TRANSIENT STABILITY ASSESSMENT FOR UNBALANCED FAULTS

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Abstract: The paper describes the model applicable for transient stability assessment for unbalanced faults. The model itself is derived using symmetrical component representation of the grid. Sensitivity analysis of zero sequence line reactance, fault location and line length was done using the built model, the influence of unbalanced faults was discussed. The model is applicable for simplified stability assessment, but it could be used also for simulation purposes.

Keywords: transient stability, unbalanced operation, symmetrical components

1 INTRODUCTION

Electrical power grids are undergoing huge development these days, mainly due to changes in source base (increase of renewables and distributed generation), which enhances the requirements for reliable and resilient power system operation. This leads to the demand for transient stability assessment (TSA) enhancement. Currently used and researched methods are combining following aspects:

a. The simplest grid model used for TSA is called "Single Machine – Infinite Bus", abbreviated as SMIB (single line diagram is shown in Figure 1). Assessing stability using this model is straightforward and relatively easy [1]. Even large power systems are convertible to the SMIB model [2], but the precision of results need not be accurate.

b. It is difficult to define a measure for transient stability (how to quantify it). There is a general agreement on usage of Critical Clearing Time, abbrev. CCT [3]. CCT is the maximum allowable time of fault duration for which the assessed power system remains stable. Question remains, which fault is the most severe (leading to the lowest CCT). Usually, the three-phase short circuit occurring near to generator(s) in transmission system is used.

c. Commonly used methods for power system dynamics analyses are time domain simulations. Nevertheless, these simulations can be time-consuming and require computationally intensive, so the search for simplified methods is evident [4].

In scope of this paper is the TSA for power systems under unbalanced fault operation. Investigation of the influence of unbalanced faults on transient stability can be equally interesting, because this leads to the need of an advanced power grid modelling and can be practically used for investigation of real faults that occurred in the grid. In this paper, influence of shunt faults – Line-to-line (LL), Single line-to-ground (1LG) and Double line-to-ground (2LG) fault – and series faults – One line open (1LO) and Two lines open (2LO) – is compared using the SMIB model shown in Figure 1.

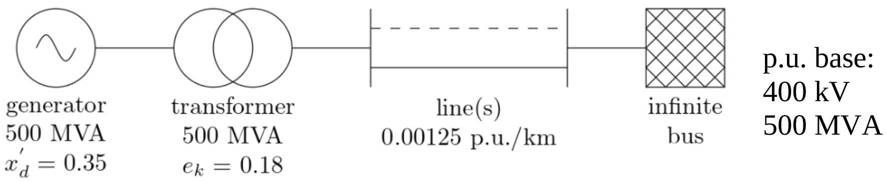
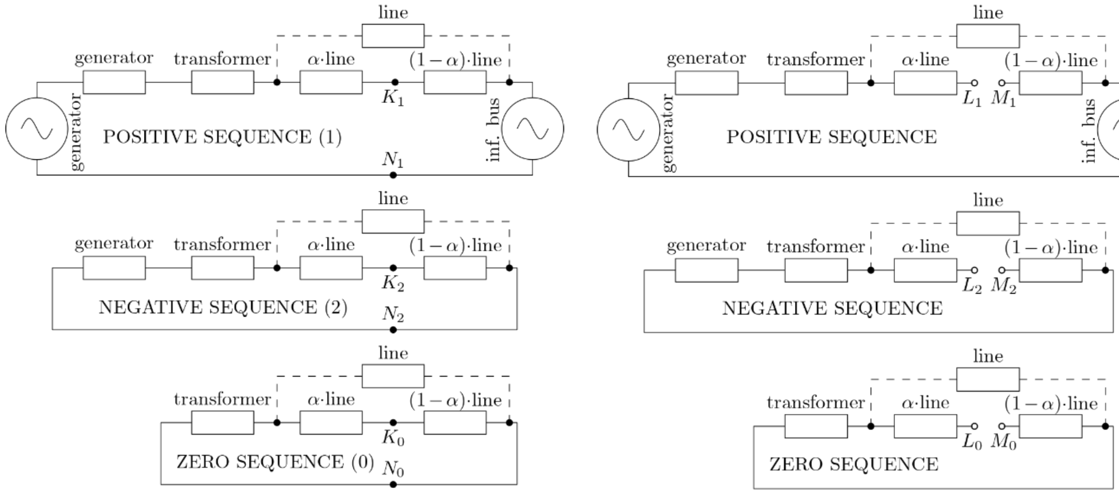


Figure 1: Single line diagram of the SMIB model.

2 GRID MODEL FOR UNBALANCED FAULTS

The common method used for analysis of power systems under unbalanced operation is the method of symmetrical components. It is described e.g. in [5] and widely used for various applications. The main idea is to decompose the unsymmetrical system into three symmetrical components – positive (1), negative (2) and zero (0) sequence. The equivalent schemes of the SMIB model from Figure 1 for all three components are shown in Figure 2 for both shunt and series faults. These schemes respect the variable fault location on the line respected by coefficient α expressing the fault distance from the beginning of the line. The common simplification that grid elements are modelled only using the reactances [6] is kept.



a) shunt faults b) series faults

Figure 2: Equivalent sequence representation of the grid (single-line diagram).

The key issue for further analysis is the interconnection of these schemes – interconnection of ports, which is derived for each fault separately e.g. in [5] and summarized in Table 1. To clarify the problem, it is possible to use the equivalent reactance X_Δ between the ports $K_1 - N_1$ for shunt faults and $L_1 - M_1$ for series faults. For stability assessment, it is important to calculate the transfer reactance between the machine and infinite bus X_{1l} for 1 line operation, respectively X_{2l} for 2 lines operation. Formulas derived from the system representation (Figure 3) are summarized in Table 1. Used indices are: g – generator, t – transformer, l – line.

Fault	Shunt faults			Series faults	
	LL	1LG	2LG	1LO	2LO
Connected ports	$K_1 - K_2$, $N_1 - N_2$	$K_1 - N_0$, $N_2 - K_0$, $K_2 - N_1$	$K_1 - K_2 - K_0$, $N_1 - N_2 - N_0$	$L_1 - L_2 - L_0$ $M_1 - M_2 - M_0$	$L_1 - M_0$, $L_0 - M_2$, $L_2 - M_1$
Neg. seq. reactance $X_{(2)}$ 1 line	$\frac{(1-\alpha)X_{l(2)} \cdot (X_{g(2)} + X_{t(2)} + \alpha X_{l(2)})}{X_{g(2)} + X_{t(2)} + X_{l(2)}}$			$X_{g(2)} + X_{t(2)} + X_{l(2)}$	
Neq. seq. reactance $X_{(2)}$ 2 lines	$\frac{\alpha(1-\alpha)}{2} X_{l(2)} + \frac{(1-\alpha)X_{l(2)} \cdot \left(X_{g(2)} + X_{t(2)} + \frac{\alpha}{2} X_{l(2)}\right)}{2X_{g(2)} + 2X_{t(2)} + X_{l(2)}}$			$X_{l(2)} + \frac{\left(X_{g(2)} + X_{t(2)}\right) \cdot X_{l(2)}}{X_{g(2)} + X_{t(2)} + X_{l(2)}}$	
Zero seq. reactance $X_{(0)}$ 1 line	$\frac{(1-\alpha)X_{l(0)} \cdot (X_{t(0)} + \alpha X_{l(0)})}{X_{t(0)} + X_{l(0)}}$			$X_{t(0)} + X_{l(0)}$	
Zero seq. reactance $X_{(0)}$ 2 lines	$\frac{\alpha(1-\alpha)}{2} X_{l(0)} + \frac{(1-\alpha)X_{l(0)} \cdot \left(X_{t(0)} + \frac{\alpha}{2} X_{l(0)}\right)}{2X_{t(0)} + X_{l(0)}}$			$X_{l(0)} + \frac{X_{t(0)}X_{l(0)}}{X_{t(0)} + X_{l(0)}}$	

Fault	Shunt faults			Series faults	
	LL	1LG	2LG	1LO	2LO
Equivalent reactance X_Δ	$X_{(2)}$	$X_{(2)} + X_{(0)}$	$\frac{X_{(2)}X_{(0)}}{X_{(2)} + X_{(0)}}$	$\frac{X_{(2)}X_{(0)}}{X_{(2)} + X_{(0)}}$	$X_{(2)} + X_{(0)}$
Transfer reactance 1 line X_{11}	$X_{g(1)} + X_{t(1)} + X_{l(1)} + \frac{(1-\alpha)X_{l(1)}\left(X_{g(1)} + X_{t(1)} + \alpha X_{l(1)}\right)}{X_\Delta}$			$X_{g(1)} + X_{t(1)} + X_{l(1)} + X_\Delta$	
Transfer reactance 2 lines X_{21}	$X_{g(1)} + X_{t(1)} + \frac{X_{l(1)}}{2} + \frac{(1-\alpha)X_{l(1)}\left(X_{g(1)} + X_{t(1)} + \frac{\alpha}{2}X_{l(1)}\right)}{\alpha(1-\alpha)X_{l(1)} + 2X_\Delta}$			$X_{g(1)} + X_{t(1)} + X_{l(1)} \cdot \frac{X_{l(1)} + X_\Delta}{2X_{l(1)} + X_\Delta}$	

Table 1: Transfer reactance

3 SENSITIVITY ANALYSIS

As was shown in Table 1, the value of transfer reactance is dependent on all three components impedances, but its calculation differs for each fault. Transfer reactance X_{11} (X_{21}) has significant influence on transient stability [6]. For TSA using simplified methods, the crucial value is the maximum transferable active power from the machine to the grid during the fault, which is, in a simplified way, inversely proportional to the transfer reactance.

To reveal the effect of selected factors on transfer reactance and therefore on transient stability, sensitivity analysis was done. The selected factors were zero sequence impedance, fault location and line length. Results accompanied by discussion are in the following subsections 3.1 – 3.3.

3.1 ZERO SEQUENCE IMPEDANCE

Negative sequence impedances are generally assumed to be the same as positive sequence impedances. The issue is the value of zero sequence impedance. Regarding power lines, zero sequence impedance is mainly influenced by the usage of ground wires. It can be calculated or measured, and its common range is 1÷5 times higher than the positive sequence reactance. This range was tested; results are shown in Figure 4. In studied case, line length was 100 km and fault location α = 0 %.

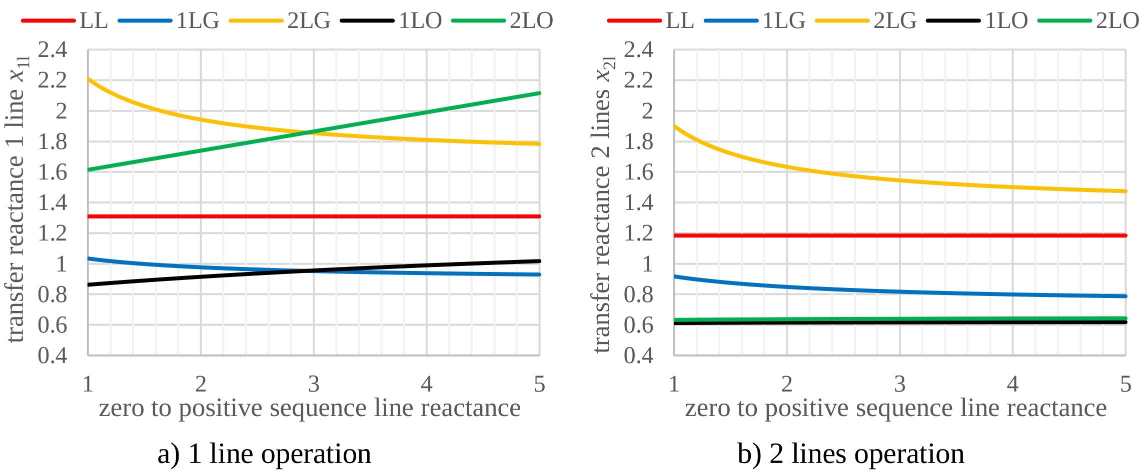
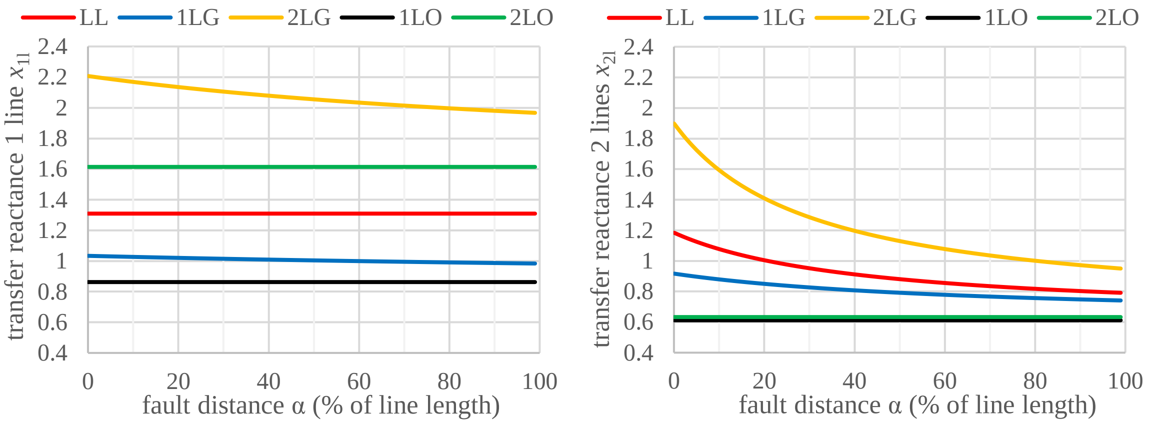


Figure 3: Effect of zero sequence line reactance on transfer reactance.

From Figure 4, it can be observed that the most significant effect of increasing zero sequence line reactance is in case of 2LO (1 line operation; X_{11} is increasing) and 2LG (X_{11} and X_{21} are decreasing). For 1LG and 1LO, the effect is small, for LL, there is no influence.

3.2 Fault location

For analysis, fault location was tested in range 0÷99 % of the faulted line. Results for line length 100 km and zero sequence line reactance ratio 1 are shown in Figure 5. Results confirms the assumption the closer a shunt fault is located to the machine, the worse effect on stability it has. The significant influence is mainly in case of 2 lines operation. Referring to formulas derived in Table 1, there is no influence of fault location in case of series faults.



a) 1 line operation b) 2 lines operation

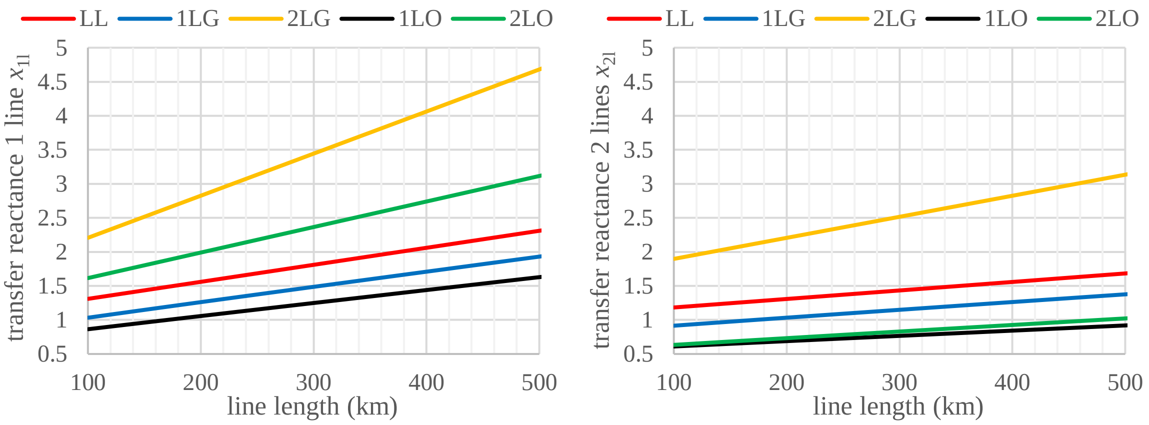
Figure 4: Effect of fault location on transfer reactance.

3.3 Line length

The influence of line length on stability is not so straightforward comparing to aforementioned aspects. This is harder to explain, but in cases 3.1 and 3.2, the steady state before fault was the same, so it was reasonable to study only the transfer reactance. The method in this case was kept, but the interpretation must be different: the question in this case is, how much each fault will increase the transfer reactance, i.e. how much it will worsen the stability for the specific line length.

From Figure 6 can be seen that the worst case is the 2LG fault, especially for long line operation. It is interesting that the 2LO fault is the second most severe in 1 line operation, but the second lowest in 2 lines operation.

Grouping and ordering the faults regarding the transfer reactance, the order is 1LG – LL – 2LG for shunt faults and 1LO – 2LO for series faults.



a) 1 line operation b) 2 lines operation

Figure 5: Effect of line length on transfer reactance.

4 CONCLUSION

The main scope of this paper was the power system representation for TSA for unbalanced faults. The simplified model SMIB was extended using symmetrical components method and the formulas for transfer reactance used for TSA were derived. The results are useful for simplified TSA methods as they allow to easily calculate the transfer reactance for unbalanced faults and do the simplified assessment using the SMIB representation of the grid. The symmetrical component representation could be also implemented to simulation tools (especially the user created ones e.g. in Matlab) allowing them to extend the simulation possibilities.

Sensitivity analysis of zero sequence line reactance, fault location and line length was carried out. Results show that the most severe unbalanced fault is the 2LG fault, which is also influenced by these factors the most. However, zero sequence line reactance has significant impact on 2LO fault. To get the accurate results, it is recommended to clearly assess the zero sequence reactance of the line. Findings also show that faults located closer to the synchronous generator have worse impact on transient stability.

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