Development of a Modified Particle Swarm Optimization Algorithm for Voltage Profile Enhancement in Distribution Network Reconfiguration

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Abstract
Distribution network reconfiguration (DNR) is the most economical method to reduce power losses in distribution network. It involves altering the topological structure of feeders by changing the switching states of normally opened switches. Previous optimization algorithms in the time past have not developed significantly enhanced the voltage profile of distribution network reconfiguration, hence the motivation for this research paper. This paper therefore develops a modified particle swarm optimization (PSO) algorithm for voltage profile enhancement in distribution network reconfiguration. In the modified PSO algorithm, the vector containing the nodal voltages is defined and the element of the vector is assigned a value of 1 p.u with zero angle. The currents of the network branding were calculated. The voltage of the node near to the reference node was calculated by subtracting the corresponding voltage drop from the voltage of the previous nodes until convergence was attained. Distribution load flow based on backward forward sweep was used to compute the losses while a number of iterations were performed until convergence was attained. The modified PSO algorithm was tested with a 28-bus radial distribution network using MATLAB programming language. The results of the work showed that the loss reduction obtained was 7.53% more than the existing approach with good convergence characteristics. The percentage power loss reduction was 47.58% which indicated a load balance in the network with a 12.32% improvement in voltage profile as a result of the efficiency and good convergence characteristic of the modified PSO algorithm, thus making it useful in large-scale network.
Keywords: Distribution Network Reconfiguration (DNR), Particle Swarm Optimization (PSO), Modified PSO Algorithm, Distribution Network, Backward- forward Sweep, Power Loss Reduction, Voltage Profile, Line Losses.

I. Introduction

The major concern of distribution utilities is to reduce the power losses in distribution network (Chiang and Rene 2009; Dolandar *et al*. 2009; Nara *et al*. 2015 and Nara *et al*. 2015). Distribution network reconfiguration (DNR) is the most economical method to reduce the power losses in distribution network (Chaturvedi 2009; Das 2016; Mostafe *et al.* 2015). DNR is the process of altering the topological structure of feeders by changing the switching states of normally closed switches and normally opened switches. These switching operations must be performed in such a way that resulting network is radial and meets all constraints. DNR is used as a planning and real-time control tool (Gonnecs and Canreins 2009; Dasheng 2005; Delhen *et al*. 2016). Regular modification in radial structure of the distribution network is performed to transfer the loads from one feeder of distribution network to another feeder to improve the operation condition of the overall network as well as reducing the line losses (Augugliaro *et al*. 2003; Chion and Chag 2015; Civaniah *et al*.2008; Shirmohammadi and Hong 2009). The daily load variation on each feeder in a distribution network is unpredictable as a result of mixture of residential, industrial and commercial load types. DNR is very useful in transferring the load from heavily loaded feeders to lightly loaded feeders which eventually balances the loads among the feeders as well as improving the voltage profiles of the network. The real power losses of the network are also reduced in the process (Boonyaritolachochai 2009; Cheng and kou 2015; Kim and Ko 2013; Schunze 2007).

The Particle Swarm Optimization (PSO) Procedures

The following are the procedural steps in PSO (Chaturvedi 2009; Chion and Chag 2015):

i. It is assumed that the size of the group of particle is J.
ii. The size of the group of particle J is assumed not too large or too small to ensure many possible positions towards the best solution or optimal.
iii. Generate initial population with range and by random order.
iv. Denote the particle velocity at each iteration by a vector 'K'.
v. Evaluate the objective function value for each particle.
vi. Calculate the speed of all the particles with the consumption that all particles move towards the optimal point with a velocity.
vii. Set the iteration
viii. At the iteration, determine the two important parameters for each particle.

Advantage of PSO

The advantage of PSO includes the following (Gonnecs and Canreins 2009; Kalivarapu 2011):

i. Intelligence
ii. Application to both scientific research and engineering use.
iii. PSO have no overlapping and mutation calculation.
iv. The search in PSO can be carried out by speed of the particle.
v. The speed of particle transmission is very fast.
vi. Calculation in PSO is very simple.
vii. PSO has the biggest optimization ability.
viii. PSO adopts the real number code which is directly described by the solution.

Disadvantage of PSO

The disadvantages of PSO include the following (Boonyaritolachochai 2009; Chiang and Rene 2009; Dolandar *et al*. 2009; Rao *et al.* 2017):

i. PSO method suffers from partial optimization.
ii. PSO method cannot solve the problem of scattering.
iii. PSO method cannot also solve the problem of non-coordinate systems.

II. Materials and Method

Steps:

i. The vector V_K containing the node voltages is defined.
ii. All element of vector is assigned a value 1 p.u. or 1.05 p.u. with zero angle, where $K\varepsilon$ [1, N_{br}] with respect to the control variable x.
iii. The current at each node i_K is computed using the relation;

$$I_{(Li)} = \left|\frac{P_L(i)}{V_i}\right| \quad 1$$

Where , $I_{(Li)}$ and P $V(t)$ V(i) are the current, apparent power and voltage of the load at node i.

iv. The current of the network branches J_{1XNbr} are calculated.
v. Velocity drop of the network is calculated using $V_d = Zj$, where Z is the impedance, $d\varepsilon[1, N_{br}]$ and V_d is the voltage drop of each branch.
vi. Since the voltage of reference node is taken as 1 or 1.05 p.u, the voltage of next node is calculated by subtracting the corresponding voltage drop from the voltage of previous node and V_K is updated.
vii. The procedure in step 3 is repeated until convergence criteria are satisfied. The convergence criteria is

$$\Delta V_K = V_L(itr) - V_k(itr-1) < \in \quad 2$$

Where itr is the number of iteration and ∈ is the threshold.

viii. Input the line and bus data as well as the voltage limit.
ix. Compute the loss using distribution load flow based on backward-forward sweep.
x. Generate an initial population (array) of particles with random positions and velocities on dimension in the solution space. Set the iteration counter K= 0 at random.
xi. If the bus voltage is within the limit for each particle, compute the total loss otherwise, that particle is infeasible.
xii. Compare the objective value of each particle with the individual best. If the objective value is lower than "P_{best}", set this value as the current "P_{best}", and record the corresponding particle positions.
xiii. Check the particle associated with the minimum individual best "P_{best}" of all particles and set the value of this "P_{best}" as the current overall best "G_{best}".
xiv. Update the velocity and position of particle.
xv. If the iteration number reaches the minimum limit, go to step (xvi). Otherwise, set iteration index K = K+1 and go back to step (xi).
xvi. Print out the bus voltages and angles before and after reconfiguration.

The modified PSO algorithm was tested ona 28-bus radial distribution network using MATLAB programming language. The distribution network is made up of 33-buses, seven normally open the switches and 34 normally closed sectionalizing switches.

III. Discussion of Results

Figure 1 shows the bus angle at different buses before reconfiguration. Between buses 1 and 5, the bus angles increase accordingly from 0 to 0.2321 radians. Thus at bus 1, the voltage angle is 0 radian. At buses 2,3, 4 and 5, the bus angles are 0.0128, 0.0965, 0.1638 and 0.2321 radians respectively before reconfiguration. At bus 6, the bus angle reduces to 0.1426 radians at this time owing to the nature of the network before network reconfiguration. Between buses 7 and 24, the bus angle fluctuates along the time thus at bus 7,8,9,10,11 and 12, the bus angle are -0.0852, -0.0519, -0.1296, -0.1960, -0.1892 and -0.2758 respectively. Buses 25, 26, 27 and 28 have bus angles of 0.1838, 0.2423, 0.3366 and 0.4229 respectively before reconfiguration.

The bus voltage before reconfiguration is shown in Figure 2. The bus voltage decrease appreciably from 1.000 volt to 0.9114 volt for bus 1 to 16 before reconfiguration. At a bus number 17, the voltage suddenly rises to 0.9945 volt from 0.9114. The voltage of the buses then decreases to 0.9202 along the remaining buses before reconfiguration. Thus, at bus numbers 18, 19, 20, 21 and 22, the voltages are 0.9909, 0.9902, 0.9894, 0.9774 and 0.9674 which is observed to be a gradual reduction in the bus voltages along the buses concerned.

Figure 3 illustrates the bus angles at different buses after reconfiguration. For the 28 bus grid system, the bus angles increase from 0.0128 to 0.0229, 0.0965 to 0.1631, 0.1638 to 0.2757 and 0.2321 to 0.3897 for buses 2, 3, 4 and 5 after reconfiguration. In the same manner, the bus angles also increase from 0.1426 to 0.2391.

The bus angles fluctuate along the various buses with the bus angles being -0.1459, -0.0887, -0.2182, -0.3285 and -0.3179 for buses 7, 8,9,10 and 11 respectively after the network reconfiguration.

The voltages for the various buses are depicted in Figure 4. At bus numbers 2, 3, 4, 5, 6, 7 and 8, the voltages are 1.0000, 0.9960, 0.9811, 0.9761, 0.9635, 0.9611 and 0.9578 respectively after the network reconfiguration. In a similar manner, the voltage for buses 20, 21, 22, 23, 24, 25, 26, 27 and 28 are 0.9912, 0.9815, 0.9836, 0.9784, 0.9526, 0.9468, 0.9410, 0.9368 and 0.9289 respectively after the network reconfiguration. This shows appreciable level of voltage reduction for the concerned buses after the network reconfiguration.

Figure 5 illustrates the bus voltages before and after reconfiguration for the 28-bus grid system. at buses 1, 2, 3, 4, 5 and 6, the voltages before reconfiguration are 1.0000, 0.9950, 0.9810, 0.9735, 0.9662 and 0.9443 respectively while for the same buses, the voltages are 1.0000, 0.9960, 0.9863, 0.9811, 0.9761 and 0.9635 respectively after the network reconfiguration. This indicates appreciable level of voltage increase along the buses after reconfiguration as compared to the bus voltages before network reconfiguration. The least bus voltages before the network reconfiguration is 0.9114 which was recorded at bus number 16 while the highest bus voltage in this case is 1.0000 which was recorded in bus number 1 before the network reconfiguration. After the network reconfiguration, the least bus voltage is 0.9289 which was recorded at bus number 28. The highest bus voltage in this regard is 1.0000 at bus number 1.

The bus angle before and after the network reconfiguration is depicted in Figure 6. Before the network reconfiguration, the bus angles at buses 1, 2, 3, 4 and 4 are 0, 0.0128, 0.0965, 0.1638 and 0.2321 respectively. After the network reconfiguration, the bus angles for buses 1, 2, 3, 4 and 5 are 0, 0.0229, 0.1631, 0.2757 and 0.3897 respectively. Thus, the least bus angle before the network reconfiguration is -0.5100 at bus 17 after network reconfiguration, the least bus angle is -0.8315 at bus 17. However, the highest bus angle before and after the network reconfiguration are 0.4229 at bus 28 and 0.5594 at bus 28. This shows an appreciable level of voltage angles after the network reconfiguration.

After the network reconfiguration, the open switch vector obtained with this approach are 6, 8, 13, 31 and 35. The minimum line voltage is 0.7326 p.u. at bus 28. The real power loss of the configured network is 113.82 kW. An overall power loss reduction of 47.23% was achieved after reconfiguration as compared to the method proposed by Rao *et al* and Shirmohammadi and Hong that recorded an overall power loss reduction of 23.58% after reconfiguration.

In addition, 12.32% improvements in minimum voltage are achieved as compared to the original network before reconfiguration. After the loads, transfer from one branch reduced at every branch after the reconfiguration of the network as a result of the load balancing.

Voltage profile and voltage angles before and after reconfiguration for 28-bus.

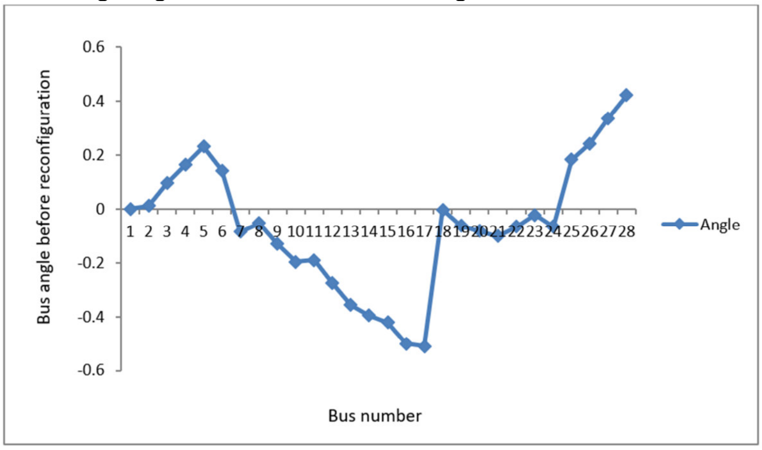

Figure 1: Bus angles at different buses before reconfiguration for 28 bus grid system.

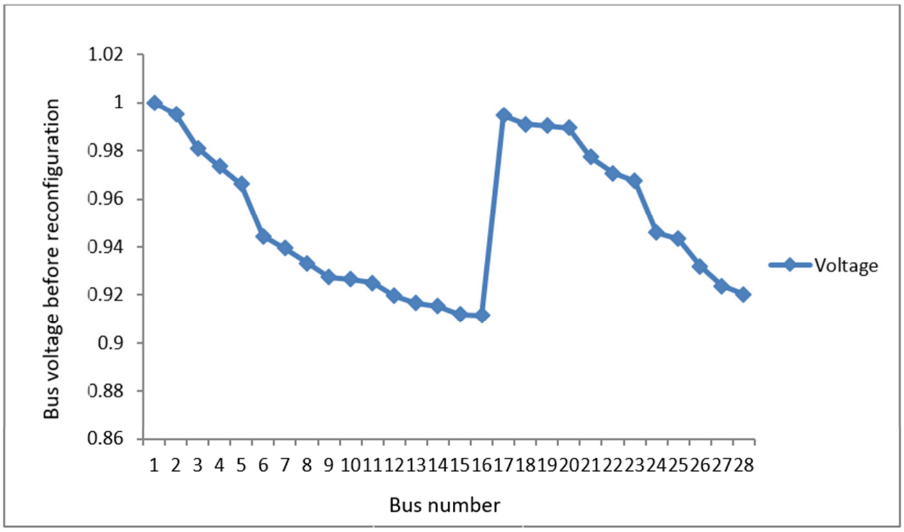

Figure 2: Bus voltages at different buses before reconfiguration for 28 bus grid system.

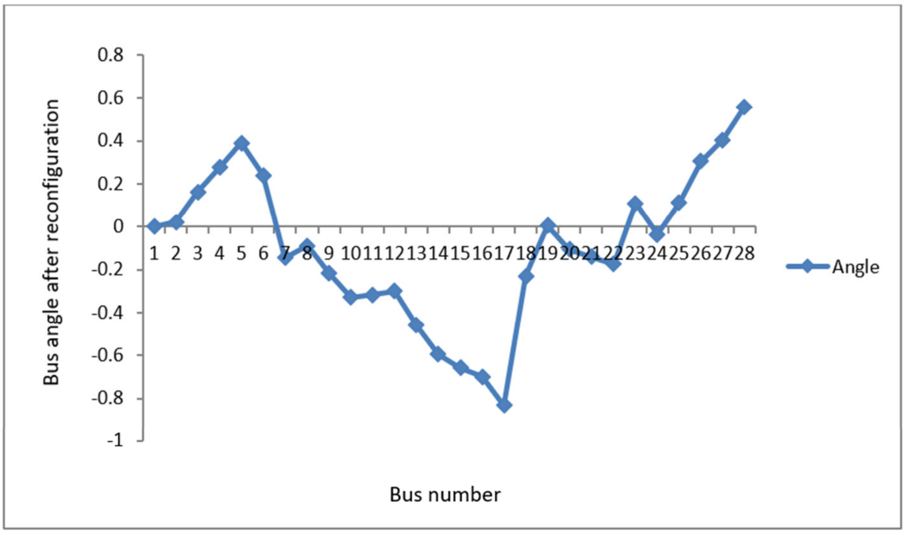

Figure 3: Bus angles at different buses after reconfiguration for 28 bus grid system.

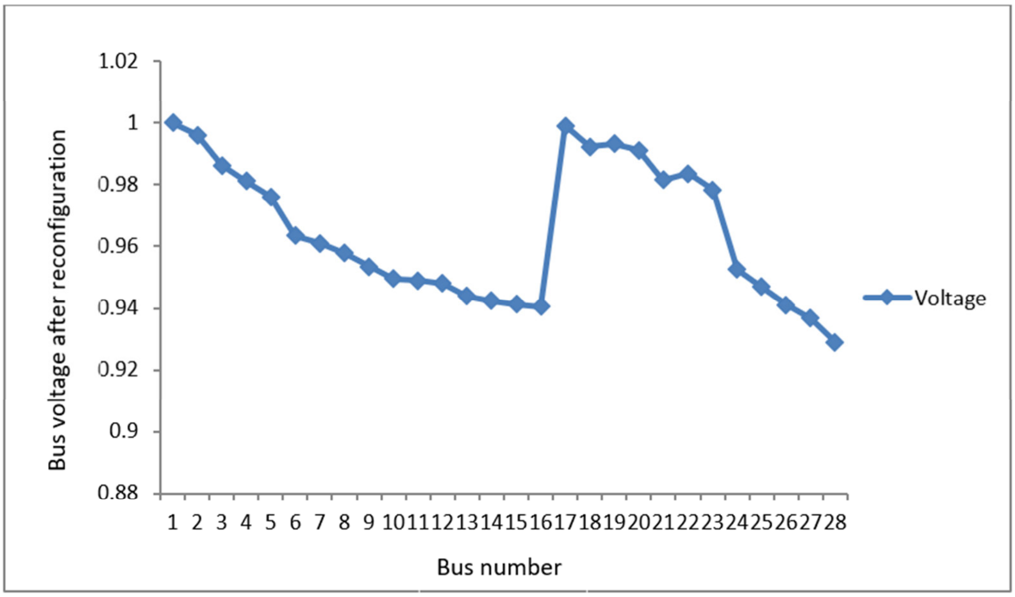

Figure 4: Bus voltages at different buses after reconfiguration for 28 bus grid system.

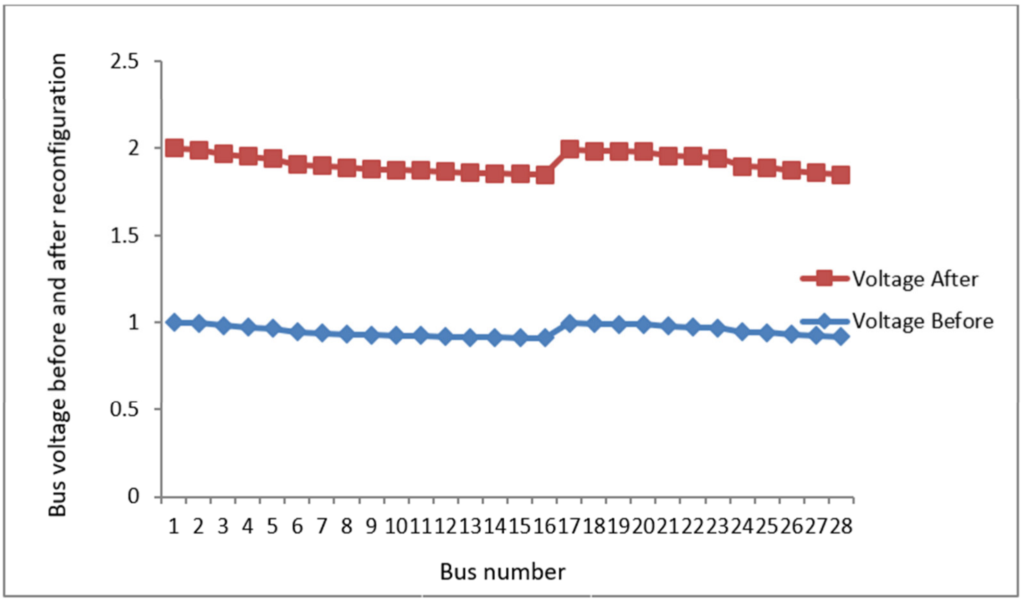

Figure 5: Bus voltages at different buses before and after reconfiguration for 28 bus grid system.

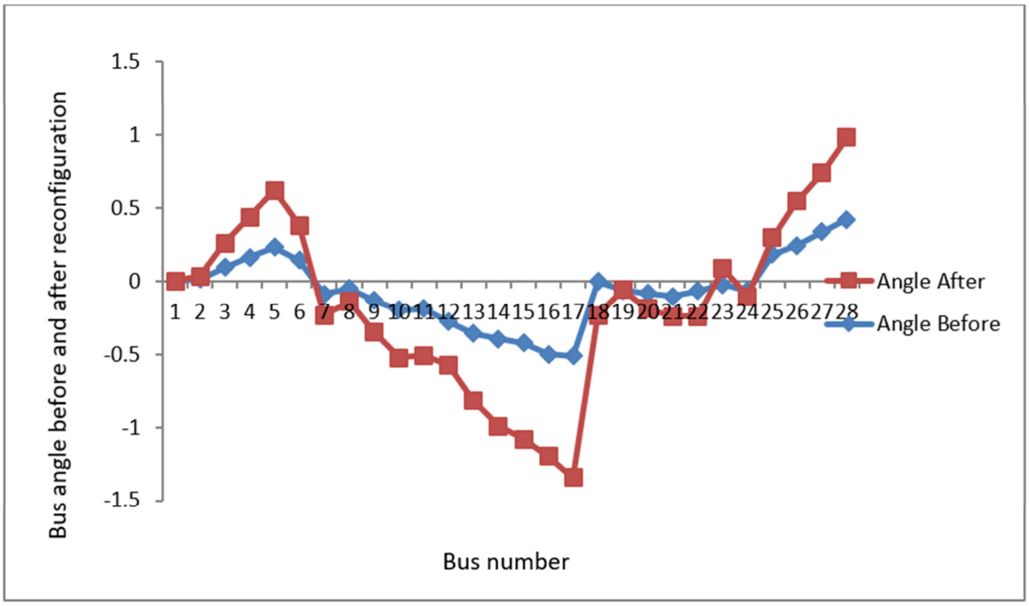

Figure 6: Bus angles at different buses before and after reconfiguration for 28 bus grid system.

IV. Conclusion

A modified PSO algorithm for voltage profile enhancement in distribution network reconfiguration has been presented. The simulation is performed on IEEE 28- bus radial distribution network using MATLAB programming language. The results from this work were compared with other methods proposed by Rao *et al*., as well as Shirmohammadi and Hong .

The result shows a loss reduction of 7.53% more than the existing approaches with good convergence characteristics. The percentage power loss reduction is 47.58% which is an indication of load balance in the network after reconfiguration. A 12.32% improvement in voltage profile is recorded after the network reconfiguration due to the efficiency and good convergence nature of the modified PSO algorithm.

V. References

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