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The Method Based on Voltage Stability Margin to Load Shedding in the Power System

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Abstract- If the power is not increased by raising the load admittance and lowering the bus voltage, as a result, the voltage collapse with all its effects is realized, which results in the spread of disturbances in power systems. The final option is to eliminate the load during a significant disturbance. The stability margin may be extremely minimal. To do this, we need automatic equipment to reduce the stability margin and remove the load. In this method, the performance of each piece of equipment depends on the voltage level, and the disadvantage of this method is the dependence on the voltage level and stability range and power factor. To overcome this problem, this paper proposes new criteria for voltage stability. The power derivative s and the admittance derivative are employed in this equation. Given that power and admittance can be measured, this is fairly simple to execute. The load of the transformer tap changer is constantly shifting and turning on and off due to continuous load changes.

Keywords: Load shedding, voltage drop, voltage stability, power system.

1. Introduction

The IEEE/CIGRE association defines power system stability as the ability of the electric power system to maintain the previous state and balance again after a physical disturbance with the largest range of changes and ultimately the system remains unchanged [1–2]. The spread of disorder results in instability in the system. Several modes are defined for stability.

- Rotor angle stability: which may be a small disturbance in rotor angle or transient stability.
- Frequency stability: which may be short-term or long-term.
- Voltage stability: which may be a major or minor disturbance and both of them are normal in the short and long term.

Many instabilities contribute to the spread of disturbances. Finding abnormal conditions and taking preventive action as necessary are necessary to contain the effects and stop the spread of illnesses. The main task of the device is to automatically limit the disturbance. In many cases, removing the load is the last solution for stability [3-6].

Starting to remove the load and its value is a dangerous operation that causes the problem of voltage reduction in the stability margin, which cannot be cleaned and isolated.

A load-shedding technique employing the PSO algorithm is suggested in [7] for an environment with a competitive power market. In a restructured power network, the techno-economic goal function used takes into account things like grid loads and the economics of generation and consumption. In [8], it is shown that the PSO algorithm outperforms GAMS and SA in resolving network stability issues while minimising load shedding. As a result, numerous methods for under-voltage load shedding have been presented utilising the PSO algorithm, with both technical goals (e.g., least shed load) and economic goals (e.g., lowest incurred shedding costs). Results from these methods have been compared to one another [9, 10].

To get the greatest outcomes in the shortest amount of time, load-shedding optimisation approaches use many heuristic methodologies. In [11], the estimation problem of the ideal amount and location of load shedding at transformer tap positions is applied using PSO in conjunction with modal analysis. Although this method is used to supplement the power grid in Iran, it cannot be easily adapted to other networks. Additionally, a method is provided in [12] to choose the ideal amount and location of load shedding in a 30-bus network by combining PSO and Firefly algorithms. The quantity of shed load obtained by the PSO method is not less than that obtained by other methods, despite the PSO algorithm's faster convergence. Additionally, GA and ANN have been used to address a voltage stability issue in order to reduce network load shedding and voltage variation [13].

To find the lowest load shedding amount while taking into consideration the loading capability of network equipment, the authors in [14] use ZIP voltage-dependent load models using mixed integer programming (MIP). Furthermore, reference [15] discusses voltage-based load models and illustrates how these models impact network power equilibrium, the amount of shed load, and the relocation of voltage collapse points in the smart grid. The concept of voltage stability using local measurements forms the basis of the novel way of estimating the margin of voltage stability that is provided in this study.

2. Voltage Stability

According to the IEEE technical committee, the power system's voltage stability is described as follows: Voltage stability is the capacity of a system to retain its voltage when the load and power are both raised, allowing for the regulation of both power and voltage. This occurrence can be frequent. It has been researched, and Figure 1 depicts the corresponding circuit.

Each system consists of a load bus, impedance Z$_s$, and force E, which is equivalent in the circuit.

Voltage V and power are expressed by well-known formulas.

$$V=\frac{EZ_L}{\left[Z_L^2+Z_S^2+2Z_LZ_S\cos\beta\right]^{0.5}} \tag{1}$$

$$S=\frac{E^2Z_L}{\left[Z_L^2+Z_S^2+2Z_LZ_S\cos\beta\right]} \tag{2}$$

where β is equal $\varphi_S-\varphi_L$, and φ_S is the impedance angle Z$_s$ and φ_L is the load impedance angle Z$_L$.

Figures 2 to 4 were made with the assumption of E=1, Z$_s$=1, which shows the general results. Figure 2 shows the voltage V against the power S.

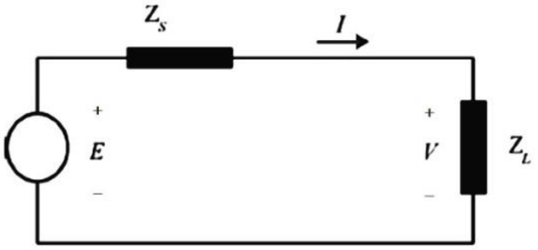

Fig. 1. Simplified equivalent circuit for studying voltage stability

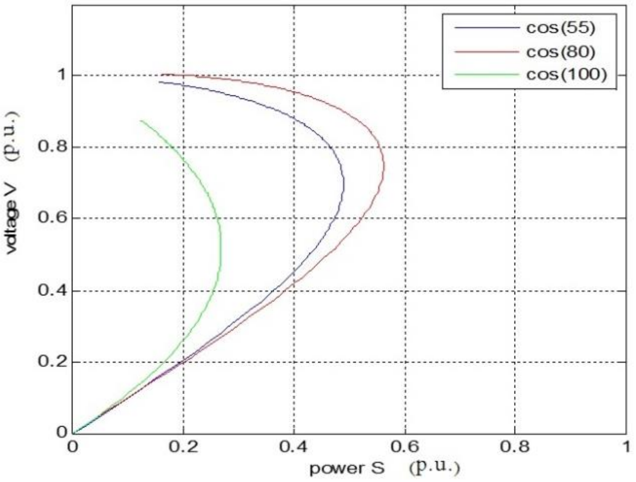

Fig. 2. Power-voltage relationship in the equivalent circuit

In each figure, there are three curves whose β values are 55, 80, and 100 degrees respectively. Figure 3 shows the power S versus impedance with the source impedance $\frac{Z_L}{Z_S}$. Figure 4 shows the voltage versus the rate of change of the impedance of the load to the source.

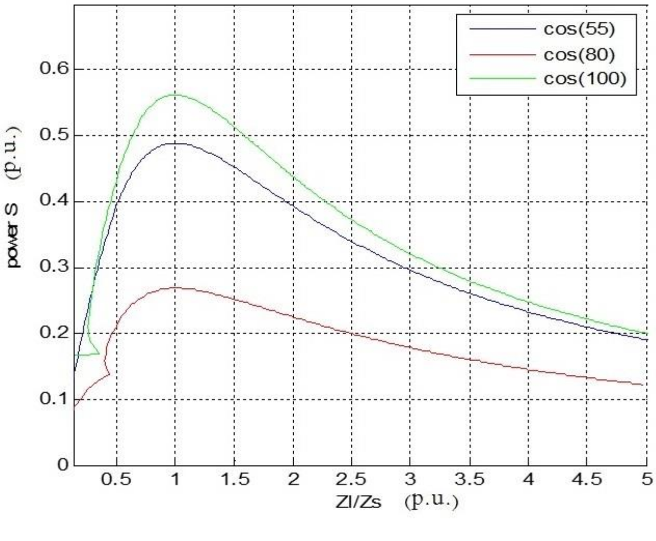

Fig. 3. The power S versus the impedance of the source impedance $\frac{Z_L}{Z_S}$.

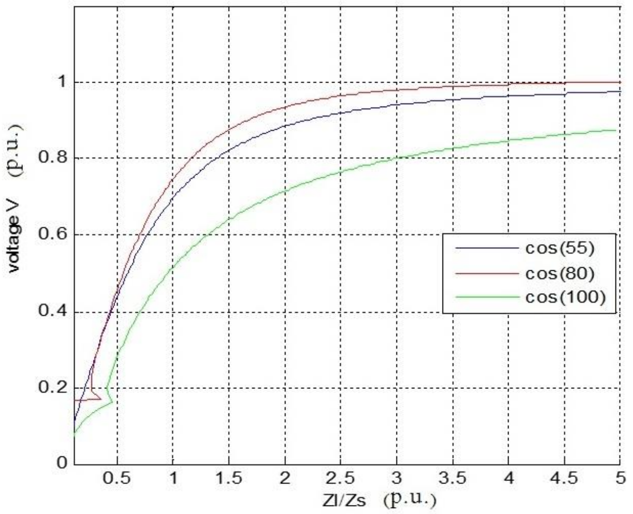

Fig. 4. The voltage versus the rate of change of the impedance of the load to the source.

The figures confirm that the critical level is the unit in that the voltage stability is limited, where the power value S_{max} and the critical voltage value V_C are equal to the value below.

$$V_c = \frac{E}{(2+2\cos\beta)^{0.5}} \tag{3}$$

$$S_{max} = \frac{E^2}{2Z_S\,(1+\cos\beta)} \tag{4}$$

3. Prevention of Voltage Collapse

There are various tools to prevent voltage collapse, so the last defense is to remove the load, which has two features. The value $\frac{Z_L}{Z_S}$ should always be greater than the value of the critical level. The desired value should be chosen so that increasing Z_S and decreasing Z_L does not cause instability.

The value of V should be enough so that the engine does not stop. In practical applications, removing the load is the first step of under voltage relays, so look at figure 4 for a good explanation. To specify the value $\frac{Z_L}{Z_S}$, the voltage level is dependent on the value β, so if the undervoltage relay settings value is equal to 0.85E, then for $\beta = 55$ load removal in time $\frac{Z_L}{Z_S}$=3.75 and for $\beta = 90$ in time $\frac{Z_L}{Z_S}$ =1.7 and if it is a capacitor load, load removal in $\beta = 100$ Considerably, it starts from $\frac{Z_L}{Z_S}$=1.25. Under voltage relay settings may be an agreement and may be based on equation (1). The level of excitation angle β of each relay is within the range of ground phase angle and load angle φ_l . To show it, we look at E level and phase angle φ_s and compare them.

The impedance value of the source is the root of the problem, so any efforts to overcome the undervoltage standard should be based on local measurement values [16, 17]. The calculation used to define voltage stability is based on the method given in this work for the long line model and the calculation of the rate $\frac{Z_L}{Z_S}$ and value of the voltage stability margin [18-21].

4. Calculation of Voltage Stability Margin

If the value of the power derivative for the corresponding circuit in Figure 1 is expressed in terms of conductance, the computation of stability in terms of voltage stability may be quite precise.

$$\frac{dS}{dY} = \frac{V^2[1-(Z_SY)^2]}{1+(Z_SY)^2+(2Z_SY\cos\beta)} \tag{5}$$

where $Y = \frac{1}{Z_L}$

If both sides of the equation are divided by V^2, the final equation will be as follows.

$$\frac{dS^*}{dY^*} = \frac{1-(Z_SY)^2}{1+(Z_SY)^2+(2Z_SY\cos\beta)} \tag{6}$$

where $\frac{dS^*}{dY^*} = (\frac{Y}{S})(\frac{dS}{dY})$ and using equation (6) the value $\frac{Z_L}{Z_S}$ is calculated and $M = \frac{dS^*}{dY^*}$.

$$\frac{Z_L}{Z_S} = \frac{M+1}{-M\cos\beta+[(M\cos\beta)^2-M^2+1]^{0.5}} \tag{7}$$

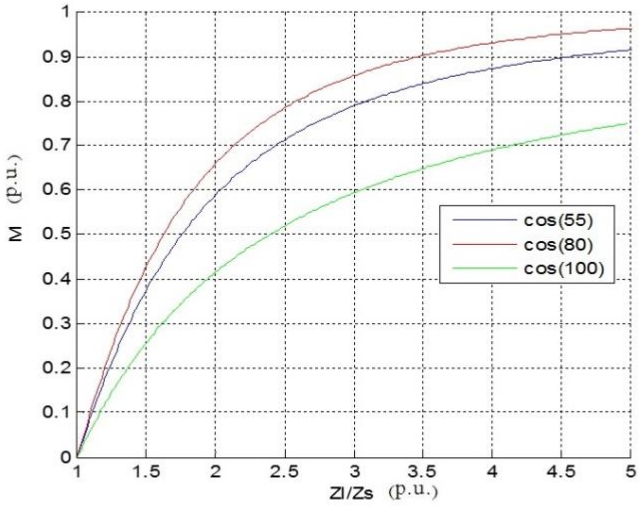

Fig. 5. Relationship between $\frac{Z_L}{Z_S}$ and M

The relationship between $\frac{Z_L}{Z_S}$ and M is shown in Figure 5, which is dependent on the angle β , which $\beta = \varphi_S - \varphi_L$ that includes the phase angle of the load φ_L and the phase angle of the source φ_S. The actual value depends on the system structure, but in most cases it is equal to 80, +7, -7 (87 and 73). This means that the phase angle of the circuit is equivalent to the impedance of the source equal to 73 to 87 and the time constant of the source $\frac{Ls}{Rs}$ is equal to 10ms, 60ms.

In Figure 6, the relationship between the coefficient M and the value $\frac{Z_L}{Z_S}$ in the case of active load and the three phase angle values φ_S are assumed to be 73, 80 and 87. In figure 7, there is a certain value $\varphi_L = 37^o$ for active and reactive load. In one case, even if the phase angle of the source is estimated between -7 and +7, the accurate value $\frac{Z_L}{Z_S}$ is enough for the decision to remove the load.

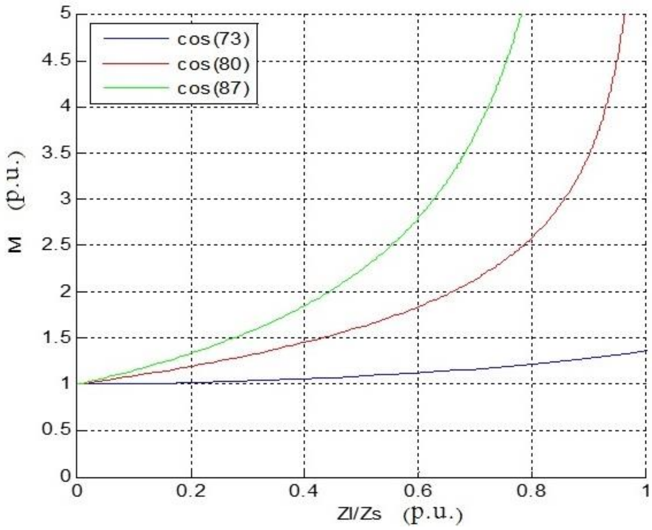

Fig. 6. Calculation diagram of impedance change rate - load to impedance change - source with $\varphi_l = 0$ and $\varphi_s = 80$

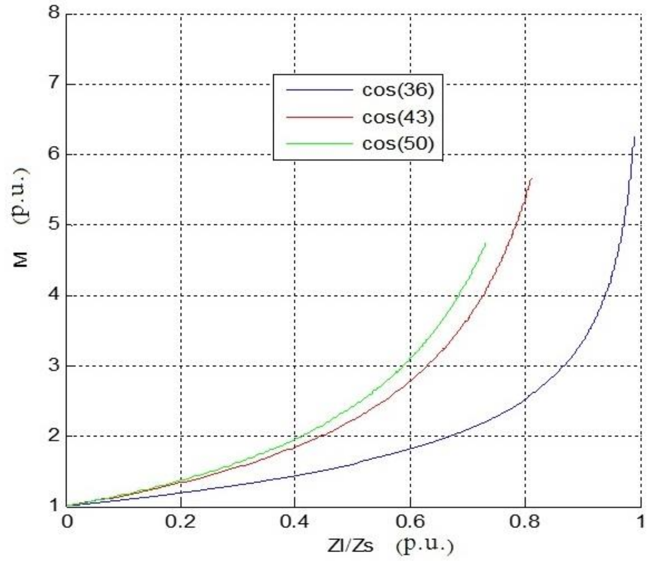

Fig. 7. Calculation diagram of impedance change rate - load to impedance change - source with $\varphi_l = 37$ and $\varphi_s = 80$

The correctness of this particular case is with the M factor below 0.6 and increasing the phase angle φ_l. In other words, if the value of E is known, the value of $\frac{Z_L}{Z_S}$ can be expressed from relations 1 and 6 as follows.

$$\frac{Z_L}{Z_S} = \frac{1}{\left[1-M(\frac{E}{V})^2\right]^{0.5}} \qquad (8)$$

5. Measurement Curve

The shifts in power S and admittance Y serve as the foundation for this entire idea. In actuality, the variations in load admission are nearly constant. Although this always occurs in large and small steps, the coefficient M can be calculated from the following formula.

$$M = \left(\frac{dS^*}{dY^*}\right) = \frac{(S_2-S_1)(Y_2+Y_1)}{(S_2+S_1)(Y_2-Y_1)} \qquad (9)$$

where Y_1, S_1 are power and admittance before change (time t_1) and Y_2, S_2 are power and load admittance after change (time t_2). The change time between t_1 and t_2 should be 500ms.

The digital calculation of S, Y, φ_L and the voltage and current of the phasor are measured on the high voltage side, and this does not affect the problem. The information window for the calculation must be done in a basic frequency period. Therefore, for the entire calculation, the value of M coefficient is taken from equation (9) and the value is taken from equation (7).

There are three steps to controlling the stability margin. When $\frac{Z_L}{Z_S}$ reaches a certain level, we must continue with routine operations, at which point the alarm will sound. The tap transformer changing equipment must be shut out of operation if this problem persists and reaches a level of 2–2.5. When it falls below 1.5 to 2, load reduction should begin.

6. Conclusion

Load removal is the final line of defense against voltage drop during development. The voltage criteria are used to verify the stability margin and remove the load; however, the standard has no bearing because the voltage level relies on the phase angle when proportional levels are used. By changing the load angle, there may be a certain improvement in the voltage due to a significant improvement in the stability margin. This paper presents several estimation methods for the voltage stability margin that are based on the voltage stability definition. The value of $\frac{Z_L}{Z_S}$ can be determined by calculating the changes in power for admission $\frac{dS}{dY}$. The computation of the impedance ratio of the load to the source is simplified in the final formula because the phase angle of the source may be measured with adequate accuracy. Measurement of reactive power fluctuations against load susceptance may be used as an alternate method to calculate the stability margin, particularly for the reactive load. The ratio of the load's reactance to the source can be calculated using this technique. The real power system mode should be used to test this method. The station computer programs the bus signal processing known through equations 7 and 9 for the direction of the stability margin. The obtained results are compared with other methods, those related to local signal processing and with online calculations in a power system. This can be interesting and if the comparison is done well it can cover the voltage decay.

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