

Voltage Sag Profile Analysis for Single Line to Ground Fault Based on Static Impedance Load Model

Lilik Jamilatul Awal, H. Mokhlis, Fadi Albatsh, Bazilah Ismail, Ibrahim Alhamrouni

Abstract—This paper were carried to investigate the effect of self-impedance and mutual impedance in the estimation of the voltage sag in each node. The voltage sag estimation were carried on the TNB 132/11kV distribution network with a single-line-to-ground fault occur in the network. The result shows that when a high fault impedance occur, the impact of mutual impedance will be less. Impedance-based method have a reasonable accuracy in estimate the voltage sag value for each node in the network. Further work can be continue for fault distance estimation based on the accuracy of voltage sag estimation.

Keywords—voltage sag, self impedance, mutual impedance, distribution network

I. Introduction

Electric power system in general contains of generation, transmission and distribution of electricity energy [1]. Generation is where the electric is generate either through hydro, wind, coal, and fuel. Transmission is the medium to transmit the electric from one place to another place while distribution is the substation that reduce the amount of voltage through the demand and separate it to the consumer [1]. Distribution is an important part in separating the power to the consumer. Therefore, any insecure connectivity and insulating in distribution system will causes to a major disaster called fault [2].

Based on paper in [3] state that the frequency of fault occurrence is depends on the type of the fault. 85 to 90 percent of fault occur is unsymmetrical fault while symmetrical fault only happened in average thirty to thirty five percent only.

Various studies have shown that between seventy to ninety percent of fault is occur on the overhead line transmission due to the transient fact. Less than eighty percent of fault is occur in the distribution line system while ten to thirty percent of fault is occur in the branches at distribution line [4]. The impact of fault can be seen in the monitoring node base on voltage sag or voltage dip measurement. Voltage sags are momentary dips in voltage with a magnitude of 0.9 p.u. or below and duration between half a cycle to 1 minute [5]. It is recognized as the most important power quality problem affecting industrial customers because it may cause sensitive equipment like adjustable speed drives and programmable logic controllers to trip, thus affecting industrial production losses. Voltage sags at equipment terminals can be caused by short circuit faults hundreds of kilometers away in the transmission system.

The measurement of a voltage sag is stated as a percentage of the nominal voltage, it is a measurement of the remaining voltage and is stated as a sag to a percentage value. Due to the limitation number of the measurement in the distribution network, the estimation of voltage sag is acquired as a pre-fault calculation method.

On the other hand, most of the fault location method was determine fault point based on each section of the system. Impedance-based method are one of the method which estimate the fault point based on each section. For that reason, impedance based methods are required updating the voltage sag at each feeder. So it is crucial to estimate the voltage sag for each section the distribution system. The method which used impedance based method are mention in papers [6-12].

In order to investigate the accuracy of the updating voltage sag, self and mutual impedance will consider in the algorithm. The accuracy of the voltage sag for each section is identified by comparing the voltage measurement value with the estimation value.

Such occurrences have major economic impact as well as impact on the quality of products or services. Therefore, the detection of voltage sag during faults has become a major effort at many electric utilities and industrial customers worldwide. Voltage sags normally have three possible sources: sudden application of certain loads (motor and transformer connections), direct faults (short circuits, over current, and line faults), and overvoltage induced faults.

II. Voltage Sag Pattern

In order to justify the use of voltage sag magnitude for estimation voltage sag in each feeder, studies on the voltage sag profile in the different locations was conducted. For this purpose, faults are created at different nodes. The pattern of

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voltage sag magnitude due to Single Line to Ground Fault at node 4 are shown in the following Figure.

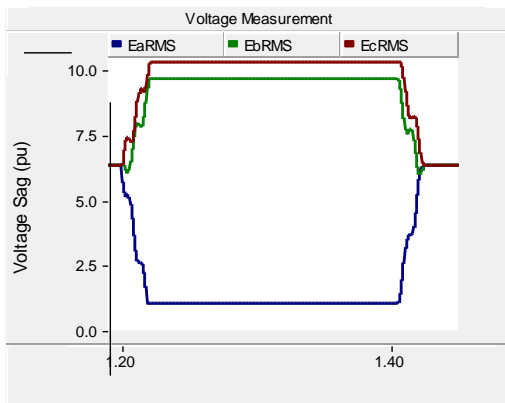


Figure 1: voltage waveforms

Figure 1 is presenting the voltage sag when fault occur on node 3 as depicture in Figure 3. It can be seen that the voltage magnitude have significant sag due to fault occur in the short distance from the measurement node (node 3). Since SLGF is tested in this research, only voltage in one phase which sag, namely phase A.

III. Review of Estimation Voltage Sag

The updating of voltage sag is including voltage sag magnitude and voltage sag angle. The method is discussed from [7,9]. In this paper, analysis of accuracy for voltage sag estimation was utilized Matlab programming. Adopted from [7,9], the author mention about updating voltage sag magnitude and voltage sag angle are shown in equation (3.1). By updating the voltage sag magnitude and angle, the estimation process for detecting the fault location can be carried out. The estimation value for the fault location estimation is generated by using Matlab programming simulation. Since the voltage sag data are only used measurement at the primary substation. An estimation of the voltage value for the incoming node of each line section is needed.

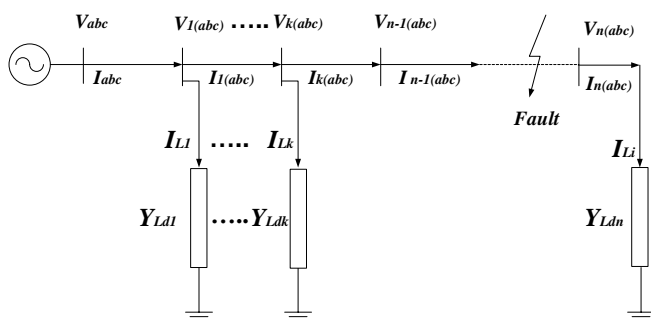


Figure 2. Single-line feeder model [9]

Based on the above figure, the voltage at node $k + 1$ can be obtained by using the equation below [9].

$$V_{k+1} = V_k - Z_k I_k \quad (3.1)$$

$$\begin{bmatrix} V_{LKa} \\ V_{LKb} \\ V_{LKc} \end{bmatrix} = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} - \begin{bmatrix} Z_{aa} & Z_{ab} & Z_{ac} \\ Z_{ba} & Z_{bb} & Z_{bc} \\ Z_{ca} & Z_{cb} & Z_{cc} \end{bmatrix} \begin{bmatrix} I_{Ka} \\ I_{Kb} \\ I_{Kc} \end{bmatrix} \quad (3.2)$$

Where :-

- V_k = voltage vector at k th node
- Z_k = impedance matrix of k th line section
- I_k = current vector of k th section

Assuming the constant impedance load, the current flowing out to the k th load tap can be calculated using formula below :

$$I_{LK} = V_k \times Y_{LK} \quad (3.3)$$

$$\begin{bmatrix} I_{LKa} \\ I_{LKb} \\ I_{LKc} \end{bmatrix} = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} - \begin{bmatrix} Y_{aa} & Y_{ab} & Y_{ac} \\ Y_{ba} & Y_{bb} & Y_{bc} \\ Y_{ca} & Y_{cb} & Y_{cc} \end{bmatrix} \quad (3.4)$$

Where I_{LK} is the load current vector of k th load tap and Y_{LK} is the load admittance matrix at k th load tap. The current at k th section, I_k is given.

$$I_k = I_{k-1} - I_{Lk} \quad (3.5)$$

Where Self Impedance and mutual impedance are calculate by using equation (3.6) and (3.7):

$$Z_{AS} = \frac{1}{3} (Z_{A0} + 2Z_{A1}) \quad (3.6)$$

and:

$$Z_{AM} = \frac{1}{3} (Z_{A0} - Z_{A1}) \quad (3.7)$$

Where:

- Z_{AS} = self-impedance
- Z_{AM} = mutual impedance
- Z_{A0} = zero sequence impedance
- Z_{A1} = positive sequence impedance

After the calculation for obtaining the self-impedance and mutual impedance, the impedances are then used in form of 3-by-3 identity matrix, Z_k , for further calculation. For the matrix that consider only self-impedance, the value of the self-impedance will be on the diagonal (Z_{aa}, Z_{bb}, Z_{cc}) and everywhere else will be '0' (zero's). Whereas for the matrix that consider both self impedance and mutual impedance, the self impedances value will also be on the diagonal and the mutual impedances value will be on everywhere else as follows.

$$Z_k = \begin{bmatrix} Z_{aa} & Z_{ab} & Z_{ac} \\ Z_{ba} & Z_{bb} & Z_{bc} \\ Z_{ca} & Z_{cb} & Z_{cc} \end{bmatrix} \quad (4.3)$$

IV. Test Network

In order to analyze the proposed method performance, a real distribution network, as shown in Figure 3, which belongs to a Malaysian power utility company TNB, is used. This network is connected to the grid via a step down 132/11 kV transformer (Y- Δ), and it consists of 6 branches, with a total 19 nodes.

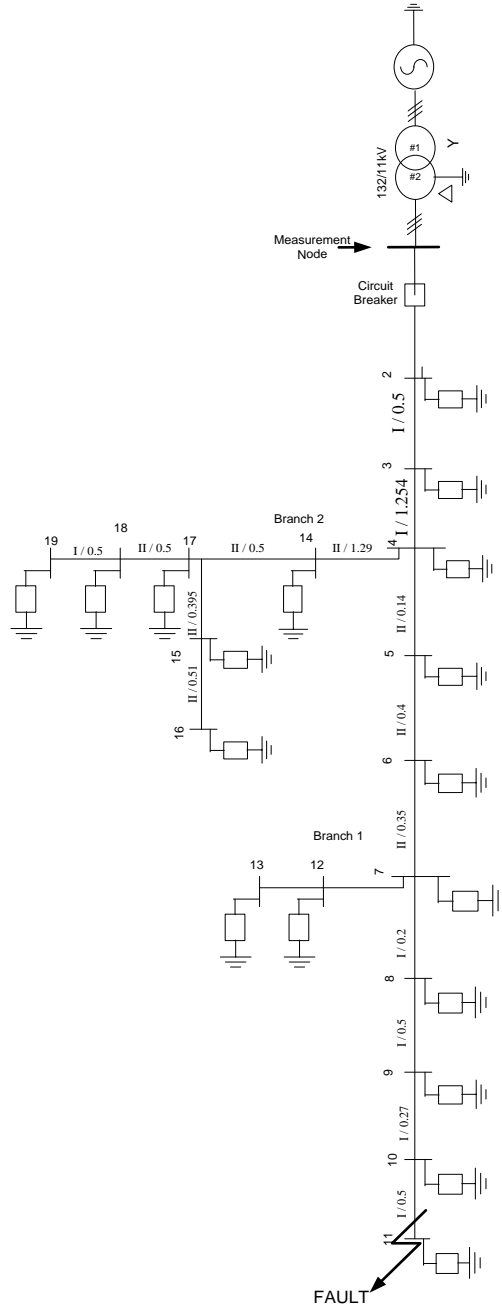


Figure 3. Single Line Diagram of Test Network

v. Result and Discussion

In this section, the impact of self and mutual impedance are discussed. The various fault impedance also tested. To shows the impact of distance to the accuracy of voltage sag estimation, node 11 is chosen due to have longest distance.

A. Impact of Self and Mutual Impedance

In this research, the author only consider the single-line-to-ground fault (phase A) as it is the most often fault occur in the distribution network. The fault were occur on the node 11. For the table of fault impedance 0.01 ohm, by considering only self-impedance it give a lower difference between the estimation value with measurement value and a lower percentage of error. This is because the self-impedance are the real impedance value of the power line especially in a balanced system [10]. Mutual impedance only need to be consider when there are more than one line in parallel position and only when the distribution network is a unbalanced system. Normally the mutual impedance have a differences with the self-impedance in 3 to 7%. Therefore, it can be said that zero sequence of the mutual impedance have a range between 50 to 70% of the self-impedance. By that means, the result have a greater differences when considering the mutual impedance in the voltage estimation process when the tested distribution network is a balanced system.

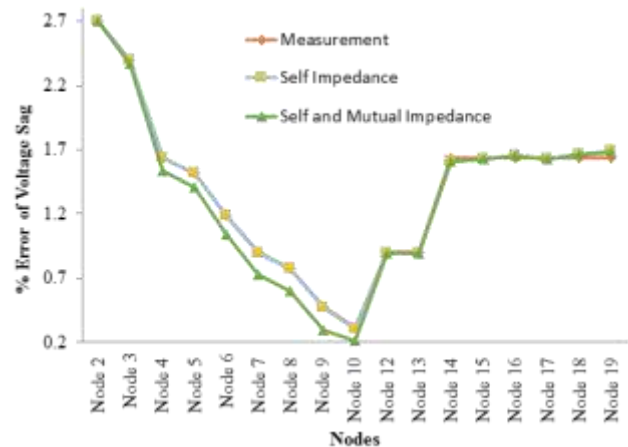


Figure 4. Voltage Estimation Value for Fault Impedance 0.01Ω at Node 11

B. Impact of Fault Impedance

From figure 4-5, it shows that the lower fault impedance will create a lower voltage sag value. It follows the principle of Ohm's Law as the lower resistance will create lower voltage as the current gets higher. The effect of the fault impedance in the distribution network is more severe compared to transmission network because of its small short circuit capacity [11]. The fault impedance will influence the type of voltage sag directly to its magnitude and phase angle [12].

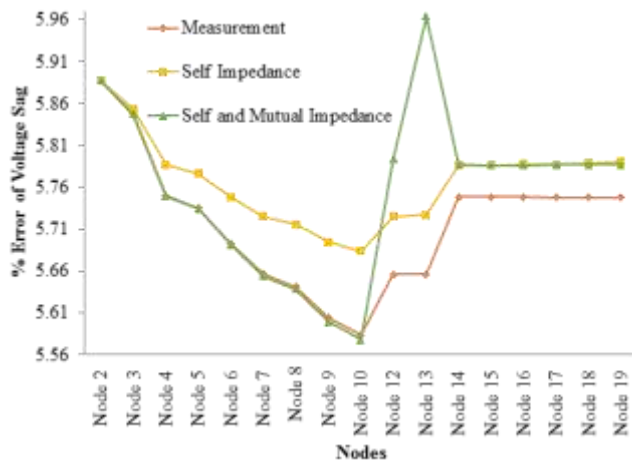


Figure 5. Voltage Estimation Values For Fault Impedance 50Ω At Node 11

For table of fault impedance 50 ohm, it shows by comparing the voltage value that only consider self-impedance with both self and mutual impedance, it have a lower differences and lower percentage of error. This is because a higher fault impedance can cause the mutual impedance to be neglected. The basic concept in determining the voltage sag is fault analysis. The voltage sag value in each nodes were determine by the voltage, current and impedance values of the node. Therefore, each node will have a difference value of voltage sag.

C. Impact of Distance

For node 2 to node 10, it shows that the voltage sag value is became lower. The closer node to the faulty node, the lower voltage sag value it will get. This is due to the fact that when voltage sag occur, the current will become higher as the voltage become lower [13]. This reflected to the result shown in the table as the closest node to the faulty node have a greater impact compared to the further node. Nevertheless, for node 12 to node 19, it have a more stable voltage value compare to other nodes because it is located in branches of the distribution network. This is because as the fault occur and voltage sag happen on node 11, it create an easier path for current to flow from node 2 to node 10 compared with node 12 to node 19 as it has higher impedance which is have only the load impedance. This is because the fault resistance is lower compared with the network impedances causing a higher value for current to flow to the faulty node. The non-homogenous cable in the distribution network also contributed to the self and mutual impedance value as each section have a difference types of cable.

VI. Conclusion

Impedance-based method is proven to have a reasonable accuracy in estimating the voltage sag value in the distribution network. This is proven by the result shown as the highest error is only 30% which is when considering the mutual impedance with a lower fault resistance. This method can be used as a practical solution is estimating the

voltage sag value because of its reasonable accuracy and only utilize the measurement at the primary substation. At the end of this research, the effect of self-impedance with mutual impedance and fault resistance value to the voltage sag estimation is known. Higher fault resistance will lower the effect of the mutual impedance in the non-homogenous cable. Due to the result obtained, it can be used for the further works which the fault location determination by using the results. Nevertheless, the accuracy of the voltage sag estimation will influence the accuracy of the fault location determination.

Acknowledgment

I am greatly thankful for the support from Universiti Kuala Lumpur, International College (ICOLE), Malaysia.

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