Indian Journal of Science and Technology, *Vol 8(35), DOI: 10.17485/ijst/2015/v8i35/77480, December 2015*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Coordinated Reconfiguration and Voltage Control for Increasing the Allowable Distributed Generation Penetration using Modified Binary Particle Swarm Optimization

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Abstract

Background/Objectives: Several advantages of Distributed Generation (DG) have created incentives to increase DG penetration in distribution networks. In order to meet this requirement, Coordinated Reconfiguration and Voltage Control (CRVC) is used in this paper. **Methods:** To do so, simulations are done in two parts. In the first part, the power loss of a distribution system is decreased through CRVC, and in the second part, DG allowable capacity is increased through CRVC. In order to decrease the computational time for finding the best network configuration and voltage control devices values, modified Binary Particle Swarm Optimization (BPSO) is used. The method has been tested on a 33-bus radial distribution system. **Findings and Improvements:** Simulation results in both two parts show the efficiency of the method. In the first part, CRVC method could decrease power loss 33%. In the second part, the DG allowable penetration is increased 140% thorough CRVC. This shows that this method is more robust than various techniques that have been proposed to increase DG allowable capacity in the past. Moreover, without using complex voltage control methods, CRVC improved the voltage of all busses considerably. Furthermore, simulations verified the decrease in computational time for reconfiguration which is an important challenge in using reconfiguration.

Keywords: Binary Partcile Swarm Optimization, Distributed Generation, Loss Reduction, Reconfiguration, Voltage Control

1. Introduction

Despite positive effects of Distribution Generation (DG), currently, the penetration level of DG sources in many networks is limited due to operational constraints of actual networks. Consequently, various methods should be used to increase the DG connection capacity such as reconfiguration or voltage control. Shunt Capacitors (SCs) and Voltage Regulators (VRs) are of the most effective voltage control devices which are used in today distribution systems. However, when the DG capacity increases, the voltage violations will become a problem. Therefore,

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the optimal capacity of SCs, the step of VRs and the best configuration of the network should be found.

Publications with the aim of loss reduction through reconfiguration until 1994 are reviewed in[1]. Reconfiguration was also used for other purposes such as improvement of voltage profile, load balancing[2], service restoration[3]. In[4], reconfiguration and DG placement were used simultaneously in order to improve the voltage sag index. The number of times the voltage of sensitive loads decreases to the critical voltage was used as a voltage sag index. The results of the paper showed that the configuration that is best for having minimum voltage sag would not be the best when the DG is introduced. Reconfiguration is a complex optimization problem for which different approaches have been used before such as Ant Colony Search[5], Plant Growth Simulation Algorithm[6], Honey Bee Mating Optimization[7] and Differential Evolution[8]. Reference[9] introduced an approach for feeder reconfiguration considering different model of DGs in order to reduce power loss. Decimal coded quantum particle swarm optimization is used to solve feeder reconfiguration. In reference[10], enhanced Genetic Algorithm (GA) is used to find the best configuration of a distribution system in order to maximize network reliability and minimize its power loss. The Bat Algorithm and Cuckoo Search were used in[11] for finding best location and size of capacitors in order to reduce the power loss and maximize network savings. The results were compared with the results of the other intelligent methods.

Refrence[12] worked on optimal placement and estimation of DG capacity for improving loss reduction, voltage profile, environmental effects, installation and exploitation and maintenance expenses and costs of load prediction of each bus by using Genetic Algorithm. In[13], two approaches are used to determine the size and location of DG units. Four objective functions containing power loss, cost, voltage profile and environmental attributes are used. An efficient hybrid approach based on Imperialist Competitive Algorithm and GA was used in[14] for finding optimal place and capacity of DG sources and capacitors at the same time, and the results were compared with PSO algorithm. The authors did not use reconfiguration which is the drawback of the paper. In[15] Memetic algorithm was used for simultaneous placement of capacitors and DG sources in order to decrease active and reactive power loss, and improve voltage profile and voltage stability while considering variability of loads. The drawback of the paper is that the voltage control devices are not used for loss reduction. By using GA, PSO and Cat Swarm Optimization (CSO), reference[16] maximized annual energy loss reduction and improved system node voltage profile at three different load scenarios through allocation of SCs and DGs in distribution system.In[17], a new control method, in which DG contributes in steady-state voltage control, along with an under-load tap changer and SCs is suggested. Reference[18] used multi objective PSO in order to find the optimal location and size of shunt capacitor banks and DGs at the same time. The uncertainty of loads was modeled in the paper by using fuzzy logic theory. Although using voltage control approach for increasing DG penetration is advantageous, it is not adequate in heavy loads. Consequently, it is highly recommended to apply other methods such as reconfiguration.

In this paper, primarily, the power loss of a distribution system is reduced through Coordinated Reconfiguration And Voltage Control (CRVC). Voltage control devices which are used in this paper are SCs and VR. In the second part of the paper, in order to increase the DG allowable capacity, CRVC is used while the main purpose of the reconfiguration, which is power loss reduction, is also satisfied. The BPSO algorithm is modified to decrease the computational time of reconfiguration in both parts.

2. Formulation

In this section, the load flow method, and PSO algorithm are described.

2.1 The Load Flow Method

According to Figure 1, which shows the model of a feeder, the following basic recursive equations are used to find the power flows and the voltages.[10]

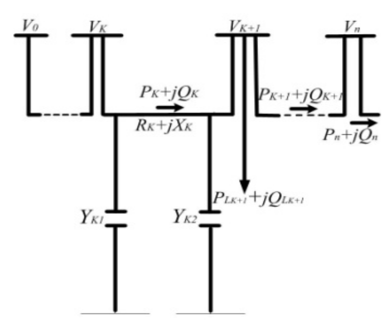

Figure 1. Model of a feeder.

$$P_{k+1} = P_k - P_{Loss,k} - P_{Lk+1} = P_k - \frac{R_k}{|V_k|^2}\left\{P_k^2 + \left(Q_k + Y_{k1}|V_k|^2\right)^2\right\} - P_{Lk+1} \quad (1)$$

$$Q_{k+1} = Q_k - Q_{Loss,k} - Q_{Lk+1} = Q_k - \frac{X_k}{|V_k|^2}\left\{P_k^2 + \left(Q_k + Y_{k1}|V_k|^2\right)^2\right\} - Y_{k1}|V_k|^2 - Y_{k2}|V_{k+1}|^2 - Q_{Lk+1} \quad (2)$$

$$|V_{k+1}|^2 = |V_k|^2 + \frac{R_k^2 + X_k^2}{|V_k|^2}\left(P_k^2 + \left(Q_k + Y_k|V_k|^2\right)^2\right) - 2\left(R_kP_k + X_k\left(Q_k + Y_k|V_k|^2\right)\right) \quad (3)$$

2.2 Binary Particle Swarm Optimization

PSO is a population based optimization approach which is proposed in[19]. Due to simplicity, different version of PSO has been used in different fields[20]. The main variables in the reconfiguration problem are switches status which are discrete. Consequently, the Binary version of PSO algorithm named BPSO is used. In BPSO, the position and the velocity of the i^{th} particle are represented as vectors $xi = (xi1, xi2,\ldots, xiD)$ and $vi = (vi1, vi2,\ldots, viD)$ where xij is the status of switches. The best previous experience of the i^{th} particle is represented by $pi = (pi1, pi2,\ldots, piD)$. The challenge in reconfiguration problem is that the most distribution systems must be configured radially. Most intelligent optimization techniques, due to their random nature, generate non-radial configurations which increase computational time. Therefore, Equation (4) and Equation (5) are used to update the state of xij[21].

$$\begin{aligned} &for\, d = 1:D \\ &\quad vid = \omega \times vid + c_1 \times randNO_1 \times (p_{id} - x_{id}) \\ &\qquad + randNO_2 \times (p_{gd} - x_{id}) \\ &\quad rid = S(vid) - randNO_1 \\ &end \end{aligned} \quad (4)$$

$$\begin{aligned} &\text{for } d = 1:D \\ &\quad \text{if (rid < the qth lowest value of all } ri) \\ &\qquad \text{then } xid = 0 \\ &\quad Else\; xid = 1 \\ &\quad End \\ &end \end{aligned} \quad (5)$$

Where C_1 and C_1 are learning factors which are also named acceleration coefficients. According to the researches, the learning factors C_1 and C_1 are often set to 2.0[22]. $randNO_i$ is a random number between 0 and 1. ω_{damp} is inertia weight. Larger inertia weights facilitate global exploration while smaller ones facilitate local exploration. ω_{damp} is frequently in the range 0.4-0.9[22]. Although many publications, had used linear function for ω_{damp}, Equation (6) showed better results in the simulations.

$$\omega(MaxIt) = w(1) \times \omega_{damp}^{MaxIt} \rightarrow 0.9 = .04 \times \omega_{damp}^{MaxIt} \rightarrow \omega_{damp} = \frac{4}{9}^{(1/MaxIt)} \quad (6)$$

Where $\omega(1)$ is the initial weight, $\omega(MaxIt)$ is the final weight, and $(MaxIt)$ is the maximum iteration number.

3. Implementation of the Method

Simulations of both two parts in this paper are done in MATLAB.

3.1 Power Loss Reduction through CRVC

In this part, the objective is to reduce power loss through CRVC. The voltage control devices which are used are SCs and step VR. The voltage control scheme is similar to the one used in[23] which is shown in Figure 2. Table 1 shows the voltage control devices and their specifications.

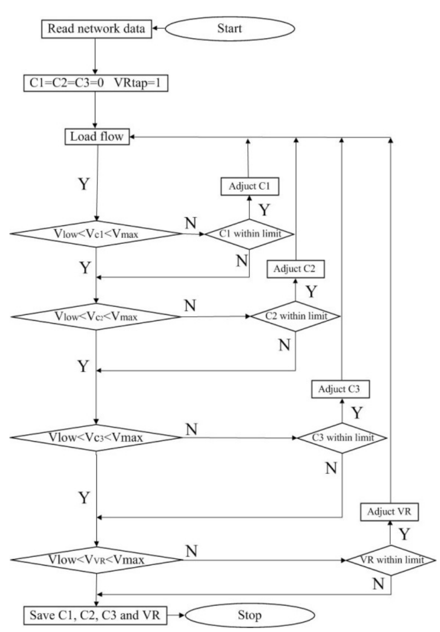

Figure 2. Voltage control flowchart.

Table 1. Specification of voltage control devices

	SCs	VR
Operation Mode	6 Steps with 0.3 Mvar/step	33 steps with 0.00625 p.u./step
V_{low}- V_{max}	0.975-1.025p.u.	0.975-1.025 p.u.

The main flowchart of this part is shown in Figure 3. In this flowchart, after inputting the network data and determining PSO parameters, the particles are initialized. In each iteration the objective function is the power loss of that configuration after conducting the voltage control of Figure 2.

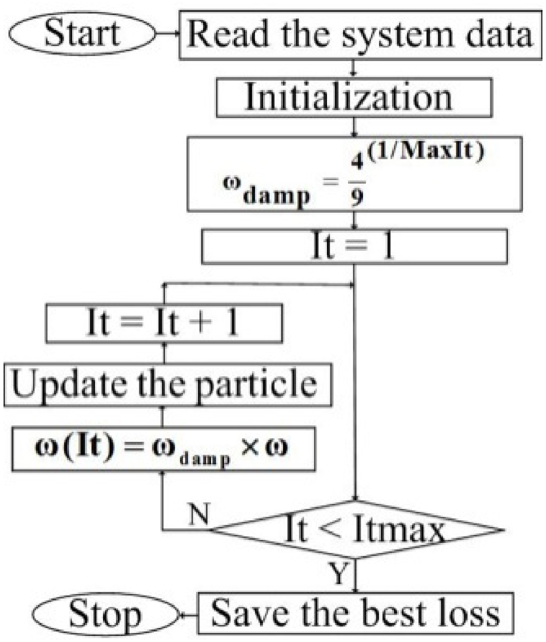

Figure 3. Loss reduction flowchart.

3.2 Increasing DG allowable Capacity by CRVC

The aim of this part is to increase the DG allowable capacity by CRVC while the main objective of the reconfiguration which is loss reduction is also satisfied. Equation (7) shows the objective function which is used in this part.

$$\begin{aligned} &Maximize\ P_{DG} \\ &\quad Subject\ to: \\ &\det(A) = 1\ or -1 \\ &S_{k,k+1} < S_{k,k+1}max \\ &V_{min} \le |V_k| \le V_{max} \end{aligned} \tag{7}$$

A is bus incidence matrix which indicates that the network is not radial when its determinant is equal to zero. $S_{k,k+1}$ is the power flow between buses k and $k+1$ which must not exceed the maximum permitted power flow between buses k and $k+1$. Moreover, the voltage of buses must be in normal range.

In this part, the DG is installed at bus 17 of the network. Then, it is tried to reduce the power loss through CRVC. If the loss in the final iteration is below the loss in the initial configuration of the network (203KW), the capacity of DG will be increased. This process will be repeated until the configuration with the loss blow 203KW could not be found in that DG capacity. The flowchart of this part is shown in Figure 4.

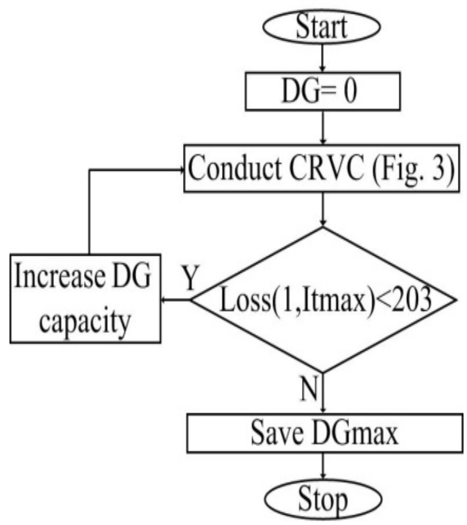

Figure 4. Increasing DG allowable capacity flowchart.

4. Case Study and Results

In this part, the test system, and the results are discussed.

4.1 Test System

The test system is a 33-bus radial distribution system which is firstly introduced in[24]. This test system has 32 sectionalizing (normally closed) switches numbered from 1 to 32, and 5 tie (normally open) switches numbered from 33 to 37. The voltage, active and reactive loads are 12.66 KV, 5084.26 KW and 2547.32 KVAR respectively. The test system, tie switches, sectionalizing switches and location of voltage control devices are shown in Figure 5. The total power loss for initial configuration is 203KW.

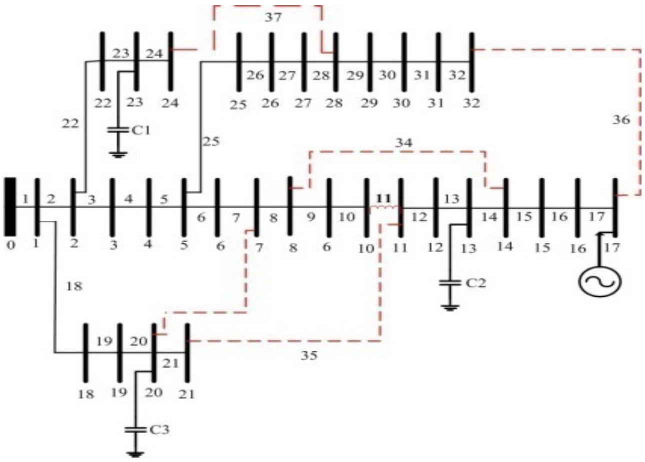

Figure 5. Test system.

4.2 Power Loss Reduction through CRVC

The iteration and population number of BPSO algorithm selected in this paper are 150 and 50 respectively. The convergence characteristic of BPSO algorithm is shown in Figure 6. As illustrated in Figure 6, through CRVC, the power loss reduced from 230 to 138 KW, showing 33% decrease. In the best configuration, the switches 7, 10, 14, 36 and 37 are open, and the step of C_1, C_2, C_3 and VR are 0.3, 0, 0 and 1 respectively.

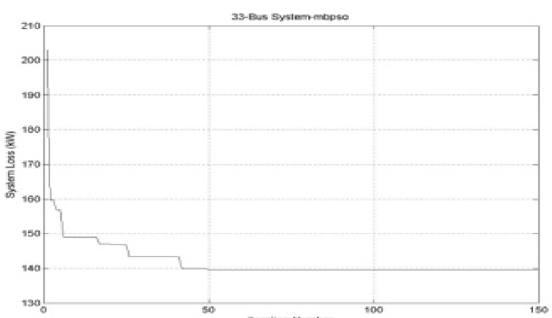

Figure 6. Convergence behaviour of BPSO algorithm.

4.3 Increasing DG allowabe capacity through CRVC

The results of this section are shown in Table 2. This table shows the configuration and the values of control voltage devices in each DG capacity. Without making advantage of CRVC, the allowable DG capacity at bus 17 is 1.8 MW. Table 2 shows that DG allowable capacity is increased to 4.2MW through CRVC. Voltage profile of all busses before and after applying the proposed method are illustrated in Figure 7. This Figure shows that voltage magnitude of all buses improves except for 5 busses.

Table 2. Results of increasing DG allowable capacity

DG (MW)	Loss (KW)	($C_1 C_2 C_3$ VR)	Open switches
1	66	(1 0 0 0.9)	6,10,13,23,26
2	62	(1 0 0 0.9)	7,9,26,33,35
3	85	(1 0.6 0 0.9)	6,21,22,29,33
4	155	(0 1 1 0)	2,5,7,9,21
4.2	189	(1 1.2 0 0.9)	2,5,8,11,34

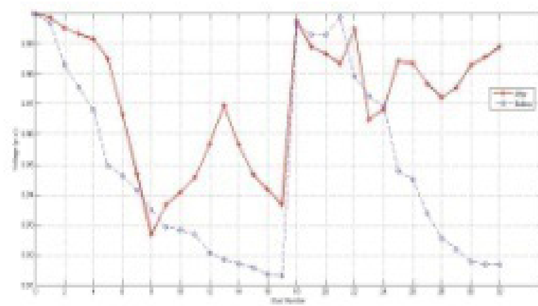

Figure 7. System voltage profile before and after CRVC.

5. Conclusion

The research reported in this paper involved in increasing the DG allowable capacity in a distribution system through CRVC. The voltage control devices that are used in this paper are SCs and VR. First, the power loss of the test system is decreased through CRVC. Second, when the DG is introduced in the system, its allowable capacity is increased through CRVC. In order to decrease the computational time, the inertia weight equation of BPSO algorithm is modified. The results show that the power loss is decreased 33% in the first part, through CRVC. In the second part, the DG allowable capacity is increased from 1.8 MW to 4.2 MW. In addition, through using CRVC, voltage profileimproved significantly. It is highly recommended to use tap changer along with the other voltage control devices. Furthermore, it is suggested to repeat the simulation of this paper on another test system.

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