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# Voltage sag assessment and Area of vulnerability due to balanced fault for 11 bus system

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**ABSTRACT: The voltage sag is very common issue of power quality. In order to assess voltage sag stochastic method is used. This paper presents an analytical method to assess voltage sag frequency and area of vulnerability for buses given in the system. The area of vulnerability (AOV) graphically represents fault zones which lead to voltage sag of desired magnitude on observation bus. The results are presented for 11 bus test system. As voltage sag occurs due to short circuit faults *i.e* balanced and unbalanced fault. This study is done for balanced faults occurring in the system.**

**Keywords:** Power quality, stochastic method, voltage sag, Area of Vulnerability.

## I. INTRODUCTION

An interruption of the power service can originate important economic losses to affected customers. Present power networks are regularly improved in order to reduce the number and duration of interruptions. However, the main concern for many industrial and commercial users is the maloperation originated by voltage sags. In recent years, voltage sag is most emerging issue for electric power industry due to consumer sensitivity needs. The voltage sag is short duration reduction in r.m.s voltage between 0.1 and 0.9 p.u with duration from 0.5 cycles to 1 min [1]. The main cause of voltage sag is due to fault due to short circuit in transmission and distribution networks. In order to identify voltage sag affected zone, it is necessary to predict voltage sag in the desired network. Voltage sag effected zones are shown through AOV (area of vulnerability), which is helpful for estimation of mitigation of voltage sag. For assessment of voltage sag two approaches are there: Monitoring, Stochastic Assessment. The first approach is very time consuming requires several years to assess voltage sag. In stochastic assessment two methods are approached: fault position, critical distance. The method of critical distance is applicable to radial network whereas method of fault position is applicable to meshed network.

In this paper voltage sag due to balanced fault is assessed for 11 bus test system. An analytical algorithm is used to assess the voltage sag. Also, areas of vulnerability maps are shown for bus 6 and 8 respectively. The voltage sag per year graph is shown for bus 6 and 8 respectively.

## II. VOLTAGE SAG ASSESSMENT METHOD

This paper assesses the voltage sag at the desired bus using method of fault position, as it is applicable to mesh network. The voltage sags caused in the network are assumed due to short circuit fault occurring in the system. This paper considers balanced faults in the for 11- bus test system.

*A. Fault at bus*

The proposed method starts with the bus impedance matrix of the network currently used for 3-ph symmetrical short circuit calculations. The voltage seen at bus *m* can be due to fault occurring at bus *n* can be given by [2]

$$V_{mn} = V_m^{pf} + \Delta V_{mn} \qquad \ldots(1)$$

Where as

$V_m^{pf}$ Pre fault voltage at bus m

$\Delta V_m$ Voltage change at bus *m* due to fault at bus *m* due to fault at bus *n*

For 3-ph fault and voltage sag at bus *m* due to fault at bus *n* is given by

$$V_{sag}(m,n) = V_m^{pf} - \frac{Z_{mn}}{Z_{nn}} \times V_n^{pf} \qquad ...(2)$$

Where as

$V_{sag}(m,n)$ Voltage sag at *m* due to fault at bus *n*

$V_m^{pf}$ Pre-fault voltage at bus *n*

$Z_{mn}$ Impedance between bus *m* and *n*

$Z_{nn}$ Self-impedance of bus *n*

The sag matrix can be formed from equation (2) for i-bus network; the sag matrix can be shown as

$$V_{sag} = \begin{bmatrix} 0 & V_{sag(1,2)} & V_{sag(1,3)} & \cdots & V_{sag(1,i)} \\ V_{sag(2,1)} & 0 & V_{sag(2,3)} & \cdots & V_{sag(2,i)} \\ \vdots & \vdots & 0 & \vdots & \vdots \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ V_{sag(i,1)} & V_{sag(i,2)} & \cdots & \vdots & 0 \end{bmatrix} (i \times i) \qquad ....(3)$$

*B. Fault along lines*

The probability of fault on buses is very less. Most of the short circuit fault occurs along the lines. In order to find voltage sag along the line, method of fault position is applied.Fig1shows, location of fault along the line at position *p*.

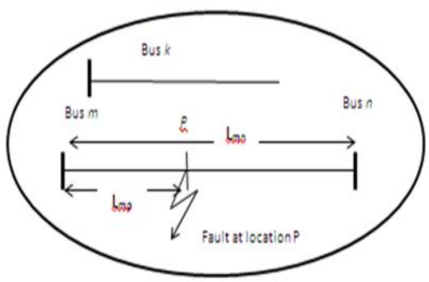


**Fig.1.** Location of fault at P.

The voltage sag at bus *k* due to fault at location *p* along the line can be calculated as follows

$$V_{sag}(k,p) = V_k^{pf} - \frac{Z_{kp}}{Z_{pp}} \times V_p^{pf} \qquad …(4)$$

The new impedances due to this fault location *p* to be calculated with respect to bus *k*. These new impedance$Z_{mp}$ , $Z_{pp}$ is given as

$$Z_{kp} = (1-\lambda) \times Z_{km} + \lambda \times Z_{kn} \qquad …(5)$$

$$Z_{pp} = (1-\lambda)^2 \times Z_{mm} + \lambda^2 \times Z_{nn} + 2\lambda(1-\lambda) \times Z_{mn} + \lambda(1-\lambda) \times z_{mn} \qquad …(6)$$

$$\lambda = \frac{L_{mp}}{L_{mn}} \qquad …(7)$$

Whereas,

$L_{mn}$ distance between two interconnected buses *m* and *n* in network.

$L_{mp}$ distance between bus *m* and fault location *p*

$Z_{kp}$Transfer impedance between bus *k* and fault point *p*

$Z_{pp}$ Self-impedance between fault point *p*

$z_{mn}$ Impedance of bus *m* and *n*

The pre fault voltage at location *p* is given as

$$V_p^{pf} = (1-\lambda) \times V_m^{pf} + \lambda \times V_n^{pf} \qquad \text{…(8)}$$

The location of fault can be also evaluated for desired magnitude of voltage sag, $V_m$. This is evaluated by solving quadratic equation given by

$$A1\lambda^2 + B1\lambda + C1 = 0 \qquad \text{…(9)}$$

Whereas,

$A1 = A - A \times V_m$;

$B1 = B - V_m \times B + Z_{pm} - Z_{pn}$

$C1 = C - C \times V_m - Z_{pm}$

$A = Z_{mm} + Z_{nn} - 2 \times Z_{mn} - z_{mn}$

$B = 2 \times Z_{mn} - Z_{mm} - z_{mn}$

$C = Z_{mm}$

*C. Assessment of voltage sag*

The probability function of a fault to occur between the specified position by $\lambda$ lower and $\lambda$ higher is given by[3]

$$P(lower \le v_1 \ge higher) = \int_{lower}^{higher} f(v)dv$$

Where $P(lower \le v_1 \ge higher)$is the probability of $lower \le v_1 \ge higher$, and $f(v)$ is the probability distribution function associated with fault distribution along the line considered.

The number of sag/year at bus k caused by faults on the line m-n can be calculated as:

$$N(lower \le v_1 \ge higher) = \lambda_f \times P(lower \le v_1 \ge higher)$$

Where, $\lambda_f$is the fault rate per year for line.

## III. METHODOLOGY

A methodology is proposed for determining the voltage sag and area of vulnerability. The flowchart is shown in fig 3. Firstly pre fault voltage for each bus is specified. In this work pre fault voltage is taken as 1 p.u for each bus. On the basis of data provided for network, impedance matrix Z bus is prepared. Next step is to select the threshold voltage sag magnitude for which number of voltage sag is to be predicted for one year. After that total numbers of lines in the given network are set and to select the line on which voltage sag is predicted. Calculate voltage sag magnitude at $\lambda$ = 1 and $\lambda$ = 0 from equation (4), (5) and (6) respectively. If threshold voltage is lesser than voltage sag magnitude at $\lambda$ = 1 and $\lambda$ = 0 than move to next line. Now in next step, if threshold voltage sag is lesser than voltage sag magnitude at $\lambda$ = 1 and $\lambda$ = 0 respectively then value of probability function is equal to one. This infers that whole line comes under the area of vulnerability. After that the last possibility is that, voltage sag magnitude lies under the voltage sag magnitude at $\lambda$ = 1 and $\lambda$ = 0. Now solve the quadratic equation given in equation (9) to find the value of probability of occurrence. The uniform distribution function is considered for this line. After that calculate the number of voltage sag for that line. Sum the number of voltage sag for all line. Apply to total number of given lines in the network. Finally, total number of voltage sags is estimated on bus for desired voltage sag magnitude.

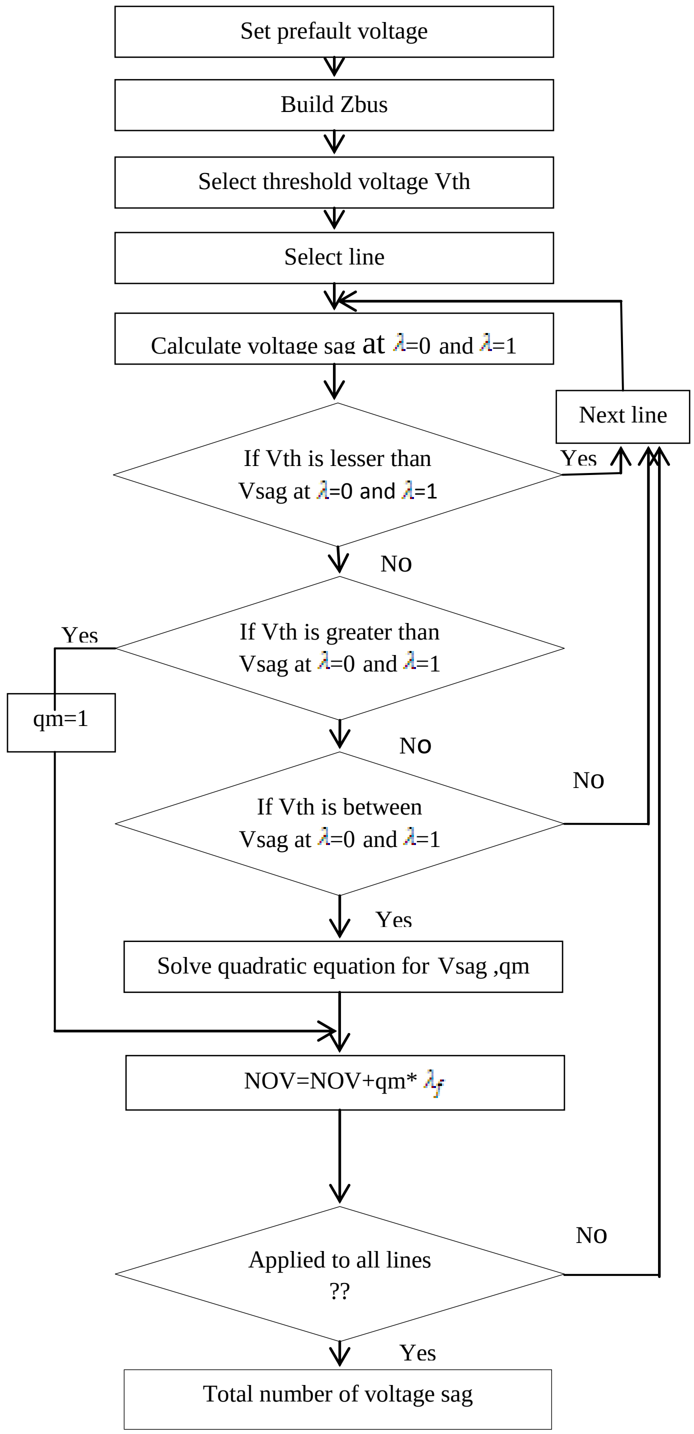


**Fig 2.** Flowchart for determining voltage sag and AOV.

## IV. RESULT

The proposed algorithm is applied to 11 bus test system. The data is provided in [4] .The network is shown in fig3. This system has 11 buses, and 44 interconnected lines, 3 generating stations and 3 transformers.

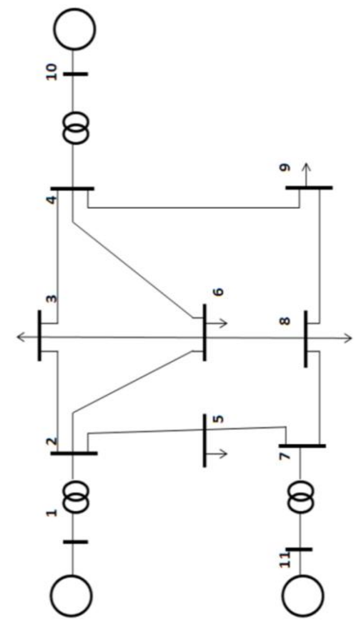


**Fig. 3.** 11 bus test system.

*A. Number of voltage sag/year*

Balanced fault is considered to show effectiveness of proposed analytical method to estimate the voltage sags per year. Figure 4 and 5 shows number of voltage sag per year for system buses 6 and 8 respectively for all threshold values of voltage sags. The maximum voltage sag occurs at threshold value of 0.8 p.u in case of bus 6. Whereas in case of bus 8, maximum voltage sags are occurring at threshold value of 0.7 p.u.

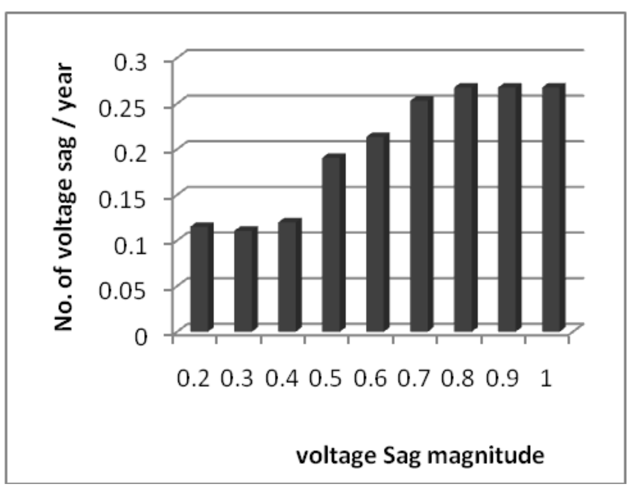


**Fig. 4.** Number of Voltage sag at bus 6.

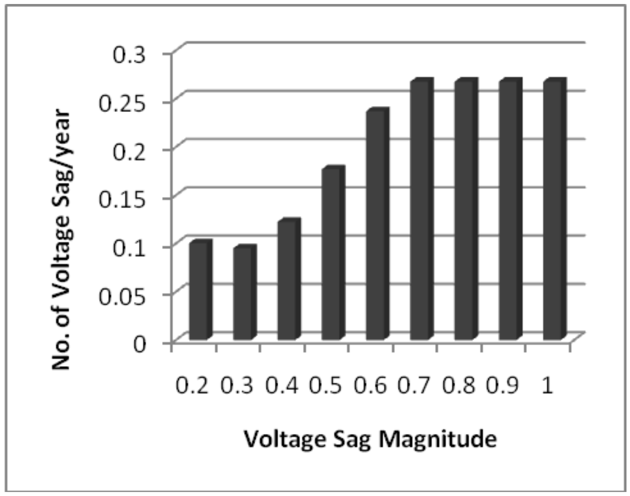


**Fig. 5.** Number of Voltage sag at bus 8.

*B. Area of vulnerability*

The exposed area or area of vulnerability is contained in the rows of the voltage-sag matrix and can be graphically presented on the one line diagram. Exposed area is the region of the network that encloses buses and line segments where the occurrence of faults will lead to voltage sags more severe than a given value at the observation bus. The 0.5 p.u. area of vulnerability for bus 6 contains buses 1,2,3,4,6,10 and lines connecting them indicating the faults at these buses and line will cause less residual voltage then 0.5 p.u for bus6. Fig 6 presents the area of vulnerability for bus 6. Similarly fig 7 shows area of vulnerability for bus 8 for 0.5 p.u. This includes buses 6, 7, 8 and 11. The area included in AOV is represented by dashed line.

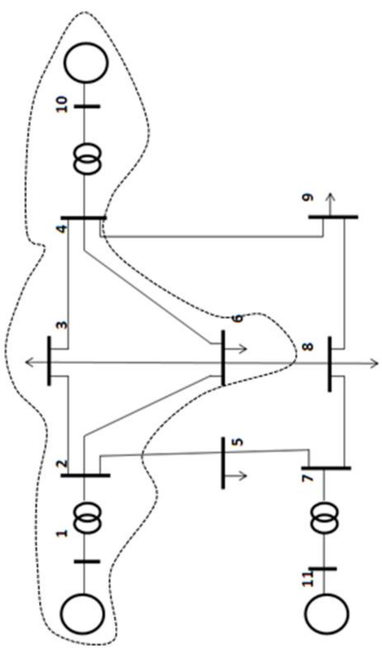


**Fig. 6.** Area of vulnerability for bus 6.

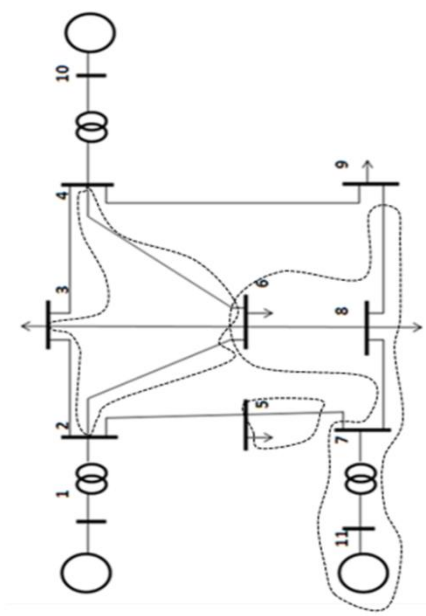


**Fig. 7.** Area of vulnerability for bus 8.

## V. CONCLUSION

An analytical method is proposed for prediction of voltage sags in the proposed network. This method is based on fault method and by use of bus impedance matrix. The voltage sag is predicted on any observation bus with minimal effort, directly without constructing voltage sag matrix.

Similarly area of vulnerability can also be obtained from this analytical method. The concept of an area of vulnerability is useful for evaluation of the likelihood of sensitive zones being subjected to voltage sag. This study is helpful for protective schemes and mitigation of voltage sags. This paper limits this study to balanced fault, but can be extended to unbalanced fault also.

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