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Congestion Management in Power Systems Via Intelligent Method

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Abstract

In the deregulated power systems, transmission congestion is one of the significant and main problems of the electrical networks which can cause incremental cost in the energy. This problem has resulted to new challenging issues in different parts of power systems which there was not in the traditional systems or at least had very little importance. Transmission congestion happens when the maximum available power transmission capacity is lower than the consumption side. As congestion happens, the system power losses are increased which can cause problem in the voltage constraints. Therefore, this paper proposes a new method to handle the optimal management and control of congestion problem by the use of distributed generations (DGs). In this regard, the optimal size and location of DGs are investigated using the powerful bacteria foraging algorithm (BFA) as a new intelligence-based optimization technique to solve the congestion problem on the three IEEE 14-bus, 30-bus and 57-bus test systems. The simulation results show the high speed, fast convergence and accurate performance of the proposed algorithm to solve the congestion problem in the system.

Keywords: Bactria foraging algorithm, Power losses, Congestion management, Distributed generations (DGs).

1. Introduction

Nowadays, as the result of recent growths in the electrical power consumption part, deregulation and movement of power systems from traditional structure to the competitive environment (electricity market) and economical and environmental problems associated with the large power stations, DGs have found a significant role in the new power systems. According to the recent report by CIGRE, the amounts of power produced by DGs in the Denmark and Netherlands are 37% and 40%, respectively. Recently, the DG usage is widely increased which along with their many benefits, releasing the power market in Europe is one of the main reasons of its popularity. It is predicted that after Kyoto contract among all countries to support the green energy, the utilization of these kinds of power sources to produce electrical power would be increased more than before. However, the key issue is that utilization of DGs in any circumstances cannot yield suitable results. The wrong allocation and sizing of DGs can increase the total power losses in the system. the congestion management in the power system is investigated by the genetic algorithm (GA) [1]. wind turbines (WTs) are utilized to solve the congestion problem in the system operation[2]-[3]. the particle swarm optimization (PSO) algorithm is used to handle the complex and sophisticated congestion problem with the purpose of cost minimization, suitably[4]. the power sensitivity to the line reactance is employed as a criterion to reduce the congestion in the system [5]. TCSC and SVC are utilized to increase the security margin and congestion concurrently in [6]. In the area of long term planning, the instruction of new power stations as well as transmission system planning are proposed as proper methods to solve the congestion problem [7]. Since the operational cost minimization considering the congestion is a complex problem. PSO algorithm as a powerful optimization technique is utilized [8]. Congestion management in the transmission system considering the network voltage security is investigated in [9]. the DG sizing and allocation is implemented using LMP and MIP [10].

2. Explaining DG definition

Distributed generation (DG) is generally defined as power production locally at the consumption place but sometimes it is defined as technologies which include the renewable power sources. The most general aspect of DGs is that neglecting the process of power production, the capacities of DGs are small and are connected to the network directly. According to the international energy agency (IEA), DG is defin ed as the power source which supplies the consumer energy on-site and help network in electrical power services. From GIGRE point view, DG is a power source which has the bellow characteristics: is not constructed centralized, its dispatching is not implemented centralized, its size is usually lower that 50 MW to 100 MW. Considering DGs in the power system can have many benefits such as high power quality, voltage profile enhancement, loss reduction, reducing peak load shedding, increasing the system reliability, reducing THD and line congestion minimization. In addition to the above mentioned benefits, the small size of these kinds of power sources makes it possible to install it in a very short time at the specific place. Distributed generations can be divided into 4 main types:

The first type can just produce and supply active power which photovoltaics belong to this category. Photovoltaics just produce active power which enters directly to the battery to be stored. Therefore, it can just produce active power.

The second type can just produce reactive power. Synchronous condensers belong to this category. Synchronous condenser is a synchronous machine which works at no-load. It is connected to the network to improve its condition by producing or consuming reactive power through exciting control.

The third type can produce both of active and reactive components. WTs are in this category which gets use of induction motors to produce electricity. Gas turbines and diesel generators are other examples of this group.

The forth type is bus voltage regulator. Here, the DG unit along with the active power, it can produce or consume reactive power to regulate buts voltage in the system.

This paper gets use of the third type which can produce both of active and reactive powers.

3. Congestion definition and its roots

Congestion in definition means to employ the transmission system over the determined operational limitations. In other words, when the sudden changes in the output power generation of at least one generator in the network, transmission line disruption or load increase cause malfunction in the operation of the power system, the network would experience congestion.

4. Objective function and the constraints

The objective function and the relevant constraints are shown below:

The congestion in a line is evaluated as follows:

$$Congestion\ in\ per\ line = \frac{P'_{ij}}{P_{ij}} \tag{1}$$

Where P'_{ij} is the power flow between the two buses of i and j and P_{ij} is the power flow between the two buses of i and j. The objective function of the problem is then formulated as follows:

$$objective\ function = \left\| \frac{P'_{ij}}{P_{ij}} \right\|_{\infty} \tag{2}$$

Also, the power loss after using DG in the system is reduced. The voltage and power constraints are shown from Eq. 2 to Eq. 7 as follows:

$$V_{i_{\min}} \le V_i \le V_{i_{mzx}} \tag{2}$$

$$Q_{DG_{\min}} \le Q_{DG} \le Q_{DG_{\max}} \tag{3}$$

$$P_{DG_{\min}} \le P_{DG} \le P_{DG_{\max}} \tag{4}$$

$$Q_{g_{i\min}} \le Q_{gi} \le Q_{g_{i\max}} \tag{5}$$

$$P_{g_{i\min}} \le P_{gi} \le P_{g_{i\max}} \tag{6}$$

$$P_{loss} = \sum_{line(i,j)=1}^{m} P_{line(i,j)} \tag{7}$$

Where V_i is the voltage of i^{th} bus; Q_{gi} and P_{gi} are the reactive and active power produced at i^{th} bus; Q_{DG} and P_{DG} are the active and reactive power produced by

DG; $P_{line(i.j)}$ and $P_{line(i.j)_{\max}}$ are the active power flow between i^{th} and j^{th} bus and the maximum active power flow between i^{th} and j^{th} respectively and P_{loss} is the power loss.

4.1. The proposed method

In this paper, a new method is proposed to handle the management and control of congestion problem as well as to find the optimal place and size of DGs using bacteria foraging algorithm (BFA). The simulations are implemented in the MATLAB software to minimize the objective function.

5. Bactria Foraging Algorithm (BFA)

Natural selection tends to eliminate animals with poor foraging strategies and favor the propagation of genes of those animals that have successful foraging strategies. The Escherichia coli (E. coli) bacteria that are present in our intestines, also undergo this foraging strategies. The social foraging behaviour of E. coli bacteria has been used to solve optimization problems. The optimization in BFA comprises the following process: chemotaxis, swarming, reproduction, elimination and dispersal. The chemotaxis is the activity that bacteria gathering to nutrient-rich area naturally. The characteristic of E. coli bacteria is: the diameter is 1μm, the length is 2μm, under appropriate conditions can reproduce (split) in 20 min. The move of the E. coli is done with flagellum [16]. An E. coli bacterium alternates between running and tumbling.

5.1. Chemotaxis step

The process in the control system is achieved through Swimming and tumbling via flagellum. To represent a tumble, a unit length random direction, Say $\varphi(j)$, this will be used to define the direction of movement after a tumble, then:

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\varphi(j)$$

Where $\theta^i(j,k,l)$ is the position of the ith bacterium at jth chemotaxis step, kth reproduction step and lth elimination and dispersal step. $C(i)$ is the size of step taken in the random direction that specified by the tumble (run length unit). If the new position of bacterium $\theta^i(j+1,k,l)$ is better than the old position, then the bacterium will keep taking successive step in that direction. The number of iteration chemotaxis step is NC. And the maximum number of permissible successive steps is Ns.

5.2. Swarming step

The bacteria in times of stresses release attractants to signal bacteria to swarm together. It however also releases a repellant to signal others to be at a minimum distance from it. Thus all of them will have a cell to cell attraction via attractant and cell to cell repulsion via repellant. The mathematical representation for swarming can be represented by:

$$J_{cc}(\theta) = \sum_{i=1}^{s} J_{cc}^{i}(\theta) =$$
$$\sum_{i=1}^{s}\left[-d_{attract}\, exp\left(-w_{attract}\sum_{j=1}^{p}\left(\theta_j-\theta_j^i\right)^2\right)\right] +$$
$$\sum_{i=1}^{s}\left[-d_{repellant}\, exp\left(-w_{repellant}\sum_{j=1}^{p}\left(\theta_j-\theta_j^i\right)^2\right)\right]$$

Where :

$d_{attract}$: depth of the attractant
$w_{attract}$: measure of the width of the attractant
$h_{repellant}$: height of the repellant effect
$w_{repellant}$: measure of the width of the repellant
p: number of parameters to be optimized
S : total number of bacteria
J_{cc}: the cost function to be added to the actual cost function to be minimized, to present a time varying cost function.

5.3. Reproduction

After NC chemotaxis step, a reproductive step is occurs. The fitness of bacteria is calculated, that is, during all chemotaxis steps:

$$J_{health} = \sum_{j=1}^{NC} J(i,j,k,l)$$

Then this fitness is sorted in ascending order. The least healthy bacteria die and the other bacteria, each bacterium split into two bacteria, thus the size of the population is constant.

5.4. Elimination and Dispersal:

The chemotaxis step provides a basis for local search, and the productive step speeds the convergence. While to a large extent, only chemotaxis and reproduction are not enough for global optima searching. Then an elimination and dispersal event is necessary.

For each elimination and dispersal event each bacterium is eliminated with a probability P_{ed}, and dispersed them to a new environment. The selection of P_{ed}, play an important role in convergence of the algorithm.

If P_{ed} is large, the algorithm can degrade to random exhaustive search. If however, it is chosen appropriately, it can help the algorithm jump out of local optima and into a global optimum.

5.5. Pseudo code for BFA:

```
[step1]: Initialization
1. p: number of parameter that be optimized
2. S: the total number of bacteria
3. NC, Nre, Ned: the number of chemotaxis steps, the number of reproduction steps, the number of elimination and dispersal events, respectively.
4. Ns: the maximum number of permissible successive steps
5. The values of : $d_{attract}$, $w_{attract}$, $h_{repellant}$, $w_{repellant}$
6. $P_{ed}$: the probability of elimination and dispersal event
7. C(i) : the step size
[step2]: Elimination and dispersal loop: l=l+1
[step3]: Reproduction loop: k=k+1
[step4]: chemotaxis loop: j=j+1
    [a]. for i = 1,2,…,N take a chemotaxis step for each bacterium i as follows:
    [b]. compute fitness function, $J(i,j,k,l)$
    Let
    $J(i,j,k,l) = J(i,j,k,l) + J_{cc}$
    [c]. let $J_{last} = J(i,j,k,l)$ to save this value since we may find a better cost via a run.
    [d]. Tumble: generate a random vector $\Delta(i)$ that $1 \leq \Delta(i) \leq -1$
    [e]. Move: Let
    $\theta^{i}(j+1,k,l) = \theta^{i}(j,k,l) + c(i)\frac{\Delta(i)}{\sqrt{\Delta^{T}(i)\Delta(i)}}$
    [f]. compute J(i,j+1,k,l) and let
    $J(i,j,k,l) = J(i,j,k,l) + J_{cc}$
    [g]. swim
    i) Let m = 0(counter for swim length)
    ii) While $m<N_s$
        ● Let m=m+1
        ● If J(i,j+1,k,l) < $J_{last}$ (if doing better), Let $J_{last}$=J(i,j+1,k,l) and
        $\theta^{i}(j+1,k,l) = \theta^{i}(j,k,l) + c(i)\frac{\Delta(i)}{\sqrt{\Delta^{T}(i)\Delta(i)}}$
        ● Else let m = $N_s$
    [h]. Go to next bacterium (i+1) if $i \neq N$
[step5]. If j<NC, go to step 3.
[step6]. Reproduction
    [a]. for the given k and l, and for each i = 1,2,…,N , Let
    $J^{i}_{health} = \sum_{i=1}^{NC+1} J(i,j,k,l)$
Sort this fitness in order of ascending.
    [b]. The Sr bacteria with the highest $J_{health}$ values die, the remaining Sr bacteria with the best values split
[step7]. If k < Nre, go to step 3.
[step8]. Elimination and dispersal
    For i=1,2,…,N, with probability $P_{ed}$, eliminate and disperse each bacterium, and this result in keeping the number of bacteria in the population constant.
    To do this, if a bacterium is eliminated, simply one to a random location on the optimization domain.
If l< Ned, then go to step 2; otherwise END.
```

6. Simulation Results

The proposed method to solve the congestion problem as well as to find the optimal place and size of DGs is based on BFA. The 14-bus, 30-bus and 57-bus IEEE test systems are utilized to examine the method. The complete network data can be found in [11]. The network diagrams of the 14-bus, 30-bus and 57-bus IEEE test systems are shown in the appendix. The 14-bus test system has 20 lines, 5 generators, 11 loads; the 30-bus test system has 41 lines, 6 generators, 20 loads and the 57-bus test system has 80 lines, 7 generators, 42 loads. The output active and reactive powers for DGs are supposed to be in the range of 5 MW to 50 MW and -5 MVar to 10 MVar, respectively. This limitation belongs the DGs with the type of gas turbine. At first, one DG is placed in the system and the results are investigated. Then 2 and 3 DGs are placed and the results are again checked. If the power flow in a line is more than 80% of its nominal capacity it is supposed to be in congestion. In the 14-bus IEEE test system, line 1 (between buses 1-2) has the most congestion with the value of 82.5% (evaluated by Eq. 1). In Eq. 6, the nominal capacity of line 6 is 190 MW which after load flow it is 156.8338 MW. According to Eq. 6, since the value of 82.5% is more than 80% as the criterion, line 1 is passing power more than its capacity and is supposed to be in congestion. In the 30-bus test system, a 5% increase in the loads would cause line 10 (line between the two buses of 6 and 8) to experience congestion with the value of 82.23% which is calculated in Eq. 7. Eq. 8 is for the 57-bus test system. In Eq. 7, the nominal power of line 10 is supposed to be 32 MW which after load flow it carries 26.31 MW which means 82.23 % or congestion situation. Similar analysis is implemented for the other lines. In the 57-bus test system, all loads are increased 8 % and the nominal power flow for all lines is supposed as 225 MW. In this situation, the system is in congestion and line 15 has the maximum congestion by 82.88% which is shown in Eq. 8. In Eq. 8, the nominal capacity of the line 15 (between the buses 1 and 15) is supposed 225 MW which after load flow the power flow of this line is 186.49 MW. According to Eq. 8, since the value of 82.88% is more than 80% so line 15 is in congestion. Now, it is time to get use of DG and BFA to solve the congestion problem in the network. After that the algorithm searching process is finished, three values indicating the bus number, the active power value and the reactive power value are shown in the output. The results are shown in Table.1. Fig.1 shows the parameter convergence. The algorithm parameters are shown in appendix.

Congestion in line number 1 = $\frac{156.8338}{190}\times 100 = 82.54\%$ (6)

Congestion in line number 10 = $\frac{26.31}{32}\times 100 = 82.23\%$ (7)

Congestion in line number 15 = $\frac{186.49}{225}\times 100 = 82.88\%$ (8)

According to the equation 6,7 and 8, there are 2.54%, 2.23% and 2.88% congestion in the 14-bus, 30-bus and 57-bus test systems, respectively. This congestion is as the result of malfunction process in the network. If this congestion is not solved in a short time, it will disconnect the congestion line. If the problem is not solved again, it will disconnect the other lines too. This process will continue to result in islanding. In this paper, the congestion problem is detected at the first moments and therefore, the system would be kept safe. Table.2 shows the results of running the algorithm for the 14-bus, 30-bus and 57-bus test systems. Table.1 shows the system power losses before and after using DG in the system. In Table.2, for the 14-bus test system 2 DGs are allocated, for the 30-bus test system 3 DGs are allocated and for 57-bus test system 1 DG is allocated.

Table.1.
Power losses before and after using DG

Case study	Power losses before using DG		Power losses after using one DG		Power losses after using two DGs		Power losses after using three DGs	
	Ploss (MW)	Qloss (MVAR)	Ploss (MW)	Qloss (MVAR)	Ploss (MW)	Qloss (MVAR)	Ploss (MW)	Qloss (MVAR)
14-bus	13.386	54.5	8.631	37.65	5.728	24.33		
30-bus	2.736	9.91	2.308	8.37	2.144	8.42	1.79	8.08
57-bus	37.982	162.46	32.269	139.75				

Table.2.
Result of running the algorithm

Case study	Bus No	DG size (MW)	DG size (MVAR)	Bus No	DG size (MW)	DG size (MVAR)	Bus No	DG size (MW)	DG size (MVAR)
14-bus	4	49.9936	-2.3454						
	4	49.9668	8.8779	7	49.8469	-1.9678			
30-bus	8	8.8628	8.4203						
	20	37.3178	-4.9999	8	39.7890	2.3887			
	20	37.6641	1.5029	9	17.2353	7.1493	21	10.2001	8.0210
57-bus	11	49.3051	8.7475						

According to the Table.1, the active and reactive power losses in presence of DG are reduced which the amount of reduction by increasing the number of DGs is notable. For example, in the 30-bus test system by the use of 1 DG, the active power loss is reduced from 2.736 MW to 2.308 MW and by the use of 2 DGs it has reached to 2 DGs and after using 3 DGs it has reached to 1.79 MW. The convergence diagrams of the algorithm for 14-bus, 30-bus and 57-bus test systems are shown in Figs. 1-6.

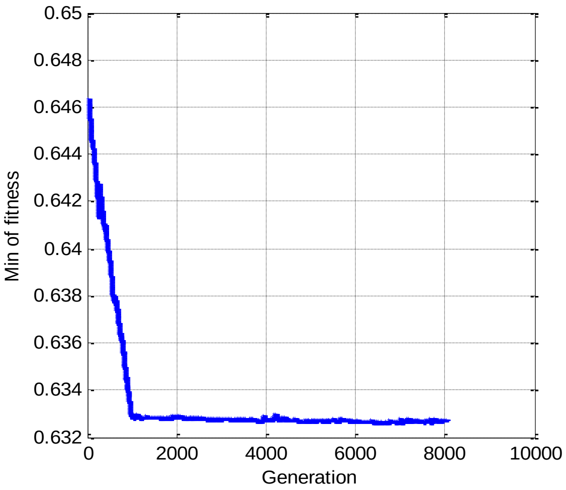

Fig.1. The convergence speed of the algorithm after using 1 DG (14-bus IEEE test system)

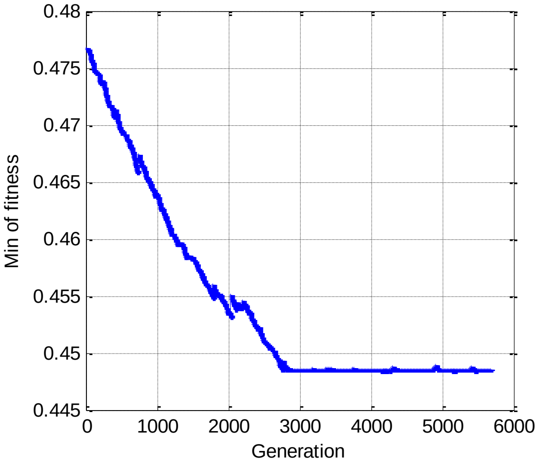

Fig.2. The convergence speed of the algorithm after using 2 DGs (14-bus IEEE test system)

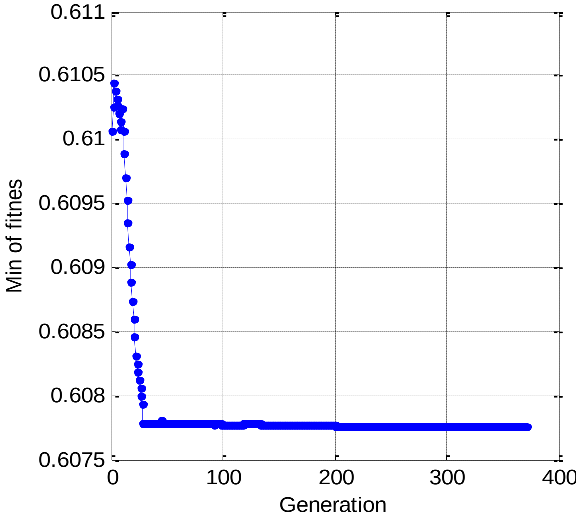

Fig.3. The convergence speed of the algorithm after using 1 DG (30-bus IEEE test system)

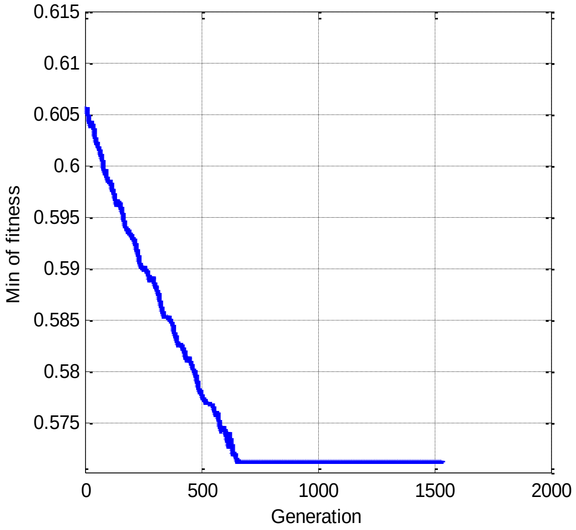

Fig.4. The convergence speed of the algorithm after using 2 DGs (30-bus IEEE test system)

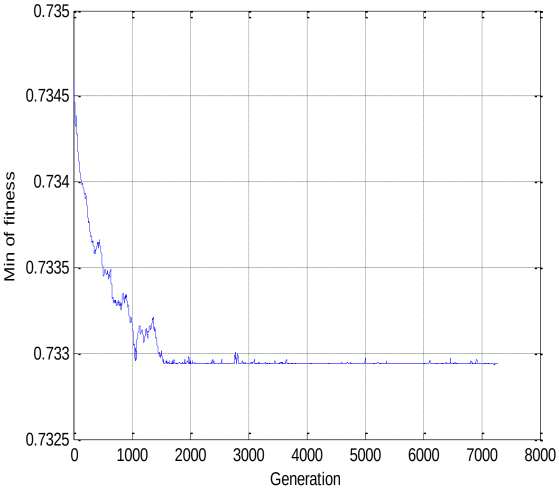

Fig.5. The convergence speed of the algorithm after using 3 DGs (30-bus IEEE test system)

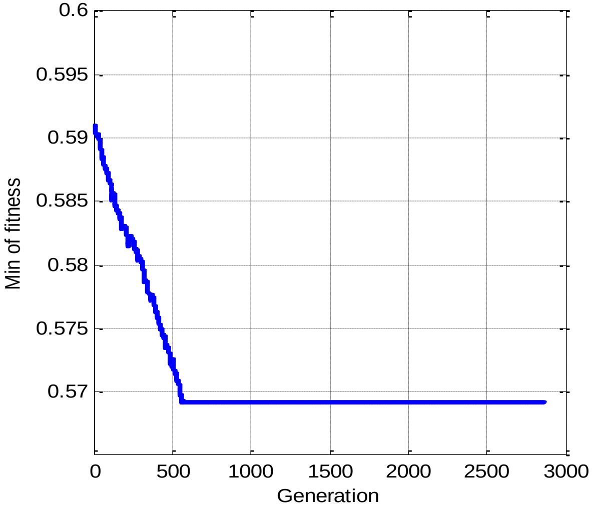

Fig.6. The convergence speed of the algorithm after using 1DG (57-bus IEEE test system)

After using DG in the 14-bus, 30-bus and 57-bus test systems, the congestion in the lines as well as the total power losses are reduced. The results of congestion for the lines with the most congestion value are shown in Table.3.

Table.3.
The results of Congestion

Case study	Congestion value in the line before using DG	Congestion value in the line after using one DG	Congestion value in the line after using two DGs	Congestion value in the line after using three DGs
14-bus	82.54%	63.22%	44.8%	
30-bus	82.23%	58.12%	27.75%	32.59%
57-bus	82.88%	73.18%		

As it can be seen from Table.3, the amount of congestion for the 14-bus system in the line 1 has been 82.54 % which after using 1 DG it is reduced to 63.22% value and by using 2 DGs it is reduced to 44.80% value. In the 30-bus test system, the most congestion is for line 10 with the value of 82.23% which after using 1 DG it is reduced to 58.12% value and by using 2 DGs it is reduced to 27.75% value and after using 3 DGs it is reduced to 32.59% value. In the 57-bus test system, the line 15 the most congestion is for line 15 with the value of 82.88% which by the use of 1 DG has reached to the value of 73.18%. Figs. 7 to 12 show the amount of congestion reduction in all lines of 14-bus, 30-bus and 57-bus test systems after using DGs.

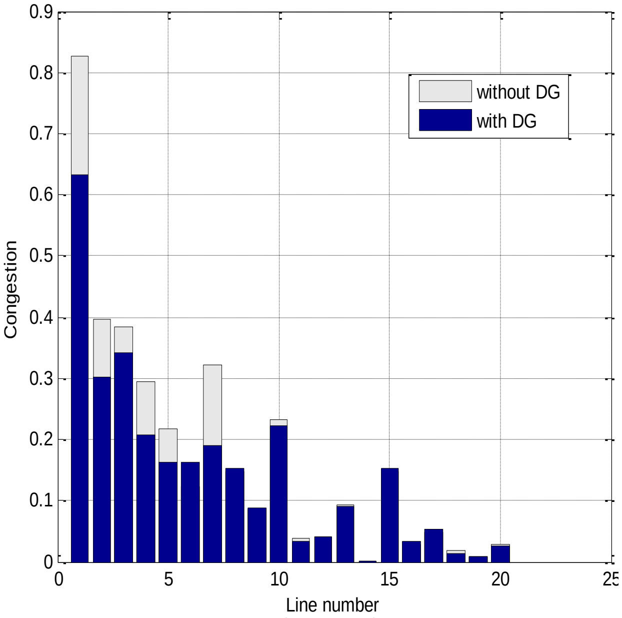

Fig.7. The congestion amount before and after using one DG in the 14-bus test system

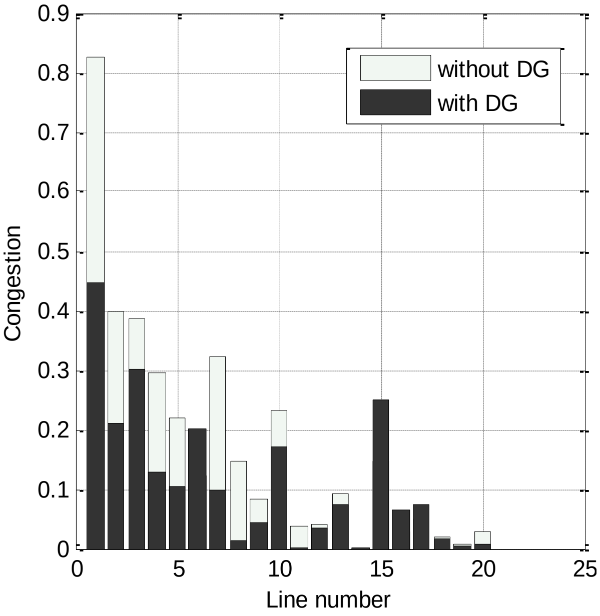

Fig.8. The congestion amount before and after using two DGs in the 14-bus test system

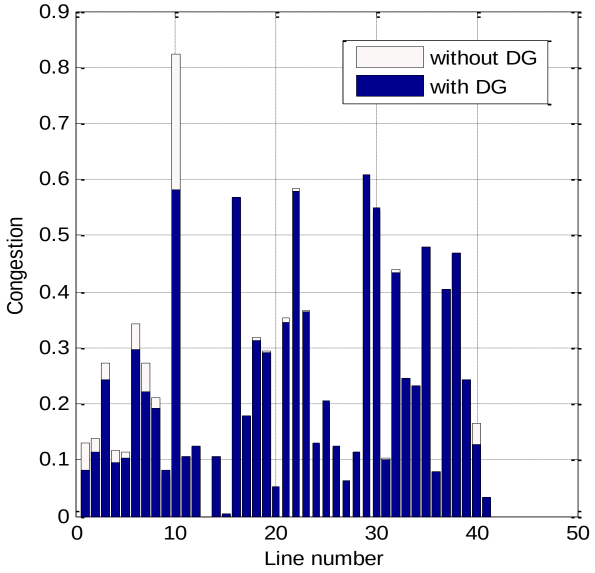

Fig.9. The congestion amount before and after using one DG in the 30-bus test system

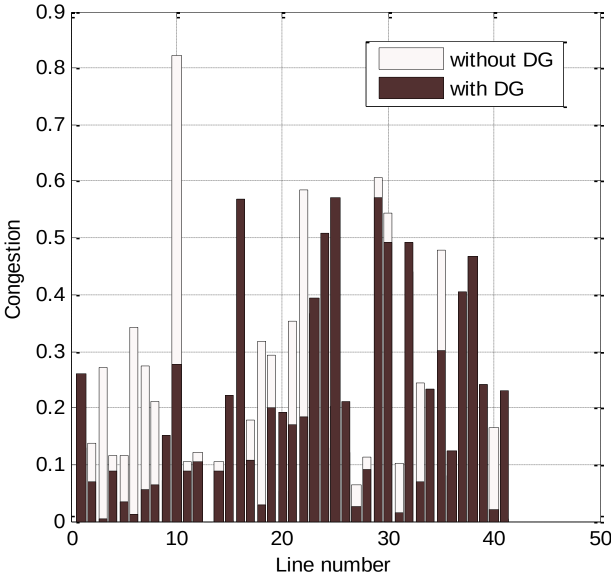

Fig.10. The congestion amount before and after using two DGs in the 30-bus test system

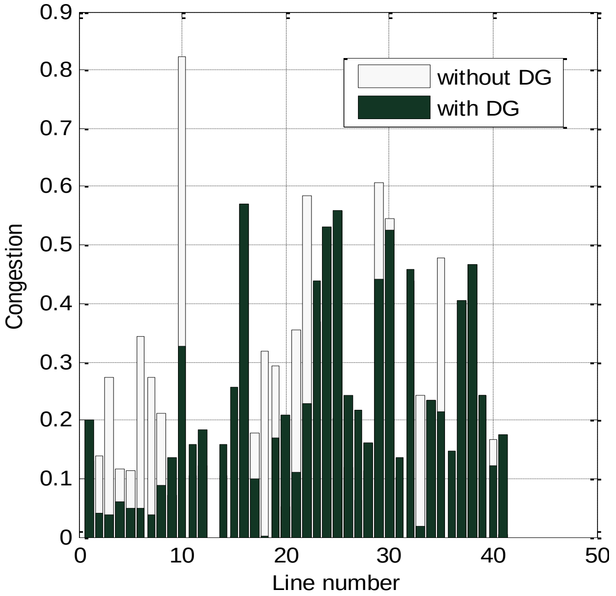

Fig.11. The congestion amount before and after using three DGs in the 30-bus test system

According to the Table.2 which shows the optimal place and size of DG in the system as well as Figs. 7 to 12, when the number of DGs is increased, the congestion is managed and controlled more suitably. Also, as shown in Table.2, the amount of power losses in the system is reduced by increasing the number of DGs. Fig.7 shows the congestion value before and after using DG in the system. As it can be seen from Fig.7, line 1 experiences the most congestion reduction. However, by the use of 2 DGs, the amount of congestion reduction is more which can be seen in Fig.8. Fig.9 shows the amount of congestion reduction after using 1 DG in the 30-bus test system which the most reduction has happened for line 10. Fig.10 shows the amount of congestion before and after using 2 DGs in the 30-bus test system which in comparison to Fig.9 has reached to better values. Also, Fig.11 shows the amount of congestion before and after using 3 DGs in the 30-bus test system which shows better values in comparison to Figs.9 and 10. Fig.12 shows the congestion value before and after using 1 DG in the 57-bus test system. As it can be seen from Fig.12, the best congestion reduction has been for line 15. It is worth to note that if DG allocation is not implemented truly, the network will experience high power losses, high congestion in the lines, low reliability, etc. In this paper, with the aid of BFA we could reach the best optimal values from both of locating and sizing points of view.

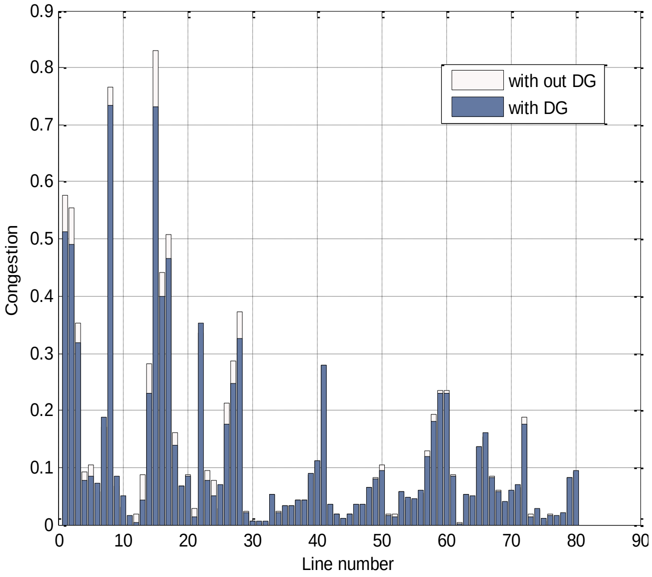

Fig.12. The congestion amount before and after using one DG in the 57-bus test system

7. Conclusion

In the power systems, as the result of different reasons such as permitted voltage drop and limitations associated with different stabilities, the system operation is not implemented in the full capacity of the transmission lines. This event will causes that the power flow capacity limit of the transmission lines would be lower than their maximum values or their maximum temperature limits which would result to power losses and congestion in the lines. In this paper, we employed DGs with the capability of producing both active and reactive powers to achieve the optimal management and control of congestion problem using the bacteria foraging algorithm. The proposed method was tested on the 14-bus, 30-bus and 57-bus IEEE test systems as the case studies. The algorithm by finding the optimal place and size of DGs could reach to the main purposes of the paper, precisely. The simulation results show the accuracy and feasibility of the proposed method.

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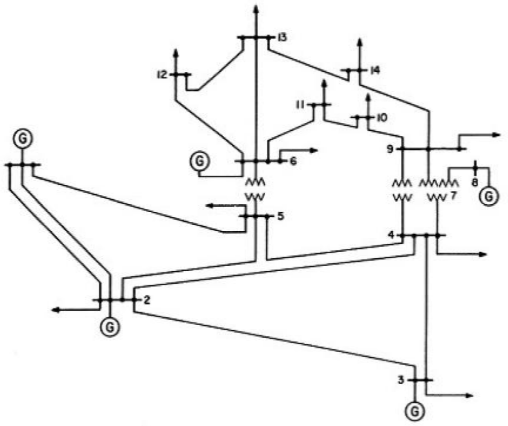
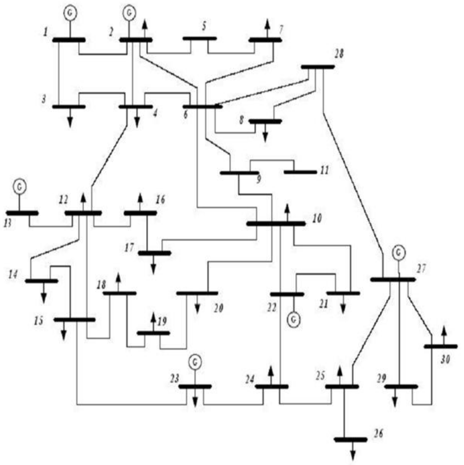
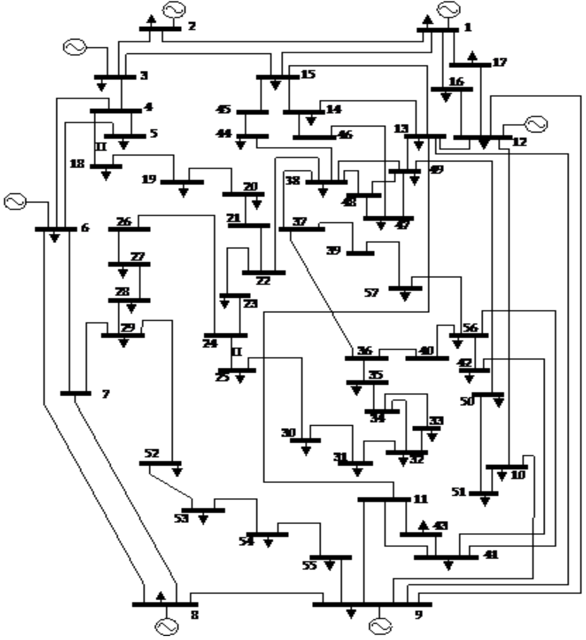
Appendix



14-bus IEEE test system



30-bus IEEE test system



57-bus IEEE test system

Table.4
Algorithm parameters

Case study	No. DG	S	Ns	Nc	Nre	Nel	Pe
14-bus	1-DG	16	10	80	8	10	0.25
	2-DG	16	15	80	6	9	0.25
30-bus	1-DG	14	6	30	2	3	0.25
	2-DG	22	8	50	4	5	0.25
	3-DG	20	9	50	6	7	0.25
57-bus	1-DG	38	12	90	7	9	0.25