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INTEGRATION OF DISTRIBUTION GENERATION IN PRIMARY DISTRIBUTION SYSTEM

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Abstract- *There is significant changes on power distribution due to incremental use of distributed generator. This is due to its economic benefits but power industry is facing challenges for its optimal integration. Governments are beginning to acknowledge DG as an economically viable alternative to deferring investment at generation, transmission and distribution levels, meeting demand growth and improving distribution network performance and security. Optimal sizing and placing of DG is well researched, traditionally studying the technical impact on distribution system such as real power loss reduction and voltage profile improvement. Whether the impact of DG is positive or negative will depend on its location and size. This thesis presents an algorithm to obtain the optimum size and optimum location of the DG at any bus in the distribution network. The proposed algorithm is based on minimizing power losses in the distribution network. Thus the main objective of this thesis is to find the optimum location and size of DG so that system losses are minimized. For this an Improved Analytical approach is used. In this method DG delivering active power is considered for placing. An algorithm is applied to IEEE 14 bus system. Results of loss reduction obtained by this method with help of programming in MATLAB software and results are compared with the conventional LSF method. The results can be used as a look-up table, which can help design engineers when inserting DG's into the distribution networks.*

Keywords- *Distribution generator; IEEE 14 bus system; optimal location; optimal size; loss sensitivity factor method; improved analytical method.*

I. INTRODUCTION

Electrical power system has played a vital role in human civilization. The requirements are growing continuously and so its increase in demand is achieved through maximum utilization of renewable energy sources like photovoltaic cells, wind turbines etc. and these have started playing a vital role in energy generation. The integration of renewable energy into the power system can potentially cause severe challenges for the control and protection of large central generators and the distribution system. Nowadays smart grid technologies have come to meet the customer demand more efficiently and economically. Distributed generation is an important part of this technology. This modification has also aimed at modernizing the electric power grid to satisfy the demand for higher energy efficiency, reliability and security of the system. Meanwhile, the concept of the smart grid has been introduced as an important part of this modification to facilitate high penetration of distributed generation. However, with the high penetration of such resources, along with demand variations has introduced many challenges to distribution networks like power fluctuations, high losses, voltage rise and low voltage stability etc. since from the last decade, the grid of many countries such as the united states, Germany, the United Kingdom, Denmark, Australia and Spain have been modified to accommodate various renewable resources as distributed generation.

II. DISTRIBUTED GENERATION

Distributed generation or dg is generally small scale generation of typically ranging from 1 KW to 50 MW electric generators which are installed at distribution side or near to customer at distribution end. DG is also referred as "decentralized generation". Decentralized generation is characterized by some features which are not been mentioned in centralized plants. These DGs are integrated in power system along with the centralized power plant to meet the consumer demand. This integration of DG in power systems give rise to many problems such as voltage profile, voltage regulation, short circuit, power losses etc. So by considering above problems proper integration of DG in power system is very important.

The introduction of generation sources on the distribution system can significantly impact the flow of power and voltage conditions at customers and utility equipment. These impacts may manifest themselves either positively or negatively depending on the distribution system operating characteristics and the DG characteristics. Positive impacts are generally called "system support benefits."

General benefits of introducing a Distributed generator in power systems are mentioned below [1]:

2.1. Advantages

1. Voltage support and improved power quality- connection of DG to power system will improve power quality by reducing the transmission line losses and increasing its efficiency.
2. Loss reduction- DG connection will improve the receiving end voltage thus improving voltage profile and reducing transmission and distribution line losses.
3. Transmission and distribution capacity release.
4. Deferments of new or upgraded TBD infrastructure- Adding up to DG in distribution system will prevent increasing capacity of central generation systems on increment of connected load thus it becomes and economical choice.
5. Improved utility system reliability- as DG can also work under islanding situation if proper size and on load shedding.
6. Some DG technologies have low pollution and good overall efficiencies like combined heat and power (CHP) and micro-turbines. Besides, renewable energy based DG like photovoltaic and wind turbines contribute to the reduction of greenhouse gases.
7. The installation of DG takes less time and payback period. Many countries are subsidizing the development of renewable energy projects through a portfolio obligation and green power certificates.
8. Increase loading of system.

2.2. Impact of DG on Losses

One of the major impacts of Distributed generation is on the losses in a feeder. Locating the DG units is an important criterion that has to be analyzed to be able to achieve a better reliability of the system with reduced losses [1]. According to [1], locating DG units to minimize losses is similar to locating capacitor banks to reduce losses. The main difference between both situations is that DG may contribute with active power and reactive power (P and Q). On the other hand, capacitor banks only contribute with reactive power flow (Q). Mainly, generators in the system operate with a power factor range between 0.85 lagging and unity, but the presence of inverters and synchronous generators provides a contribution to reactive power compensation (leading current).
The optimum location of DG can be obtained using load flow analysis software, which is able to investigate the suitable location of DG within the system in order to reduce the losses. For instance: if feeders have high losses, adding a number of small capacity DGs will show an important positive effect on the losses and have a great benefit to the system. On the other hand, if larger units are added, they must be installed considering the feeder capacity boundaries [3]. For example: the feeder capacity may be limited as overhead lines and cables have thermal characteristic that cannot be exceed.

Most DG units are owned by the customers. The grid operators cannot decide the locations of the DG units. Normally, it is assumed that losses decrease when generation takes place closer to the load site. However, as it was mentioned, local increase in power flow in low voltage cables may have undesired consequences due to thermal characteristics [2].

III. OBJECTIVE

Main objective is to find the optimal location and size of DG delivering active power so that the total system losses are minimized.

IV. PROPOSED METHODS FOR DG PLACEMENT AND SIZING

4.1. Loss Sensitivity Factor (LSF) Method

4.1.1. Algorithm for LSF Method

Step 1) Enter the number of DG units to be installed.
Step 2) Run the load flow for the base case and find losses using Eq (1).
Step 3) Find the optimal location of DG using the following steps.
- **a)** Find LSF using (2). Rank buses in descending order of the values of their LSFs to form a priority list.
- **b)** Locate the highest priority bus.

Step 4) Find the optimal size of DG at particular bus using Eq (3) and calculate losses using the following steps.
- **a)** Place a DG at the bus with the highest priority obtained in step 3, change this DG size in “small” step and calculate the loss for each case using (1) by running the load flow.
- **b)** Select and store the optimal size of the DG that gives the minimum loss.

Step 5) Stop if either the following occurs:
- **a)** the voltage at a particular bus is over the upper limit;
- **b)** the total size of DG units is over the total load plus loss;
- **c)** the maximum number of DG units is unavailable;

d) the new iteration loss is greater than the previous iteration loss. The previous iteration loss is retained; otherwise, repeat steps 2 to 5.

The loss sensitivity factor method is based on the principle of linearization of the original nonlinear equation (loss equation) around the initial operating point, which helps to reduce the amount of solution space. The loss sensitivity factor method has been widely used to solve the capacitor allocation problem [3]. The real power loss in a system is given by Equation given below. This is popularly referred to as the "exact loss" formula [3].

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)] \text{ .... Eq (1)}$$

Where; $\alpha_{ij}= \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j)$ and $\beta_{ij}= \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_j)$

$V_i\angle\delta$= complex voltage at i th bus

$r_{ij} + j\,x_{ij} = Z_{ij}$; ijth element of impedance matrix

P_i, P_j = active power injection at i and j bus

Q_i, Q_j = reactive power injection at i and j bus

N= no of buses

And rij + jxij = Zij are the ijth element of [Zbus].

Sensitivity factors are evaluated at each bus, firstly, using the value obtained from the base case power flow. The sensitivity factor, $\propto$, is thus the partial derivative of the exact loss formula with respect to the injected power given by [3].

$$\alpha_i = 2\sum_{j=1}^{N}(\alpha_i P_j - \beta_i Q_j) \text{ .... Eq (2)}$$

Sensitivity factors are evaluated at each bus, firstly, using the value obtained from the base case power flow. The buses are ranked in descending order of the values of their sensitivity factors to form a priority list. The top-ranked buses in the priority list are the first to be studied as alternative locations.

4.2. Priority List

This method will reduce the solution space to a few buses, which constitute top ranking in the priority list. The effect of the number of buses taken in priority will affect the optimum solution obtained for some systems. For each bus in the priority list the DG is placed and the size of the DG is varied from minimum to a higher value until the minimum system losses are found with the DG size. Thus this process is computational demanding as a large amount of load flow solution is needed and this may not determine exactly the size and location of the DG, as varying the size of the DG will be in steps.

4.3. Improved Analytical Method

Duong Quoc Hung, Nadarajah Mithulananthanin their work [5] proposes an improved analytical method expression for finding optimal size and power factor of four types of distributed generation (DG) units. DG units are sized to achieve the highest loss reduction in distribution networks.

4.3.1. Algorithm for IA Method

Step 1) Enter the number of DG units to be installed.
Step 2) Run the load flow for the base case and find losses using (4).
Step 3) Calculate the power factor of DG using (8) or enter the power factor of DG.
Step 4) Find the optimal location of DG using the following steps.
- **a)** Calculate the optimal size of DG at each bus using (2) and (3).
- **b)** Place the DG with the optimal size, as mentioned earlier, at each bus one at a time. Calculate the approximate loss for each case using (1) with the values α and β of the base case.
- **c)** Locate the optimal bus at which the loss is at minimum

Step 5) Find the optimal size of DG and calculate losses using the following steps.
- **a)** Place a DG at the optimal bus obtained in step 4, change this DG size in "small" step, update the values α and β, and calculate the loss for each case using (1) by running the load flow.
- **b)** Select and store the optimal size of the DG that gives the minimum loss.

Step 6) Stop if either the following occurs:
- **a)** the voltage at a particular bus is over the upper limit;
- **b)** the total size of DG units is over the total load plus loss;
- **c)** the maximum number of DG units is unavailable;
- **d)** the new iteration loss is greater than the previous iteration loss. The previous iteration loss is retained; otherwise, repeat steps 2 to 5.

The total real power loss in power systems is represented by below equation, popularly known as "exact loss formula" [4]

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)] \quad \text{………. Eq (4)}$$

V. SIMULATION AND RESULTS

Numerical results are computed using two methods:

1. Loss Sensitivity Method (LSF)
2. Improved Analytical Method (IA)

The proposed methodology is tested on IEEE 14 bus system with total load of 259 MW and 73.5 Mvar using MATLAB software tool for load flow, calculate losses and identify the optimal location and size of DG. NR method is used for load flow. Results of type 3 DG (injecting real power) by IA method and its comparison with LSF are computed. DG penetration considered is 100%.

5.1 Calculating LSF factor at each bus

Table 1: LSF factor at each Bus

Bus no	LSF factor	DG size (MW)
2	1.3916	14.697
3	-1.8030	27.694
4	-4.3510	11.351
5	-4.5875	11.913
6	0.3485	18.057
7	7.5623	10.813
8	7.0975	11.165
9	-5.9293	6.991
10	-7.2057	6.226
11	-3.2997	2.795
12	-1.3320	6.936
13	-2.9700	2.804
14	-9.8319	4.802

Table 2: Bus arranged in descending order as per LSF

Bus no	LSF factor	Loss (MW)	%Loss Reduction
7	**7.5623**	**5.673**	**58%**
8	**7.0975**		
2	**1.3916**		
6	**0.3485**		
12	**-1.3320**		
3	**-1.8030**		
13	**-2.9700**		
11	**-3.2997**		
4	**-4.3510**		
5	**-4.5875**		
9	**-5.9293**		
10	**-7.2057**		
14	**-9.8319**		

Table 3: Optimum location and size of DG as per LSF Method

Optimum bus	with optimum DG size	Base case losses	Total losses with DG	% loss reduction
7	10.813	13.593	5.673	58%

5.2 IA Method

Table 4: DG size at each bus as per IA method

Bus no	value of DG (MW)
2	14.697
3	27.694
4	11.351
5	11.913
6	18.057
7	10.813
8	11.165
9	6.991
10	6.226
11	2.795
12	6.936
13	2.804
14	4.802

Table 5: Total losses at each bus after DG placement

Bus no	Cal. value of DG from Eq. (MW)	Total losses (MW)	Optimum placement @ bus 4
2	14.697	12.803	
3	2.769	10.177	
4	11.351	5.012	Loss reduction is 63.1%
5	11.913	6.239	
6	18.057	11.989	
7	10.813	5.673	
8	11.165	5.750	
9	6.991	7.746	
10	6.226	8.734	
11	2.795	11.114	
12	6.936	12.8	
13	2.804	10.855	
14	4.802	9.52	

Table 6: Optimum location and size of DG as per IA Method

Optimum bus	with optimum DG size	Base case losses	Total losses with DG	% loss reduction
4	**11.4**	**13.593**	**4.992**	**63.3%**

VI. CONCLUSION

Above results are computed on same system by two different methods.
For type-3 DG: Injecting real power only

Table 7: Comparison of LSF & IA methods results

Method	Size (MW)	Bus	Total Ploss without DG	Total Ploss with DG	% reduction
LSF	10.8	7	13.593 MW	5.793 MW	58%
IA	11.4	4	13.593 MW	4.992 MW	63.3%

From the results we conclude that IA method is more accurate than LSF method. Loss reduction is more in IA than LSF.LSF method can be used only for placing DG injecting real power only. Loss reduction of system by LSF method by placing DG on bus 7 was 58 % while loss reduction by IA method by placing DG on bus 4 was 63.3% thus IA method is more efficient than LSF method.

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