the induction motor is connected to the grid directly. In the variable speed type, firstly, by the use of synchronous or a double-fed induction generator the wind energy is converted to the electrical energy and then by the use of power electronic devices, the generated electrical energy is changed to the grid compatible AC power [14]:

$$P_{WT}^{t}=\begin{cases}0\,;\,w^{t}\le w_{1}\quad or\quad w^{t}\ge w_{3}\\ \psi(w^{t})\,;\,w_{1}<w^{t}<w_{2}\qquad t=1,2,\ldots n\\ P_{WT}\;;\;w_{1}\le w^{t}\le w_{3}\end{cases} \tag{1}$$

2.2 Photovoltaic

One of the huge sources of energy which can support a big part of the required energy of the human beings is solar energy. In order to get use of this everlasting source of energy, PV as an inevitable technology in the area, has attracted the attention of many researchers in recent years[1]. In fact, by the use of arrays of cells which are constructed by some kinds of semiconductors that exhibit the photovoltaic effect, the solar radiation can be converted into direct current (DC) electricity sufficiently. The output power and the solar radiation are related to each other as follows [15].

$$P_{PV}(G^{t})=\begin{cases}P_{sn}\dfrac{(G^{t})^{2}}{G_{std}R_{c}};\;0<G^{t}<R_{c}\\ S_{n}\dfrac{G^{t}}{S_{std}};\;G^{t}>R_{c}\end{cases}\qquad t=1,2,\ldots n \tag{2}$$

2.3 The effect of WFs and PVs on voltage profile of distribution networks

With installation of WFs and PVs in the distribution networks, any changes in the power flow may change the voltage profile. Since the X/R ratio of the distribution lines is small, the WF or PV has much impact on the voltage profile. The voltage drop along the line is calculated as follows [9]:

$$\Delta V=V_{1}\angle\delta_{1}-V_{2}\angle\delta_{2}=(R+jX)I \tag{3}$$

$$I=\frac{P-jQ}{V_{2}^{*}} \tag{4}$$

$$P=P_{g}+P_{Load}\;;\quad Q=Q_{g}+Q_{Load} \tag{5}$$

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$$|\Delta V|^2 = \frac{(RP+XQ)^2+(XP-RQ)^2}{V_2^2} \approx \frac{(RP+XQ)^2}{V_2^2} \quad (6)$$

It is obvious from the above equation that neither RP nor XQ is negligible. Also, since the X/R ratio is small and Q is less than P, the impact of the active power of WFs or PVs on the system voltage is much more than their reactive power.

2.4 Objective functions

The multi-objective daily Voltage control in distribution networks considering DGs is a nonlinear optimization problem with both continuous and discrete parameters and variables. In the following the objective functions and constraints are presented. As mentioned before, power systems are inherently stochastic due to uncertainties in both intermittent energy sources and load demands. Consequently, the bus voltages, the active and reactive power flows and power losses; the emission generated by power grid, WFs and Photovoltaic (PV).Such objective function can be formulated as follows.

2.4.1 Total costs of electrical energy generation

The total electrical energy cost is the summation of the cost related to the power produced by the grid and the cost related to the power produced by the RESs.

$$Min \quad f_1(X) = \sum_{i=1}^{T} Cost^t$$

$$Cost^t = \sum_{i=1}^{N_{Sub}} \mathrm{Price}^t_{Sub.i} \times P^t_{Sub.i} \times h^t + \sum_{j=1}^{N_g} \mathrm{Price}^t_{DG.j} \times P^t_{DG.j} \times h^t \quad (7)$$

Where Nsub is the number of the grid, Ng is the total number of WFs and WPV. Price^t_{Sub} and Price^t_{DG} are the prices of the electrical energy grid and the electrical energy generated by the ith DG. $P^t_{Sub.i}$, $P^t_{DG.j}$ respectively represent the active power of the distribution company, wind farms and PV for the tth load level step.

2.4.2 Total power losses

The second objective is to minimize the total active power losses for the next day, which can be modeled as:

$$Min \quad f_2(X) = \sum_{t=1}^{T} \sum_{i=1}^{N_{br}} (R_{i.} |I_i^t|^2 .h^t) \quad (8)$$

Where N_{br} is the number of branches.

2.4.3 Voltage deviations of the buses

Voltage deviation determines the difference between the voltages in nodes with respect to the nominal voltage. It is assumed that tap position of transformers and the values of capacitors change stepwise.

$$Min \quad f_3(X) = \frac{1}{N_d} \sum_{t=1}^{N_d} \sum_{i=1}^{N_{bus}} \left| \frac{V_i^t - V_i^*}{V_i^*} \right| \quad (9)$$

Where V_i^* is desired voltage of network at the ith bus, V_i^t is actual voltage of network at node i during time t. N_{bus} is number of buses. N_d is number of load variation steps.

2.4.4 Pollutants emission

Three of the most important pollutants are involved in the objective function: CO2 (carbon dioxide), SO2 (sulfur dioxide) and NOx (nitrogen oxides). The mathematical formulation of the objective can be described as [12]:

$$Min \quad f_4(X) = \sum_{t=1}^{T} E^t = \sum_{t=1}^{T} (E^t_{Sub} + E^t_{WF} + E^t_{PV}) \quad (10)$$
$$= \sum_{t=1}^{T} E^t_{Sub} = \sum_{t=1}^{T} (CO_2 + NOx + SO_2)$$
$$= (2031 + 5.06 + 7.9)^{1b/MWh} . P^t_{sub}$$

2.5 Constraints

In order to have an optimal plan while maintaining the security and operational conditions, the following constraints should be met:

-Power balance

$$P_i = \sum_{i=1}^{N_{bus}} V_i V_j \cos(\theta_{ij} - \delta_i + \delta_j)$$
$$Q_i = \sum_{i=1}^{N_{bus}} V_i V_j \sin(\theta_{ij} - \delta_i + \delta_j) \quad (11)$$

-Active power constraints of DGs

$$P_{PV.\min} \le P^t_{PV} \le P_{PV.\max}$$
$$P_{WF.\min} \le P^t_{WF} \le P_{WF.\max} \quad (12)$$

-Line flow limits

$$\left| P_{ij}^{Line} \right|^t < P_{ij.\max}^{Line} \quad (13)$$

-Limits on the transformers' tap

$$Tap_i^{\min} < Tap_i < Tap_i^{\max} \quad (14)$$

-Hourly limits on Substation power factor

$$Pf_{\min} < Pf^t < Pf_{\max} \quad (15)$$

-limits on bus voltage magnitude

$$V_{\min} < V_i^t < V_{\max} \quad (16)$$

3. MULTI-OBJECTIVE OPTIMIZATION

Multi-objective optimization is the process of optimization of different conflicting objective functions when all the constraints and limitations are observed simultaneously, and it is called multi-objective optimization problem (MOP). The MOP can be described as [16]:

$$Min \quad F = [f_1(X), f_2(X), ... f_n(X)]^T \quad (17)$$

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$$s.t: \begin{cases} g_i(X) < 0 & i = 1,2...\text{Nueq.} \\ h_i(X) = 0 & i = 1,2...\text{Neq} \end{cases}$$

X is the control variable of making decision. Also n is the number of objective functions. For a multi-objective optimization problem, two solutions X and Y can have one of these two possibilities: one dominates the other or none dominates the other. In a minimization problem, without loss of generality, a solution X dominates Y if the following two conditions are satisfied:

$$\forall j \in \{1,2...n\}, f_j(X) \leq f_j(Y)$$
$$\exists k \in \{1,2...n\}, f_k(X) \leq f_k(Y) \qquad (18)$$

3.1 Original HBMO

Honey bee as a social insect with special behaviors and instructions has been the source of inspiration for the human beings during the years[17]. The honey bees' society consists of three groups in general: 1) the queen or female, 2) the drones or males and 3) the workers. Each of these groups has a special task which should be implemented in such a way that the total condition of their society improves effectively. HBMO algorithm simulates each of the phases of the natural mating process so that to give a satisfying algorithm which would be profitable in the optimization applications. The mating process between the queen and each of the drones is implemented probabilistically with an annealing function as follows[18]:

$$prop(D) = \exp\left(-\frac{\Delta f}{S(t)}\right) \qquad (19)$$

After each mating process, the queen speed decreases. If the mating process is successful, the corresponding drone sperm is added to the queen spermatheca, else it is discarded and the next drone is chosen for mating. The speed of the queen after each mating process is updated as follows:

$$S(t+1) = \alpha \times S(t) \qquad (20)$$

The mating process continues until the time that the speed of the queen reaches to a specific value or her spermatheca become full. Now the breeding process is simulated. If the position of any of the new broods is better than that of the queen, then it will replace the queen. This process of mating and breeding continues until the time that the best satisfying queen (solution) would be achieved.

3.2 Fuzzy-based clustering

As mentioned before, the set of Pareto optimal solutions which are found during the optimization process are stored in an external memory (or repository). Since the repository size is constant, the number of the Pareto solutions should not exceed a specified number. Therefore a fuzzy-based clustering technique is utilized here to control the size of the repository. The membership function assigned to each objective function is as follows:

$$\mu f_i(X) = \begin{cases} 1 & f_i(X) \leq f_i^{\min} \\ \dfrac{f_i^{\max} - f_i(X)}{f_i^{\max} - f_i^{\min}} & f_i^{\min} \leq f_i(X) \leq f_i^{\max} \\ 0 & f_i(X) \geq f_i^{\max} \end{cases} \qquad (21)$$

The values of $f_i^{\min}$ and $f_i^{\max}$ are separately evaluated by single optimization of each objective function. Finally, for each of the solutions in the repository, the normalized membership function can be evaluated as follows:

$$N_\mu(j) = \frac{\sum_{i=1}^{n} \omega_i \times \mu_{fi}(X_j)}{\sum_{j=1}^{m}\sum_{i=1}^{n} \omega_i \times \mu_{fi}(X_j)} \qquad (22)$$

Where n is the number of the objective functions and m is the number of the Pareto solutions in the repository. Therefore, after the evaluation of N_μ for all the Pareto solutions by Eq. (22), the repository is sorted in descending order. The best compromised solution is that for which the value of N_μ is maximum. Note that here ω_i is supposed to be unit so that to give equal preferences to all the objective functions. For multiple objective problems, the fuzzy solution can be calculated as:

$$Object(X) = \min[\mu_{f1}(X), \mu_{f2}(X), \mu_{f3}(X), \mu_{f4}(X)]$$

The maximum value of object (X) is considered as the optimal solution.

3.3 Modified HBMO (MHBMO) algorithm

The original HBMO suffers from two main deficiencies; that is the reliance of the HBMO algorithm on its parameters and the possibility of being trapped in local optima. These two shortcomings root from the mating process. Thus, in order to improve the algorithm performance, the mating process should be corrected sufficiently. In the original HBMO, after that the process of adding the drones' sperm to the queen spermatheca is completed and the queen spermatheca is constructed, then the breeding process is implemented as follows:

$$X_{brood\ j} = X_{queen} + \gamma \times (X_{queen} - S_{Pi}) \qquad (23)$$

After that the queen spermatheca is constructed similar to original HBMO, three drones k1, k2 and k3 are chosen from the queen spermatheca randomly in a way that k1sk2sk3si where i is the ith individual in the drones' population. Thus by the use of the queen spermatheca, a new improved brood is generated as follows:

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$$X_{mut} = S_{Pk1} + \beta \times (S_{Pk2} - S_{Pk3}) \qquad (24)$$

Now by the use of Xmut, Xqueen and Xi (the ith drone), three new modified broods would be generated. The modification process is implemented as follows:

$$X_{brood1,j} = \begin{cases} x_{mut\,j}; & \text{if } \varphi_1 \le \varphi_2 \\ x_{queen\,j}; & \text{otherwise} \end{cases}$$

$$X_{brood2,j} = \begin{cases} x_{mut\,j}; & \text{if } \varphi_3 \le \varphi_2 \\ x_{j}; & \text{otherwise} \end{cases}$$

$$X_{brood\,3} = \eta X_{queen} + \alpha \times (X_{queen} - SP(I_{rand,SP})) \qquad (25)$$

Now by the use of Eq.(18), the non-dominated solutions among Xbrood,1, Xbrood,2, Xbrood,3 and the ith individual in the drones population are evaluated and stored in the repository.

In order to improve the HBMO algorithm, the process of generating drones' population should be amended too. In the original HBMO, after that the breeding process for all the drones' population is finished, then the old drones' population is discarded and a new generation is produced randomly. In the MHBMO algorithm, this process is corrected as follows: As mentioned before, for each drone in the population (Xi), three new modified broods are generated by Eq. (25). After selection of the non- dominated solutions among the three generated modified broods and the ith drone, the individual who the summation of its membership functions is the most will replace the corresponding drone (Xi) in the drones' population. Subsequently after a complete breeding process, the old drones' population is up-dated and utilized as the new generation of drones satisfactorily.

3.4 Apply MHBMO to voltage deviation control

Step 1: defining the input data.

Step2: changing the constrained MOP to an unconstrained one: in this step, the constrained MOP is changed to an unconstrained one by constructing an augmented objective function.

Step 3: generation of the initial population. The initial population (IP) is as follows:

$$IP = \begin{bmatrix} X_1 \\ X_2 \\ \dots \\ X_{Ni} \end{bmatrix}_{N_i \times (N_{Tie} + N_{sw} + N_g)} \qquad (26)$$

$$N_g = N_{PV} + N_{WF}$$

Step 4: evaluation of the objective functions. In this step the values of the objective functions and their corresponding membership functions are evaluated.

Step 5: formation of the repository. Here by the use of Eq.(21) and the membership functions evaluated in the last step, all the Pareto solutions are evaluated and stored in the repository.

Step 6: selection of the queen. The queen is selected from the repository randomly.

Step 7: formation of the queen spermatheca matrix. Firstly, the queen flies by her maximum speed far from the nest. Now a drone is selected from the drones' population randomly and mates with the queen. Therefore according to the values of the objective functions and by the use of Eq. (19), prob(D) would be evaluated. Now a value in the range of [0,1] is generated randomly and compared to prob(D). If prob(D) is bigger than the generated random value, then the sperm of the specified drone is added to the queen spermatheca, else another drone is chosen from the population randomly and the mating process is repeated. The mating process continues until the time that the queen spermatheca becomes full or her speed reduces to the specified value.

Step 8: breeding process. This process is implemented as described in Section 3.3.

Step 9: generation of the new drones' population. Among the ith drone, Xbrood, 1, Xbrood,2 and Xbrood, 3 the individual who the summation of its membership functions is the most (so the fittest individual) will replace the ith drone.

Step 10: if all the drones are checked, go to step 11, else return to step 8.

Step 11: updating the repository. In this step the repository is updated so that all solutions in the repository would be Pareto optimal solutions.

Step 12: updating the queen. A new queen is selected from the updated repository randomly.

Step 13: generation of the queen speed: The queen speed will be generated randomly as follows:

$$S_{queen} = rand(.) \times (S_{\max} - S_{\min}) + S_{\min}$$

Step 14: termination criterion. If the termination criterion is achieved, finish the algorithm, else return to step 6.

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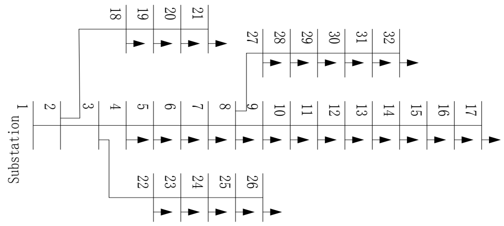


Figure1.The IEEE 32 Bus Distribution Test System

4. SIMULATION RESULTS

To demonstrate the effect of uncertainty in WFs, PVs and load demands on the voltage control problem, the IEEE32-bus distribution test feeder shown in Figure 1.

The tap position of voltage regulators ranges from 0.95 to 1.05 with a step of 0.01. The cost of energy generated by WFs and PV are 0.41, 0.65 ($/MWh), the maximum power outputs obtained from RESs are also estimated for a day ahead by using an expert prediction model. Such predicted values are shown in Figure 2. The daily load variation is shown in Figure 3.

There are several parameters to be determined for implementation of MHBMO algorithm. The best values for these parameters are selected as: $S_{max}=1$, $S_{min}=0.2$, $\alpha=0.92$, $N_D=20$, $N_W=N_S=N_B=10$.

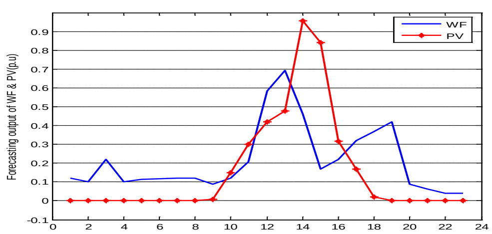


Figure2. Forecasting Output Of WT & PV

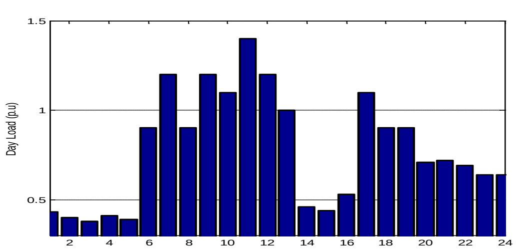
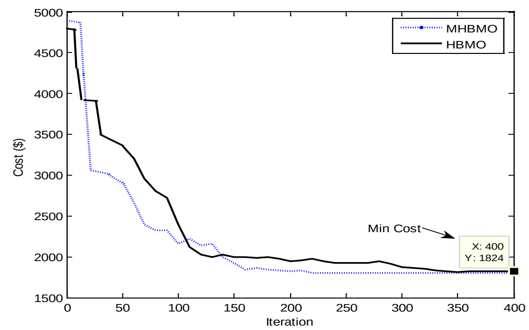
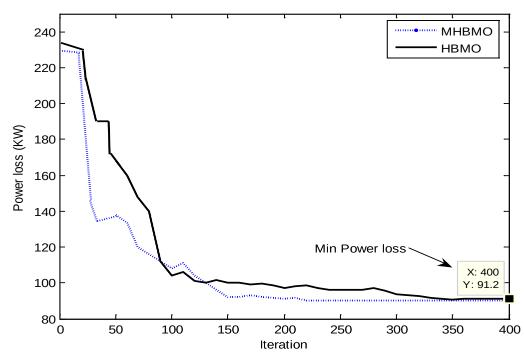


Figure3.The Daily Load Variation In The System

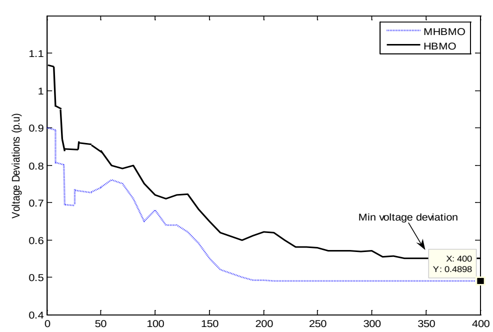
These values before applying the proposed algorithm are 2433.6($), 251.79(kWh), 0.9512(p.u) and 14624.12(Kg). The best solutions obtained by optimizing the four objectives separately are 1824.06($), 91.21(kWh), 0.4898(p.u), and 6840.24(Kg). It is obvious that the total electrical energy cost, total electrical energy losses and voltage deviation are greatly reduced by controlling DGs. Figure 4 shows the convergence characteristics of MHBMO and HBMO algorithms for the best solution. It can be seen from Figure 4 that for MHBMO algorithm the objective function reaches its minimum after about 232 iterations, and does not vary thereafter while the HBMO algorithm converges to global optimum in about 356 iterations. So MHBMO algorithm has better outperforms the original HBMO.



(A) The Best Solution For Electrical Energy Cost



(B) The Best Solution For Power Loss



(C) The Best Solution For Voltage Deviation

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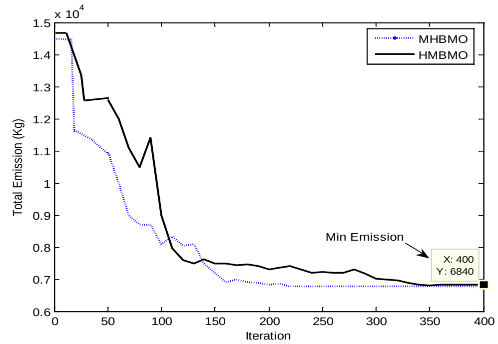

(D) The Best Solution For Total Emission
Figure4. Convergence Characteristics Of MHBMO And HBMO Algorithms For The Best Solution

To show that the constraints are satisfied under the proposed optimization method, the voltages of buses # 6, and #29 are illustrated in Figure 5 and Figure6. It can be observed from the figures that the bus voltages are maintained within the permitted range of tolerance, i.e. ±10% of the nominal value. The simulation results show that the control scheme improve performance of the system.

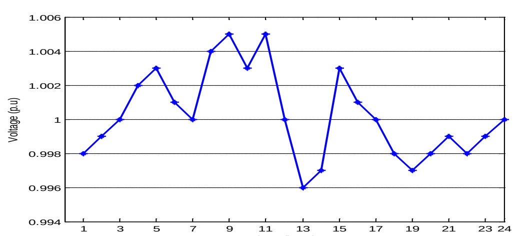

Figure5. The Voltages Of Buses # 6

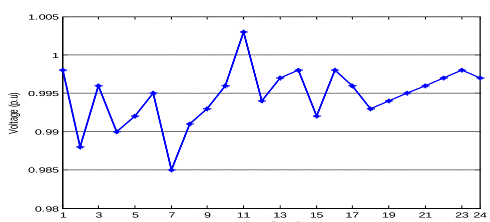

Figure6. The Voltages Of Buses #29

5. CONCLUSIONS

In this paper, a new multi-objective approach for the daily Voltage control in distribution systems regarding the hybrid use of solar PV and wind energy sources is presented. The uncertainty in the load demands and the electrical power generated by WFs and solar PV was taken into account. The total cost of power generated by Wind Farms (WFs) and Photovoltaic (PV) pants and the grid; the total electrical energy losses; the total emission and the grid and the voltage deviations of the bus were included in the objective function. The multi-objective optimization problem was solved by using fuzzy optimization method with the max-min operator. A new optimization algorithm based on Modified Honey Bee Mating Optimization (MHBMO) algorithm was proposed to determine the strategy, which is optimal from economical, operational, and environmental perspectives. The simulation results show that the voltage magnitude of buses is in the desired limits.

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