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Multi-Objective Function Optimization for Locating and Sizing of Distributed Generation Sources in Radial Distribution Networks with Fuse and Recloser Protection

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Abstract- Power quality, reliability, loss reduction, and fault clearing times are essential factors in distribution networks. Radial distribution networks often face two problems, line losses and voltage drop at the end of the grid. Connecting distributed generation (DG) can resolve these problems, but it can also cause miscoordination. Protection coordination in the presence of DGs is a major challenge of radial networks. Herein, the optimal location and size of DGs in a radial distribution network protected by fuse and recloser were determined to modify bus voltage profile and reduce active-reactive lines' losses. Since the protection coordinate was eliminated by connecting DGs to the network, by using the SFCL in the output of DGs and minimizing its size, it attempted to restore the protection coordination between the fuse and the recloser. In this method, a nonlinear multi-objective function was introduced to be optimized by genetic and PSO algorithms. The simulation was performed in DIgSILENT software. The effectiveness of the proposed method was verified via IEEE 33-bus test systems.

Keyword: Voltage profile, line losses, SFCL size, Fuse-recloser coordination.

1. INTRODUCTION

The operation of distribution systems is changing with the development of new technologies that aim to improve energy supply. The use of small production units near consumers, known as distributed generation (DG) units, is an effective solution to meet the growing demand for consumption and improve energy supply [1]. DGs can reduce power losses in distribution systems and improve power quality and voltage profile [2-3]. Traditional radial distribution networks are not designed for DG connectivity. Therefore, the presence of DG in these networks causes challenges in network operation such as voltage control, active and reactive energy management, and protection coordination [4]. To connect DGs to the distribution network, two important characteristics of size and location must be considered. In recent studies, for sizing and locating DGs, some parameters such as grid power losses and voltage profiles have been optimized with single and multi-objective functions[5-6].

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Research Paper

Overcurrent protection in distribution networks is very important. On the other hand, by connecting DGs to the networks, protection coordination may be disrupted and needs to be restored according to the type of protection equipment [7-8]. About 80% of faults occurring in distribution systems are temporary, and reclosers and fuses are widely used for overcurrent protection because a recloser can clear a temporary fault before melting the fuse [9]. Reclosers are usually installed at main feeders and fuses on lateral branches. The operation coordination of fuses, reclosers, and relays is a crucial issue. DG integration to a distribution network causes changes in fault current. Thus, the coordination between the protection devices can be eliminated [10]. Several methods have been proposed to keep the coordination of protection devices in the presence of DGs and tried to improve the operation time of protective devices, but the location and size of the DGs is not optimized [12–14]. In Ref. [11] the maximum capacity of DGs that would assure coordination between the recloser and fuses on the distribution network has been determined. However, this method limits the size of the DG connected to a system and blocks other operational benefits of DG such as the best voltage profile and loss reduction. Fault current limiters (FCL) have emerged as an active and effective way to limit fault currents. They provide sudden extra impedance on the way of the increased current. In general, an FCL provides small impedance under normal system conditions and large impedance during fault conditions. FCLs may lower system reliability and increase cost and operational complexity [15,16]. FCLs have various types, such as explosive limiters, solid-state FCL, and SFCL [17]. In Ref. [18], the effectiveness of R-SFCL to restore recloser-fuse coordination without considering an auto-reclosing scheme was studied. This reference also proposed solution methods based on three configurations of R-SFCL to maintain recloser-fuse coordination when the auto-reclosing scheme was considered, but the minimum time of operation of fuse and recloser was not considered. In Ref. [19], a genetic algorithm was utilized to find the optimal FCLs to minimize fault current under DG integration. The same was done in Ref. [20] using particle swarm optimization (PSO), but by changing the size of DG, the coordination was eliminated. Moreover, the minimum time of operation of the fuse and recloser was neglected.

Based on the valuable studies conducted on locating and optimizing DG size, conservation coordination has been studied in a variety of ways. In this paper, the locations and size of DG resources are first optimized using the primary objective function, and this optimization is carried out with respect to the active and reactive lines' losses and the voltage drop of the buses with the weighted function. Then, the fuse and the recloser coordination in the presence of the distributed sources with creating faults in the network is checked. Depending on the level and direction of the network fault currents, the protective coordination parameters may change or disappear. Next, by using the minimum SFCL size, it is attempted to reduce faults' currents and restore the protective coordination by reducing the operating time of the fuse and recloser.

2. LOCATING AND OPTIMIZING DG SIZE

To solve the problems of the radial network, it is possible to use DGs and connect them to the distribution network. The main achievements of using DGs are active and reactive power loss reduction, the rectification of the voltage profile, and improvement of reliability. For this purpose, the size and installation location of DGs are of great importance.

2.1. Voltage Profile index

Connecting the DGs to DN can improve the bus voltage drop from the reference value. The bus voltage drops are due to the long lines and their impedance; thus, increasing the load will increase the main feeder current and causes voltage drops. By connecting the DGs, one can generate power in the load location and reduce the voltage drop caused by line resistance losses. Eq. (1) can be used to calculate the total voltage drop of buses and adopted as an objective function [2]:

$$\mathrm{VPI}=\sum_{bus=1}^{All\ buses}\frac{V_{ref}-V_{busi}}{V_{ref}} \tag{1}$$

Where, V_{ref} is the normal voltage of slack bus and equal to 1 per unit, and V_{busi} is the voltage of any bus that can be under- or overvoltage.

2.2. Power losses in distribution lines

Active and reactive power losses change after the presence of DGs in the distribution networks because of the changing power flow in all lines. By connecting DG to a radial distribution network, the power flowing from the main source is reduced; then, by reducing the current of their distribution lines, active and reactive power losses are also decreased. Equations (2) and (3) are defined to evaluate the variations of active and reactive power losses compared to not using a DG [2].

$$\mathrm{PLI}=\frac{\sum^{All\ Lines}PL_{dg}}{PL_{nodg}} \tag{2}$$

$$\mathrm{QLI}=\frac{\sum^{All\ Lines}QL_{dg}}{QL_{nodg}} \tag{3}$$

Where PLI is variations of active power losses, PL_{dg} is active power losses in the presence of DG, PL_{nodg} is active power losses with no DG, QLI is variations of reactive power losses, QL_{dg} is reactive power losses in the presence of DG, and QL_{nodg} is reactive power losses with no DG in all the lines. This equation can be used for a part of the multi-objective function.

2.3. Restrictions and constraints on the use of DG

Interconnecting a DG to the network should not corrupt the operation of network protection devices. which means that the requirements for proper network operation would be met and load response is done correctly. The considered constraints are as follows:

- The sum of all inputs and the load of the network is zero with respect to losses and DGs' power.

$$P_{sys}=P_d+Ploss-Pdg \tag{4}$$

Where P_{sys} is the main source power, P_{loss} is network power losses, P_D is network demand, and P_{dg} is power generation by DGs.

- The bus voltage should not exceed the upper and lower limits of the grid. This value is provided by the distribution company and is usually between 0.95 and 1.05 *PU*.

$$V_{min}\le V_{bus}\le V_{max} \tag{5}$$

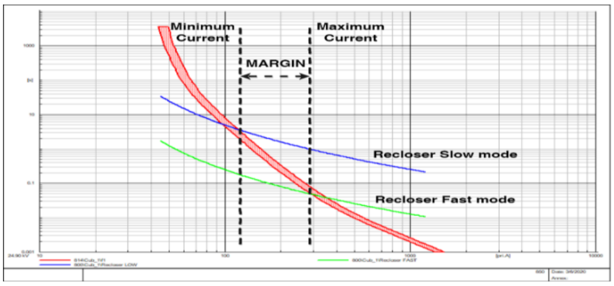

Fig. 1. Coordination of fuses and reclosers

Where the V_{bus} is the voltage of each bus, V_{min} is the minimum bus voltage and equal to 0.95 *PU*, and V_{max} is the maximum bus voltage and equal to 1.05 *PU*.

- The permitted capacity of each DG varies depending on its type. There may also be restrictions on the location of DG units for all types of networks.

$$S_{min} \le S_{dgi} \le S_{max} \tag{6}$$

Where S_{dgi} is the capacity of each DG, S_{min} is the minimum capacity of DGs, and S_{max} is the maximum capacity of DGs.

- The following requirement must be met in order to limit the transmission power to the upstream network:

$$\sum S_{dgi} \le \sum S_d + S_{loss} \tag{7}$$

Where, S_{dgi} denotes the apparent power of each DG, S_D indicates the apparent demand, and S_{loss} stands for active and reactive energy losses in the network.

3. NETWORKS PROTECTION COORDINATION

The operation time of overcurrent protection is according to the maximum load and fault currents that can be calculated in the offline mode. Protective coordination means that the operation of each protection device must be at the proper time. Protection coordination may be impaired for a variety of reasons. The most important protection devices in distribution networks are relays, fuses, and reclosers. In the meantime, the use of fuses and reclosers in distribution networks has been greatly welcomed due to lower installation costs. The DG entry can be a reason for the fuse and recloser protection miscoordination in distribution networks due to the change in the value and direction of short-circuit currents.

3.1. Protection Coordination of Fuse and Recloser

One of the essential requirements of protection systems is the coordination of protection devices so that the protection system minimizes uninterrupted subscribers when the fault occurs with the least possible interruption. Coordination between the fuse and recloser as two main protection devices is one of the most challenging issues in the distribution system, especially in the presence of DG. The reclosers are usually installed on the main feeders of the distribution networks and the fuses are mounted on the branches. The order of performance should be as follows:

- The first step involves the fast operation of a recloser, opening the main feeder temporarily, and closing it after a certain period. If the fault is temporary, the high-pass current will be eliminated at this stage, and there will be no need for other protective equipment to operate.
- In the next step, if the fault exists after the fast operation of a recloser, the fuse will operate, and the faulty branch is completely disconnected.
- If each lateral fuse fails to operate, the recloser delay function will open the network and the main feeder will be powered off until the fault is completely eliminated.

Fig. 1 displays this coordination of fuses and reclosers in the specified current range. Usually, this range is selected so that it includes the minimum short-circuit current to the maximum short-circuit current.

3.2. Fuse and Recloser Operation time

The operation time of the fuse and recloser can be described mathematically. The operation time of the fuse is obtained using Equation (8) [10].

$$t_{opF} = \exp(a \times \log(I_{FF}) + b) \tag{8}$$

Where t_{opF} is the burning time of the fuse, I_{FF} is the current passing the fuse in fault times, and *'a'* and *'b'* are performance characteristics depending on the type of fuses. The operation time of the recloser is obtained using Eqns. (9) and (10) [10]:

$$t_{opR,fm} = TDS_{fm} \times \frac{A}{(I_{FR} / PCS)^P} + B \tag{9}$$

$$t_{opR,sm} = TDS_{sm} \times \frac{A}{(I_{FR} / PCS)^P} + B \tag{10}$$

Where $t_{opR,fm}$ is the fast operation time of the recloser, $t_{opR,sm}$ is the delayed operation time of the recloser, TDS_{fm} and TDS_{sm} are the time dial setting of the recloser, I_{FR} is the current passing the recloser in fault times, *'A'* and *'B'* are performance characteristics depending on the type of the recloser, and *PCS* is the fault current factor obtained using Equation (11) [10]:

$$PCS = OLF \times I_{Lmax} \tag{11}$$

where I_{Lmax} is the maximum load current and *OLF* is the overloading factor. Using mathematical equations and the current passing through protection devices, operation time can be calculated, and the coordination of the protection devices can be studied.

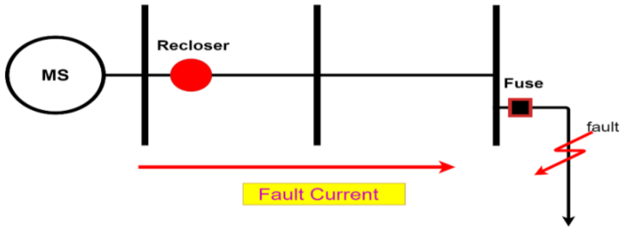

Fig. 2. Radial distribution networks no dg

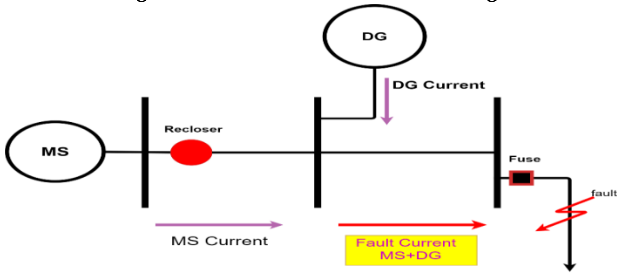

Fig. 3. Radial distribution networks with DG

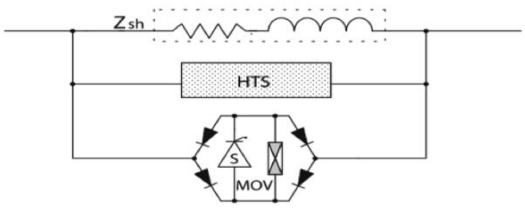

Fig. 4. Hybrid SFCL

In radial distribution networks, the TDS settings are usually adjusted so that the fuse inverse time-current diagram is between the fast and delay inverse time-current diagram of the recloser. In this case, since the fault current flows through both fuse and recloser, the order of operation will be: 1) fast recloser, 2) fuse, 3) delayed recloser, showing that protective coordination exists. Fig. 2 shows this radial type of network.

By connecting a DG to the network, the fault and stream direction will change. Due to Equations (1-3) and the protective devices' setting, the operating time of the devices is only dependent on the flows' current and by increasing the current, the device operates faster. As shown in Fig. 3, with the presence of DG, the increased fuse current and the order of operation can be: 1) fuse, 2) fast recloser, 3) delayed recloser, showing that miscoordination has occurred.

3.3. Protection Coordination Formulation

The protection coordination problem of fuses and reclosers are formulated as an *NLP* optimization problem with nonlinear objective function and nonlinear constraints. The proposed objective function intends to minimize the sum of operating times of all fuses and reclosers for all fault locations F as follows:

$$POT=\sum_{f=1}^{f=n}\sum_{i}^{k} t_{opRfm}+t_{opRsm}+t_{opF} \tag{12}$$

The nonlinear constraints for this multi-objective function are:

- The time interval between the first fuse and fast mode recloser must be available, and the recloser must operate faster than the first fuse:

$$t_{opF,jk}-top_{R,fm}>MRCTI \tag{13}$$

- The time interval between all fuses and the backup fuse must be available:

$$t_{opF,(jk+1)}-top_{F,jk}>MFCTI \tag{14}$$

- The time interval between the last fuse and the slow mode recloser must be available, and the recloser must be operated after the last fuse:

$$t_{opR,sm}-top_{F,nk}>MRCTI/2 \tag{15}$$

- The time interval between the fast and the delayed mode for reclosers must be available:

$$t_{opR,sm}-top_{R,fm}<MRCO \tag{16}$$

- All the time dial settings can change their value in a certain range:

$$TDS_{min}\le TDS_{fm}\le TDS_{max} \tag{17}$$

$$TDS_{min}\le TDS_{sm}\le TDS_{max} \tag{18}$$

To use this objective function as a multi-objective function and optimization problem, it can be introduced as *CTDI* (coordination time deviation index) by considering all above constraints. Eq. (19) explains this:

$$CTDI=\sum_{f=1}^{f=n}\sum_{i}^{k}\frac{t_{opRfm\ with\ DG}}{t_{opRfm\ no\ DG}}+\frac{t_{opRsm\ with\ DG}}{t_{opRsm\ no\ DG}}+\frac{t_{op\ F\ with\ DG}}{t_{op\ F\ no\ DG}} \tag{19}$$

4. USE SFCL TO RESTORE PROTECTION COORDINATION

Various methods have been proposed in radial distribution networks with fuse and recloser protection to restore lost protection coordination. One of the best ways is to use SFCLs. The SFCL includes a variable current-temperature-current impedance that has no effect on the normal operating condition of the network but can increase impedance by raising the passing current. These limiters have different types of resistor, inductive, diode bridge, and hybrid. This article uses a hybrid type to restore lost conservation coordination [14]. Fig. 4 illustrates the circuit of this limiter.

Since the loss of protection coordination is due to the connection of DGs, it is best to install them at the output of these sources to limit their injections' current at faulty times. The size of these limiters determines their impedance and the amount of current limiting. If they are low, the limitations are not implemented properly, there is no protection coordination, and high amounts cause network losses. Consequently, its size is very important. Using Eq. (20) one can calculate the minimum size of SFCLs when there is protection coordination in the network. Since the cost of producing SFCLs is highly dependent on their size, the cost of producing them will also be greatly reduced.

$$SFCL_{size} = \sum_{i=1}^{AllSFCL} Ri + jXi \tag{20}$$

The constraint for this objective function is:

$$Z_{min\ sfcl} \le R_i + jX_i \le Z_{max\ sfcl} \tag{21}$$

5. PROPOSED MULTI-OBJECTIVE FUNCTION

The proposed multi-objective function consists of two separate parts: The first part modifies the bus voltage profiles and reduces line losses by considering Equations (1-3), and the second part optimizes the protection coordination and decreases the total operating time using SFCL.

5.1. First multi-objective function

The location of DGs in the radial distribution network is obtained by optimizing Objective Function 1 (22):

$$OF1 = MIN\left(w1*\sum_{L=1}^{Ln} PLI + w2*\sum_{L=1}^{LN} QLI + w3*\sum_{B=1}^{BN} VPI \right) \tag{22}$$

Where *"L"* is each line and *"B"* is each bus in the distribution network. This function minimizes the deviation from the reference voltage and reduces the sum of the line losses, each function being weighted by *W1-W3*. Depending on the importance of each parameter, they can include more weight, and the sum of weights (*W1*, *W2*, and *W3*) is equal to 1. This multi-objective function can be minimized by finding the best location of DGs and considering all the constraints.

5.2. Second multi-objective function

Connecting the DG to the network can cause fuse and recloser miscoordination. The developed Multi-objective Function 2 (23) from Eqns. (19–20) can restore the lost protection in the presence of DGs, reduce operation protection time, and decrease the size of SFCLs.

$$OF2 = \begin{cases} MIN\left(\sum_{f=1}^{f=n} \sum_{i}^{k} \frac{t_{opRfm\ with\ DG}}{t_{opRfm\ no\ DG}} + \frac{t_{opRsm\ with\ DG}}{t_{opRsm\ no\ DG}} + \frac{t_{opF\ with\ DG}}{t_{opF\ no\ DG}} \right) \\ MIN \sum_{i=1}^{All\ SFCL} Ri + jXi \end{cases} \tag{23}$$

This multi-objective function must be minimized with all the constraints for all parameters. Both objective functions can be minimized by optimization algorithms. The flowchart of the proposed design performance is displayed in Fig. 5.

6. SYSTEM TEST

The IEEE 33-bus network (Fig. 6) is simulated in DIgSILENT to evaluate the performance of the proposed strategy. Detailed data of this test system can be accessed in Ref. [20]. In the first step, to reduce line losses and improve bus voltage profile, 2 synchronous-

Table 1. Specifications of DGs

Name	Max Rated Power	Type	Max power SC
DG1	600kVA	synchronous	1.4MVA
DG2	800kVA	synchronous	1.9MVA

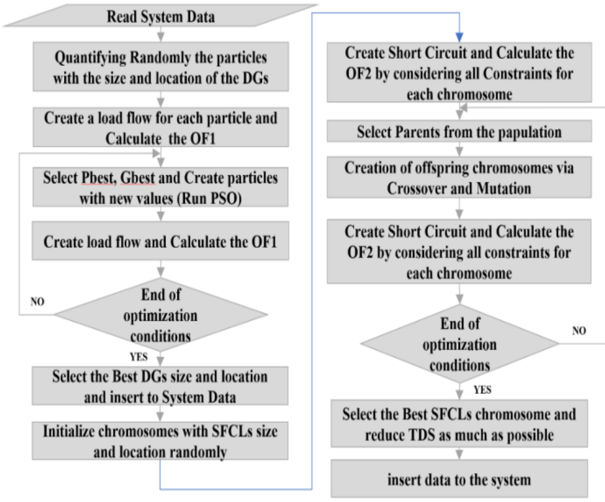

Fig. 5. The Flowchart of the proposed design

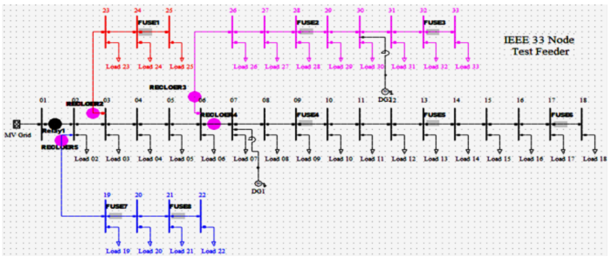

Fig. 6. IEEE 33-bus network

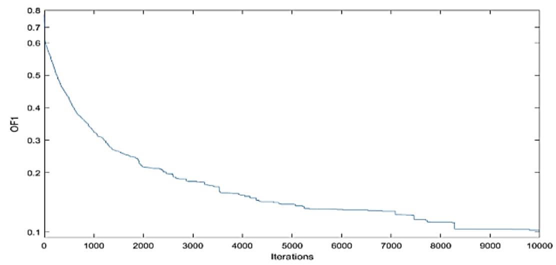

Fig. 7. Convergence diagram of PSO

-based DGs with a maximum of 600 kVA and 800 kVA capacity to this radial network system are connected. Details of DGs are presented in Table 1.

For the best location and sizing of DGs, one should minimize *OF1*. The DIgSILENT Programming Language (DPL), an added dimension to the DIgSILENT Power Factory program, allows the creation of new calculation functions for power system analysis, such as network optimization. Such calculation functions are written as program scripts that use load flow or short-circuit commands and mathematic expressions. The PSO algorithm coded in DPL-

DIgSILENT software is used for better performance. In this step, *w1=0.3*, *w2=0.3*, and *w3=0.4*, and the sum of DGs size <1310 kVA (30% of the maximum network loads) are considered. Optimization is performed with 50 particles and 10,000 replicates. Fig. 7 depicts the convergence diagram of PSO optimization. The best location and size of DG are obtained to minimize Objective Function 1 in Table 2. Fig. 8 shows all the buses' voltage profiles, and Fig. 9 illustrates total energy losses before and after connecting DGs to the network.

In the next step, protective coordination is examined. This network consists of one relay at the main feeder, four reclosers at the first point of the lateral network, and eight fuses on lateral branches. The details of the protection devices are depicted in Table 3.

Table 2. Size and install location of DGs

Name	Installing BUS	Active power	Reactive power
DG1	07	487kW	297kVAr
DG2	30	632kW	385kVAr

Table 3. Fuse, Relay and Recloser characteristics

Protection	Rated Current	Installed location	Type/configuration
Fuse1	250	Line 24	TYPE LBU-II
Fuse2	260	Line 28	TYPE LBU-II
Fuse3	200	Line 32	TYPE LBU-II
Fuse4	330	Line 09	TYPE LBU-II
Fuse5	280	Line 13	TYPE LBU-II
Fuse6	180	Line 17	TYPE LBU-II
Fuse7	310	Line 19	TYPE LBU-II
Fuse8	300	Line 21	TYPE LBU-II
Relay1	150A	Line 1	TDS=5.3, A=28.2, B=0.12, P=2, OLF =1.5
Recloser2	100A	Line 22	TDSF=0.75, TDSS=1.74, A=28.2, B=0.12, P=2, OLF =1.5
Recloser3	120A	Line 25	TDSF=0.85, TDSS=1.35, A=28.2, B=0.12, P=2, OLF =1.5
Recloser4	120A	Line 6	TDSF=1.32, TDSS=2.01, A=28.2, B=0.12, P=2, OLF =1.5
Recloser5	80A	Line 18	TDSF=1.51, TDSS=3.25, A=28.2, B=0.12, P=2, OLF =1.5

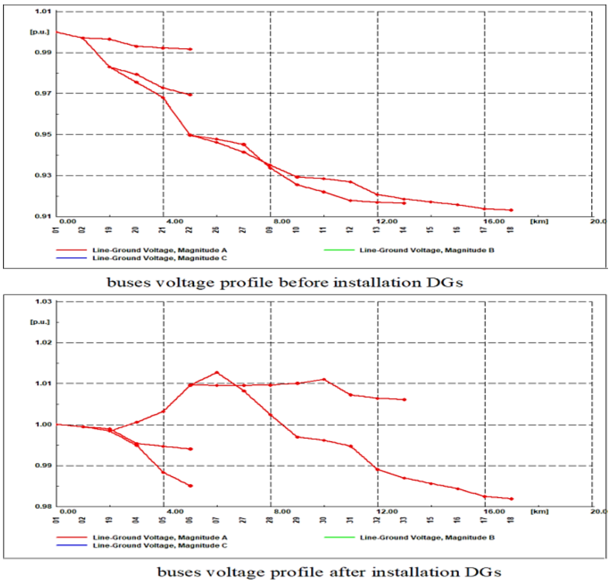

Fig. 8. All buses voltage profile before and after installation DGs

Table 4. Fuse, Relay and Recloser operating time

	Faulted bus	11	18	22	25	33
Without DGs	Operating Sequence FOR 3PH fault currents(ms)	R4F	R4F	R5F	R2F	R3F
		58	68	75	50	69
		F4	F6	F8	F1	F3
		654	269	283	259	278
		R4S	F5	F7	R2S	F2
		859	474	485	496	479
		RELAY	F4	R5S	RELAY	R3S
		1240	680	685	827	690
		----	R4S	RELAY	----	RELAY
		----	882	887	----	1623
		----	RELAY	----	----	----
		----	3272	----	----	----
	COORDINATION	YES	YES	YES	YES	YES
With DGs	Operating Sequence FOR 3PH fault currents(ms)	F4F	F4F	R5F	R2F	R3F
		58	81	74	49	78
		F4	F6	F8	F1	F3
		654	266	275	245	262
		R4S	F5	F7	R2S	F2
		758	469	476	492	491
		RELAY	F4	R5S	RELAY	R3S
		2037	672	685	869	783
		----	R4S	RELAY	----	RELAY
		----	1048	897	----	3231
		----	RELAY	----	----	----
			7703	----	----	----
	COORDINATION	NO	NO	YES	NO	NO

Table 5. Fuse, Relay and Recloser new TDS after optimization

Protection	Type/configuration
Relay1	TDS=5.2, A=28.2, B=0.12, P=2, OLF =1.5
Recloser2	TDSF=0.73, TDSS=1.81, A=28.2, B=0.12, P=2, OLF =1.5
Recloser3	TDSF=0.86, TDSS=1.31, A=28.2, B=0.12, P=2, OLF =1.5
Recloser4	TDSF=1.23, TDSS=2.11, A=28.2, B=0.12, P=2, OLF =1.5
Recloser5	TDSF=1.48, TDSS=3.28, A=28.2, B=0.12, P=2, OLF =1.5

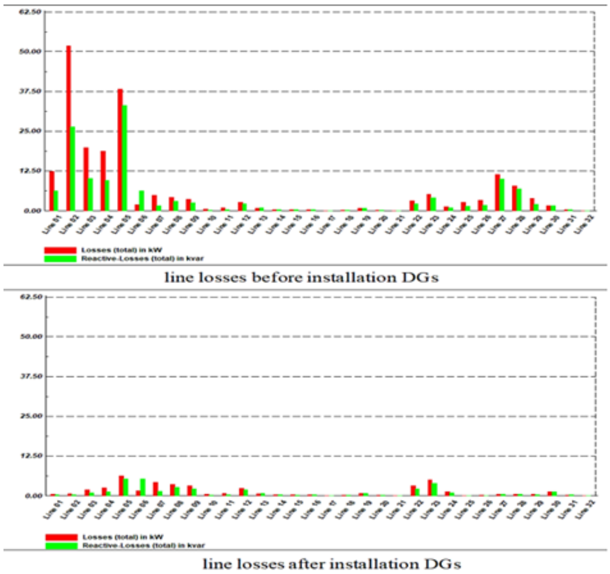

Fig. 9. All line energy losses before and after installation DGs

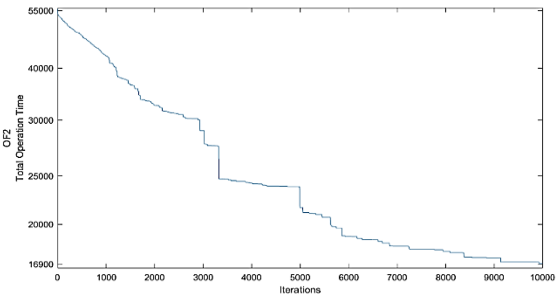

Fig. 10. Convergence diagram of GA

Table 6. Fuse, Relay and Recloser Operating time with DGs

	Faulted bus	11	18	22	25	33
With DGs AND SFCL	Operating Sequence FOR 3PH fault currents(ms)	R4F	R4F	R5F	R2F	R3F
		70	72	74	52	71
		F4	F6	F8	F1	F3
		630	272	283	255	271
		R4S	F5	F7	R2S	F2
		836	473	473	495	478
		RELAY	F4	R5S	RELAY	R3S
		1335	677	685	841	709
		----	R4S	RELAY	----	RELAY
		----	921	891	----	1904
		----	RELAY	----	----	----
		----	4198	----	----	----
	COORDINATION	YES	YES	YES	YES	YES
	TOTAL OPERATION TIME			16966 ms		

To determine the coincidence range of the minimum and maximum fault currents, the single-phase fault with *20-ohm* impedance and the three-phase fault with *1-ohm* impedance are taken into account. Protective coordination should exist in this area. Table 4 lists the operating time of the protective devices for maximum fault current without DGs and with DGs conditions. In the simulation, protection coordination for minimum fault currents is also considered.

Based on Table 4, by connecting the DGs with location and size obtained from the first step to the network, protection coordination is lost. It is suggested that this miscoordination be restored by connecting SFCL to the DGs' output. To calculate the SFCL impedance, Objective Function 2 and its optimization in DIgSILENT software such as Step 2 are used. This multi-objective function consists of two parts, the operating time of the protective devices and the size of the SFCLs. Since decreasing the SFCL size can increase the fault current and this increase in current will make the protective devices operate faster, SFCL value can be calculated by a genetic algorithm to minimize its size, and coordination at a minimum time can be achieved.

In this optimization, the range of SFCLs is $5-5j<R+jX<100+100j$ with respect to Ref. [21]. Moreover, protection coordination $CTI = 200ms$, $TDSmin = 0.2$, and $TDSmax = 9$ are also intended. The optimization was performed with 50 particles and 10000 replicates, which obtained the best values for both DGs ($DG1= 23.5+14.1j$ and $DG2= 11.53+6.8j$). Table 5 shows relay and reclosers' TDS after optimization in the presence of DGs. Fig. 10 illustrates the convergence diagram of GA optimization. Table 6 shows the operating time of the protective devices in the presence of DGs and SFCL. According to the settings obtained in Table 5 for the specifications of reclosers, as well as the sizes obtained for the SFCLs, and by applying these settings to the network and creating faults in different locations on network, performance time of protective devices (Table 6) shows that protective coordination for all reclosers and fuses is restored, and total operating time of network protection devices is reduced.

7. CONCLUSION

This paper proposed a two-part multi-objective function for optimizing voltage profiles and reducing network line losses. In the first part, the specification of the location and size of the DGs was assigned to minimize losses and bus voltage profiles. For this purpose, a weighted objective function was introduced to minimize the desired parameters, and then the protective coordination was checked in the presence of the obtained DGs. Since changes to network fault currents when connecting DGs caused miscoordination between the fuse and reclosers, the SFCL was used to recover miscoordination at the DGs output. In the second part, a multi-objective function was proposed for minimizing the operation time of the fuse and reclosers in fault time. According to the proposed method, the lowest SFCL value was calculated for which there was protective coordination with the desired constraint. The results showed that the proposed method can optimally optimize the two parts of loss reduction, voltage profile, and protection coordination in the presence of DGs.

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