PROCEDURE FOR OPTIMAL SIZING AND LOCATING DISTRIBUTED GENERATOR ACCORDING NETWORK LOSSES AND PROTECTION CONSTRAINTS

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ABSTRACT

This paper introduces a procedure for sizing and locating Distributed Generator (DG) in order to loss reduction considering protection coordination constraints. Proposed method of the paper is a mixing of two different issues. One network losses and the other are impacts of DG on network protection. The procedure is useful in finding optimal size and location of DG that after installing to the primary distribution network lead to reducing active power losses of the network while satisfying protection constraints of the network. These protection constraints define an allowable range for DG size. Finally the effectiveness of procedure by help of MATLAB codes for a radial distribution network is examined.

INTRODUCTION

Penetration of distributed generators has different effects on network operation. Suitable sizing and locating DG, can reduce losses, improve voltage profiles and increase network reliability. Adverse effects of DG installing in the case of unsuitable sizing and locating is possible. So for achieving the maximum benefits of installing DG should define the problem as an optimization problem that depends on many parameters. Many researches are published in last years in the field of finding the optimal size and location of DGs. These researches are divided to two main branches. One branch is solving the DG Integration Problem via analytical and deterministic methods and the other solving the DG integration problem via Metaheuristic methods means that methods like GA (Genetic Algorithms), PSO (Particle Swarm Optimization), ACO (Ant Colony Optimization) and so on. However these researches is discussing the optimally dispatching DGs in distribution networks (DSs) and have different advantages and drawbacks but none of them considering the protection problems of connecting DGs to the network.

Adding the protection constraints to the optimally sizing and locating DG may be for its complex nature is not an interesting issue for researchers. Because it is very case dependent and needs to consider a lot of fault scenarios especially in large networks. Another problem is that uncertainness that is with distributed resources. DG may be connecting to the network or be disconnected. These make the problem more challenging. In some papers like [1] Short circuit level of the network after adding DG is considered as a protection coordination index. This simplification doesn't cover many protection problems of adding DG to the network. [2] Proposes a method for finding the optimal size of a wind turbine (when its location is fixed) considering voltage regulation and coordination of overcurrect relays. In [2] for desired location the proposed formulation of the paper for voltage regulation proposes a size. Then this size is applied to the network and coordination of overcurrent relays is checked. in [3] maximum allowable size of DG with respect to maximum and minimum allowable voltage of network buses, network losses reduction and protection coordination of fuses and reclosers of network, is achieved. The main drawback of [2] and [3] is that minimum allowable size of DG for prevent some of protection problems is not considered.

In this paper objective of finding optimum size and location of DG is to minimize the active power losses of the network while the size of DG is restricted by protection constraints after installing DG. Proposed method of the paper is a mixing of two different issues. One is network losses and the other protection problems of network after installing DG. Here all loads and generated power of DG is assumed to be constant.

OPTIMAL SIZE OF DG FOR LOSS REDUCTION

Expression (1) gives the total real power loss in power systems (P_L) that popularly known as "exact loss formula" [4].

$$P_L=\text{sum}_{i=1}^{n}[\text{sum}_{j=1}^{n}[\alpha_{ij}(P_iP_j+Q_iQ_j)+\beta_{ij}(Q_iP_j-P_iQ_j)]] \quad (1)$$

Where:
$\text{sum}_{i=1}^{n}$ and $\text{sum}_{j=1}^{n}$: summation symbol when desired parameter changes from 1 to n.
$\alpha_{ij}=(r_{ij}\cos(\delta_i-\delta_j))/(V_iV_i)$. $\beta_{ij}=(r_{ij}\sin(\delta_i-\delta_j))/(V_iV_i)$.

$P_i=P_{DGi}-P_{Di}$, $Q_i=Q_{DGi}-Q_{Di}$.

$a = \tan(\arccos(PF_{DG}))$.

$S_{DGi}=P_{DGi}+jQ_{DGi}$. $P_{DGi}= aQ_{DGi}$.

$Z_{ij}=x_{ij}+jy_{ij}$: ijth element of impedance matrix Z[bus].

$V_i\angle\delta_i$: voltage of ith bus. $V_j\angle\delta_j$: voltage of jth bus.

$P_{Di}+jQ_{Di}$: consumed power at ith bus.

$P_{DGi}+jQ_{DGi}$: injected power at ith bus.

PF_{DG}: power factor of DG ($\cos\phi$).

n: number of buses.

Equaling partial derivative of (1) with respect to the active power injection from DG at bus i to zero, expression (2) that is the optimal size of DG in order to minimize the real power losses of the network will achieved [4].

$$P_{DGi}=(\alpha_{ii}(P_{Di}+aQ_{Di})-X_i-aY_i)/(\alpha_{ii}(a^2+1)) \quad (2)$$

Where:

X_i= $sum_{i=1}^n$ [$\alpha ij Pj - \beta_{ij}Q_j$] ,Y_i= $sum_{i=1}^n$ [$\alpha_{ij}Q_j + \beta_{ij}P_j$].

Thus for each bus should install optimal size of DG on that bus separately and in each case by help of (1) total losses of active power will achieved. The difference between this paper with other papers like [4] is in the modeling of DG. In papers like [4] DG is modeled only by an injecting power in desired bus and impedance of DG source and its unit transformer are ignored. Here such impedances are considered and DG is modeled as an ideal source and series impedance. So impedance matrix [Zbus] after installing DG should change.

PROPOSED FORMULATION OF PAPER FOR FINDING ALLOWABLE RANGE OF DG SIZE ACCORDING PROTECTION CONSTRAINTS

In this section one DG is considered and according to position of fault with respect to DG location, requirements for maintaining protection coordination of overcurrent relays and allowable range of DG size for correct operation of this relays in distribution network will achieved. Figure 1 shows a radial network that substation is upward network. Each bus of network and its connected load are depicted.

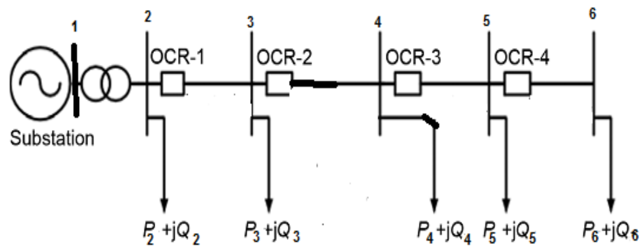

Figure 1 radial distribution network.

Two different scenarios of malfunction of protection scheme after installing DG is possible. One is loss of coordination of protection devices and the other is blocking or delayed operation of protection devices. Below each problem is discussed separately.

Loss of coordination of protection devices

for visualizing such problems in Figure 1 for instance consider that a DG is installing at bus 4 and a fault is occurred at the location of bus 6(totally the faults that are downward of DG place and is feeding by both DG and upward network). OCR-4(over current relay-4) that at this situation is as primary protection, for maintaining coordination of relays, should operate before OCR-3(backup protection). This means for maintaining coordination the contribution of DG in fault current should be limited by a maximum value. So the size of DG should be limited by a maximum value. Finding this maximum size accurately is difficult, instead in literatures(like [5]) for limiting the contribution of DG in fault current in such situations, and for utilize the maximum benefits of DG in the network, FCL(fault current limiter) is introduced.

Blocking or delayed operation of protection devices

In Figure 1 consider that a DG is connected at the bus 4 and a fault is occurred between buses 2 and 3(totally the faults that are upward of DG place). One line diagram of equivalent circuit of this case when occurred fault is a three phase fault is depicted in Figure 2.

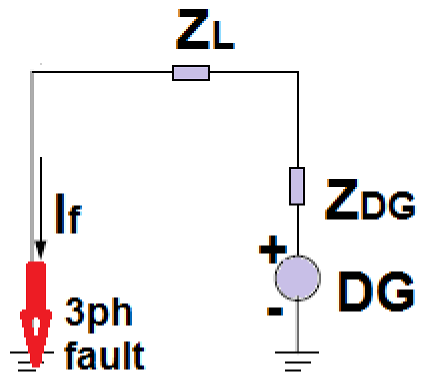

Figure 2 one line diagram of Figure 1when a DG is installed at bus 4 and a 3phase fault is occurred between bus 2 and bus 3.

In this situation operation of OCR-1 cause to stopping the contribution of substation in fault current. But if OCR-2 because of small contribution of DG in fault don't operate or having a delayed operation, fault continue to be feeding by DG. So the operation of OCR-2 in this situation for safety reasons should be guaranteed. Changing the setting of OCR-2(in this case) may be cause to tripping even in the rating current of the network. At other hand DG may be connected or be disconnected and setting of relays should handle both situations. So it seems that the best solution is limiting the size of DG for avoiding such problems.

For finding this limits should considering the worst case. A three phase fault produces a smaller current comparing other fault types so lead to worst case [6]. In this case for proper operation of OCR-2 should:

$$|I_f| \geqq (2I_S/\sqrt{3}) \quad (3)$$

Where:

$|I_f|$: is the magnitude of fault current.

I_S: current setting of the relay (OCR-2 in this case).

According to figure.2 this magnitude is introduced in (4):

$$|I_f|=|U_f/(\sqrt{3}\ (Z_L+Z_{DG}))| \quad (4)$$

Where:

U_f: is the voltage of line at the fault location that is considered as one per unit [6] at the base of network. Z_L: is the impedance of line between fault location and location of connected DG in per unit at the base of network.

Z_{DG}: is the total impedance of DG and its unit transformer in per unit at the base of network.

By considering Z_{DG} as (5):

$$Z_{DG}=Z_{dg}((U_{DG}^2 S_B)/(U_B^2 S_{DG})) \quad (5)$$

Where:

Z_{dg}= is the total impedance of DG and its connecting transformer in per unit at the base of DG.

U_{DG}: is the rating voltage of DG. U_B: is the base voltage that is the rating voltage of the network.

S_{DG}: is the rating MVA of the DG.

S_B: is the base MVA that is the rating MVA of the network.

The relationship between U_{DG} and U_B is according (6):

$$U_B=\alpha\ U_{DG} \quad (6)$$

Where α directly depends on transfer ratio of DG unit transformer and type of connection of its primary and secondary windings.

By replacing (6) in (5) and some manipulation (7) will obtain:

$$\alpha^4(I_S^2|Z_L|^2-1)S_{DG}^2+2\alpha^2(I_S S_B(R_L R_{DG}+X_L X_{DG}))S_{DG}+(R_{DG}^2+X_{DG}^2)S_B^2\leqq 0 \quad (7)$$

Where:

R_L and R_{DG}: real part of Z_L and Z_{DG} respectively.

X_L and X_{DG}: imaginary part of Z_L and Z_{DG} respectively.

According to (7) allowable size of DG for avoiding the problem of blocking or delayed operation of protection device at the presence of DG, by solving an inequality that is of order two and discussion in the regions of its answer will defined. This inequality at the normal range of network parameters (note that impedances and I_S are in per unit) have two real root for S_{DG} that one of them is always negative and is not acceptable. At the other hand in (7) the factor of S_{DG} and constant factor are always positive, so the sign of the factor of S_{DG}^2 will define the allowable range. Thus this equation may define a maximum or define a minimum for DG size. In long feeders with a large I_S it defines a maximum. In short feeders with a rarely small I_S it defines a minimum.

PROPOSED PEROCEDURE OF THE PAPER

In this section of the paper a procedure is proposed for finding the optimal size and location of DG that lead to minimum losses while satisfying protection limits stated above.
Step one: performing power flow for base network (without DG) and by help of (1) finding the total active losses.

Step two: inserting the power flow results in (2) and finding the proposed optimal size of DG for each bus of the network and for each case calculate the total active power losses of the network (in this step is considered that DG is connected to the network by a additional bus and have a interface impedance that is the total impedance of DG and its unit transformer).

Step three: ranking the buses according to total active losses of the network. DG location with its optimal size that leads to minimum losses is first and the other locations becomes later.

Step four: looking at the ranking from top and checking the limits that comes from (7) for each location. If the size of DG is in the limits, then this is the optimal size and location for installing DG that satisfies the protection limits. If not checking the limits for next location and so on.

SIMULATING THE PROSEDURE

In order to examine the effectiveness of proposed procedure, network of Figure 1 that its data are available in Table 1 is considered. All network loads are 0.2103MVA with a lagging power factor of 0.95. the magnitude of I_S multiplied by CT ratio for OCR-1 to OCR-4 is 64A,48A,32A and 16A respectively. In addition a simplified model of DG that consist of a ideal source and a series impedance that this impedance for fault calculations is the transient impedance of the DG that have a transient reactance of order 0.18 per unit in the DG base. This reactance for loss calculation is considered to be 1.8 per unit in the DG base. For both case the resistance of DG is 15 percent of its transient reactance. Unit transformer of DG is modeled as a series reactance and resistance of 0.2 per unit and 0.01 per unit in the base of transformer respectively. Proposed procedure by help of MATLAB codes is applied to network of Figure 1. Without DG real power loses of network is equal to 14.8363 kW. The results of simulations are available in Table 2. In this table locations are ranked according to step three of the procedure.

Table 1 a set of data for network of Figure 1.

From bus	To bus	Series resistance(ohm)	Series reactance (omh)
1	2	0	2.7614
2	3	2.4	9.6
3	4	1.6	6.4
4	5	2	8
5	6	3.2	12.8

Table 2 result of simulating proposed procedure.

Bus location	Expression (2) optimal (7) minimum	Size of DG(MVA)	Total losses of network after DG(kW)
4	(2)	0.3407	3.2359
	(7)	0.49635	1.1062
5	(2)	0.2227	9.6779
	(7)	0.61373	7.2462
3	(2)	0.4338	12.0862
	(7)	0.43056	12.0927
6	(2)	0.0687	12.5147
	(7)	0.95354	16.6764
2	(2)	0.6635	20.3058
	(7)	-	-

U_{DG}=4.16KV, U_B=13.8KV, S_B=10MVA, $U_{substation}$=1.05p.u.

DISCUSSION

According to Table 2 can see that proposed sizes of expression (2) for location of 4 and 5 are not in allowable range of protection constraint. Thus should look at next candidate location that is bus 3. In this bus the proposed size is in the allowable range and procedure for finding optimal location and size for loss reduction considering protection constraints should be stopped. According to [4] proposed size of expression (2) for each location lead to minimum losses rather than any sizes. but as in this paper the procedure for calculating total active power losses of the network by considering total impedance of DG and its unit transformer in Zbus matrix after installing DG is modified, in Table 2 some interesting results are obtained. In buses 4 and 5, proposed size by expression (7) lead to minimum losses rather than one proposed by (2) for each bus. In bus 2 that there is not any constraint from assumed protection problem point of view, the proposed size by expression (2) lead to total losses that is more than base case losses without DG. So for achieving to a better performance expression (2) should be modified to handle DG impedance and its unit transformer. Although in this paper only network losses are considered, in general the proposed expression for finding protection constraints can be applied to any kind of objective functions with suitable number of network parameters for optimization. Because the constraints are independent of objective function form and its solution way.

REFERENCES

[1] M.M. Elnashar, R. El Shatshat and M.M.A. Salama, 2010, "Optimum siting and sizing of a large distributed generator in a mesh connected system", Electric Power Systems Research. vol.80, 690-697.

[2] H.J. Lee, G. T. Son and J. W. Park, 2011, "Study on Wind-Turbine Generator System Sizing Considering voltage Regulation and Overcurrent Relay Coordination", IEEE Transactions on power system, vol. 26, no.3.

[3] T.Saksornchai, B.Eua-arporn, 2009, "determination of allowable capacity of distributed generation with protection coordination consideration", engineering journal, vol.13.

[4] Q.H.Duong, N.Mithulananthan and R.C.Bansal, 2010, "Analytical Expressions for DG Allocation in Primary distribution Networks", IEEE Transactions on Energy Conversion., vol. 25, no. 3.

[5] W.El-Khattam and T.S. Sidhu, 2008, "Restoration of Directional Overcurrent Relay Coordination in Distributed Generation Systems Utilizing Fault Current Limiter", IEEE Transactions on power delivery, vol. 23, no. 2.

[6] Y.Lu, L.Hua, J.Wu, G.Wu and G.Xu, 2007, "A Study on Effect of Dispersed Generator Capacity on Power System Protection", Power Engineering Society General Meeting, IEEE conference.