INVESTIGATION OF THE IMPACT OF DG ON THE BEHAVIOUR OF NDEDC PROTECTION SYSTEMS

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ABSTRACT

The current global trend in the distribution networks is to use Distributed Generation (DG). The coordination problem between protection devices is a challenge which faces DG insertion to the distribution network. In this paper, the effect of DG on the distribution networks protection system is investigated. The real network of the North Delta Electric Distribution Company (NDEDC) in northern Egypt is studied. The study focuses on the over-current, the earth fault relays and auto-recloser (AR), where they represent the protection system used in distribution networks. The NDEDC real data are implemented with all of the protective devices which are modelled with their practical settings using Matlab/Simulink. Different scenarios for integrating the DG with the studied system have been implemented and discussed. Finally, recommendations are introduced for NDEDC protection systems.

INTRODUCTION

The traditional power system grid in most of the developing countries has a structure with an up-down power flow. The International Energy Agency (IEA) estimates that by 2020, the developing countries will need to double their electrical power output [1].
DG provides an attractive alternative solution for the world energy crisis. DG is an electrical power source connected directly to the distribution network and/or the customer site [2-3]. In [4] the positive impact of DG is presented. It mainly includes provision of voltage support, improved power quality, reduction in network losses, release of addition transmission and distribution capacity and improved reliability.
The protection issue is one of the main technical constraints which face DG insertion to the distribution network [5]. Relays false tripping and blinding of protection are mainly issues from the protection issues. False tripping occurs when a generation installed on a healthy zone contributes to the fault in another zone connected to the same substation; this can lead to false tripping of the relay in the healthy zone.
The protection blinding occurs because the DG contribution to the fault which reduces the grid contribution to the fault. Therefore, the short circuit current may be undetected by the grid protection relays [6].
In this work the impact of DG on the protection of traditional distribution networks in developing countries is studied. The study is applied on a part of the Egyptian distribution network; NDDEC, in northern Egypt. NDEDC is a sample of a traditional network designed for unidirectional electricity feeding.
The main objective of the paper is to find the maximum allowable DG penetration level that maintains the same protection system before DG integration. A Matlab/Simulink model is used to implement the investigated system. The study includes the over-current, earth fault relays and auto-recloser.

NETWORK DESCRIPTION AND MODELING

NDEDC Network Description

NDEDC network is supplied from the 220 kV Egyptian grid through 220/66/11 kV substations (SS). The 11 kV substations sides supply 167 Distribution Panels (DP). The 11 kV network feeders consist of either rural lines (OHL) or urban underground cables. The NDEDC real data are implemented with all of the protective devices which are modeled with their practical settings. Three real selected systems are used to simulate all protection systems in NDEDC: cable systems, OHL systems, and OHL-AR systems.

Cable System Modeling

Fig. 1 illustrates EL-Mokhtalat DP as a section of NDEDC network. It is a cable system which consists of three incoming feeders and eight outgoing feeders. Modeling has been performed in Matlab/Simulink with the help of Sim-Power-Systems toolbox (SPS) [7]. The loads of the outgoing feeders are centralized using constant impedances based on 11 kV. The cable data is verified with the actual onsite measured cable impedance. Then, the aging factor of the cables is calculated and implemented in the simulation. The system parameters are given in Table 1.
Both over current and earth fault relays are modeled in Simulink. The overcurrent relay model is picked from [8]. The vectorial sum of the three phase currents is used to represent the earth fault relay operation. A logic function is used to combine the output signals of the earth fault relay and the three overcurrent relays outputs, as shown in Fig. 2. The time delay is set to 0.2 seconds for outgoing and 0.5 seconds for incoming feeders. The current setting is given in Table 1.

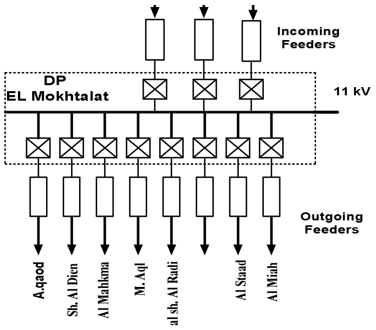

Fig. 1: The single line diagram of the test cable system

Table 1: The detailed feeder's data and protection setting

Feeder Name	*Impedance [Ω/km]*	*Overcurrent Setting [A]*	*Earth Fault Setting [A]*
Outgoing feeders	R=0.206 $X_{L=}$ 0.3	300	40
Incoming feeder	0.6	400	80

The cable system modeling is verified using both normal and fault conditions. The actual current flow is recorded and is compared with the simulation results of the same operating conditions. Table 2 gives a comparison between the measured and the simulated load currents for normal operating condition which verifies the model.

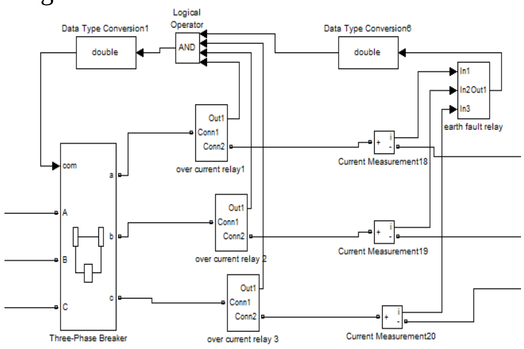

Fig. 2: Overcurrent and earth fault relays model

OHL System Modeling

The second feeder type is the OHL systems. The test feeders are selected in Qulongel substation. This studied part consists of five outgoing feeders. Table 3 gives a comparison between the actual measured and the simulated load currents which verifies the model. Table 4 gives the parameters of two feeders, the normal load current, the simulation fault current, and the over current and earth fault relays setting.

OHL-AR System Modeling

The third feeder type is the OHL system which contains AR. The test system consists of ten outgoing feeders from EL-Gamalia SS. The studied feeder is EL-Robiah feeder which feeds industrial heavy loads. The data of the feeders are given in Table 5. The studied system model is verified using the steady state conditions. The actual current flow is compared with the simulation results at the same operating conditions, as given in Table 5.

Table 2: Measured and simulated load currents for cable system

Feeder Name	*Measured load Current [A]*	*Simulated load Current [A]*	*%Error*
A. Qaood	95	97	2.1
Al Mahkma	110	110.4	0.363
AL-Sh. al-Radi	47	47.2	0.425
Qasr Al Thaqafa	70	72	2.85
Al Staad	80	82	2.5

Table 3: Measured and simulated load currents of OHL

Feeder Name	*Measured load Current [A]*	*Simulated load Current [A]*
Mansoura 5	196	199.5
Mansoura 4	222	227
Salamon	250	251.6
Mahl-Damna	280	279.5

Table 4: The OHL feeder's data and protection setting

Feeder Name	*Impedance (Ω)*	*Peak Load based on MV Side (A)*	*Over Current Setting (A)*	*Earth Fault Setting (A)*
Salamon	R=1.0771 X=0.853	250	480	80
Mahl-Damna	R=3.0771 X=0.853	280	720	80

Table 5: OHL-AR System Data and simulated load currents

Feeder Name	Total Impedance (Ω)		Load Current (A)	
	R	XL	Measured	Simulated
EL-Gamalia 1	0.201	0.28548	141	146
EL-Gamalia 2	0.21	0.28548	130	135
EL-Kafr EL-Gedid	2.96	5.387	195	194
EL-Robiah	8.588	8.98	250	251.8
Miah–Gamailiah	0.375	2.76	60	60

The minimum fault current and AR current setting for the selected El-Robiah feeder are 518 A and 500 A, respectively. It can be seen that, the feeder impedance is relatively high due to the long feeder path. This feeder is heavy loaded. Also, it can be observed that the minimum fault current value at the end of this feeder is close to the AR current setting value. This mean that, at the DG penetration with a small value, when the minimum fault analysis is applied, the fault current passing through AR may be less than AR pickup value that may cause protection blinding.

IMPACT OF DG ON PROTECTION DEVICES

In this section, the impact of the DG penetration on the protection devices is discussed for the three sample systems. The DG is added to the 2.9 MVA Al-Staad cable feeder, 7.5 MVA Salamon feeder as OHL system and 6.86 MVA EL-Robiah as OHL-AR system. Through this study two points are selected for the DG implementation; firstly at the end of the feeder and secondly at the middle of feeder.

The system is subjected to three phase faults because they are the most dangerous ones for both grid and the DG units. The protection devices coordination is tested by applying the fault and then the DG contribution to the fault current is examined. Three points are selected for fault application, namely; at the end and at the midpoint of the feeder and at the DP busbar. Furthermore, the DG penetration level is studied starting from 10% of the total feeder rated power.

Impact of DG on protection of cable feeders

In this section, DG1 is added to Al-Staad cable feeder. Firstly, DG1 is connected at the end of the feeder as shown in Fig. 3. Three phase faults are applied at points F1, F2, and F3, respectively.
For the faults at F1 or F2, both the network and DG1 share the fault current. The main protection relay, R2, operates to clear the fault, but DG1 still feeds the fault. The total results for this test case indicates to successful operation of the main protection relay, R2, and the successful coordination between R2 and the backup protection relay, R1.

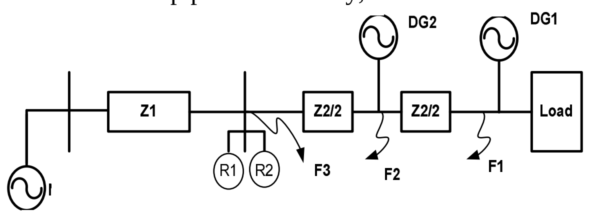

Fig. 3: Implementing the DG at the end of the feeder

For the fault at F3, the main protection relay, R1, is successfully operates for all DG1 penetration levels. Whereas, the DG1 continue feeding fault current even after the relay R1 operates. This leads the relay R2 to operate when the DG1 fault current exceeds its pickup value. This unexpected operation of the relay R2 is considered as an incoordination condition. The results are given in Table 6. It is observed that successful operation (S) is occurred up to 34% of DG penetration level. After that level there is incoordination and unexpected operation (F) for relay R2.
DG2 is added at the midpoint of the feeder instead of DG1 and the faults are applied. For the faults at F1 or F2, both the network and DG2 share the fault current. R2 operates to clear the fault, but DG2 still feeds the fault. It is found that, R2, successfully operates for all levels of the study and the coordination between R2 and R1 still success.

Table 6: DG1 implementation at the end of the cable feeder

DG Penetration Level	10%	30%	34%	40%	50%	60%
Fault Without DG [kA]	12.5					
DG Fault Current Sharing [A]	116	295	297	383	469	553
Relay Operation & Coordination	S	S	S	F	F	F

For the fault at F3, it can be seen that, the relay R1 operates to clear the fault, but DG2 still feeds the fault. Table 7 gives the total results for this test case. It can be observed that, fault current is still feeding from DG2 even after the relay R1 operates. This forces the relay R2 to operate when DG2 fault current exceeds its pickup value. This incoordination is occurred at 33% of the DG penetration level.

Table 7: DG implementation at the midpoint of the cable feeder

DG Penetration Level	10%	30%	33%	40%
Fault Without DG [kA]	12.5			
DG Fault Current Sharing [A]	100	297	318	390
Relay Operation & Coordination	S	S	F	F

From the results of the above test cases, it can be concluded that, the integration of DG at either the end or the midpoint of a feeder don't affect the coordination between the overcurrent relays at the feeder for small DG penetration levels. The DG doesn't affect the coordination between relays for any penetration levels when the faults occur at the end or at the midpoint of the feeder. In case that a fault occurs at the DP busbar (at F3), an incoordination starts to occur at 34% DG penetration level for the DG integrated to the end of the feeder and at 33% DG penetration level for the DG integrated to the midpoint of the feeder

Impact of DG on protection of OHL feeders

In this section, Salamon feeder as an industrial rural feeder is chosen to investigate the DG impacts on its protection system. The previous scenario is applied. For the faults at F1 or F2, the main protection relay, R2, successfully operates for all DG1 penetration levels. The coordination between the main protection relay, R2, and the backup protection relay, R1, still success.
For the fault at F3, it can be seen that, the relay R1 operates to clear the fault, but DG1 still feeds the fault. Table 8 gives the results for this case. It can be seen that, fault current is still feeding from DG1 even after the relay R1 operates. This leads the relay R2 to operate when the DG1 fault current exceeds its pickup value. This unexpected operation of the relay R2 is occurred at 24% of the DG penetration level.

Table 8: DG implementation at the end of the OHL feeder

DG Penetration Level	10%	22%	24%	30%
Fault Without DG [A]	9600			
DG Fault Current Sharing [A]	231	478	500	620
Relay Operation & Coordination	S	S	F	F

DG2 is then connected at the midpoint of the feeder instead of DG1. For the faults at F1 or F2, the main protection relay, R2, successfully operates for all DG2 penetration levels. The coordination between the main protection relay, R2, and the backup protection relay, R1, still success.
For the fault at F3, Table 9 gives the total results for this test case. It can be observed that the incoordination and unexpected operation of the relay R2 is occurred at 22% of DG2 penetration level.

Table 9: DG implementation at the middle of the OHL feeder

DG Penetration Level	10%	20%	22%	30%
Fault Without DG [A]	9600			
DG Fault Current Sharing [A]	193	450	557	492
Relay Operation & Coordination	S	S	F	F

Impact of DG on OHL-AR feeders

In this case, the effect of DG penetration on AR protection settings is investigated. EL-Robiah feeder is chosen for this case study. The feeder has industrial load and the AR is connected downstream of the feeder. For this case study DG is applied only at the end of the feeder. It is found that the minimum fault current at the end of this feeder is close to the current setting of the AR. Applying DG at this feeder reduces the network fault current passing through AR. The phase to phase fault is considered as the minimum fault that could be occurred in the network.

With increasing DG penetration level for the case that the fault is applied at the end of the feeder, the fault current passing through AR is reduced. At certain value of DG penetration level, the AR fault current is decreased to a value smaller than the AR current setting; i.e. AR will not operate to clear the fault. This case is called protection blinding which is a case that must be avoided for any protection system. The results are given in Table 10.

It is shown that the protection blinding of AR takes place at the value more than 12%, where the network sharing in fault current is 502.9 A which is very close to AR setting of 500 A. Above this critical penetration level, DG fault sharing is increased resulting in reducing the AR fault current than the current setting.

Table 10: DG implementation at the OHL-AR feeder

DG Penetration Level	10%	12%	20%	30%
Fault Without DG [A]	518			
DG Fault Current Sharing [A]	76.5	106	136.5	188
AR Fault Current [A]	509.5	502.9	476	463
AR Successful Operation ($I_{setting}$ =500A)	S	S	F	F

CONCLUSIONS

In this paper, the effect of DG on the distribution networks protection system is investigated. The real traditional network of NDEDC in Egypt is used for practical application of this investigation. Three real selected systems are used to simulate all protection systems in NDEDC: cable system, OHL system and OHL with AR system. Matlab/Simulink models of the NDEDC network and the protection devices are developed and detailed simulations with the real data are performed. The DG sharing in the fault current and the DG impact on the protection relays coordination for different DG locations are studied. Different scenarios are studied include: feeder type, location of DG, DG penetration level, and fault location. The investigation determines the maximum allowable penetration level which keeps the same coordination between protective devices.

Based on the simulation it can be concluded that:

- The DG location has an important effect on the maximum allowable DG penetration level. The best location of DG is at the end of the feeder for all feeders' types and the maximum allowable DG level decreases as the DG location get closer to the main busbar
- The total SC current does not exceed the designed value of the 11 kV equipments for any DG penetration level in all cases of study.
- The fault applied at busbar has the main impact on determining the maximum allowable DG level.
- DG implementation leads to significant reduction in grid contribution in case of OHL feeders than in case of cable feeders.

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