A New Approach Based on HBMO for Volt/Var Control in Distribution Considering DGs

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Abstract--**This paper presents a new evolutionary algorithm based on Honey Bee Mating Optimization (HBMO) for daily Volt/Var control in distribution system including Distributed Generators (DGs). Due to the small X/R ratio and radial configuration of distribution systems, DGs have much impact on this problem. Since DGs are independent power producers or private ownership, a cost based methodology is proposed as a proper signal to encourage owners of DGs in active power generation. Generally, the daily Volt/Var control is a nonlinear optimization problem. Therefore, an efficient evolutionary method based on HBMO is proposed to determine the active power values of DGs, reactive power values of capacitors and tap positions of transformers for the next day. The feasibility of the proposed algorithm is demonstrated and compared with methods based on the PSO, Tabu Search (TS), Differential Evolution (DE) and Genetic Algorithm (GA) on a realistic distribution feeder.**

Index Terms-- **Distributed Generators, Honey Bee Mating Optimization, Voltage and Reactive Power Control.**

I. Introduction

Historically, Distributed Generators (DGs) have been of modest significance and the issues related to the technical and commercial integration of these generators in the power system operation and developments have received little attention. Over the last several years this has been rapidly changing due to a number of economical, technical, commercial and environmental factors surrounding the electricity industry. These include introduction of competition in the industry, advances in developments of small-scale generation technologies, availability of access to sites and fuel, aging infrastructure, etc. Studies carried out by researching centers show that DGs participation in energy production will be more than 25 percent in the near future. Therefore, it is necessary to study the impact of DGs on the power systems, especially on the distribution networks [1].

Since the X/R ratio of distribution lines is small and the configuration of distribution network is radial, the daily Volt/Var control is one of the most important control schemes in the distribution networks, which can be affected by DGs.

The daily Volt/Var control is defined as regulation of voltage over the feeders and reactive power (or power factor) at the substation bus. 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. Many researchers have investigated reactive power and voltage control in distribution networks, which are divided into two main categories [2]-[18]:

- Rule based algorithms, which use a set of rules about how to control switched capacitors and transformer tap changers based on real-time measurements and past experience.
- Network based algorithms, which use distribution network topology, impedances, real-time measurements and statistical information in order to establish the current states of the distribution system. These algorithms apply optimization techniques to get the best possible solution (combination of on/off switched capacitor statuses and transformer tap changer positions).

A network based daily Volt/Var control in distribution networks with regard to DGs is the main purpose of this article. Due to private ownership of DGs, a price based compensation methodology is proposed as a proper signal to encourage owners of DGs in active and reactive power generation. The objective function includes price of electrical energy generated by DGs and distribution companies during the next day.

Due to Equipment in distribution systems, such as Static Var Compensators (SVCs), DGs, load tap changers and VRs, the daily Volt/Var control problem is usually modeled as a mixed integer nonlinear programming problem. In this paper, an evolutionary optimization method based on HBMO has been used to solve the daily Volt/Var control, which not only has a better response but also converges more quickly than ordinary evolutionary methods like genetic algorithm.

II. Daily Volt/Var Control in Distribution Networks in the Presence of DGs

From a mathematical standpoint, daily Volt/Var control in distribution networks with regard to DGs is a nonlinear optimization problem with continuous and discrete parameters and variables. The proposed objective function is defined as following:

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$$f(X)=\sum_{t=1}^{Nd}(\Pr ice^{t}*P_{Sub}^{t}*\Delta t_{t}+\sum_{i=1}^{N_g}C_{Pgi}(P_{gi}^{t})*\Delta t_{t})$$
$$\overline{X}=[\overline{Tap},\overline{Q_G},\overline{U_C},\overline{P_G}]$$
$$\overline{Tap}=[\overline{Tap_1},\overline{Tap_2},...,\overline{Tap_{Nt}}] \quad (1)$$
$$\overline{Tap_i}=[Tap_i^{1},Tap_i^{2},...,Tap_i^{Nd}];\quad i=1,2,3,...,N_t$$
$$\overline{P_G}=[\overline{P_{g1}},\overline{P_{g2}},...,\overline{P_{gNg}}]$$
$$\overline{P_{gi}}=[P_{gi}^{1},P_{gi}^{2},...,P_{gi}^{Nd}];\quad i=1,2,3,...,N_g$$
$$\overline{U_C}=[\overline{U_{c1}},\overline{U_{c2}},...,\overline{U_{cNc}}]$$
$$\overline{U_{ci}}=[U_{ci}^{1},U_{ci}^{2},...,U_{ci}^{Nd}];\quad i=1,2,3,...,N_c$$

s.t:

1. $(P_{gi}^{t})^2+(Q_{gi}^{t})^2\le S^2_{gi,\max}\quad i=1,2,3,....N_g$
   $P_{gi}^{\min}\le P_{gi}^{t}\le P_{gi}^{\max}$
   $Q_{gi}^{\min}\le Q_{gi}^{t}\le Q_{gi}^{\max}$
2. $\left|P_{ij}^{Line}\right|^{t}<P_{ij,\max}^{Line}$
3. $\mathrm{Tap}_i^{\min}<\mathrm{Tap}_i^{t}<\mathrm{Tap}_i^{\max}\quad i=1,2,3,....N_t$
4. $\mathrm{DOT}_i^{\mathrm{Trans}}\le \mathrm{MADOT}_i^{\mathrm{Trans}}\quad i=1,2,3,....N_t$
5. $\sum_{t=1}^{Nd}\mathrm{U}_{ci}^{t}\le \mathrm{MADOT}_i^{\mathrm{Cap}}\quad i=1,2,3,...,N_c$
6. $\mathrm{Pf}_{\min}\le \mathrm{Pf}^{t}\le \mathrm{Pf}_{\max}$
7. Unbalanced - three - phase - power - flow equations
8. $\mathrm{V}_i^{\min}\le V_i^{t}\le \mathrm{V}_i^{\max}$

where N_c, N_g, N_d and N_t are the number of capacitors, DGs, load variation steps and transformers, respectively. t is an index which represents the time step of load level. $\overline{X}$ is the vector of state variables. $\overline{Tap}$ is the tap vector which represents the tap positions of transformers for the next day. $\overline{Q_G}$ is the DGs reactive power vector including the reactive powers of all DGs for the next day. $\overline{U_C}$ is the capacitors switching vector including the states of all capacitors for the next day. $\overline{P_G}$ is the DGs active power vector including the active powers of all DGs for the next day. Δt_t is the time interval. $\Pr ice^{t}$ is the electrical energy price for the t^{th} load level step. $C_{Pgi}(P^{t}{}_{gi})$ is the cost of electrical energy generated by the i^{th} DG during time "t". V_i^{t} is the current voltage magnitude at the i^{th} bus during time "t". V^{min}_i and V^{max}_i are the minimum and maximum values of voltage at the i^{th} bus, respectively. $MADOT_i^{Trans}$ and $MADOT_i^{Cap}$ are the maximum allowable daily operating times of the i^{th} transformer and capacitor, respectively. $\left|P_{ij}^{Line}\right|^{t}$ and $P_{ij,\max}^{Line}$ are the absolute power flow over distribution lines and maximum transmission power between the nodes i and j, respectively. $Tap_i^{\min}$, $Tap_i^{\max}$ and Tap_i^{t} are the minimum, maximum and current tap positions of the i^{th} transformer, respectively. $Pf_{\min}$, $Pf_{\max}$ and Pf^{t} are the minimum, maximum and current power factor at the substation bus during the time step t. Q_{gi}^{t}, P_{gi}^{t} and $S_{gi,\max}$ are the reactive and active powers for the t^{th} load level step and the apparent power of the i^{th} DGs, respectively. U_{ci}^{t} is the state of the i^{th} capacitor in the light of turning on and off during time "t" ,which equals 0 or 1.

In this problem, it is assumed that tap position of transformers changes stepwise.

III. Honey Bee Mating Optimization

One of the most familiar insects in the world is the honey bee. A colony of honey bees during the active season is composed of a queen, several hundred drones, 30,000 - 80,000 workers and broods in all stages of development. Honey bees are so highly specialized in their functions that no individual bee, even the queen, is capable of establishing a new colony alone. A queen is the only member of a colony capable of laying eggs which are fertilized by spermatozoa. To have a strong colony, there should be exists a prolific queen. She will lay up to 1,500 eggs during a 24-hour period. A young queen normally takes one or more mating flights within 4 to 12 days after emerging from her cell. A queen life time is 6-7 years.

Drones' sole function is to mate with the queen. They live about eight weeks. Only a few hundred - at most - are ever present in the hive. A drone's eyes are noticeably bigger than those of the other castes. This helps them to spot the queens when they are on their nuptial flight. Any drones left at the end of the season are considered non-essential and will be driven out of the hive to die.

Worker bees do all the different tasks needed to maintain and operate the hive. They make up the vast majority of the hive's occupants and they are all sterile females. When young, they are called house bees and work in the hive doing comb construction, rearing brood, tending the queen and drones, cleaning, regulating temperature and defending the hive. Older workers are called field bees. They forage outside the hive to gather nectar, pollen, water and certain sticky plant resins used in hive construction. Workers born early in the season will live about 6 weeks while those born in the fall will live until the following spring. Workers are about 12 mm long and highly specialized for what they do, with a structure called a pollen basket (or corbiculum) on each hind leg, an extra stomach for storing and transporting nectar or honey and four pairs of special glands that secrete beeswax on the underside of their abdomen.

The HBMO Algorithm combines a number of different procedures.

Based on mating process of honey bee, the main stages of HBMO algorithm are given as follow [20]-[21]:

- The algorithm starts with the mating flight, where a queen (best solution) selects drones probabilistically to form the spermatheca (list of drones). A drone then selected from the list randomly for the generation of broods
- Generation of new broods (solutions) with crossover the drone's and the queen's genotypes
- Use of workers (heuristics) to conduct local search on broods (trial solutions)
- Adaptation of worker's fitness, based on the amount of improvement achieved on broods
- Replacement of weaker queens by better broods

Before the process of mating begins, the user has to define a number that corresponds to the queen's size of spermatheca. This number equals to the maximum number of mating of the queen in a single mating flight. The queen mates with all of drones' genotype in its spermatica and each time the queen mates successfully, the genotype of the drone is stored. Two other parameters have to be defined, the number of queens and the number of broods that will be born by all queens. In this implementation of HBMO algorithm, the number of queens is set equal to be one, because in the real life only one queen will survive in a hive, and the number of broods is set equal to the number of the queen's spermatheca size. Then, we are ready to begin the mating flight of the queen. At the start of the flight, the queen is initialized with some energy content and returns to her nest when her energy is as minimum threshold level higher than zero or its spermatica is full [20]-[21]. A drone mates with a queen probabilistically using an annealing function as follows (Haddad et all, 2007):

$$Prob(D) = exp(-\Delta(f)/S(t)) \quad (2)$$

where *Prob(D)* is the probability of adding the sperm of drone *D* to the spermatheca of the queen (that is, the probability of a successful mating), *Δ(f)* is the absolute difference between the fitness of *D* and the fitness of the queen (for complete description of the calculation of the fitness function see below) and *S(t)* is the speed of the queen at time *t*. The probability of mating is high when the queen is with the high speed level, or when the fitness of the drone is as good as the queen's. After each transition in space, the queen's speed and energy decrease according to the following equations:

$$S(t+1) = \alpha \times S(t) \quad (3)$$

$$Energy(t+1) = \alpha \times Energy(t) \quad (4)$$

where α is a factor ∈ (0,1) and is the amount of speed and energy reduction after each transition and each step. Initially, the speed and the energy of the queen are generated at random. A number of mating flights are realized. At the start of a mating flight drones are generated randomly and the queen selects a drone using the probabilistic rule in Eq. 11. If the mating is successful (i.e., the drone passes the probabilistic decision rule), the drone's sperm is stored in the queen's spermatheca. By using the crossover of the drone's and the queen's genotypes, a new brood (trial solution) is generated, which can be improved later by employing workers to conduct local search. One of the major differences of the HBMO algorithm from the classic evolutionary algorithms is that since the queen stores a number of different drone's sperm in her spermatheca, she can use parts of the genotype of different drones to create a new solution which gives the possibility to have fittest broods more. In real life, the role of the workers is restricted to brood care and for this reason the workers are not separate members of the population and they are used as local search procedures in order to improve the broods produced by the mating flight of the queen. Each of the workers has different capabilities and the choice of two different workers may produce different solutions. This is realized with the use of a number of single local search heuristics ($N_{Worker1}$) and combinations of them ($N_{worker2}$). Thus, the sum of these two numbers ($N_{Worker} = N_{Worker1} + N_{worker2}$) gives the number of workers. Each of the broods is randomly chosen to be feed by worker, which is also randomly selected. If the new brood is better than the current queen, it takes the place of the queen. If the brood fails to replace the queen, then in the next mating flight of the queen this brood will be one of the drones.

IV. Distributed Generation Modeling

DGs are the electric energy resources connected to the distribution network. Since DGs are connected close to the loads, they can increase the power quality and reliability from the customers' perspective and help the utilities to face the load growth delaying the upgrade of distribution/transmission lines. In addition to that, small generating systems require limited capital investments and reduced authorizations to be installed. Also, DGs using renewable energies are often encouraged and financially supported thanks to their low environmental impact [17]-[20].

Generally, DGs in distribution networks can be modeled as a PV or a PQ model. Since distribution networks are unbalanced three phase systems, DGs can be controlled and operated in two forms:

- Simultaneous three phases control
- Independent three phases control or single phase control

Therefore, with regard to the control methods and DGs models, four models can be defined for the simulation of these generators:

- PQ model with simultaneous three-phase control (Fig.1.a)
- PV model with simultaneous three-phase control (Fig.1.c)
- PQ model with independent three-phase control (Fig.1.b)
- PV model with independent three-phase control (Fig.1.d)

It must be taken into account that when DGs are considered as the PV models, they have to be able to generate reactive power to maintain their voltage magnitudes. Many researchers have presented several procedures to model DGs as the PV buses [17]-[20]. Fig.1 shows model of DGs based on the type of their control. In this paper, DGs are modeled as the PQ model with simultaneous three-phase control (Fig.1.a).

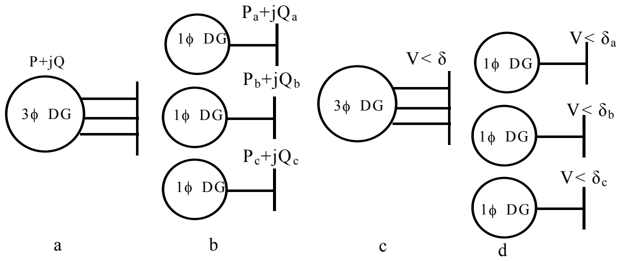

Fig.1. Models of DGs
(a). PQ Model with simultaneous three-phase control
(b). PQ Model with separately three- phase control
(c). PV Model with independent three- phase control
(d). PV Model with independent three- phase control

V. Simulation

In this part, the proposed optimization algorithm has been implemented to solve daily Volt/Var control on an IEEE 34 bus distribution system. Fig.2 shows a single-line diagram of this network whose associated specifications are presented in

[20]. It is assumed that there are 6 generators whose specifications are given in Table I. Daily energy price variations are shown in Fig.3. In this paper, it is supposed that the maximum numbers of switching operations for capacitors along the feeder and at the substation bus (main station) are 1 and 3, respectively. Also, it is assumed that the transformers and VRs have 21 tap positions ([-10, -9… 0,1,2…10]) and the MADOT of them in a day is 30. They can change voltage from –5% to +5%. Capacitors characteristics are in Table II.
Table III presents a comparison among the results of HBMO, PSO, DE, TS and GA for 300 random tails.

TABLE I
CHARACTERISTIC OF DISTRIBUTED GENERATIONS]

	Capacity (kW)	Price ($/kWh)	location	Power factor
G1	500	0.04	8	0.9 lag to 0.9 lead
G2	500	0.04	14	0.9 lag to 0.9 lead
G3	500	0.04	21	0.9 lag to 0.9 lead
G4	500	0.04	27	0.9 lag to 0.9 lead
G5	500	0.04	38	0.9 lag to 0.9 lead
G6	500	0.04	42	0.9 lag to 0.9 lead
G7	500	0.04	59	0.9 lag to 0.9 lead
G8	500	0.04	62	0.9 lag to 0.9 lead

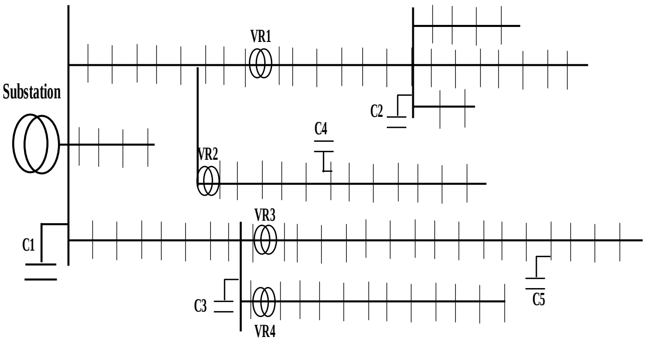

Fig.2 a single line diagram of 80-bus test system

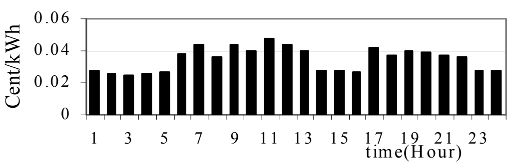

Fig.3. Daily energy price variations

Fig.4 shows daily load variations.

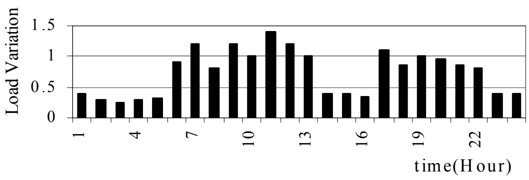

Fig.4. Daily load variations

Table II
Characteristics of Capacitors

Capacitor Number	Location (bus No)	Size (kVar)
C_{Sub1}	1	600
C_{Sub2}	70	600
C_1	5	500
C_2	28	500
C_3	35	500
C_4	55	500

Table III
Comparison of Average and Standard Deviation for 300 Trails

Method	Average	Standard Deviation	Best solution	Worst solution
HBMO	2444.1	20.13	2421.2	2466.92
ACO	2536.23	150.2	2421.2	2695.94
PSO	3001.52	190.36	2890.84	3195.75
TS	2978.64	162.74	2834.91	3160.47
DE	2967.17	160.43	2838.17	3158.64
GA	2979.64	163.47	2830.75	3150.74

The power factor variation at substation and the voltage changes of some buses are shown in Figs.5, 6, 7 and 8.

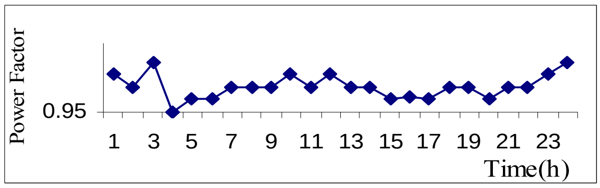

Fig5.Power factor variations at substation bus over a day

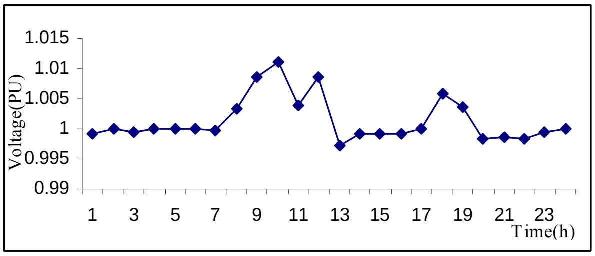

Fig.6. Voltage variations of bus29 over a day

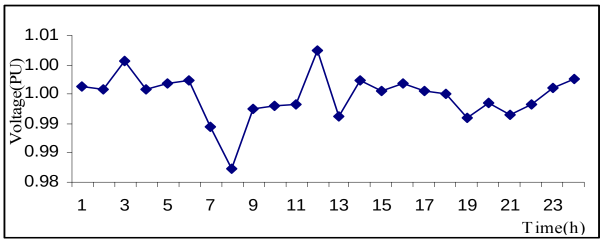

Fig.7. Voltage variations of bus50 over a day

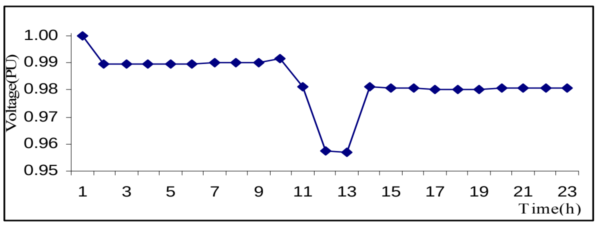

Fig.8. Voltage variations of bus60 over a day

Table IV presents the simulation results in terms of the number of capacitors' allowable switching operations. A unity power factor is considered when DG is uncontrolled.

Table IV
Influence of Maximum Allowable Switching Operation of Capacitors

Maximum number of allowable switching operation	The proposed in paper	Infinite
Energy Losses (kWh) (DG is controllable)	850.64	848.96
Energy Losses (kWh) (DG is Uncontrollable)	1450.36	1084.19

The average computing time for the method is ~7min running on a P4 1.8 GHz/512MB RAM.

The results of the tables and figures show that The HBMO method is very precise. In other words, not only does this method reach a much better optimal solution in comparison with others, but also the standard deviation for different trails is very small. Since most of DGs have private ownership, the price of active power generation can be used as an encouraging signal. The voltage magnitude at each bus is in the desire limits. The power factor at the substation bus is in the desire limits for all of hours in a day

VI. Conclusion

Distributed Generation is being widely accepted as a new paradigm in electric power industry. Due to the small X/R ratio of distribution lines, the impact of DG units on the system loss and voltage profile can be significant and should be accounted for. This paper presents a novel price-based dispatching algorithm for the daily Volt/VAr control of a distribution system with DG units, to maintain the voltage profile, power factors of substation buses and minimize the overall system costs. A HBMO algorithm has proposed as an effective optimization method to find the minimum value of an objective function. Simulation results show the effectiveness of the proposed dispatching algorithm in reducing the power losses, maintaining the voltage profile, and satisfying operational constraints.

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VIII. Biographies

Taher Niknam was born in Shiraz, Iran. He received his B.S, M.S and PhD degrees from Shiraz University and Sharif University of Technology respectively. He is a member of faculty at the electrical engineering department of Shiraz University of Technology. His interests include power system restructuring, impact of DGs on power system, power electronics, optimization methods, and evolutionary algorithms.

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