Fault Location Estimation in Power Distribution Systems with High Penetration of Distributed Generation

S. B. Karajgi. Udaykumar and R. Y, G. D. Kamalapur

***Abstract*—This paper analyses the effect of penetration of Distributed Generation on the estimation of Fault location in the power distribution systems. A single line to ground fault is considered on a real power distribution system and the estimation of the fault location is carried out using the impedance method which requires the measurement of voltages and currents at one measurement point and the heavy penetration of distributed generation alters these values causing errors in the estimated location. Simulation tests have been carried out for different DG outputs with varying fault impedances. The errors have been found to be more pronounced with larger penetration of DG and with lower values of Fault impedance.**

***Index Terms*—Fault impedance, distributed generation, fault location**

I. Introduction

The ever increasing demand for power has resulted into evolution of new technologies such as Distributed Generation in recent years. DG, which can be considered to be “taking power to the load”, has attracted greater interest worldwide [1]. As the name implies, DG uses smaller-sized generators than does the typical central station plant. DG units are typically connected to the distribution networks at the low or medium voltage levels. Also several power quality issues arise when there are multiple sources. The inclusion of a DG unit will make the power distribution system more complex [2]. The impacts of the inclusion of DG, its location and ratings, like line loss, voltage profile, safety and protection etc have been studied in [3]-[8].

When a fault occurs in a distribution network, it becomes vital to locate the fault and clear the same, for a better reliability. Many Fault Location Several methods of Fault Location have been developed in the past [9]-[14]. In this paper, the method of impedance as described in [14] is used. The impedance method uses the measured rms value of voltage and current at a specific node, usually the substation. The presence of fault in a distribution system will affect the magnitudes of voltages and currents at the substation. These quantities in the presence of DG will be usually less than those in the absence of the DG. If such quantities are used to fix the location of the fault, there may be errors in such estimated fault locations. A typical variation of voltage and currents with respect to the different values of DG and the fault impedance for single phase to ground fault are shown in Fig 1, 2

In the present work, estimation of a fault location is obtained using the measured values of voltage and currents at the substation with DG embedded in to the system. DG ratings and fault locations are varied in order to study the effect of the DG on the fault location.

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II. Model Development

The simulation model of a practical distribution system with 55 buses has been considered and the voltages and the currents at the substation are recorded with single line to ground fault with and without DG and also with varying fault impedances. The knowledge of these values along with their phase angles are used to locate the fault. The distribution feeder data is taken from a real database with the consideration that it has one DG point with varying power. The single line diagram of the feeder is shown in Fig.3 along with the location of DG. The real data of the feeder are given in Table I.

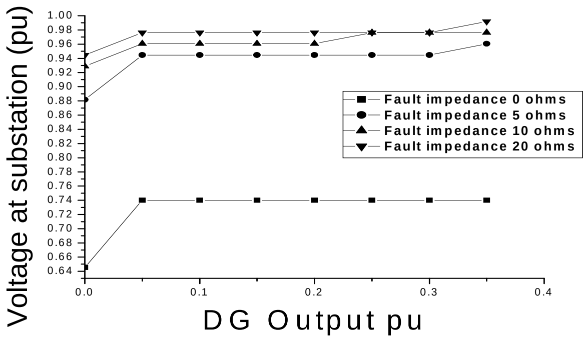

Fig. 1. Figure showing the variation in the substation voltage for various fault impedance with varying DG.

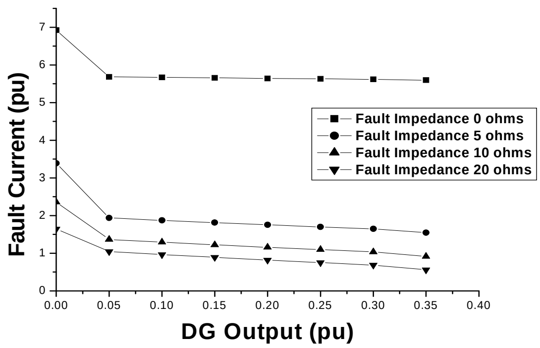

Fig. 2. Figure showing the variation in the Fault current at substation for various fault impedance with varying DG.

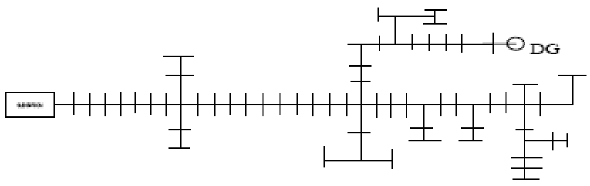

Fig. 3. Single line diagram of the feeder with DG

TABLE I: DATA OF THE DISTRIBUTION SYSTEM

Substation	UAS
Line Rating (MVA)	5
Short Circuit MVA	40
Length	7.4 KM

III. FAULT LOCATION USING IMPEDANCE METHOD

The method can be described by considering a single phase to ground fault located between the nodes x and y on a radial system, shown in Fig. 4. The system consists of a source G and the section between nodes M and N comprise several loads tapped at various points. The fault is situated at F. It is assumed that the fault impedance is completely resistive. The fault location technique consists of six steps.

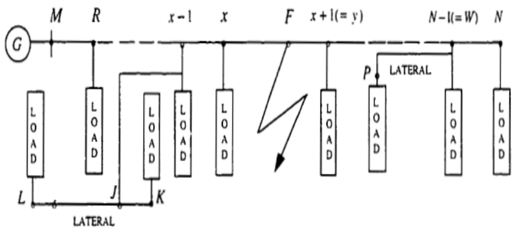

Fig. 4. Single line diagram of a system experiencing a fault

A. Location of Apparent Faulted section

By measuring the phasors of the sequence voltages and currents at the substation, the apparent impedance is calculated first at the line terminal and with the knowledge of the line parameters, modified impedance is calculated for every section of the line which is compared with this basic impedance. A preliminary location of the fault is obtained when the modified reactance becomes more than the apparent impedance. For single phase to ground fault, the modified reactance of the line between nodes *a* and *b* is calculated as

$$X_{ab}^{m} = X_{1ab} + \frac{X_{0ab} - X_{1ab}}{3} \tag{1}$$

where X_{0ab} and X_{1ab} are the zero and positive sequence reactance of the section of the line between a and b respectively. Once the Faulty section is identified, the following five steps are used to locate the exact location.

B. Modified Radial System

In order to simplify the calculations, all laterals between the node M and the apparent location of the fault are ignored and the loads on laterals beyond this faulty section are considered to be present at the node to which the laterals are connected as shown in Fig. 5.

C. Load Modeling

The effects of loads are considered by compensating for their currents. Static response type models are used for all loads upto node m and also for a consolidated load at the remote end. For a load at node say R, this model is described by

$$Y_r = \left\{ G_r \left| V_r \right|^{n_p-2} + jB_r \left| V_r \right|^{n_q-2} \right\} \tag{2}$$

where V_r is the voltage at node *R*, Y_r is the load admittance, G_r and B_r are constants proportional to the conductance and susceptance respectively and n_p and n_q are the response constants for the active and reactive of the load.

The constants G and B are estimated from the prefault load voltages and currents and appropriate values of n_p and n_q. These constants and voltages are used to estimate load admittances and sequence currents during the fault.

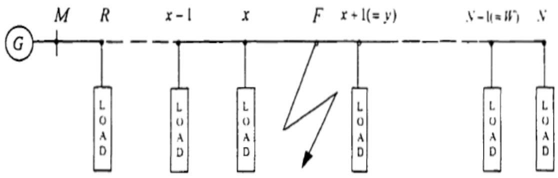

Fig. 5. Single line diagram of the modified radial system

D. Voltages and Currents at Fault and at Remote End

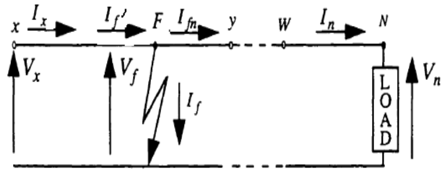

Fig. 6. The voltages and currents at nodes F and N during the fault

The voltages and currents at nodes F and x are related by

$$\begin{bmatrix} V_F \\ I_{f'} \end{bmatrix} = \begin{bmatrix} 1 & -sBxy \\ -sCxy & 1 \end{bmatrix} \begin{bmatrix} V_x \\ I_x \end{bmatrix} \tag{3}$$

where s is the per unit distance to node F from node x as shown in Fig 6. B_{xy} and C_{xy} are the impedance and the shunt admittance of the section of the line between x and y respectively.

The sequence voltages and currents at F during the fault are estimated by assuming that all loads beyond node m are consolidated into a single node N.

The sequence voltages and currents at nodes N and F during the fault are related by the following equation

$$\begin{bmatrix} V_n \\ I_{n'} \end{bmatrix} = \begin{bmatrix} D_e & -B_e \\ -C_e & A_e \end{bmatrix} \begin{bmatrix} 1 & -(1-s)B_{xy} \\ -(1-s)C_{xy} & 1 \end{bmatrix} \begin{bmatrix} V_f \\ I_{fn} \end{bmatrix} \tag{4}$$

where A_e, B_e, C_e and D_e are the equivalent constants of the cascaded section between nodes y and N.

The currents at node F are related by

$$I_{fn} = I_{f'} - I_f \tag{5}$$

The following equation is obtained by further substitutions from (3) and (5) and from an equation involving prefault voltages and currents in (4) and neglecting the second and higher order terms in s

$$\begin{bmatrix} V_n \\ I_f \end{bmatrix} = \frac{1}{K_v + sK_w} \begin{bmatrix} K_m + sK_n & sK_p \\ K_q + sK_r & K_v + sK_u \end{bmatrix} \begin{bmatrix} V_x \\ I_x \end{bmatrix} \quad (6)$$

where K_m, K_n, K_p, K_q, K_r, K_u, K_v and K_w are complex parameters and are computed using Y_n, B_{xy}, C_{xy}, A_e, B_e, C_e and D_e respectively.

IV. Estimating the Location of the Fault

The distance to the fault node F from node x, s, expressed as a fraction of the length from node x and node y, is estimated from the voltage –current relationships at the fault and the resistive nature of the fault impedance. For an A phase to ground fault,

$$\frac{Vaf}{I_{af}} = \frac{V_{of} + V_{1f} + V_{2f}}{I_{of} + I_{1f} + I_{2f}} = R_f \quad (7)$$

where V_{of}, V_{1f}, V_{2f} and I_{0f}, I_{1f} and I_{2f} are zero, positive and negative sequence voltages and current phasors at the fault F and $R_f$is the fault resistance..

Equating the imaginary parts of both sides of (7), substituting the values sequence voltages and currents at fault from (3) and (6), neglecting second and higher orders of s and rationalizing, the following equation is obtained.

$$\mathrm{Im}\left(\frac{K_A + sK_B}{K_C + sK_D}\right) = 0 \quad (8)$$

where K_A, K_B, K_C and K_D are complex parameters, which are expressed into real and imaginary parts as

$$K_A = K_{AR} + jK_{AI},$$
$$K_B = K_{BR} + jK_{BI}$$
$$K_C = K_{CR} + jK_{CI}$$
$$K_A = K_{DR} + jK_{DI}$$

Rationalizing the resulting equation, neglecting second and higher orders terms in s and rearranging, the following equation is obtained.

$$s = \frac{K_{AR} + K_{CI} - K_{AI}K_{CR}}{\left(K_{CR}K_{BI} - K_{CI}K_{BR}\right) + \left(K_{DR}K_{AI} - K_{DI}K_{AR}\right)} \quad (9)$$

An iterative solution of s is obtained using the pre-fault admittance of the consolidated load at node N and some of the above mentioned equations.

V. Converting Multiple Estimates Into a Single Estimate

The above mentioned Fault Location Technique may provide multiple estimates if the line has laterals. These estimates are collected and comparing with the information from the fault indicators provided in the system, single estimate may be arrived at.

VI. Simulation Tests

A Single Phase Line to Ground Fault (LG) has been considered to analyze the impact of the presence of DG on the location of fault. The DG output is varied and for each of these cases, two different locations of fault are considered. Following assumptions are made for simplicity.

- All sections are assumed to be short in length so that the values of line constants A and D are 1 and the value of C is zero.
- Same approximation is also made for the section of the line between the node F and the remote end so that $A_e = D_e = 1$ and $C_e = 0$
- Fault impedance is resistive in nature.

A. Without DG

The faults are located at a distance of (a) 3.23 km and (b) 5.37 km each from the substation. The fault impedance is varied from 0 to 20 ohms. For each of these impedance values, the methodology described in section 3 is employed. For a fault impedance of 10 ohms, in the first case, three different locations of the fault are obtained out of which the location which is far away from the exact location is discarded. The other locations, which are nearer to the exact locations - one at 3.18 km from the substation and the second at 3.27 km. are considered. The second location is the one very close to exact location. Both the estimated locations are shown in Fig. 7.

The error in the methodology is calculated as

$$error\ (\%) = \frac{estimated\ location - actual\ location}{length\ of\ the\ distribution\ feeder}\ X\ 100$$

For the above case the error for the location nearest to the actual location is 0.027 %. Similarly the Fault location estimates were obtained for the other case with varying fault impedances. The errors for all the cases are given in Table II.

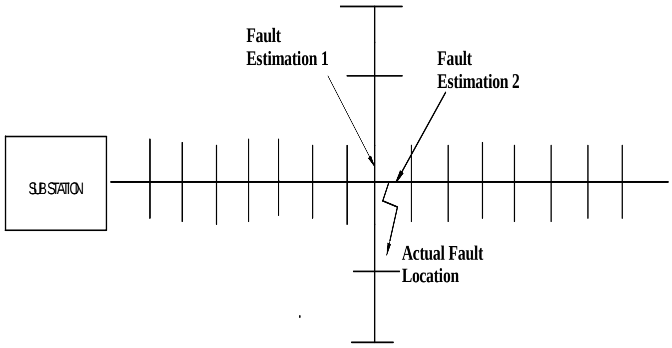

Fig. 7. Figure showing the enlarged portion of the feeder covering the exact location and the estimated locations of fault with Fault impedance of 10 ohms.

B. With DG

The DG unit is located at a distance of 6.67 km from the substation. The short circuit power of the DG is taken as 5 times the nominal rating of DG for modeling. The simulations are carried out for a single phase to ground fault at distances of 3.23 km and 5.37 km each from substation and the estimations of fault locations were obtained for different values of DG output and with different values of fault impedances in a similar manner as was carried for the case without DG. With fault impedance of 10 ohms and for a DG output of 0.15 pu, the estimated locations of the fault which was located at 3.23 km, are shown in Fig. 8. The errors in the fault location estimation for both the fault locations are given in Table III

TABLE II: TABLE SHOWING THE % ERRORS WITH VARYING FAULT IMPEDANCES FOR THE SYSTEM WITHOUT DG.

Actual Location	Fault Impedance In Ohms	Estimated Fault Locations (KM from substation)	% error
3.23 KM	0	3.16	-0.0095
		3.20	-0.0040
	5	3.17	-0.0067
		3.26	0.0040
	10	3.18	-0.0081
		3.27	0.0054
	20	3.22	-0.0013
		3.29	0.0081
5.37 KM	0	5.28	-0.0121
		5.42	0.0067
	5	5.31	-0.0081
		5.40	0.0040
	10	5.33	-0.0054
		5.39	0.0027
	20	5.34	-0.0040
		5.36	-0.0013

It is observed that the estimations obtained with the presence of DG, produce more error than the estimations which were obtained without the presence of DG. This is mainly because the presence of DG affects the values of the voltage and currents at the substation greatly. The simulations were carried out similarly for other values of fault impedances and for varying values of DG output.

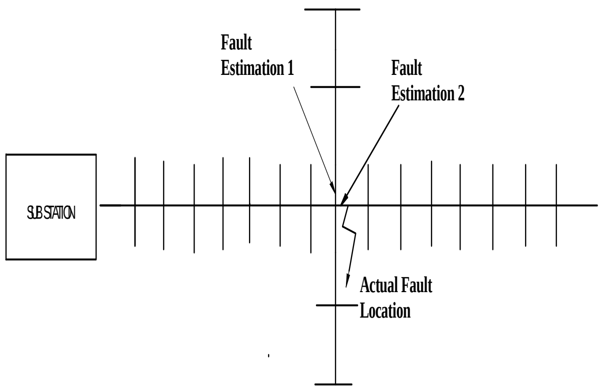

Fig. 8. Figure showing the enlarged portion of the feeder covering the exact location and the estimated locations of fault with Fault impedance of 10 ohms with the presence DG.

The errors in the estimations for all these cases are obtained and the variation of error for a particular location with varying values of DG and with different values of fault impedances is shown in Fig. 9.

It is quite clear from the results that the estimated locations of the fault in the presence of DG will be closer than the actual fault locations with the increasing values of DG output thereby increasing the error. This is because the presence of DG changes the value of the apparent reactance as seen by the substation terminal. The errors however show a reducing trend with increasing values of fault impedances.

TABLE III: TABLE SHOWING THE % ERRORS WITH VARYING FAULT IMPEDANCES WITH THE PRESENCE OF DG OF RATING 0.15 PU.

Actual Location	Fault Impedance In Ohms	Estimated Fault Locations (KM from substation)	% error
3.23 KM	0	3.09	-0.01892
		3.16	-0.00946
	5	3.10	-0.01757
		3.18	-0.00676
	10	3.17	-0.00811
		3.20	-0.00405
	20	3.19	-0.00541
		3.22	-0.00135
5.37 KM	0	5.20	-0.02297
		5.32	-0.00676
	5	5.24	-0.01757
		5.36	-0.00135
	10	5.29	-0.01081
		5.31	-0.00811
	20	5.26	-0.01486
		5.29	-0.01081

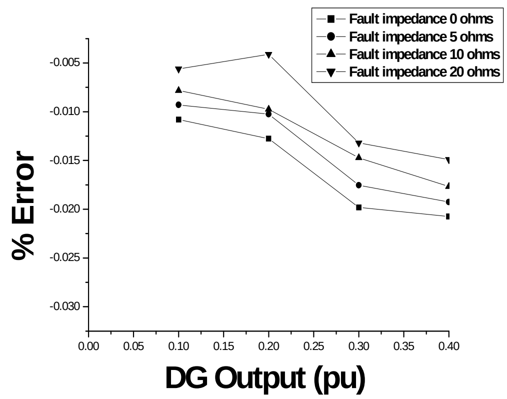

Fig. 9. Figure showing the % error as a function of DG output.

VII. CONCLUSION

This paper describes the effect of the penetration of the DG on the estimation of the fault location of the fault in a distribution system. From the simulation of a single line to ground fault, it is observed that the presence of a DG introduces more pronounced error in the estimation of the fault.

The presence of a DG in the distribution system decreases the value of the apparent reactance seen from the main substation. Thus the estimated locations of the fault obtained by using the impedance method will be more nearer than the actual ones thereby increasing the error. The future work will consist of reforming the Fault Location Algorithm which takes care of the presence of DG so that the error in the fault location estimation is minimized.

REFERENCES

[1] T. Ackermann, G. Andersson, and L. Soder, "Distributed generation: A definition," *Elect. Power Syst. Res*, vol. 57, pp. 195–204, 2001.

[2] N. Hadjsaid, J. Canard, and F. Dumas, "Dispersed generation impact on distribution networks," IEEE Comput. Appl. Power, vol. 12, no. 2, pp. 22–28, Apr. 1999.

[3] C. Ramkumar, "An Approach to quantify the Benefits of Distrributed Generation Systems," *IEEE Tran. On Energy Conversion*, vol. 19, Dec 2004, pp 764 – 773.

[4] E. Vidyasagar and P. V. N.Prasad, "Impact of DG on Radial Distribution System Reliability," in *15th National Power System Conference Conference (NPSC)*, IIT Bombay 2008, pp 467-472

[5] P. Daly, "Understanding the potential Benefits of DG on Power Delivery System," *a paper presented at Rural Electric Power conference 2001*, Little Rock, Arkansas, 2001.

[6] A. Azmy, "Impact of DG on the Stability of Electrical Power Systems," *IEEE Trans. On Power Delivery*, 2005, pp. 1 – 8

[7] R. Dugan et.al, "Distributed Generation and Power Quality," in *Electrical Power Systems Quality*, 2nd Ed. McGraw-Hill, 2002, pp 373-435.

[8] J. A. P. Lopes and N. Hatziargyriou et. al, "Integrating Distributed Generation into electric power systems: A review of drivers, challenges and opportunities," *Electric Power System Research*, vol. 77, 2007, pp 1189-1203

[9] T. W. Stringfield, D. J. Marihart, and R.F.Stevens, "Fault Location methods for overhead Lines," *Trans. AIEE, part III Power Apparatus and Syatems*, vol. 76, Aug 1957, pp 518-530.

[10] T. Takagi, Y. Yamakoshi, M Yamamura, R. Kondow and T. Matsushimha, "Development of a new type Fault Locator Using the One Terminal Voltage and Current Data," *IEEE Trans. On Power Apparatus and Systems*, vol. PAS – 101, No. 8, Aug. 1982, pp 2892 – 2898.

[11] K. Shrinivasan and A. S. Jacques, "A New Fault Location Algorithm for Radial Transmission Line with Load," *IEEE Trans on Power Delivery*, vol. 4, no.3, July 1989, pp 1676-1682.

[12] A. A. Girgis, C. M. Fallon, and D. L. Lubkeman, "A Fault Location Technique for Rural Distribution feeders," *IEEE Trans. On Industry Applications*, vol. 29, no. 6, Nov/Dec 1993, pp 1170-1175

[13] R. Das, M. S. Sachdev, and T. S. Sidhu, " A Fault Locator for Radial Subtransmission and Distribution Lines," *IEEE Power Engineering Society Summer Meeting, Seatle, Washington*, USA, July 16-20, 2000

[14] R. Das, "Determining the location of faults in distribution systems," PhD Thesis, University of Saskatchewan, Canada, 1998.

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