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Distribution network reconfiguration for loss reduction using PSO method

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ABSTRACT

In recent years, the reconfiguration of the distribution network has been proclaimed as a method for realizing power savings, with virtually zero cost. The current trend is to design distribution networks with a mesh network structure, but to operate them radially. This is achieved by the establishment of an appropriate number of switchable branches which allow the realization of a radial configuration capable of supplying all of the normal defects in the box of permanent defect. The purpose of this article is to find an optimal reconfiguration using a Meta heuristic method, namely the particle swarm optimization method (PSO), to reduce active losses and voltage deviations by taking into account certain technical constraints. The validity of this method is tested on a 33-IEEE test network and the results obtained are compared with the results of basic load flow.

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1. INTRODUCTION

Electric power has become a consumer good worldwide for both everyday life and the economy of the country, and the smallest electrical problems have a great influence on the continuity of economic activities. Therefore, the possession of reliable and cost-effective electricity networks that function properly and ensure continuity of service and good quality energy has become essential to make a positive contribution to the development of our modern societies.

The distribution network must evolve into a flexible and intelligent network that best integrates local and/or renewable energies. The opening of the electricity market and growing environmental concerns related to global climate change are driving significant changes, particularly in the distribution networks, with the massive influx of decentralized products. This development can be envisaged by developing intelligent systems capable of minimizing the impacts generated by the insertion of decentralized productions and/or the search for new architectures. These two solutions should make it possible to increase the rate of decentralized production in the distribution network in the best economic and security conditions [1].

The major problem for network managers is to propose better planning for a better management of the transit of power. From the production centers to the consumer, transmission lines inflict large losses of energy, whether active or reactive, much more in the distribution networks where about 14% of the power transiting these lines is lost [2]. All of these losses affect the quality of the voltage delivered to customers. For this purpose, the study of the power flow (Load flow) makes it possible to have the solution of the magnitudes of an electrical network in normal operation balanced in steady state. Load flow analysis in an electrical grid consisting of a number of generators, transmission lines and loads is very important for the design, planning and operation of an electrical network [3, 4]. The scheduler of this network can easily evaluate the impact of different transmission and generation configurations for any desired load level.

This makes it possible to know the conditions of production and load and the levels of the voltages of the network and several remediation techniques are put into use to circumvent this problem. Among these solutions, we mention the decentralized productions that are increasingly present on the market. The conventional techniques used in decentralized production offer the network a better quality of energy, on the other hand their need for raw material as well as their impacts on the environment make of them undesirable means of production, on top of that their time and cost of realization are excessive [5, 6]. For this decentralized production based on renewable energy is a promising alternative, the cost of implementation and maintenance is much lower than those mentioned before, their completion time is far shorter. On top of that, renewable energies are non-polluting. However, these are not magical solutions, because their impacts on the network and on the quality of energy impose the insertion of filtering, regulation and compensation means.

The incorporation of components such as FACTS devices and capacitors into the distribution system to reduce power losses comes with a high cost of implementation [7, 8]. It is necessary to reduce unnecessary expenses if there are better and cheaper alternatives to the costly options. Therefore, network reconfiguration which does not require any other additional components apart from switch manipulation of the already existing network system has been considered.

2. MATHEMATICAL MODEL

A single line diagram of the distribution power system is displayed in Figure 1 and the mathematical equation for thepower flow of the system can be stated as [9, 10]:

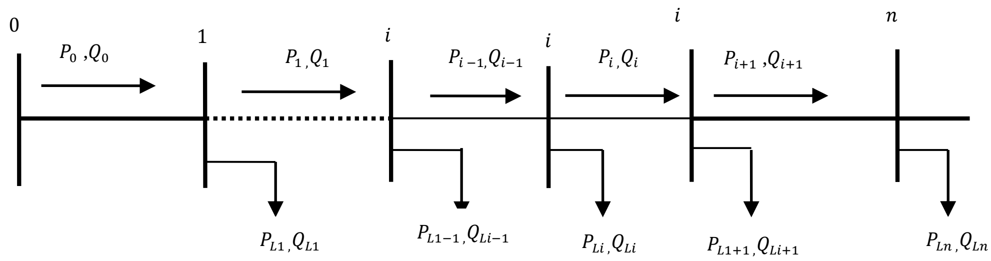

Figure 1. Single line diagram of a radial distribution network

The aim of this paper is to find the optimal reconfiguration of the network that will offer minimum power loss and voltage deviations. Single line diagram of a simple feeder-line configuration is shown in Figure 1. A set of recursive equations for computation of power flow is given by:

$$P_{i+1} = P_i - P_{Li+1} - R_{i,i+1}.\frac{P_i^2+Q_i^2}{|V_i|^2} \quad (1)$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i,i+1}.\frac{P_i^2+Q_i^2}{|V_i|^2} \quad (2)$$

$$|V_{i+1}|^2 = |V_i|^2 - 2\left(R_{i,i+1}.P_i + X_{i,i+1}.Q_i\right).\frac{P_i^2+Q_i^2}{|V_i|^2} \quad (3)$$

where, P_i and Q_i are the real and reactive power flowing out of bus i; P_{Li+1} and Q_{Li+1} are the real and reactive load powers at bus $i+1$. Line section between buses i and $i+1$ has resistance $R_{i,i+1}$ and reactance $X_{i,i+1}$. Voltage magnitude of bus i is $|V_i|$. For convergence of power flow, the power balance (1) and (2) must be satisfied in addition, magnitudes of sending and receiving end bus voltages must satisfy (3).

The well known generalized formulas for real and reactive power loss in the line section between buses i and $i+1$ are calculated by using the following equations:

$$P_{Loss(i,i+1)} = R_{i,i+1}.\frac{P_i^2+Q_i^2}{|V_i|^2} \quad (4)$$

$$Q_{Loss(i,i+1)} = X_{i,i+1}.\frac{P_i^2+Q_i^2}{|V_i|^2} \quad (5)$$

The total active and reactive power loss of the distribution system can be easily found by summing all of the branch power loss and it is expressed as:

$$P_{tloss} = \sum_{i=1}^{nbr} P_{Loss}(i, i+1) \tag{6}$$

$$Q_{tloss} = \sum_{i=1}^{nbr} Q_{Loss}(i, i+1) \tag{7}$$

where, P_{tloss} is the total real power loss and Q_{tloss} is the loss incurred due to reactive power throughout the network [11, 12].

3. PARTICLE SWARM OPTIMIZATION

3.1. Introduction

PSO particle swarm optimization is a parallel optimization technique developed by Kennedy and Eberhart [13-16]. It is inspired by the social behavior of individuals who tend to imitate the successful behaviors they observe around them, while bringing their personal variations. Kennedy and Eberhart, proposed in 1995 a new optimization method called Optimization by Swarm of Particle PSO, is a stochastic optimization method based on a population of particles a Swarm groups together several particles. Each particle makes its decision using its own experience and the experiences of its neighborhood. PSO is inspired by the social behavior of flocks of birds and schools of fish which tend to imitate the successful behaviors they observe around them, while bringing their personal variations to it. PSO starts the process of optimization by a population of random solutions that move in the search space. The position of each particle is represented by its coordinates along the two XY axes and also by its speed which is expressed by Vx (the speed along the x axis) and Vy (the speed along the x axis) [17-19].

In PSO, two different definitions are used: the individual best and the global best. As a particle moves through the search space, it compares its fitness value at the current position to the best fitness value it has ever attained previously. In PSO, to adjust the position, velocity of each particle is calculated using current position *xi*, best position of particle so far *Pbest* and global best position of particle in population *Gbest*. Velocity of each particle in the next generation can be calculated as:

$$V_i^{k+1} = wV_i^k + c_1 r_1 (Pbest - x_i^k) + c_2 r_2 (Gbest - x_i^k) \tag{8}$$

where r_1 and r_2 are random numbers between 0 and 1 while c_1 and c_2 are positive constants, respectively. Inertia weight w is formulated as follows:

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} iter \tag{9}$$

where $w_{\max}$ and $w_{\min}$ are maximum and minimum of inertia weight, $iter_{\max}$ and $iter$ are maximum iteration number and current iteration, respectively. Current position or searching point can be modified by the following equation.

The objective function to consider is to minimize active power losses and minimize deviations from nodal voltages that can be formulated as being the overlay of two separate objective functions. Where,

$$F = f1 + f2 \tag{10}$$

The first function $f1$ represents the power loss sensitivity index obtained by the ratio of losses after reconfiguration to power losses before reconfiguration which can be formulated as follows:

$$f_1 = \frac{P_{loss}^{reconf}}{P_{loss}^{initial}} \tag{11}$$

The power losses before reconfiguration are determined by the following equation:

$$P_{loss}^{initial} = \sum_{i=1}^{nl} R_i \left(\frac{P_i^2 + Q_i^2}{V_i^2}\right) for\ i = 1,2 \dots nl \tag{12}$$

The second function represents the voltage sensitivity index it is also obtained by

$$f_2 = \frac{\Delta V_{total}^{reconf}}{\Delta V_{total}^{initial}} \quad (13)$$

with V_{dev}^{reconf} deviation value after reconfiguration and $V_{dev}^{initial}$ initial deviation before reconfiguration. The voltage difference is calculated as

$$\Delta Vtotalinitial = \sum_{j=1}^{NB} |1 - Vj| \; for \; j = 1,2, \dots NB \quad (14)$$

Taking into account technical constraints to solve the problem to find the optimal reconfiguration.

4. CONSTRAINTS [20-22]

The constraints are listed as follows:

a) Distribution line absolute power limits:

$$\left|P_{ij}^{Line}\right| \leq P_{ijmax}^{Line} \quad (15)$$

$\left|P_{ij}^{Line}\right| and P_{ijmax}^{Line}$ Are the absolute power and its corresponding maximum allowable value flowing over the distribution line between the nodes i and j, respectively.

b) Bus voltage limit:
Bus voltage amplitudes are limited as

$$Vmin \leq Vi \leq Vmax \quad (16)$$

where $Vmin$ and $Vmax$ are the minimum and maximum values of bus voltage amplitudes, respectively.

4.1. Case Studies

The system used for this method is tested on standard IEEE 33 bus test system as shown in Figure 2. Thesystem load is assumed to be constant with $Sbase = 100MVA$ and $Vbase = 12.66kV$. The load and line data is referred in [23-25]. The total load of the system is 3715kW and 2300kVar. All calculation is in per unit. The simulations were carried out by using MATLAB. The result with minimum power loss is selected as shown in Table 1. The result show that the power losses for case 1 are 208.4592 kW and reduce to 33.355% for case 2. Figure 3 shows the network reconfiguration switchers.

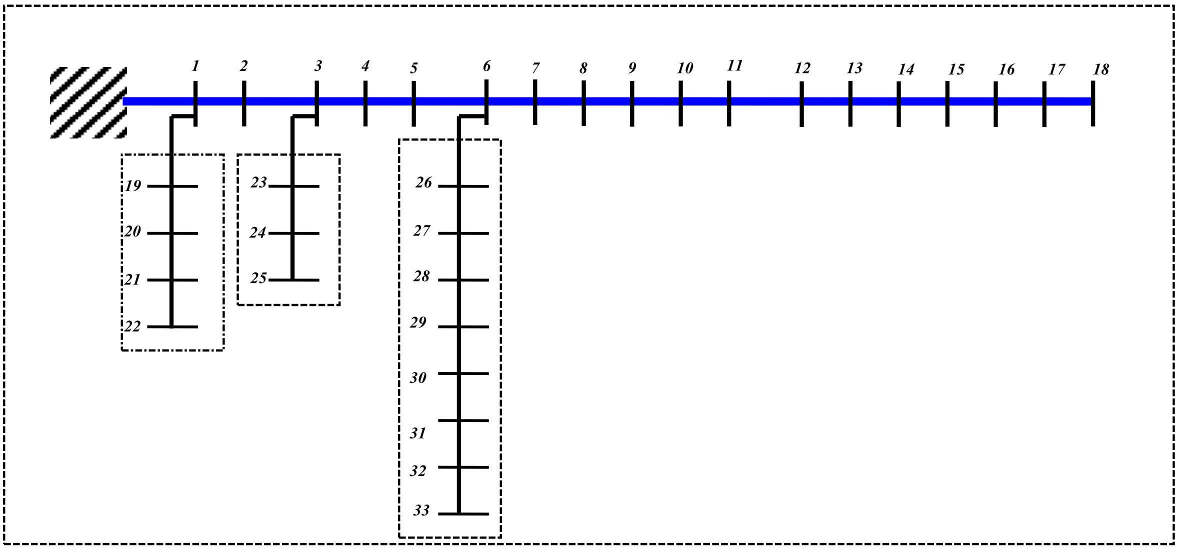

Figure 2. Single line diagram of 33 bus electric distribution

Table 1. The result consists of 5 opened switches, total power losses, voltage profile

	Before Reconfiguration	After Reconfiguration
Tie switches	33 34 35 36 37	7 9 14 32 37
Power loss	208.4592 kW	138.9275 kW
Minimum voltage	0.91075 *pu*	0.94234 *pu*
Power loss reduction	-	33.355 %

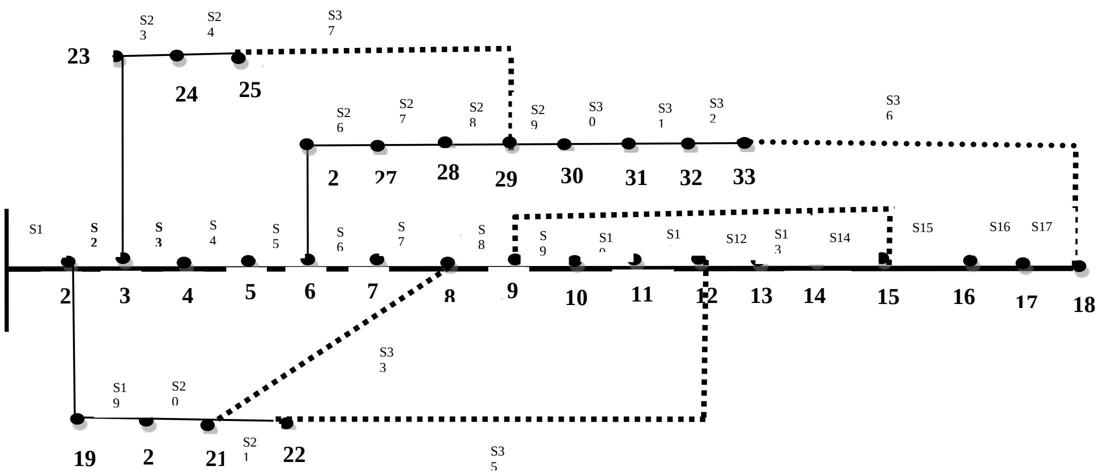

Figure 3. Optimized configuration of 33 bus test system

Figure 4 shows the comparison of the voltage profile before and after network reconfiguration for case 1 and case 2, respectively. The network before reconfiguration is represented by case 1. The minimum voltage in case 1 was 0.91075p.u at node 18. With the PSO algorithm for optimum switching, the configuration in case 1 was converted into case 2. The result of voltage improvement became 0.94234 p.u at node 32 as shown in case 2 of Figure 4.

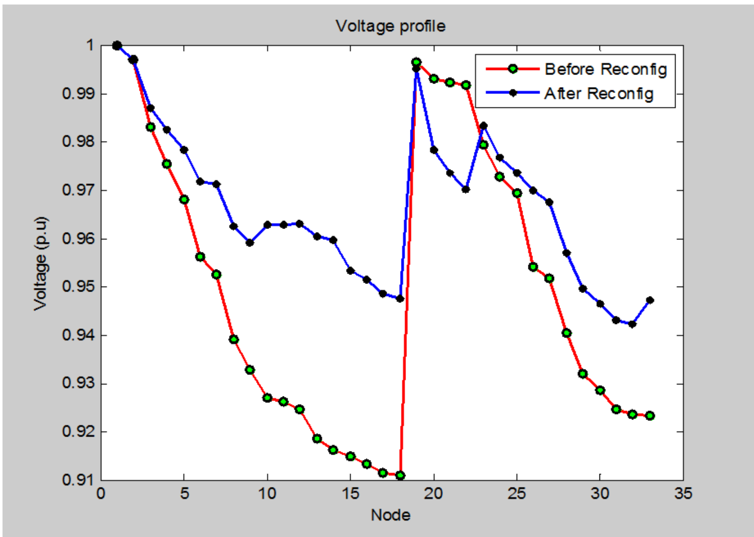

Figure 4. Voltage profile

The comparison for the real power losses in the branches is shown in Figure 5 for the initial network before and after reconfiguration (case 1 and case 2), respectively. The power losses in almost every branch in case 2 reduced, except at 18, 19, 20, 21, 33, 34 and 35, where there was a small increase in losses due to load shifting of the feeders altered by the switching as depicted in Figure 5.

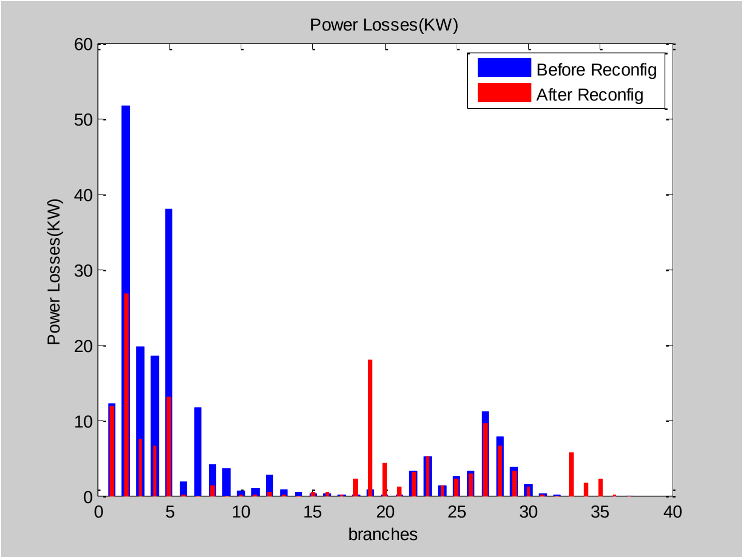

Figure 5. Real power losses in 33-bus system

5. CONCLUSION

Finally, based on the result, we went from an initial configuration with high power losses and unstable voltage at an optimal configuration including lower power losses and more stable voltage, and therefore the optimal result shows us the efficiency of the reconfiguration process in terms of reducing power losses and improving the voltage profile, and this represents a great economic and technical advantage. As a prospect, apply this approach to a large distribution network in the presence of renewable sources and determine their size and location in the distribution network.

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