# Effects of Line Parameter and Fault Location Errors on Model Verification of Fixed Series Compensation

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***Abstract*—With advent in wide area measurement systems (WAMS), measured data from different buses in the power system are now available for calculations. Model verification of power system components is identified to be an application of WAMS. Model verification of series compensation devices can be performed during fault to determine the compensation level and metal-oxide varistor characteristic. Methods for such verification find limitation due to errors in line parameters and fault location. In this study, the effect of these errors on the model verification results is studied. The error in calculated compensation level for different levels of error in line parameter and fault location is determined and the relative errors for error in line parameter and fault location are obtained. Such study is also performed for metal-oxide varistor characteristic and the relative error for this case is obtained. A need to reduce errors in line parameters and fault location is determined and thus a research scope is generated through this study.**

***Keywords—effect of error, fixed series compensation, metal-oxide varistor, model verification, spark-gap.***

## I. INTRODUCTION

Series compensation devices are widely used to improve power transmission capability of a line. These devices consist of several capacitor banks and its protection devices [1]. Aging results in change in the effective capacitance of the bank. Stressed conditions may damage the capacitors or activate the overcurrent protection of the bank resulting in a change in the capacitance. The MOV used for protection of capacitor banks may fail in fail-open or fail-short mode on the basis of the change in voltage-current characteristic of the MOV [2]. Fail-short failure of the MOV results in permanent bypass of the bank and thus the compensation level changes. Such changes in the series compensation may lead to wrong control action, protection decision and power system analysis.

Real time digital simulations (RTDS) of different elements used for power system visualization require accurate models for correct results. Any unaccounted change in the model will lead to wrong estimation from simulations. Model verification can be used for fine tuning of the dynamic power system models used in RTDS. Thus it can ensure that the simulation uses the actual power system model and the obtained results are accurate.

The relays used for transmission line protection are set using the capacitance value of the series compensation device. Change in the value of capacitance will lead to inaccurate zone settings of the relays. This would decrease the dependability of the protection system. The MOV and spark-gap operation determines the protection strategy of a series compensated line.

Spark-gap or switches are used to protect the MOV from high temperature. Energy dissipated by the MOV is a measure of its temperature rise. This is used to trigger the gaps or switches protecting MOV. The spark-gap operation must take place after the energy dissipated by the MOV reaches the threshold value and before the temperature of MOV reaches maximum.

With advances in wide area measurements time stamped data is now available for calculations [3, 4]. The sampled data synchronized using global positioning satellite can be used for power system monitoring and analysis. Methods using sampled data for fault analysis and fault location are available in [5, 6, 7, 8]. These methods use two end synchronized sampled data and distributed line model for calculation. The sampled data is sent to a data concentrator where the fault location algorithms are performed. Such an infrastructure can be used for model verification of the power system components.

In [9] a method for model verification of series compensation devices is proposed. In this work, the effects of error in data and parameters on the method are studied. Data obtained from simulation using EMTDC/PSCAD for a power network of the Indian grid is used to determine the suitability of the proposed method.

## II. THE MODEL VERIFICATION METHOD

Modal analysis is used to convert three phase system in to three different single modes. For the series compensated line (Fig. 1), the model verification method in [9] uses two end synchronized sampled data to determine the current and voltage across the bank for both healthy and faulted conditions. Then, least squares (LS) method is used to calculate the actual series capacitor value. The non-linear MOV characteristic is then determined by using the obtained capacitor value. The energy dissipated by the MOV after fault inception is calculated. The method also determines the spark-gap operation and uses the energy dissipated by the MOV to verify correct operation of the gap.

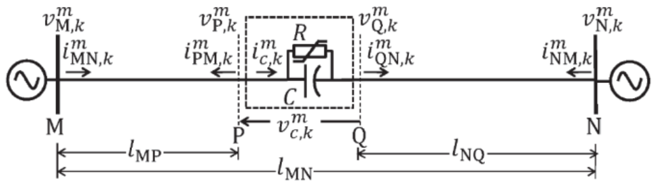



Fig. 1. Single mode of a series compensated transmission line.

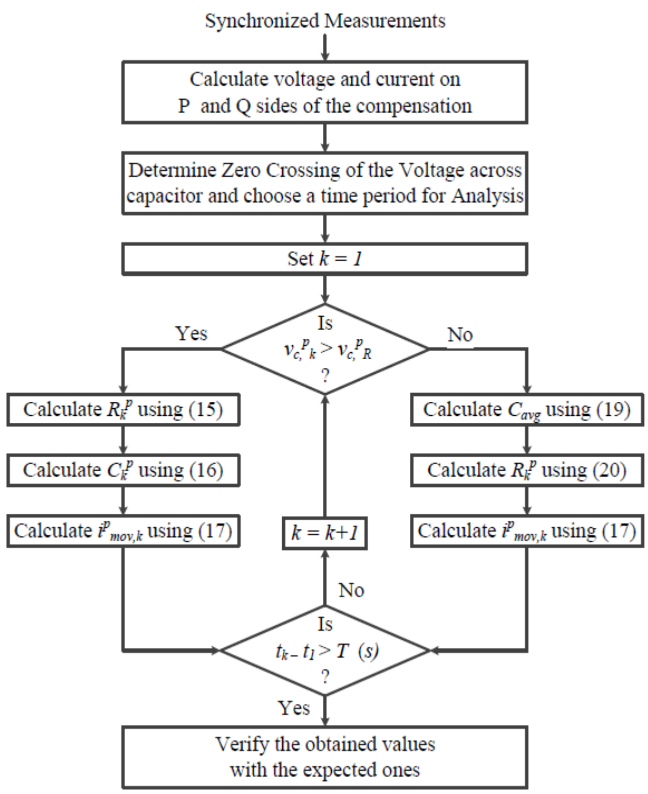



Fig. 2. Flow diagram of the model verification process.

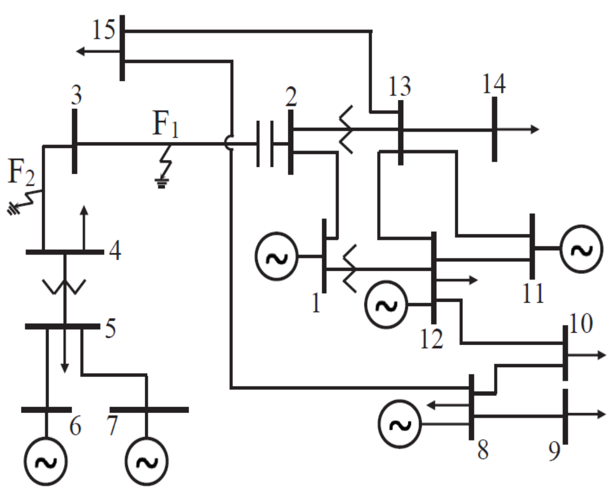



Fig. 3. A part of eastern region of Indian grid with a series compensated line between bus 2 and 3.

Data obtained from simulation using EMTDC/PSCAD for a power network of the Indian grid is used to determine the suitability of the proposed method. Model verification of the series compensation device for healthy and faulted transmission line is performed for the test system. The correct operation of the spark-gap in the system is also verified using the energy dissipated by the MOV. The flow diagram for the model verification process is shown in Fig. 2.

## III. Error Analysis

The proposed method is tested for a series compensation in a line in eastern region of Indian power system [9]. Fig. 3 shows the schematic diagram of the network. The detailed system data are available in [9]. In the 400 kV network, line 2-3 is 40 % series compensated at bus-2. The protection scheme of the series capacitor considered in this case consists of an MOV and spark-gap arrangement. A sampling frequency of 20 kHz is used for data acquisition from buses 2 and 3. Model verification of the series compensation is performed and the results are discussed below. Model verification of the series compensation is performed after introducing errors and the results are discussed below.

### A. *Fault Location Error*

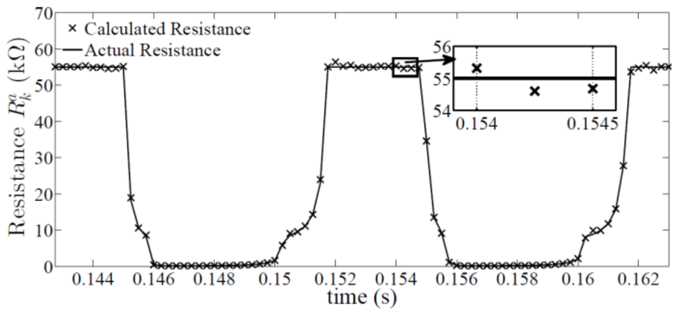
Any error in fault location will result in error in calculations and thus affects the accuracy of the method. The method in [10] that is used for fault location is rigorously tested and gives good accuracy. However, there may be some error associated at times. The effect of fault location error is studied here.

At time t = 0.12 s, an $a$-phase-to-ground fault is simulated at $F_1$ in line 2-3 at 50% from bus 2. Excess voltage across the capacitor caused due to high fault current results in MOV operation. For this faulted condition, the compensation bank voltage and current are obtained using the data from bus 2 and 3. Zero crossing of the a-phase current is determined and model verification is performed during the time 0.143 s - 0.163 s. The results of LS method in this case are, $C^p$ = 33.964 μF and $R^p$ = 55.191 MΩ and $N_c^{'}$ = 2. High $R^p$ value shows no fail-short type failure in the MOV.

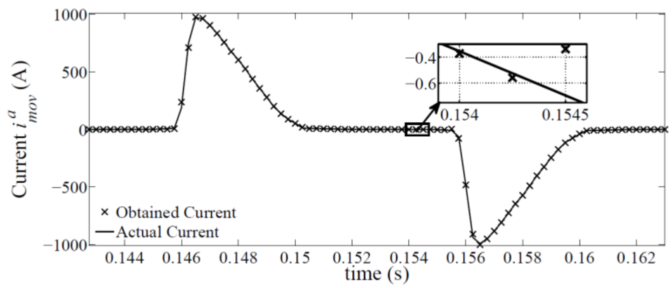
With capacitor value fixed to $C^p$ the MOV instantaneous resistance and current are obtained. The calculated value of $R^a_k$ is compared with its actual instantaneous value in Fig. 4(a). Similar comparison for $i^a_{\text{mov}}$ is shown in Fig. 4(b). The voltage-current characteristic thus determined is compared with the actual one in Fig. 4(c). MOV operation above 50 kV is observable from the obtained characteristic. Thus the MOV is determined to be healthy which is correct.

For the fault case above, model verification was performed considering 0.1% (50.1% from bus 2) and the MOV characteristic was determined. Similarly, MOV characteristic was determined considering 1% and 5% error in fault location calculation. Results for each of the cases are shown in Fig. 5.

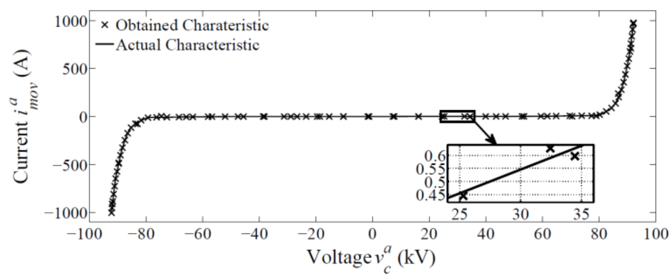
For error in fault location, the obtained characteristic deviates from the actual one. The deviation is higher for higher error. We can conclude that the proposed method is affected by fault location error. Acceptable is a relative term in the context of this study. If we are talking about calculating the change in the capacitance value, any error in fault location will adversely impact the result. If we are considering detecting MOV failure, our studies indicate that up to 5% of error in fault location still provides the correct answer.




(a)




(b)




(c)

Fig. 4. Model verification of series compensation device for a fault case.

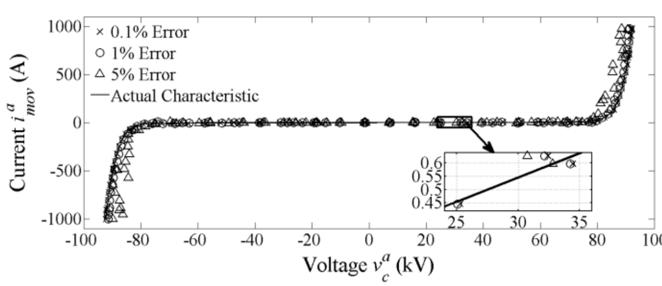



Fig. 5. The effect of error in fault location on model verification results.

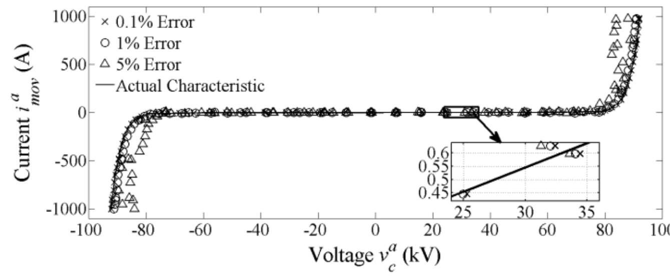



Fig. 6. The effect of line parameter error on model verification process.

### *B. Line parameter error*

In practice there is always some uncertainty related to nearly all the parameters of any power system component. The effect of the inaccuracy of parameters that are presumed to be accurate in equations thus there is a chance of error. The effect of errors in line parameters is studied here. For this, the fault case above is considered.

Three cases with 0.1%, 1% and 5% error in the line parameters were considered. The MOV characteristic was determined using proposed method for each case. Characteristic obtained for each of the cases is shown in the Fig. 6.

We can conclude that, for an error in line parameter estimation, the obtained MOV characteristic by the method deviates from the actual. However, the deviation is small for error up to 1%.

If we are talking about calculating the change in capacitance value, any error in line parameter values will adversely impact the result. If we are considering detecting MOV failure, our studies indicate that up to 5% of error in line parameters still provides the correct answer.

## IV. Conclusion

A method for model verification of series compensation device is discussed. The method uses synchronized sampled data from both ends of the line to calculate the current and voltage across the series compensation device during healthy or faulted condition. A comprehensive study of effect of the effect of fault location error and line parameter error on the method is performed. It is found that the method gives good result for small error in fault location or line parameters. The results are acceptable for larger errors. The error in model verification increases with increase in parameter error. Thus there is a need to reduce the errors in fault location and line parameters to improve model verification process.

## References


[1] IEEE Standard for Series Capacitor Banks in Power Systems, IEEE Std. 824-2004, 2005.

[2] *IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (>1 kV)*, IEEE Std. C62.11-2012, Dec. 2012.

[3] C. Zheng and M. Kezunovic, “Synchronized sampling uses for real-time monitoring and control,” in *North American Power Symposium (NAPS),* 2009, Oct. 2009, pp. 1–6.

[4] “List of important grid elements in eastern region,” POSOCO, Kolkata, India., Tech. Rep., May 2014. [Online]. Available: http://www.erldc.org/List of Important Element 20(2).pdf

[5] A. Gopalakrishnan, M. Kezunovic, S. M. McKenna, and D. M. Hamai, “Fault location using the distributed parameter transmission line model,” *IEEE Trans. Power Del.*, vol. 15, no. 4, pp. 1169–1174, Oct. 2000.

[6] N. Zhang and M. Kezunovic, “A study of synchronized sampling based fault location algorithm performance under power swing and out-of-step conditions,” in *Power Tech, 2005 IEEE Russia*, June 2005, pp. 1–7.

[7] M. Kezunovic and B. Perunicic, “Automated transmission line fault analysis using synchronized sampling at two ends,” *IEEE Trans. Power Syst*., vol. 11, no. 1, pp. 441–447, Feb. 1996.

[8] P. Dutta, A. Esmaeilian, and M. Kezunovic, “Transmission-line fault analysis using synchronized sampling,” *IEEE Trans. Power Del*., vol. 29, no. 2, pp. 942–950, April 2014.

[9] S. Gajare, A. K. Pradhan and S. M. Brahma, "Model Verification of Fixed Series Compensation Devices Using Synchronized Data," in *IEEE Trans. Power Del.*, vol. 31, no. 1, pp. 174-181, Feb. 2016.

[10] N. Kang, J. Chen, and Y. Liao, “A fault-location algorithm for series compensated double-circuit transmission lines using the distributed parameter line model,” *IEEE Trans. Power Del*., vol. 30, no. 1, pp. 360–367, Feb 2015.