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Voltage Sag Improvement in Radial Distribution Networks using Reconfiguration Simultaneous with DG Placement

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Abstract

The amount of sensitive loads in distribution networks is increasing significantly with the passing of time. It is essential to keep the voltage of these loads in normal range. Voltage sag mainly occurs due to power system faults that should be limited. Formerly reconfiguration and distributed generation (DG) resources placement were studied separately to improve the voltage sag caused by faults; however, there are many practical limits in the use of each method individually. The main task of this paper is to use reconfiguration and DG resources placement simultaneously to improve voltage sag index which enables us to overcome these limitations. The number of times the voltage of sensitive loads decreases to the critical voltage is used as an index for performance evaluation. To minimize this index, binary particle swarm optimization (BPSO) algorithm is used. The efficiency of the proposed method is proved through simulation results and their comparison with previously-performed methods.

Keywords: Binary Particle Swarm Optimization, Reconfiguration, Distributed Generation, Voltage Sag.

1. Introduction

In spite of quality improvement of generated power and advances of transmission and distribution networks technology, recent growth of sensitive loads and using them in industrial and hospital centers makes power quality issue more important than the past. Voltage sag, one of the most important power quality indices, occurs due to some reasons such as faults, sudden load increase and large motors startup. Voltage sag in industrial sensitive loads arises due to short circuit in different parts of the network. Voltage drop below critical value in this loads causes malfunctioning of electrical equipment and economical losses, thus a solution to this problem should be found.

Reconfiguration of distribution networks which is defined as the change of switch status is used mainly for Power loss minimization and overload relief. Also to increase generation capacity and to relieve public concerns about pollution, distributed generation plants have been introduced in distribution networks [1]. By increasing short circuit capacity, the installation of DG resources can prevent voltage sag in sensitive loads. The magnitude of voltage sag after fault highly depends on the path between the fault location and sensitive loads as well as short circuit capacity in these buses, so both reconfiguration and DG resources placement methods can be applied to improve voltage sag. Needless to say, altering the topology of network will not ameliorate the situation; moreover, other

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network constraints may limit the implementation of each and every configuration. Furthermore, to gain the advantage of the DG resources, some parameters, such as the best location, the number and the capacity of the units, and the best applied technology, should be definite. The other problem with DG resources arises when incorporating them on a large scale e.g. malfunction of protection circuits, frequency deviation and voltage profile rising and stability problems; therefore, each of mentioned methods are effective but there are many constraints in use each of them separately.

In previous researches, reconfiguration is used for many reasons including power quality enhancement. All the work in the area of distribution system reconfiguration for the loss reduction until 1994 is reviewed in [2]. There are some more applications for reconfiguration including load balancing, system reliability improvement and increasing DG resources penetration [3–5]. Recently, some researchers have investigated the effects of reconfiguration on power quality indices. In [6] a modified GA including a double-point crossover and an adaptive mutation, has been applied to minimize financial losses due to voltage sags. In ref. [7], by the Monte Carlo method, fault parameters are randomly generated, and then it is tried to minimize the objective function by doing the fault analysis through the evolutionary algorithm. The objective function involves network energy losses, long duration interruption costs and customer process disruption costs due to voltage sag. Using differential evolutionary algorithm, Jazebi & Vahidi [8] tried to find a configuration in which the voltage total harmonic distortion of special loads, voltage drop during faults and power loss is minimum. In spite of power-quality parameter improvement by reconfiguration in mentioned cases, no one has considered distributed generation sources, whose contribution in present distribution networks is inevitable and whose influence on improving power quality is proved.

DG resources allocation is also a complicated optimization problem for which different methods were employed to solve in the past. Viral and Khatod [9] carried out a comprehensive review of different methods such as analytical, meta-heuristic, artificial intelligence and genetic algorithms hybrid approaches. In [10] researchers applied the sensitivity analysis for DG resources allocation; furthermore, reconfiguration and DG resources allocation collaboratively reduce loss at three different load levels. In [11], Memetic algorithm which is a combinatorial form of local search and genetic algorithm is used for simultaneous placement of DG resources and capacitors. DG resources allocation for improving power quality indices is a new topic which is presented by few researchers lately. Hamedi and Gandomkar [12] compared the effect of three modes of DG resources placement on power quality. Recently, Biswas et al. [13] try to determine the optimal number, sizes and bus locations of DG resources by genetic algorithm. The considered objective function is of 3 parts including cost of line loss, voltage sag, and installation and maintenance cost of the DG resources. Although using DG resources for improving voltage sag is advantageous, it is not adequate in heavy loads or severe faults; moreover, as mentioned before, incorporating DG resources on a large scale would lead to serious consequences. Therefore it is highly recommended to apply other methods such as reconfiguration along with using DG resources.

As it was pointed out, thus far reconfiguration and DG resources placement were studied separately to improve voltage sag caused by faults. The main idea of this paper is to take the advantage of both reconfiguration and DG resources placement simultaneously to improve voltage sag while the main purpose of reconfiguration (loss reduction) is also satisfied. With placing the DG resource in one of the distribution network busses and a trade-off between power quality indices and system power loss, the best DG resources capacity and network configuration can be achieved. Owing to its simplicity and high efficiency in reconfiguration problem, BPSO algorithm is implemented for optimization. Results show the high efficiency of the proposed method in improving voltage sag.

The organization of the remainder of the paper is as follows: section 2 contains a detailed voltage dip analysis with and without the presence of DG resources; section 3 will focus on presented approach followed by a brief description about BPSO algorithm; case study and analysis of results is given in section 4, and finally sections 5 and 6 deal with the conclusion and references.

2. Voltage Sag Analysis and the Effects of Reconfiguration and DG Resources Placement

Faults are of those common sources of hazard in power systems which occur due to different reasons such as lightning and accidental shorting of the phases by trees or animals. A fault might cause a power outage in a small area; however, the voltage level of a much larger area of the grid is pulled down since the entire grid tries to feed the fault. Voltage sag is defined as a decrease in rms voltage between 0.1 and 0.9 pu, at the power frequency, for a duration of 0.5 cycles to 1 min [8]. Main utility efforts in voltage sag mitigation contain four parts: 1- Reducing the number of faults by tree trimming, the installation of lightning arresters … 2- Reducing the fault-clearing time through using faster protection equipments which affects the duration of voltage sag 3- Increasing the electrical distance between the fault and the sensitive bus by changing system configuration. 4- Increasing short circuit capacity of system by DG resources installation. Compared to asymmetrical faults (e.g. phase-to-ground, phase-to-phase or two phases-to-ground faults), symmetrical ones cause the deepest sags due to the most severe faults they cause; however, they are not the most frequent faults in the system. Considering the hazards of symmetrical faults, the worst cases are studied in this paper.

2.1 The Effect of Reconfiguration

In radial networks, the model like Figure 1 is used to calculate the voltage sag. Neglecting the load current, PCC voltage and thus the voltage at the load can be found according to equation 1 [13].

$$V_{sag} = \frac{Z_2}{Z_1 + Z_2} \tag{1}$$

where V_{sag} is the voltage magnitude of sensitive bus or PCC after fault. Z_1 is the source impedance at PCC and Z_2 is the impedance between PCC and fault location.

The voltage magnitude of sensitive loads should be never below critical value. Reconfiguration increases sensitive bus voltage after fault through the change in impedance between sensitive bus and fault location (Z_2) i.e. voltage sag can easily change with the change in network configuration. Furthermore, the network configuration is effective in the The venin impedance in sensitive bus (Z_1).

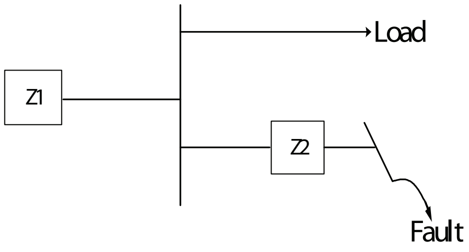

Figure 1. The model for short circuit fault analysis in radial distribution systems.

Source: Biswas S et al. [13]

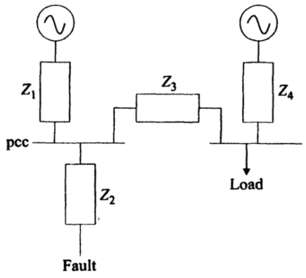

Figure 2. The modified model for including distributed generation.

2.2 The Effect of DG Resources Installation

Figure 2 illustrates the modified model when distributed generation is in the network. Z_3 is the impedance between PCC and DG resources and Z_4 is transient reactance of the DG resources. The sag magnitude at the load can be calculated in 2.

$$V_{sag} = 1 - \left[\frac{Z_4}{Z_3 + Z_4} \left(1 - V_{pcc}\right) \right] \tag{2}$$

Increasing DG resources capacity leads to branch-power flow decrease, voltage-drop decrease and approaching V_{pcc} to 1 P.U as a normal value. As a result, the sensitive load voltage increases according to 2. Moreover, the location of DG resources has effects on Z_3 and by increasing Z_3 sensitive load voltage can increase.

3. The Suggested Method: Using Reconfiguration and DG Resource Placement Simultaneously

As mentioned in section 2, both reconfiguration and DG resource installation methods can improve voltage sag. Applying both simultaneously to decrease voltage sag is the proposed method in this paper which tries to get the best configuration and DG resource capacity.

3.1 Choosing Objective Function

For sensitive loads it is necessary to estimate how many times in a year the voltage at their terminal will experience sag to avoid tripping of operation [14]. Short circuit in all buses can cause voltage sag in these loads which leads to the voltage below V_{cri} in some cases where sensitive loads cannot continue working and end in their tripping and economic losses. To Minimize the number of times that the voltage of sensitive loads fell below V_{cri} presented by N_{dist}, Equation three is the objective of this paper

$$Minimize\, N_{dist} = \sum_{i=1}^{n} N_i \quad (3)$$

where, i is the number of sensitive loads, N_i is the number of times the voltage of sensitive loads fell below V_{cri}, and n is supposed to be the number of sensitive loads.

3.2 Constraints

Some security and operational constraints should be taken into account in actual distribution systems, the considered constraints in this paper are given in next sections.

3.2.1 Radial Structure of System

In reconfiguration process, the network is required to remain radial, and to test it, graph theory is applied. A is bus incidence matrix which indicates that the network is not radial when its determinant is equal to zero. For the network to be radial, it should observe a condition in 4.

$$\det(A) = 1 \, or -1 \quad (4)$$

3.2.2 Maximum Capacity of DG Resource

In this study, DG resource location is considered to be definite and it is aimed to obtain DG resource optimal capacity. In simulation processes DG resource Capacity applies discrete values whose maximum will be determined according to Network Standards and available resource. Furthermore, the DG resource works in unity power factor and injects only active power to the network.

$$DG < DG_{\max} \quad (5)$$

3.2.3 Maximum Power Flow of Branches

$S_{k,k+1}$ is the power flow between buses k and k+1 which must not exceed the maximum power flow between buses k and k+1

$$S_{k,k+1} < S_{k,k+1} max \quad (6)$$

3.2.4 Power Loss of System

Considering the significance of the number of load disturb due to voltage sag, power loss can be taken as a soft constraint. P_{loss}(*initial*) is the power loss of main configuration A condition for singling out the configuration is having lesser loss than the initial one.

$$P_{loss} < P_{loss}(initial) \quad (7)$$

3.2.5 Maximum Allowed Voltage of Buses

The voltage of other non-sensitive buses must also be in normal range; however, the normal range in these buses encompasses a larger range than sensitive busses.

$$V_{min} \le |Vk| \le V_{max} \quad (8)$$

3.3 The Objective Function Optimization

For optimizing such a complex and constrained function, a heuristic algorithm should be used. One of the most common algorithms is PSO. PSO has been motivated by the behavior of organisms, such as fish schooling and bird flocking [15]. It is a derivative-free algorithm unlike many conventional techniques and is less sensitive to the nature of the objective function. It can also handle objective functions with stochastic nature and does not require a good initial solution to start its iteration process [16]. Since in reconfiguration problem the main variable is switches status and they are discrete, Binary version of PSO algorithm named BPSO is used.

Using BPSO as main optimization method, the flow chart in Figure 3 is implemented. To achieve the best configuration. This process is repeated in every DG resource capacity and the best configuration for having minimum voltage sag will be selected for that capacity. Comparing the voltage sag index of the best configuration in each capacity,

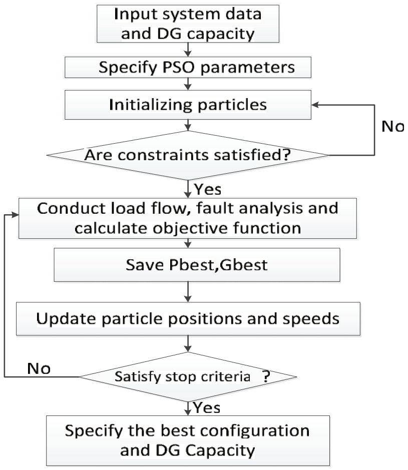

Figure 3. Flow chart of the suggested method.

the best configuration and the best DG resource capacity will be singled out.

In the BPSO method The position and the velocity of the ith individual are represented as vectors $x_i = (x_{i1}, x_{i2}, \ldots, x_{iD})$ and $v_i = (v_{i1}, v_{i2}, \ldots, v_{iD})$, respectively where x_{ij} shows the status of switch. The best previous experience of the i^{th} particle is recorded and represented by $p_i = (p_{i1}, p_{i2}, \ldots, p_{iD})$. Also reconfiguration problem will be indeed more difficult task as the electric systems must mostly configured radial for proper relay coordination. Most of intelligent optimization techniques, by their random nature, generate non-radial configurations which makes the process of reconfiguration time-consuming. So a change in the original BPSO is needed. In order to retain the radial structure and reduce search requirements, the following modified procedure is used to update the state of x_{id} [17]:

```
for $d = 1 : D$

        $vid = \omega \times vid + c1 \times randNO1 \times (pid - xid)$
                $+ c2 \times randNO2 \times (pgd - xid)$                (9)
        $rid = S(vid) - randNO1$

end

for $d = 1 : D$

        if $(rid <$ the qth lowest value of all $ri)$
            then $xid = 0$                                              (10)
        Else $rid = 1$
        End

end
```

where, C_1, C_2 are learning factors which named also acceleration coefficients. Low values of acceleration coefficients allow particles to roam far from the target regions, before being tugged Back. On the other hand, high values result in abrupt movement towards or past the Target regions [16]. Hence the learning factors C_1, C_2 are often set to 2.0 according to early experiences [18]. $Rand_i$ is a random number between 0 and 1 and w is inertia weight. A larger inertia weight facilitates global exploration while a smaller inertia weight tends to facilitate local exploration. A suitable selection of the inertia weight ω can provide a balance between global and local exploration abilities. The following weighting function is usually utilized [19].

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{iter_{\max}} \times iter \tag{11}$$

where $\omega_{\max}$ is the initial weight, $\omega_{\min}$ is the final weight, $iter_{\max}$ is the maximum iteration number, and *iter* is the current iteration number.

4. Numerical Results and Discussions

4.1 Test System

Figure 4 illustrates the base configuration of the studied network, which is basically the case study in previous papers, with 33 buses, 32 normally closed and 5 normally open switches, where the voltage, active and reactive loads are 12.66 KV, 5084.26 KW and 2547.32 KVAR respectively. Bearing more loads than the others, buses 6, 7, 23, 24 and 31 are selected as the sensitive ones. The total power loss for main configuration is 203 KW. The network detailed data is available in ref. [20].

4.2 Simulation

Based on section three, the acceleration coefficients $C1$, $C2$ are set to 2. The values $\omega_{max} = 1.2$, $\omega_{min} = 0.2$ used in simulation are derived from [5]. The number of particles of pso algorithm is 50 and the number of iteration is 200. The more the number of iterations, the more accurate the results will be, but the lesser speed. In the simulation, it was observed that the suggested particle and iteration values are appropriate. To analyze the efficiency of the proposed approach (simultaneous reconfiguration and DG installation), four scenarios are considered, all programmed in MATLAB.

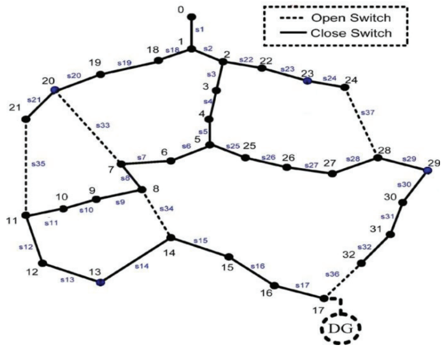

Figure 4. The network under study.

Scenario 1: The network is without reconfiguration and DG (main case)

Scenario 2: The network is with reconfiguration and without DG

Scenario 3: The network is without reconfiguration and with DG

Scenario 4: The network is with reconfiguration and DG

4.3 Discussion

In the above-mentioned network, voltage sag index is 159 before reconfiguration and DG installation (scenario I). In the third scenario DG was installed in bus 17 (in the end of the network where the voltage is normally lower than other buses) and the best capacity of DG was achieved to have the minimum index of voltage sag. Like in the third scenario, in scenario 4, DG is installed in bus 17, the best configuration was found for each capacity of DG and finally the best capacity and configuration was obtained. Simulation results are presented in Table 1.

It is observable in Table 1 that voltage sag index changes from 159 in scenario 1 to 47, 158 and 38 in scenarios 2, 3 and 4. The percentage of voltage sag reduction in scenarios 2 to 4 is respectively 70, 1 and 76. It indicates that voltage sag index in case 4 improved more in comparison with other cases, a conclusive proof to the efficiency of the suggested method. In comparison with scenario two where only reconfiguration is used, in scenario three, when only DG is installed, the improvement percentage of voltage sag is trivial which shows the inefficiency of the DG installation for current network.

Table 1. Results of simulation for test on 33-bus system

Scenario	DG	Open Swithces	N_{dist}	$\%N_{dist}$ Reduction
1	0	33,34,35,36,37	159	–
2	0	6,12,17,23,33	47	70
3	1.8	33,34,35,36,37	158	1
4	3	6,9,14,23,33	38	76

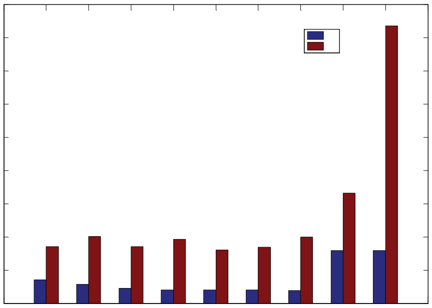

Figure 5. Number of load disturb and loss variation with DG size.

As seen in Figure 5, the increase in the capacity of DG from 0 to 3 KW will lead to the voltage sag index reduction; however, the loss will not necessarily decrease mainly because the voltage sag is assumed as the objective function, where the loss lesser than initial one is taken as a soft constraint It can also be observed that the best capacity is 3 KW.

Figure 6 illustrates the relationship between the iteration times and N_{dist} when the capacity of DG is 3 KW. This shows 75% improvement in voltage sag index, when simultaneous reconfiguration and DG placement is applied.

Figure 7 shows the power-flow comparison in branches in scenarios 1 and 4 (before and after the suggested method implementation). It is obvious that after simultaneous reconfiguration and DG placement, there is a power flow

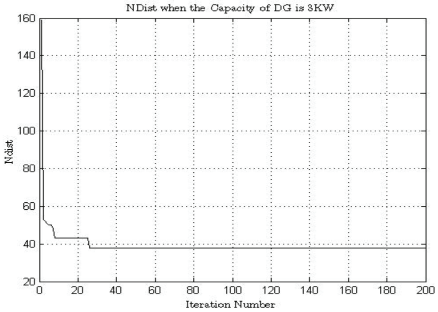

Figure 6. Convergence of PSO when DG = 3 KW.

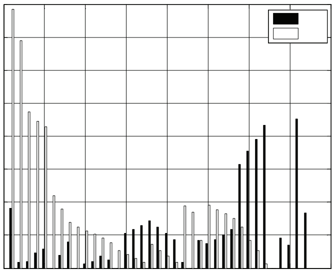

Figure 7. Power flow in branches before and after implementing the suggested method.

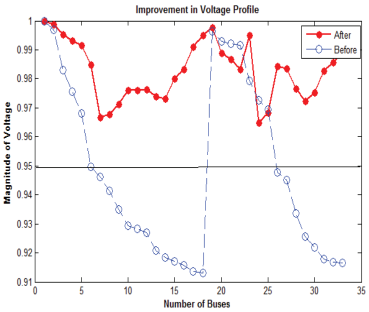

Figure 8. Voltage profile of system before and after implementing the suggested method.

decrease in all branches except for the branches 33–37 since they are open in the initial configuration.

Figure 8 illustrates the voltage profile curves of buses before and after implementing the suggested method. According to this figure before applying the suggested method, the voltages of 20 buses are below the critical voltage and after implementing suggested method are placed in normal range. The voltage profile comparison indicates that voltage becomes worse only in 4 buses which is negligible and will not fall these voltages below the critical voltage.

5. Conclusion

This paper involve in finding the best configuration and DG capacity in a distribution system for minimizing voltage sag. Simulation results show that using reconfiguration simultaneous with DG placement, can improve voltage sag index 75%. Moreover, the configuration that is best for having minimum voltage sag would not be the best when the DG is introduced, therefore the best configuration should be found. Furthermore, if Due to some constraints, the DG capacity changed, the configuration should also be changed for having minimum voltage index. In sum minimizing voltage sag requires coordination between the configuration of the network and the DG capacity. It is highly recommended to test the paper method on another radial distribution network to observe the efficiency of method properly. When the DG should be installed in the system, a comprehensive study should conduct to see its effect on many parameters, in this study, coordination between DG placement and reconfiguration is proposed which helps subsequent researches. As previously mentioned, the network under study is one of the common networks that was used in the papers about distribution networks reconfiguration; however, this network limits DG integration. The other drawback of this work is that three phase faults are only considered. This problem can be solved in future researches. While this paper focuses on DG impact on power quality and power loss, for using this method practically in actual distribution networks, the DG impact on other technical and economic issues should be considered.

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