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Identification of DG Location through Sensitivity Factors under Line Outage Condition

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Abstract

In this paper, sensitivity analysis of transmission line is carried out by using line outage of the transmission line. For each of the line outage, the highly sensitive line is identified using Line Outage Distribution Factor (LODF) and Distribution Generation (DG) is installed in the nearer to the most sensitive line at three different locations individually and the system improvement is illustrated by voltage profiles. The study is carried out on IEEE 14 bus system using Mi-Power software.

***Keywords**: DG Installation, sensitivity factor, distribution generation, Line Outage, Line Outage Distribution factor*

1. Introduction

Electrical energy is the plays a major role in human life nowadays. This form of energy is generated, controlled, dispatched and finally consume this energy is known as electrical power system [1]. The interdependence between system variable can be quantitatively determined by what is known as sensitivity analysis. Sensitivity is defined as the ratio of small change of some dependent variable to the small change of the concerned independent variable [2]. In the operation of power system sensitivity analysis is of great importance since it helps in the visualization of the cause and effect relationship between the variables and as such is the basics of many control scheme of the power system.

The derivation of linear sensitivities used in the dispatch of MW controls for the alleviation of voltage violations. Such a set of sensitivities is important for the selection and coordination of necessary changes to MW generation, phase shifter settings and, as a last resort, load shedding where reactive power controls are insufficient. The sensitivity analysis has been embedded in a qualitative reasoning based decision support tool in which operators considerations such as cost, control effectiveness, preservation of control margin and ease of implementation are modelled in such a way that priorities can be adjusted and results achieved quickly [3].

The first- order sensitivities is presented both for real power and for reactive power security control. Relations between uncompensated sensitivity factors used for corrective

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control and compensated sensitivity factors used for preventive control. The combined effects of a line outage and a line switching cannot be summed directly; because of inherent nonlinearity. Computer-aided sensitivity analysis tool is developed for analyzing nonlinear optimum systems. Real power generation rescheduling, Phase shifting transformers, Flow control through High Voltage DC (HVDC) link, Line switching, Load shedding has been given in [4, 5]. The optimal utilization of Flexible AC Transmission System (FACTS) for power flow management in the transmission lines are given in [6, 7, 8, 9]. Generation Rescheduling Technique (GRT) can directly control the generation without curtailment of the load. So rescheduling generation is widely used [10, 11].

Distributed generation (DG) is also called as on-site generation, dispersed generation, embedded generation, decentralized generation, decentralized energy or distributed energy. Distributed generations (DGs) are small-scale power generation technologies of low voltage type and to produce electricity close to the end users of power [12, 13].

In the distributed power system, the energy management works on the distribution of the power generated by the regenerative sources of energy as well as the demand of the load. With the management system developed not only the power generation of the shortest term dispatchable conventional plants but also controllable or switchable the rescheduled loads [14].

The rest of the paper is organized as follows: Section 2 explains about the Line Outage Distribution Factor. Section 3 explains the proposed algorithm incorporating DG in the system and line outage condition. Section 4 deals with the case study and results of the proposed algorithm. Finally, the conclusion is presented in section 5.

2. Line Outage Distribution Factor

Linear sensitivity coefficients give an indication of the change in one system quantity (*e.g.*, MW flow, MVA flow, bus voltage, *etc.*) as another quantity is varied (*e.g.*, generator MW output, transformer tap position, *etc.*). Linear sensitivity coefficients can be expressed as partial derivatives.

$$\frac{\partial MVA_{flow(ij)}}{\partial MW_{gen(k)}} \tag{1}$$

Equation (1) shows the sensitivity of the flow (MVA) in line (i to j) with respect to the power generated at bus-k. Some sensitivity coefficients may change rapidly as the adjustment is made and the power flow conditions are updated. This is because some system quantities vary in a nonlinear relationship with the adjustment and resolution of the power flow equations. This is especially true for quantities that have to do with voltage and MVAR flows. Sensitivities such as the variation of MW flow with respect to a change in generator MW output are rather linear across a wide range of adjustments [15].

The line outage distribution factor is used for calculating Sensitivity factor. By definition, the line outage distribution factor has the following meaning:

$$d_{l,k} = \frac{\Delta f_l}{f_k^0} \tag{2}$$

$d_{l,k}$: Line outage distribution factor when monitoring line l after an outage in line k.

Δf_l : Change in MW flow on line l.

f_k^0 : Original flow in line k before it was an outage.

If one knows the power in line-l and line-k, the flow in line-l with line-k out can be determined using "d" factors.

$$\hat{f}_l = f_l^0 + d_{l,k} f_k^0 \tag{3}$$

Where:

f_l^0, f_k^0 : Pre outage flows on lines l and k, respectively

$\hat{f}_l$: Power flow of line l with line k out.

3. Proposed Algorithm

Read the load flow data.

1. Compute Ybus using the line data.
2. Carryout the base case load flow for computing the power flows at each line, voltages at each bus using Mi-Power software.
3. Create the line outage of different lines.
4. Under each line outage condition, calculate the line sensitivity factor of each line using equation 2.
5. Rank the more sensitive line under each line outage condition which has the highest value of sensitivity factor.
6. Install DG at the bus, which is near to the sensitive line.
7. Analyze the improvement of the bus voltage & sensitivity factor of the line.
8. Create line outage with DG and repeat step-5 to step-8.
9. Compare the step 5 & step 9 results.

4. Case Study and Results

In this section, numerical results are carried out on IEEE 14-bus system shown in Figure 3 to show the robust performance of the proposed algorithm. Initially, the load flow solution using Newton - Raphson (NR) method without contingency was carried out & voltages at each bus were obtained. Next, for the same system, the load flow solution is obtained using NR method with contingency.

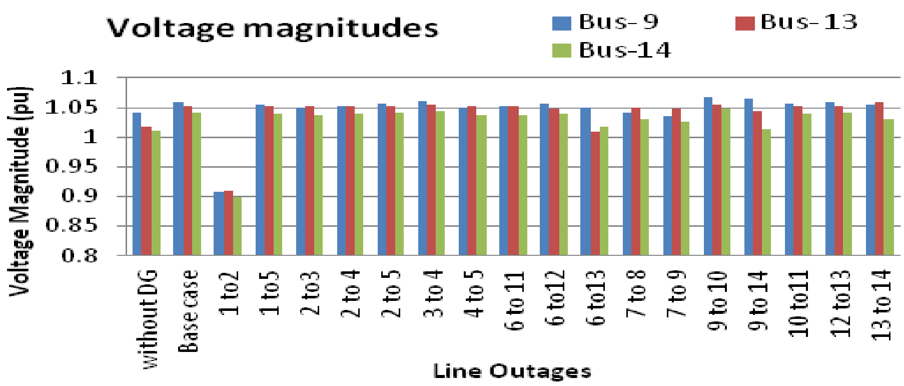

Figure 1. Voltage Magnitudes for 2MW

Figure 1. shows the voltage magnitude of the buses-9, 13 & 14. The DG was placed at these buses and the line outage was performed. The DG capacity placed here is 2 MW. The voltages have been improved after placing DG for all the three buses; it can be seen as a base case in the figure. During line 1-2 outage the voltages have drastically changed. But, for the remaining line outage, there is a slight change in the voltage magnitudes.

Similarly, Figure 2. shows the voltage magnitude of the buses-9, 13 & 14. The DG was placed at these buses and the line outage was performed. The DG capacity placed here is 2 MW. The voltages have been improved after placing DG for all the three buses; it can be seen as a base case in the Figure. During line 1-2 outage the voltages have drastically changed. But, for the remaining line outage, there is a slight change in the voltage magnitudes. But the bus-9 has negative voltage value during line 1-2 outage condition.

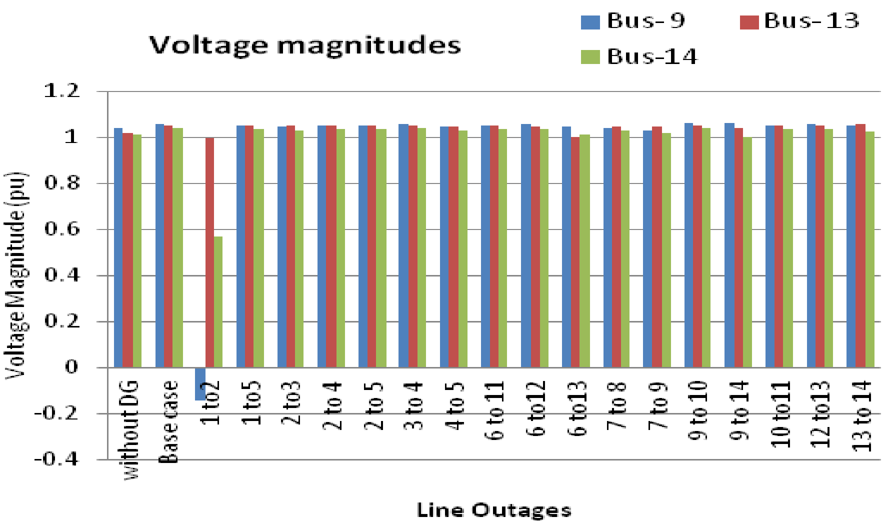

Figure 2. Voltage Magnitudes for 4MW

Table.1 shows the Sensitivity Factor of each line with DG (DG^1) and without DG (DG^0). The highest sensitive line has been given for individual line outage with and without DG. It is noticed from the table for all the line outages the sensitivity factor of the corresponding lines has considerably reduced which indicate that the line loadings are properly readjusted. Line 1-5 was the most sensitive line under 1-2 line outage condition. Sensitivity factor has been reduced with DG under line outage condition.

Table 1. Sensitivity Factor for 2 MW DG at Bus-9

Line outage From-To	DG^0		DG^1	
	Sensitive Line From-To	Sensitivity Factor	Sensitive Line From-To	Sensitive Factor
1-2	1-5	**1.1961**	2-3	0.8211
1-5	1-2	**1.1095**	1-2	**1.1003**
2-3	3-4	0.9682	3-4	0.9684
2-4	4-5	0.6897	4-5	0.6365
2-5	4-5	0.5885	4-5	0.5918
3-4	2-3	1.0829	2-3	1.0792
4-5	2-4	0.5296	2-4	0.5375
6-11	7-9	1.000	9-10	1.0001
6-12	6-11	1.0349	12-13	0.9908
6-13	4-5	0.8675	6-12	0.6686
7-8	NOT APPLICABLE			
7-9	12-13	0.9901	4-5	0.4411
9-10	6-12	0.6914	6-11	1.0369
9-14	9-10	1.0000	13-14	1.0262
10-11	6-11	1.0230	6-11	1.0135
12-13	13-14	1.0277	6-12	1.0173
13-14	7-9	1.0349	9-14	1.0241

Table 2. Sensitivity Factor for 4 MW DG at Bus-9

Line outage From-To	DG^0		DG^1	
	Sensitive Line From-To	Sensitivity Factor	Sensitive Line From-To	Sensitive Factor
1-2	1-5	1.1961	1-5	1.22407
1-5	1-2	1.1095	1-2	1.099057
2-3	3-4	0.9682	2-4	0.51139
2-4	4-5	0.6897	2-5	0.45269
2-5	4-5	0.5885	4-5	0.591782
3-4	2-3	1.0829	2-4	0.28112
4-5	2-4	0.5296	2-5	0591782
6-11	7-9	1.000	9-10	1.035404
6-12	6-11	1.0349	6-13	0.668569
6-13	4-5	0.8675	12-13	0.884539
7-8	NOT APPLICABLE			
7-9	12-13	0.9901	4-5	0.4925
9-10	6-12	0.6914	6-11	1.05304
9-14	9-10	1.0000	10-11	0.99377
10-11	6-11	1.0230	6-11	0.647235
12-13	13-14	1.0277	6-13	0.647235
13-14	7-9	1.0349	9-14	1.02373

Table.2 shows the Sensitivity Factor of each line with DG (DG^1) and without DG (DG^0). The highest sensitive line has been given for individual line outage with and without DG. It is noticed from the table for all the line outages the sensitivity factor of the corresponding lines has considerably reduced which indicate that the line loadings are properly readjusted. Line 1-5 was the most sensitive line under 1-2 line outage condition. Sensitivity factor has been reduced with DG under line outage condition.

Table 3. Sensitivity Factor for 2 MW DG at Bus-13

Line outage From-To	DG^0		DG^1	
	Sensitive Line From-To	Sensitivity Factor	Sensitive Line From-To	Sensitive Factor
1-2	1-5	1.1961	6-13	0.4933
1-5	1-2	1.1095	1-2	1.1002
2-3	3-4	0.9682	2-3	0.5117
2-4	4-5	0.6897	2-5	0.4528
2-5	4-5	0.5885	4-5	0.5917
3-4	2-3	1.0829	2-3	0.4884
4-5	2-4	0.5296	2-5	0.4724
6-11	7-9	1.000	6-13	0.9995
6-12	6-11	1.0349	9-10	0.8869
6-13	4-5	0.8675	7-9	0.6436
7-8	NOT APPLICABLE			
7-9	12-13	0.9901	4-5	0.4417
9-10	6-12	0.6914	7-8	1.0381

9-14	9-10	1.0000	12-13	1.0226
10-11	6-11	1.0230	7-8	1.0138
12-13	13-14	1.0277	9-10	0.8847
13-14	7-9	1.0349	9-14	1.0201

Table.3 shows the Sensitivity Factor of each line with DG (DG^1) and without DG (DG^0). The highest sensitive line has been given for individual line outage with and without DG. It is noticed from the table for all the line outages the sensitivity factor of the corresponding lines has considerably reduced which indicate that the line loadings are properly readjusted. Line 1-2 was the most sensitive line under 1-5 line outage condition. Sensitivity factor has been reduced with DG under line outage condition.

Table 4. Sensitivity Factor for 4MW DG at Bus-13

Line outage From-To	DG^0		DG^1	
	Sensitive Line From-To	Sensitivity Factor	Sensitive Line From-To	Sensitive Factor
1-2	1-5	1.1961	2-4	1.2258
1-5	1-2	1.1095	1-2	1.0988
2-3	3-4	0.9682	2-3	0.5115
2-4	4-5	0.6897	2-5	0.4527
2-5	4-5	0.5885	4-5	0.5918
3-4	2-3	1.0829	2-3	0.4882
4-5	2-4	0.5296	2-5	0.4725
6-11	7-9	1.000	6-13	0.9983
6-12	6-11	1.0349	9-10	0.8859
6-13	4-5	0.8675	7-9	0.6616
7-8	NOT APPLICABLE			
7-9	12-13	0.9901	4-5	0.4429
9-10	6-12	0.6914	7-8	1.0412
9-14	9-10	1.0000	13-14	1.0298
10-11	6-11	1.0230	7-8	1.0145
12-13	13-14	1.0277	9-10	0.8837
13-14	7-9	1.0349	9-14	1.0204

Table.4 shows the Sensitivity Factor of each line with DG (DG^1) and without DG (DG^0). The highest sensitive line has been given for individual line outage with and without DG. It is noticed from the table for all the line outages the sensitivity factor of the corresponding lines has considerably reduced which indicate that the line loadings are properly readjusted. Line 2-4 was the most sensitive line under 1-2 line outage condition. Sensitivity factor has been reduced with DG under line outage condition.

Table 5. Sensitivity Factor for 2 MW DG at Bus-14

Line outage From-To	DG^0		DG^1	
	Sensitive Line From-To	Sensitivity Factor	Sensitive Line From-To	Sensitive Factor
1-2	1-5	1.1961	6-13	0.4933
1-5	1-2	1.1095	1-2	1.10002
2-3	3-4	0.9682	2-3	0.5117
2-4	4-5	0.6897	2-5	0.4528
2-5	4-5	0.5885	4-5	0.5917
3-4	2-3	1.0829	2-3	0.4884
4-5	2-4	0.5296	2-5	0.4724
6-11	7-9	1.000	6-13	0.9995
6-12	6-11	1.0349	9-10	0.8869
6-13	4-5	0.8675	7-9	0.6436
7-8	NOT APPLICABLE			
7-9	12-13	0.9901	4-5	0.4417
9-10	6-12	0.6914	7-8	1.0381
9-14	9-10	1.0000	13-14	1.0226
10-11	6-11	1.0230	7-8	1.0138
12-13	13-14	1.0277	9-10	0.8847
13-14	7-9	1.0349	9-14	1.0201

Table.5 shows the Sensitivity Factor of each line with DG (DG^1) and without DG (DG^0). The highest sensitive line has been given for individual line outage with and without DG. It is noticed from the table for all the line outages the sensitivity factor of the corresponding lines has considerably reduced which indicate that the line loadings are properly readjusted. Line 1-2 was the most sensitive line under 1-5 line outage condition. Sensitivity factor has been reduced with DG under line outage condition.

Table 6. Sensitivity Factor for 4MW DG at Bus-14

Line outage From-To	DG^0		DG^1	
	Sensitive Line From-To	Sensitivity Factor	Sensitive Line From-To	Sensitive Factor
1-2	1-5	1.1961	2-4	1.2199
1-5	1-2	1.1095	1-5	1.0989
2-3	3-4	0.9682	1-2	2.0013
2-4	4-5	0.6897	1-2	8.0853
2-5	4-5	0.5885	1-2	13.2961
3-4	2-3	1.0829	2-4	8.0853
4-5	2-4	0.5296	2-4	3.3996
6-11	7-9	1.000	1-2	21.5767
6-12	6-11	1.0349	1-2	20.7685
6-13	4-5	0.8675	1-2	9.4195
7-8	NOT APPLICABLE			
7-9	12-13	0.9901	1-2	5.7471
9-10	6-12	0.6914	1-2	28.3365

9-14	9-10	1.0000	1-2	21.9433
10-11	6-11	1.0230	2-4	52.3477
12-13	13-14	1.0277	1-2	122.8176
13-14	7-9	1.0349	1-2	38.6093

Table.6 shows the Sensitivity Factor of each line with DG (DG^1) and without DG (DG^0). The highest sensitive line has been given for individual line outage with and without DG. It is noticed from the table for all the line outages the sensitivity factor of the corresponding lines has considerably reduced which indicate that the line loadings are properly readjusted. Line 1-2 was the most sensitive line under 12-13 line outage condition. Sensitivity factor has been reduced with DG under line outage condition.

5. Conclusion

The effect of line outages in a DG placed power system has been studied. Sensitivity analysis has been carried out for understanding the most sensitive line. Under line outage condition most of the transmission lines were not affected which is far from the generator buses. Thus, the identification of DG placement/installation with respect to the transmission lines connected to the associated bus was carried out. In this process, the real power flow sensitivity index and the bus voltages have improved.

Appendix

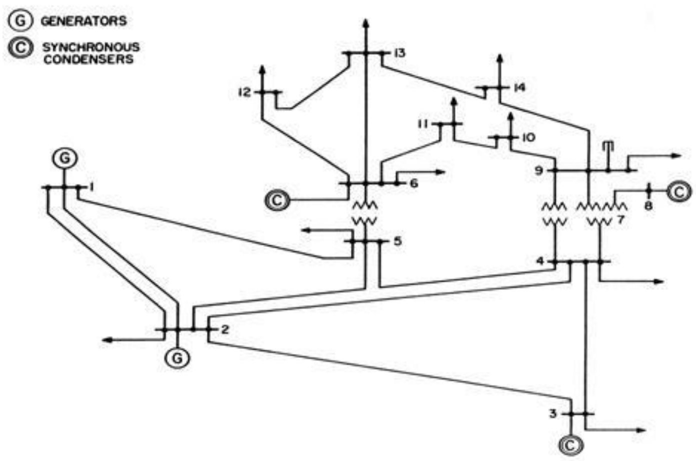

Figure 3. IEEE-14 Bus System

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