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Distinction of Normal and Abnormal Conditions in Transmission Line Using Entropy Called Lyapunov Exponent

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***Abstract*— This paper proposes a fault detection method based on an entropy calculation technique from the experimental output at the receiving and sending end of the transmission line network. Transmission lines are the most vital network systems meant for transmitting power from one corner of a place to the farthest most in the other direction. Fault diagnosis is a pervasive part of power system operation. Fault diagnostic assists in identifying the various power system apparatus defects. We have developed a software simulation model of a power system transmission line for the detection of faults by computing the entropy from the transmission line network variables. The hypothetical model is simulated in MATLAB. Fault is introduced in the system and the entropy called Lyapunov Exponent is computed from the time series generated values of voltage and current at the sending and receiving end terminal of the transmission line. The value of the Lyapunov Exponent of a faulty line is matched with the value of the Lyapunov Exponent computed during normal conditions, It has been observed that the value of entropy changes abruptly during fault. These observations are really helpful for the diagnosis of abnormal conditions in transmission lines for the safe and reliable operation of power system networks.**

Keywords—Transmission Lines, Faults, Lyapunov Exponent, Rosenstein Algorithm, Entropy curve

I. Introduction

The transmission line network is an important part of the power system and hence it is essential to identify faults in the transmission line for safe and reliable operation of the transmission line network. In this work, we have taken the help of an entropy called Lyapunov Exponent (LE) to detect abnormal conditions in the transmission line. A hypothetical model of a transmission line network has been developed in the MATLAB-based Simulink platform and is simulated for different types of symmetrical and unsymmetrical faults. Faults that occur under the category of unsymmetrical fault are line to ground(LG), double line to ground(LLG), and line to line (LL), while three-phase short circuit fault(LLL) and three-phase to ground fault(LLLG) are categorized as a symmetrical fault. LE is calculated from sending and receiving end data generated at the scope both for abnormal and normal conditions. The value of LE of a faulty line is matched with the value of LE computed for the healthy line. A difference is observed in the value of LE, which indicates the presence of anomalous conditions in the system.

The usual method for calculating LE is to use systemic equations. When we are unaware of the mathematical definition of any nonlinear system LE is calculated from the time series generated at the output of the system [1][2][3]. Out of the various algorithms available for the computation of LE from time series or experimental data, in this work, the Rosenstein algorithm has been chosen for the robustness of the algorithm. Rosenstein algorithm can efficiently calculate LE from a small data array generated at the output of the transmission network system. With the help of this algorithm, we were able to calculate the value of LE precisely. The method is consistent in a noisy environment also. To compute the LE from experimental data in this research, we successfully used the Rosenstein algorithm.

II. Literature Review

The referred paper [4] describes a methodology that employs a numerical computing environment in the MATLAB platform to actively simulate the transmission line performance for the short, medium, and long transmission line instances. To calculate line performance

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metrics like power factor, transmission line efficiency, and voltage regulation, among others, a program is developed taking into account the unique ABCD constants of the various length transmission lines. The Author has also measured the receiving end voltage, receiving end power, voltage regulation, and transmission efficiency for the transmission line of different lengths. At last, the author has concluded that as the line length increases transmission efficiency falls significantly because the transmission line loss increases.

In [5] the authors have addressed the most significant issue i.e. using the Lyapunov exponent and Lyapunov dimension, one may determine if a power system is experiencing chaotic motion or not. For specific nonlinearities, parameter ranges, and external forces, chaotic dynamics are present by default, and they would need to be managed to enhance the performance of the power system. To quell chaos, the state feedback control mechanism is used in this paper. Overall, it was discovered that the state feedback control methodology, when compared to other chaos control methods, is straightforward enough to be applied to chaotic suppression.

In paper [6], a three-segment piecewise linear resistor and a DC bias voltage source connected in series with a load resistor at one terminal each make up a generic lossless transmission circuit. The circuit behavior is then described by a one-dimensional map that is created. This paper concludes by discussing the formal chaos mathematical definition and the necessary conditions for its existence based on a chaotic one-dimensional map of the system.

This paper [7] narrates about different types of faults on three-phase transmission lines, Both symmetrical and unsymmetrical faults have been considered, the faults might be L-G (line to ground), L-L (line to line), L-L-G (double line to ground) etc. The research in this study concentrated on the causes and effects of faults in the overhead transmission lines. There are various reasons why problems occur, including lighting, wind damage, trees cutting through gearbox lines, cars or planes crashing into gearbox towers or poles, birds shorting wires, or vandalism. The author has computed the values of the output voltages, MVA ratings, and the per-unit reactance of the transmission line before and after the fault. As per the result, a significant amount of changes were obtained in the values of parameters after the occurrence of faults.

The Maximum Lyapunov Exponent (MLE) is used in the paper [8] to evaluate the post-fault transient stability of the power system. The phase angles that the phase measuring units (PMUs) report are utilized to calculate the system's MLE. The author has estimated the Maximum Lyapunov Exponent (MLE) for detection of the transient instability. The phase angle of the system buses is assumed to be measured by the PMUs once the fault is resolved, and the MLE is calculated from that measurement. The sign and magnitude of the MLE are used to calculate the transient stability of the system.

III. Rosenstein Algorithm for Computation of LE

When the dynamical system's descriptive equations are accessible, by resolving the system equations, the whole Lyapunov spectrum may be calculated with ease [9][10]. This strategy is not appropriate when system's equations are not defined. The sole remaining alternative is to determine the Maximum Lyapunov Exponent (MLE) using the time series data received at the system's output [11][12]. The process is directly related to the LLE technique. There are some algorithms available for computing LLE using time series generated by dynamical systems, like Wolf's Algorithm, the Grassberger-Procaccia Algorithm, the Rosenstein Algorithm, the Sato's Algorithm, etc. The Rosenstein Algorithm is one of the most trustworthy techniques for determining LLE from limited sets of data as the algorithm is robust to the changes in algorithm parameters.

Most of the time, experimental time series data are obtained from a single variable of a system. Rosenstein's Algorithm starts with the attractor reconstruction dynamics from single-dimensional experimental data using the method of delay. The success of the said process depends on the proper selection of the algorithm parameters such as embedding dimension, mean period, and time delay. The techniques for estimation of the above parameters are described below.

The time-delay embedding procedure of attractor reconstruction is found in mathematical topology related to Takens' theorem. Using Takens' theorem one can obtain a structure that is topologically equivalent to the said attractor using a delay embedding technique. This theorem gives us the guideline regarding the estimation of embedding dimension. The reconstructed attractor is not identical to the real-world attractor, rather it has the same dynamical properties as that of the actual system. The topological structure of the attractor is preserved by the reconstruction. The other significant parameter is delay and it is equal to the lag where the autocorrelation function of the time series drops to $1-\frac{1}{e}$ of its initial value. This is the most common approach to find delay. Another option is to estimate the delay from the first minimum of the mutual information function. The mean period is estimated as the reciprocal of the mean frequency of the power spectrum of the time series.

After rebuilding the attractor dynamics, the algorithm traces the adjacent neighbor of each point on the trajectory. The Largest Lyapunov Exponent (LLE) is then assessed as the mean rate of separation of the nearest neighbors as the system dynamics change with time. A curve is generated by plotting the average separation concerning the number of iterations. Then LLE is easily and precisely computed using a curve fitting technique i.e. the slope in the linear region of the curve gives the value of LE [13]. The steps for Rosenstein Algorithm are explained in the flowchart as given in Fig-1.

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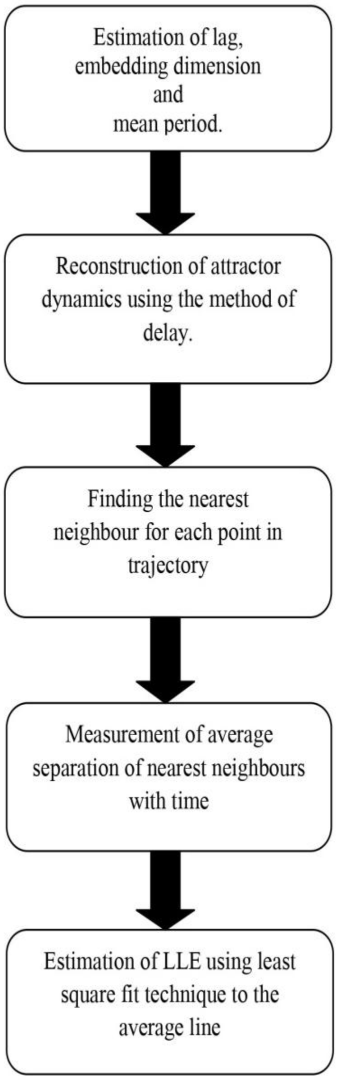

Fig.1. Flow Chart of Rosenstein Algorithm [2]

IV. SIMULATION OF TRANSMISSION LINE IN SIMULINK

A transmission line network is simulated in MATLAB-based Simulink software as shown in Figure 2. The sending and receiving end voltages are at the level of 11 and 0.4 kV. After introducing various symmetrical and asymmetrical faults, values of faulty voltages and currents are captured from the scope connected at the sending and receiving end side of the transmission line network. In the software simulation model, we have introduced broadly two types of faults i.e. symmetrical and unsymmetrical faults. We have simulated the model in healthy as well as in faulty conditions. For both cases, data has been captured from scopes of sending and receiving end sides. A program is developed in MATLAB as per the concept of flow chart as shown in figure-1 for computing LE from time series data for voltage and current both at normal and faulty conditions. A drastic change is observed in the two values of LE i.e. both for normal and faulty conditions which ultimately indicate the presence of anomalies in the transmission line. Actions are taken consequently.

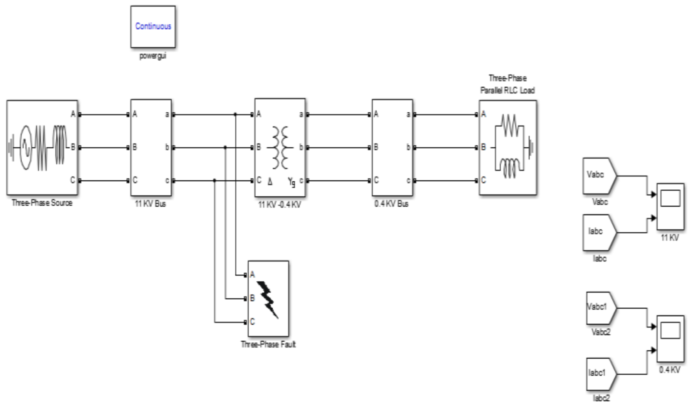

Fig. 2. Simulink Model

V. SCOPE OUTPUT WAVEFORMS

Though different types of faults are simulated in the transmission line model, the output for a few of them is attached below. The nature of the fault is also mentioned along with the figure captions. Scope data are captured and exported to mfile written in MATLAB for computing LE using Rosenstein Algorithm from time series. The methodology is explained through a flowchart in section III. The Y-axis of the upper plot of each figure represents voltage (V) and the same for the lower plot represents current (mA). The X-axis reflects the time for both plots.

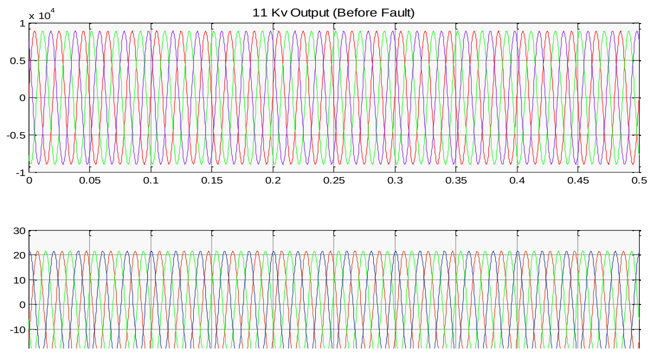

Fig. 3. Scope output for Voltage and Current at 11 KV side before the Occurrence of Fault

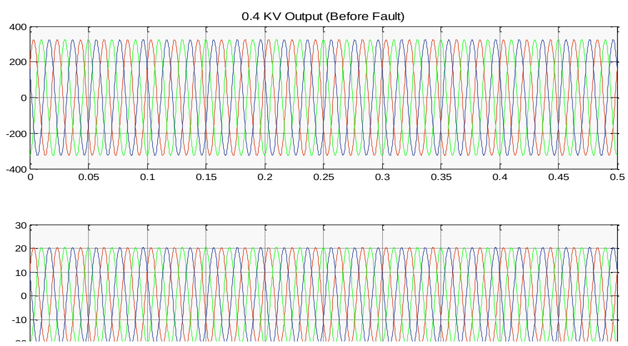

Fig. 4. Scope output for Voltage and Current at 0.4 KV side before the Occurrence of Fault

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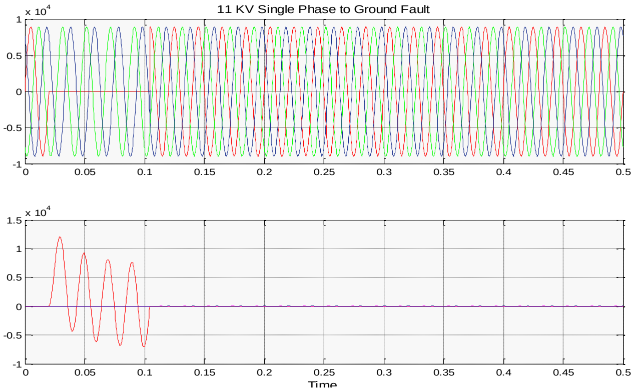

Fig. 5. Scope output for Voltage and Current at 11 KV side after the Occurrence of Unsymmetrical Fault (LG).

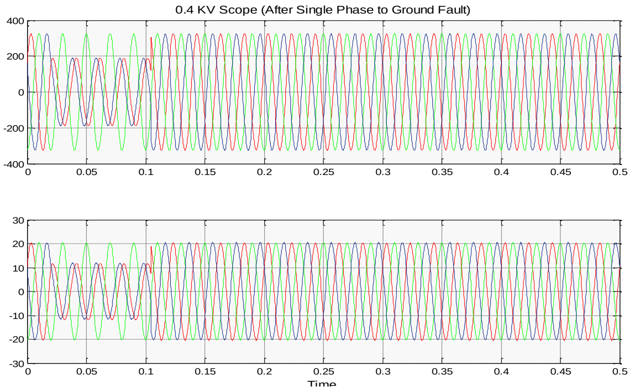

Fig. 6. Scope output for Voltage and Current at 0.4 KV side after the Occurrence of Unsymmetrical Fault (LG).

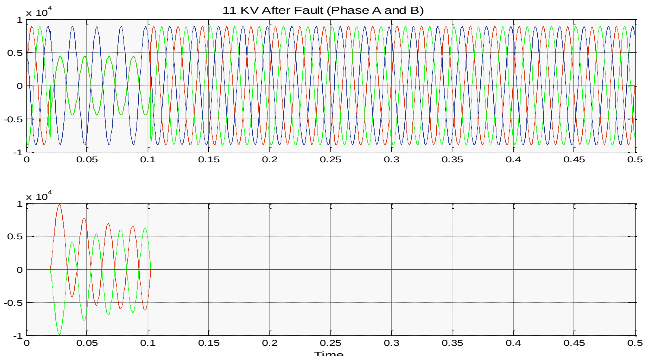

Fig. 7. Scope output for Voltage and Current at 11 KV side after Occurrence of Unsymmetrical Fault (LL)

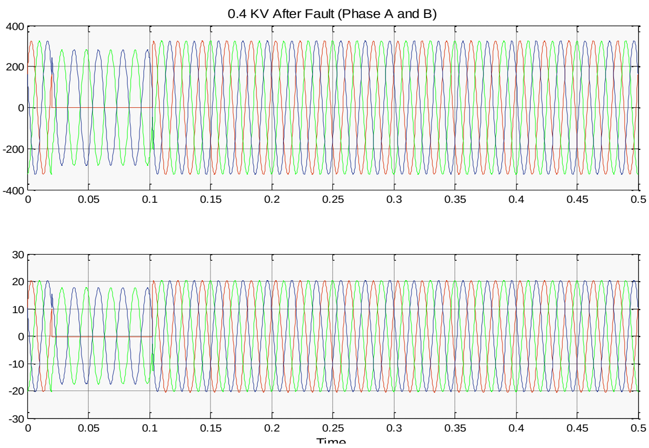

Fig. 8. Scope output for Voltage and Current at 0.4 KV side after the Occurrence of Unsymmetrical Fault (LL)

VI. Simulation Results And Discussions

The entropy curves generated before the occurrence of a fault and as well as after the occurrence of a fault are attached below. Numerical Experiments are conducted for various types of faults. Some of them are shown below.

Values of LE are also mentioned along with the entropy curves. Entropy curves before and after the occurrence of fault are shown in the following figures (Fig-9 to 14). The variable along the x-axis represents the number of iterations and the variable along the y-axis represents the average rate of separation of the nearest neighbor of the reconstructed system. Curves are generated from the experimental data captured from the scope in the Simulink platform. The value of LE is calculated from the slope in the linear region of the curve.

The given figures depict the changes in the values of LE during the fault concerning normal conditions. It is evident from the figures that the stiffness of the slope of entropy curves in the linear region increases after the system is disturbed by faults. This means the positivity of LE increases leading the system toward instability. Appropriate steps must be taken immediately to prevent further damage to the system.

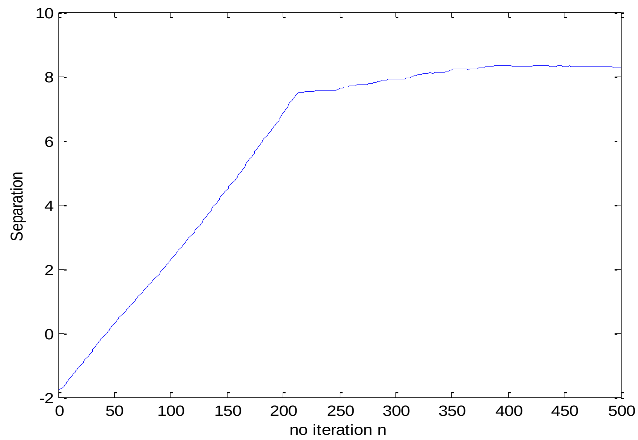

Fig. 9. Entropy Curve generated at 11 KV side for Healthy Condition (LE=0.1)

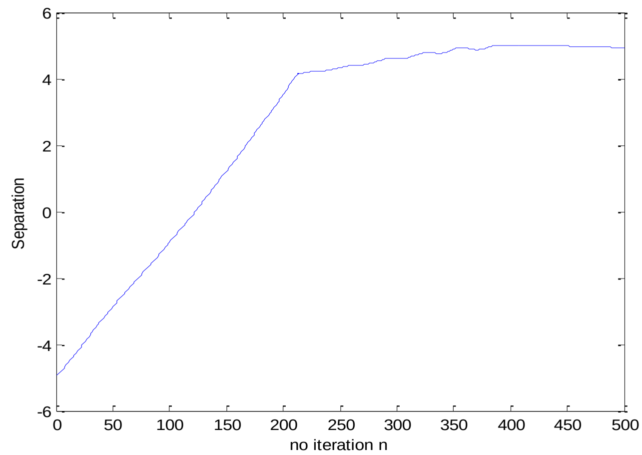

Fig. 10. Entropy Curve generated at 0.4 KV side for Healthy Condition (LE=0.05)

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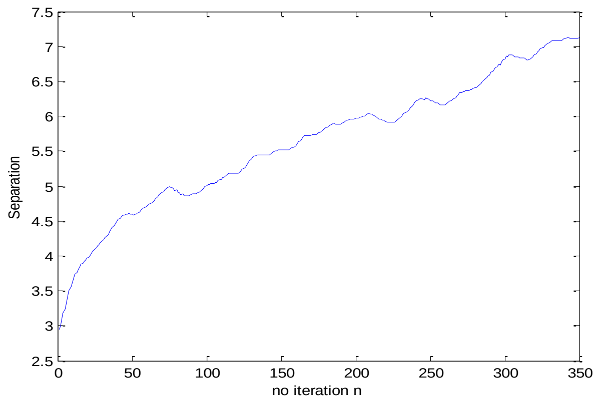

Fig. 11. Entropy Curve generated at 11 KV after Single Phase to Ground (Phase A to ground) fault (LE=0.25)

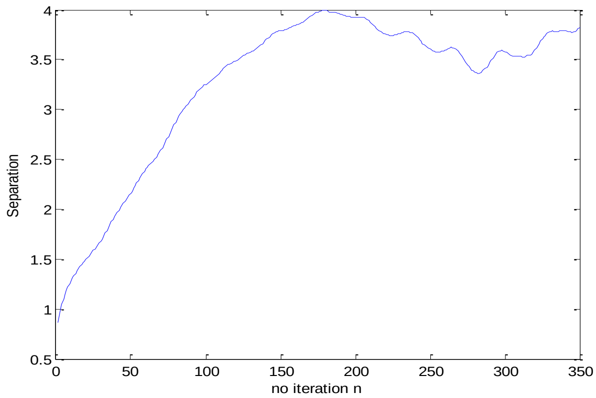

Fig. 12. Entropy Curve generated at 0.4 KV after Single Phase to Ground Fault (Phase A to ground) (LE=0.125)

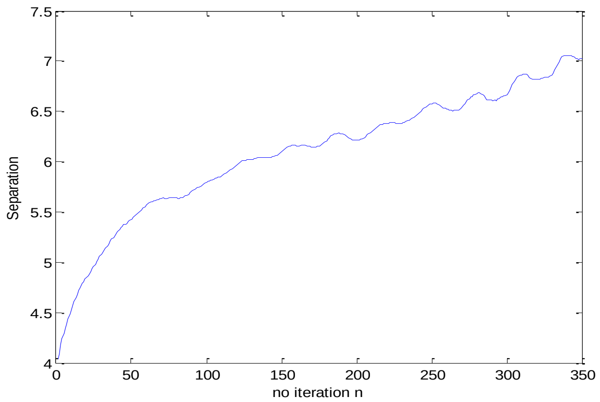

Fig. 13. Entropy Curve generated at 11 KV after LL fault (Phase A to B short-circuited) (LE=0.2)

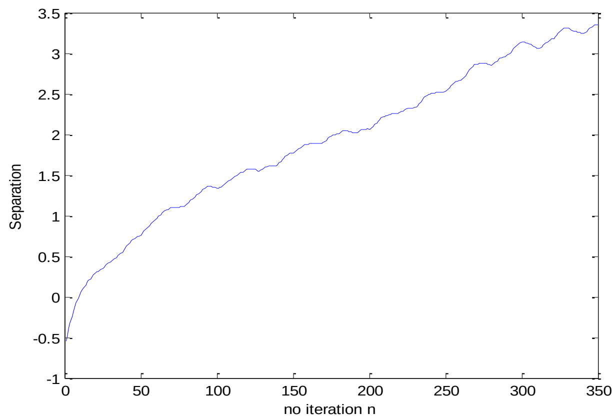

Fig. 14. Entropy Curve generated at 0.4 KV side after LL fault (Phase A to B short-circuited) (LE=0.112)

VII. Conclusion and Future Scope

Fault detection and analysis is a common practice in power system operations. Diagnosis of fault is essential in revealing the various failures of power system apparatus [14][15][16]. In our work, we have shown that it is possible to detect the presence of faults or disturbances in the transmission line just by computing the values of LE of the system both for healthy and abnormal conditions. So continuous monitoring of the system will help us to take immediate action for clearing faults from the system. It will ultimately help to avoid an unnecessary shutdown of the power system. Here in this work Rosenstein Algorithm is used to calculate the LE from experimental data. In future some other popular algorithm like Wolf Algorithm may be explored. A comparative study may be done based on these two algorithms.

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