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Phasor measurement unit application-based fault allocation and fault classification

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ABSTRACT

This paper makes a contribution to the field of fault location finding in a new way that helps in the improvement of grid reliability. This paper proposes a study-based approach for fault allocation and fault type classification that uses the study of voltage and current frequency during the abnormal condition. Although, ideally frequency of voltage and current are the same in the abnormal condition they may differ from each other. This difference in frequency is separately measured by the phasor measurement unit (PMU) block at MATLAB/Simulink platform. The PMU (PLL-based, positive-sequence) block is inspired by the IEEE Std C37.118.1-2011. In this approach, we measure the line voltage and current frequency variation with the help of installed PMU after this we present this measurement in characteristics form with the help of the scoping tool in MATLAB/Simulink and study them one by one, and proposed a conclusion for fault location identification and fault type classification. The proposed approach is able to identify the source side and load side fault location and also able to classify faults into two categories namely symmetrical and asymmetrical. The proposed approach is tested on two MATLAB/Simulink models and observed satisfactory.

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1. INTRODUCTION

In the present, if we see anywhere we found that everything is modernized for obtaining a more efficient and reliable outcome. Now, it is clear that for every modern appliance operation, we required electrical energy. As we know that world population increases day by day, therefore with this the requirement for energy also increases continuously. For full fill this energy requirement we need a large size grid. The large size grid has more possibility of occurring abnormality in it that is a fault. This problem makes the grid less efficient and less reliable. For increasing the efficiency and reliability of the grid it is necessary to find out the abnormality cause and reduce or mitigate way. After finding the fault mitigation way we can improve the efficiency and reliability of the grid. In this reference, various types of research are carried out and more work also pursuing in this field. In them, some developed methodologies for obtaining the fault location in the line are the theory of traveling wave [1]–[3], impedance-based fault location technique [4]–[6], autoregressive integrated moving average (ARIMA) method [7], novel traveling phase component based fault location method [8], phasor measurement unit (PMU) based fault location [9]–[12]. These developed methodologies are able to find out the location of a fault in the line. The above-mentioned methods of finding fault location plays a major role in the transition of the traditional grid into the modernized grid or in other words smart grid.

In the current scenario, we use an advanced technology PMU. It is a measurement device, that is able to provide phasor measurement of the bus at which it is installed and also able to provide the current phasor of a branch which are adjacent to it, due to these features it is used for monitoring purpose in power system [13]. The high accuracy and high reporting rate measurements of phasor and frequency enabled many new system monitoring and control tools, such as oscillation detection and damping control, system disturbance detection and location, and linear state estimation [14]–[16]. The PMU is also equipped with a global positioning system (GPS), therefore, PMU-provided measurement data can be calculated in real-time due to timestamping and synchronization. The communication infrastructure for a wide area measurement system (WAMS) is explained with proper attention to the cost of the system and formulated in the optimal cost problem [17].

This paper proposes a PMU application-based approach that gives fault location and fault type classification in line. This approach uses the voltage and current frequency measurement and representation of this measurement in the form of characteristics is done with the help of the scoping tool. The proposed approach is able to find the source side and load side fault and location and also able to make a classification of fault types that occurred in line.

The paper is organized into five sections in them: section 1 is the introduction, section 2 contains faults and their types, section 3 contained fault allocation and fault classification approach, section 4 gives test results, and section 5 comprises a conclusion.

2. FAULT AND ITS TYPES

The fault is explained in term of anomaly, which arises when the system quantities (voltage, current, and phase angle) exceeds its threshold value [18]. Sometimes, faults can become severe and can damage the power system equipment or the complete power system. It also becomes the cause of the fire and can affect the operating personnel and might cause death [19], [20]. There is more chance of occurrence of a fault in the transmission line as compared to underground cables because the transmission lines directly make touch with open atmospheric conditions. The faults related to the overhead transmission line are categorized into two parts, the first one is a series fault and the second one is a shunt fault.

Figure 1 shows the classification of the various types of faults which are occurred in the overhead transmission lines. A brief description of the various types of faults is given in the forthcoming section. By observing each phase voltage of the line, the series can be identified more easily. by observing any phase voltage, if we found the increased voltage value of any one phase then we can identify that the occurred fault is a single open conductor fault if two-phase voltage value found increased then the occurred fault is two conductor open type fault, these are the part of the series fault. The series fault is further classified into two parts namely one and two conductors open fault. These are the rarely occurring type of faults in the power system. The series-type faults are not considered in the major faulty category [21], [22]. Short circuit faults have more possibility of occurrence as compared to a series fault.

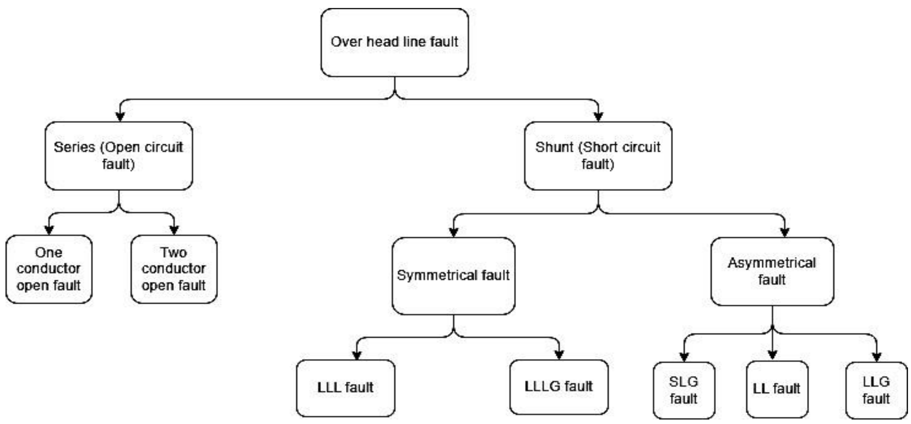

Figure 1. Fault and its types

We can also identify the short circuit type of fault, if any phase has an increased current value then the occurred fault is a shunt type of fault. The short circuit-type fault is divided into two parts in them one is a symmetrical fault and the other is an asymmetrical fault. Short circuit fault is classified into two parts namely symmetrical and asymmetrical fault. The symmetrical fault also has two parts that are line to line to line (LLL) and line to line to line to ground (LLLG) fault and the asymmetrical fault is categorized into three parts namely line to ground (LG), line to line (LL), and line to line to ground (LLG) fault.

2.1. Open circuit fault

The failure of one or two conductors becomes the cause of an open circuit fault. These occur in series with the line that's why these are known as series faults. These types of faults strongly affect the reliability of the system, they are also further classified onto two parts: i) Open conductor fault: this type of fault occurs due to the failure of one conductor and ii) Two conductors open fault: this type of fault occurs due to failure of two conductors.

2.2. Short circuit fault

The short circuit type parts are divided into two parts namely symmetrical and asymmetrical fault. The given faults are further divided into five types. These are described in the order of occurrence in the following section:

2.2.1. Asymmetrical fault

This type of fault becomes the cause of the rise of an unsymmetrical current that has a different magnitude and phases of a power system. These faults make the system unbalanced. It is also categorized into the following three parts: i) Single line to a ground fault: the single line to fault occurs when one conductor falls to the ground or contacts the neutral conductor. It has a possible occurrence of about 70%-80%; ii) Line to line fault: the major condition for the occurrence of this fault is short-circuited of two conductors to each other. It has a possibility of occurrence about 15% to 20%; and iii) Double line to a ground fault: when two conductors come in contact with each other along with the ground. It has a possibility of occurrence of about 10%.

2.2.2. Symmetrical fault

All three phases are equally affected in the condition of symmetrical fault; it becomes the cause of the flow of abnormal current in lines that have the same magnitude and different phase angles with 120-degree phase shifts. It is also called a balanced three-phase fault. It has the possibility of occurrence with a 2%-3% only [23]: i) Three phase line to ground fault: when all three phases (red, yellow, and blue (RYB)) shorted to each other and make a connection with the ground then this type of fault occurred and ii) Three phase line to line fault: when all three phases shorted together and do not have involvement of ground then this type of fault occurred.

3. FAULT ALLOCATION AND FAULT CLASSIFICATION APPROACH

3.1. Fault allocation

In the modern world, most appliances and machinery are depending on electricity. As we know that with the increase in population, the supply point for electricity also increases continuously. This increased supply point increases the grid size. Supplying electricity with proper continuity to every supply point required a well-maintained grid. In the large-size grid, there is a possibility of occurring of various types of abnormal conditions i.e., fault. To overcome the problem of the occurrence of a fault, it is necessary to find the fault location and clear the fault. Now, fault location finding is the big challenge in front of us. In a general way, we check the whole line and find the fault location but this is the more time-consuming procedure. Many researchers are developed various types of fault location methodologies. Earlier and recently developed methodologies/approaches have a lot of calculation parts, this part becomes tough to understand, and sometimes due to this part, mistakes can be seen in the fault calculation. So, in this reference to overcome this problem of calculating part, this paper proposes a study-based approach for fault allocation and fault type classification that uses the study of voltage and current frequency during the abnormal condition. Although ideally, the frequency of voltage and current are the same but in abnormal conditions, these may differ from each other. This difference of frequency is separately measured by PMU block at MATLAB/Simulink platform.

This method is mainly based on the study of voltage and current frequency characteristics during various types of fault conditions. As we know that PMU is capable to gives the time-synchronized measurements of voltage and current phasors along with frequency & rate of change of frequency (ROCOF) synchronized with GPS satellite [24]. These measurements are widely used for the power system operation and analysis of events in post-dispatch scenarios [25]. Different applications along with the benefits of PMU are demonstrated in [26]. Low-frequency oscillation can be detected with the help of PMU [27], [28]. The feature of frequency measurement of PMU is adopted in this approach. Here in this approach, the frequency of voltage and current are separately measured with the help of PMU. For this purpose, we use MATLAB to organize PMU-placed two models. This method comprises the study of voltage and current frequency characteristics during the normal and abnormal conditions of a system. The study is done at the source side and load side bus. The abnormal condition contains short circuit faults. Under the faulty condition, we record the voltage and current frequency characteristic at both the source and load side even faults applied at the load or source side. Finally, we have concluded that if both voltage and current frequency characteristic shows the same behavior then the fault location will be the source side and if the frequency characteristic shows the opposite behavior, then the fault location will be on the load side. For the frequency measurement purpose, we use PMU Bock in MATLAB/Simulink platform that is inspired by the IEEE Std C37.118.1-2011. The characteristics are observed with help of the scoping tool. Now we explain the approach in a detailed way that is completed with the following points:

3.1.1. Model description

Figure 2 and Figure 4 shows the two and three bus system respectively for the purpose of study about fault location confirmation. In Figure 2, firstly we take two buses in them one is the source bus and the other one is the load bus start our experiment by applying the various faults at the source side and load side bus. Figure 2 shows model-1 one source bus and one load bus and Figure 3 shows the PMUs arrangement for model 1. In Figure 4, we take two load buses and one source bus for the fault location confirmation purpose, Figure 4 shows model 1 one source bus, and one load bus and Figure 5 shows the PMUs arrangement for model 1. Here we add one more load bus because of the study of the frequency characteristic during the no-fault condition. The load bus contains three phases parallel resistor-inductor (RL) circuit, the parameter for load is 1000 V phase-to-phase voltage, 50 Hz, Active power 10000 Watt, and 100 Var reactive powers. The sources in both figures model have 11 Kv, 50 Hz, and 30 MVA ratings. Also, use a three-phase two-winding transformer of Delta-Star configuration to step down the voltage from 11 Kv to 0.4 Kv. Three phase series L type branch for line purpose that has inductance 0.001 H. in both model figures we use PMU for the recording of voltage and current frequency characteristics. Here in both figures, we use a three-phase fault block for applying various types of faults.

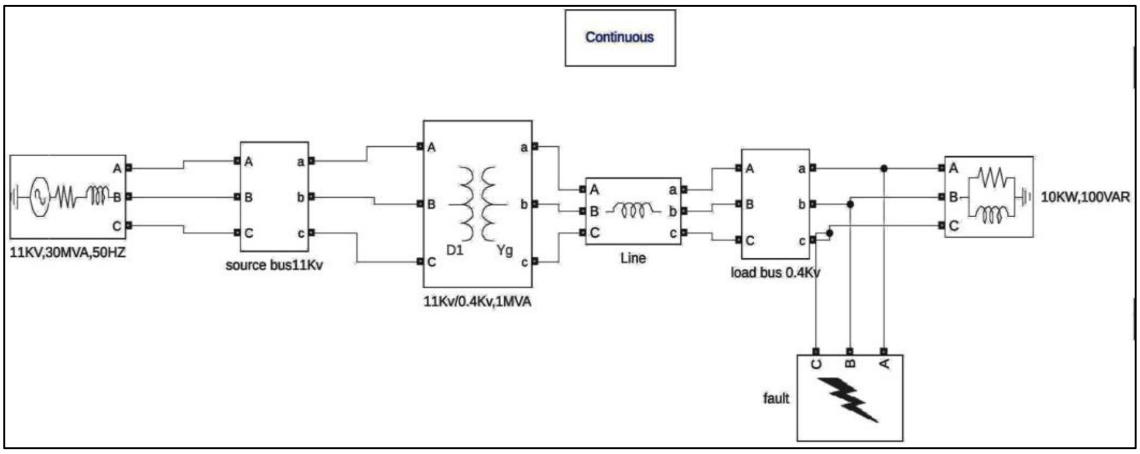

Figure 2. Model-1 one source bus and one load bus

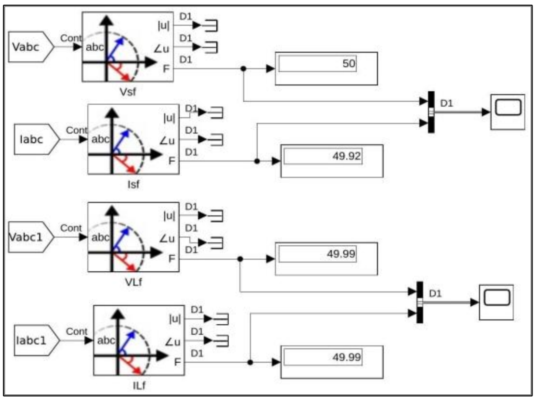

Figure 3. PMUs arrangement for Model-1

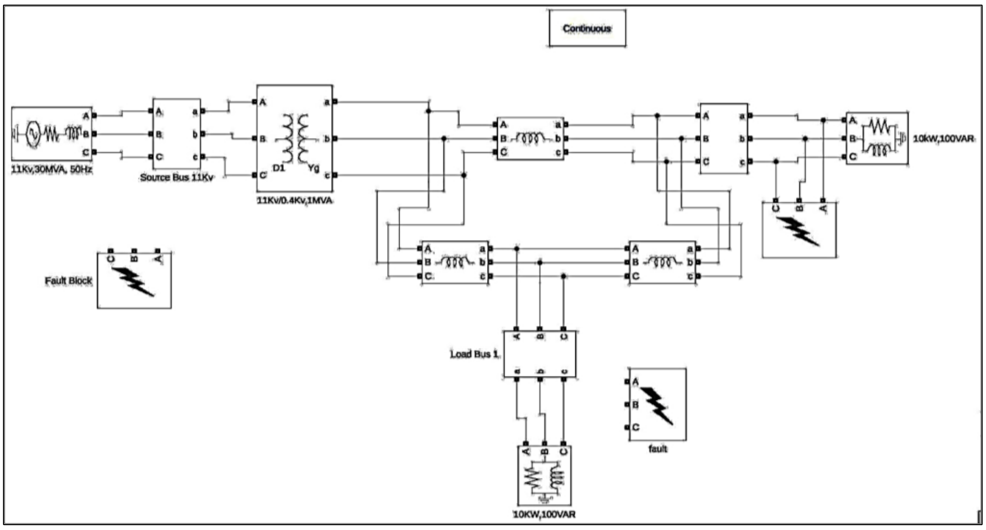

Figure 4. Model 2-one source bus and two load buses

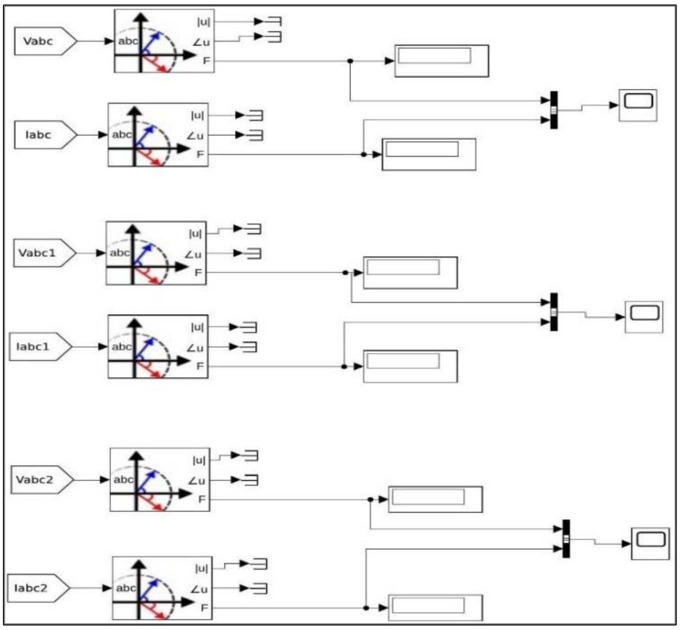

Figure 5. PMUs arrangement for model-2

3.1.2. Fault applied at the source side

When we apply faults LG, LL, LLG, LLL, and LLLG at the source side. After applying fault on the source side, we observe that source side voltage and current frequency characteristics follow the same pattern most likely in decreasing order. The voltage and current frequency characteristics at the load side have the same pattern or in other words, the voltage and current frequency characteristic graphs overlap with each other.

Figure 6 and Figure 7 shows the voltage and current frequency characteristic during LLL, LLLG, LG, LL, and LLG respectively. This characteristic is obtained when the fault is applied at the source side. in the above, both Figure 6 and Figure 7 green color line shows the characteristic of voltage frequency characteristic, and the red color line shows the characteristic of current frequency characteristic. From the above figures, it is clear that both lines draw approximately the same behavior. On this basis, we can confirm that the fault is occurred at the source side according to our methodology of fault location confirmation.

Source side characteristic:

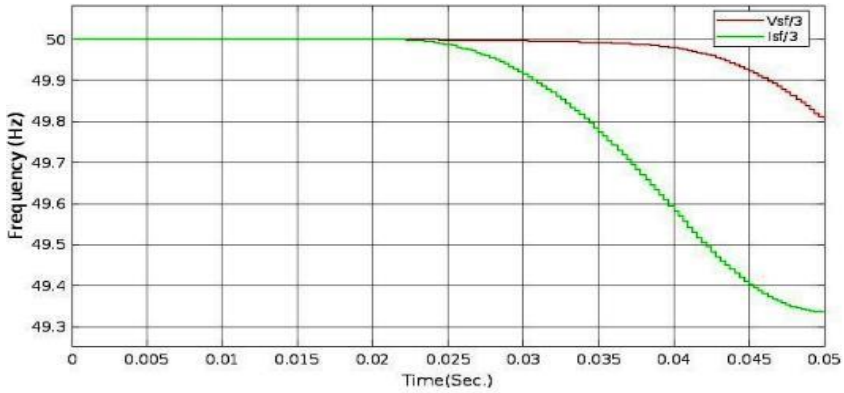

Figure 6. V and I frequency characteristics for LLL and LLLG fault

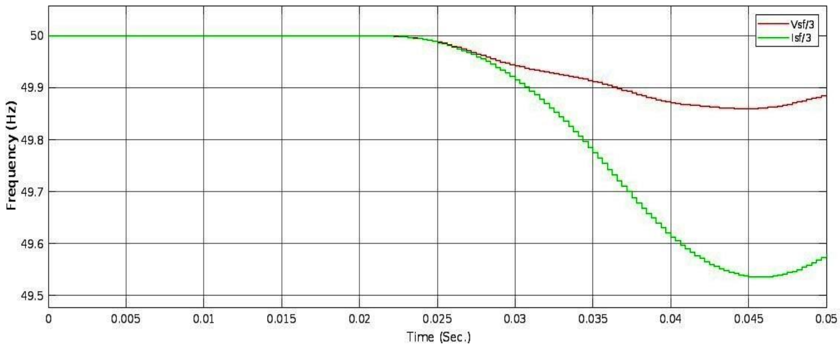

Figure 7. V and I frequency characteristics for LG, LL, and LLG fault

Figure 8 and Figure 9 shows the voltage and current frequency characteristic during LLL, LLLG, LG, LL, and LLG respectively. Figure 8 and Figure 9 show the load side voltage and current frequency variation on the characteristic in the condition when the fault is applied at the source side. From both above figures it is clear that there is no different frequency characteristic or in other words, both current and voltage frequency overlap each other, which means both frequency characteristic shows the same behavior. So according to our fault location deciding methodology, it is clear that the fault is observed at the source side.

Load side characteristics:

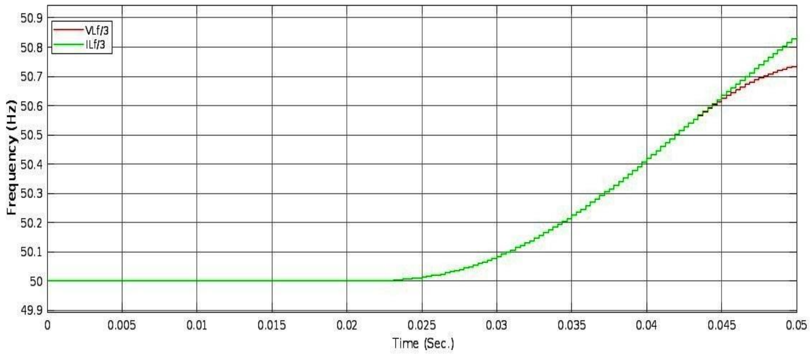

Figure 8. V and I frequency characteristics for LLL and LLLG fault

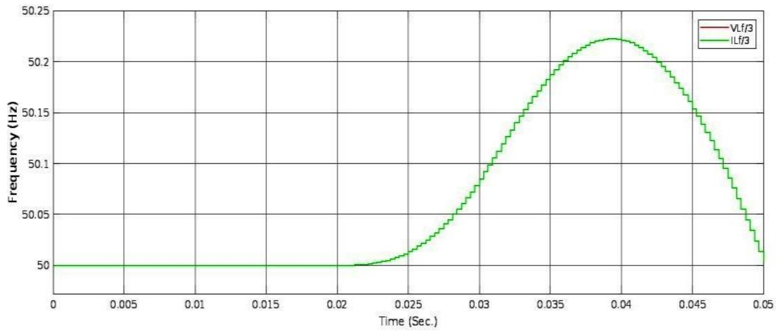

Figure 9. V and I frequency characteristics for LG, LL, and LLG fault

3.1.3. Fault applied at the load side

When we apply faults LG, LL, LLG, LLL, and LLLG at the load side. After applying fault on the source side, we observe that source and load side voltage and current frequency characteristics follow the opposite pattern. In the case of more than one load bus, the overlapping frequency characteristic graph is observed at the non-faulty bus. After the study of the voltage and current frequency characteristic characteristics under faulty conditional source side and load side. We can assure the fault location only on the source side and load side.

Figure 10 and Figure 11, shows the source voltage and current frequency characteristic during LLL, LLLG, LG, LL, and LLG respectively. Figure 10 and Figure 11 show the source side voltage and current frequency characteristic when the fault is applied at the load side. From both figures, it is observed that the voltage and current frequency characteristics show the opposite behavior. So, now we can confirm the fault location at the load side based on our fault location deciding methodology.

Source side characteristics:

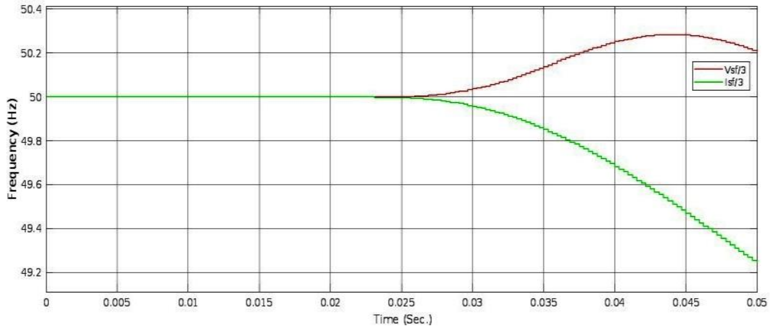

Figure 10. V and I frequency characteristics for LLL and LLLG fault

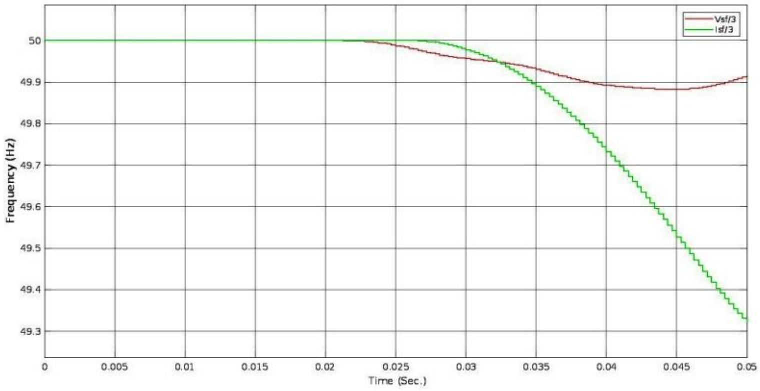

Figure 11. V and I frequency characteristics for LG, LL, and LLG fault

Figure 12 and Figure 13, show the load side voltage and current frequency characteristics during LLL, LLLG, LG, LL, and LLG respectively. From Figure 12 and Figure 13, it can be observed that both voltage and current frequency characteristic shows opposite behavior. Now according to our fault location deciding methodology, we can confirm that the occurred fault location is at the load side.

Load side characteristics:

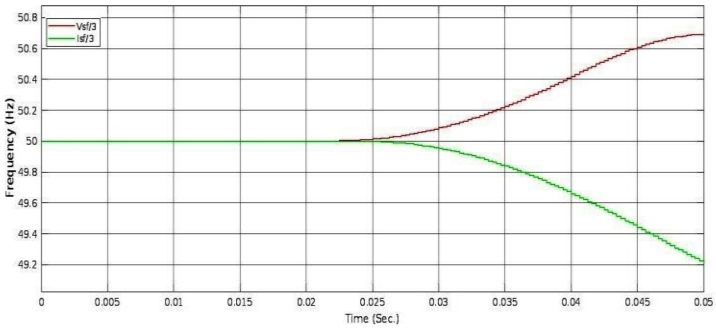

Figure 12. V and I frequency characteristics for LLL and LLLG fault

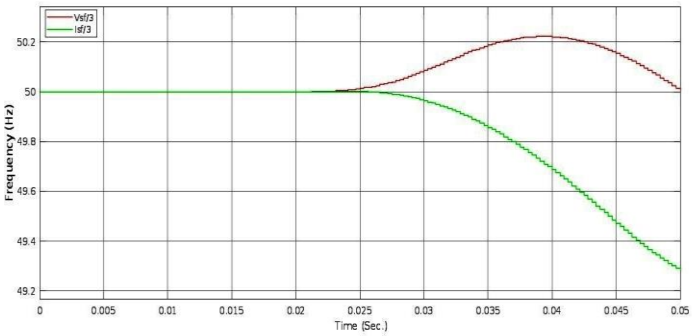

Figure 13. V and I frequency characteristics for LG, LL, and LLG fault

3.1.4. No fault at any bus

When there is no fault at any bus then we observe the following frequency characteristics: Figure 14 and Figure 15 shows the voltage and current frequency characteristic for a non-faulty condition at the source bus and load bus side. From the above figure, we can observe that there is no variation in the voltage and current frequency characteristic, which means both waveforms overlap with each other. From this result, we can confirm that there is no fault with this bus.

Source side characteristics:

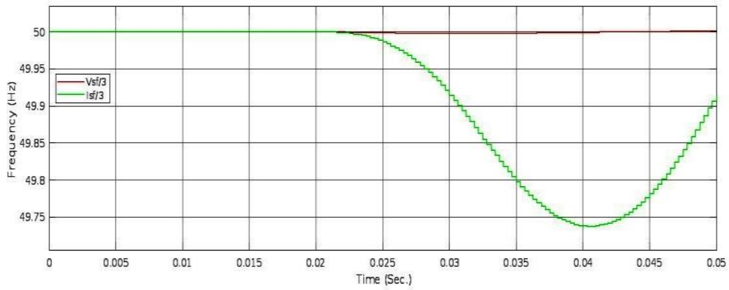

Figure 14. V and I frequency characteristic during no fault condition at any source bus

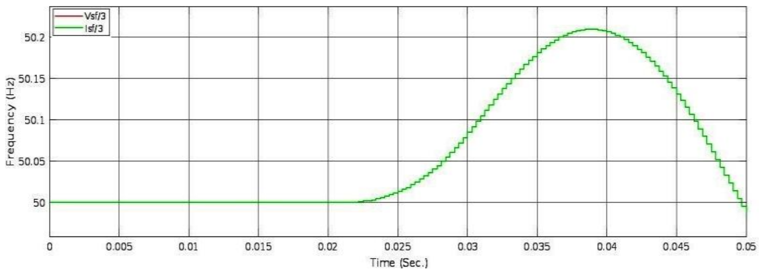

Figure 15. V and I frequency characteristics during no fault condition at any load bus

3.1.5. Fault classification

From the observation of voltage and current frequency characteristics under the faulty condition at the load and source side, we classify the faults into two categories that are symmetrical and asymmetrical. The classification is mainly based on the observation of the similarity of the characteristic of frequency characteristic. In other words, we can make two categories of faults that are symmetrical faults and unsymmetrical faults. From this study, we can identify the faults category-wise that are explained above.

4. TEST RESULTS

4.1. Fault allocation

The following Table 1 and Table 2 show the results of fault allocation in line on the basis of frequency characteristics during various fault conditions. These tables provide source side and load side bus results of frequency characteristics for voltage and current. Table 1 shows one source and one load bus, whereas Table 2 shows one source and two load buses.

Table 1. For one source and one load bus

S. No.	Nature of V and I frequency variation characteristics		Fault location result	Remark
	Source side bus	Load side bus		
1	Overlapping to each other	Overlapping to each other	No fault location	It means there is no fault at any location
2	Same behavior	Overlapping to each other	Source side bus	Here overlapping means no fault at the load side
3	Opposite behavior	Opposite behavior	Load side bus	In case of fault at load side bus this characteristic to be seen

Table 2. For one source and two load bus

S. No.	Nature of V and I frequency variation characteristics			Fault location result	Remark
	Source side bus	Load side bus			
		Load bus 1	Load bus 2		
1	Overlapping to each other	Overlapping to each other	Overlapping to each other	No fault location	It means there is no fault at any location
2	Same behavior	Overlapping to each other	Overlapping to each other	Source side bus	Here overlapping means no fault at the load side
3	Opposite behavior	Opposite behavior	Overlapping to each other	Load 1 side bus	Here overlapping means no fault at load 2 side bus
4	Opposite behavior	Overlapping to each other	Opposite behavior	Load 2 side bus	Here overlapping means no fault at load 1 side bus

4.2. Fault classification

The following Table 3 and Table 4 show the results for the fault type classification in line. These tables also comprise source side and load side results of frequency characteristic similarity figure's identity. Table 3 shows when the fault occurred at the source side bus and Table 4 shows when the fault occurred at the load bus side.

Table 3. When a fault occurred at the source side bus

Bus	Source side bus		Load side bus	
Fault type	Symmetrical fault	Asymmetrical fault	Symmetrical fault	Asymmetrical fault
Figure	Figure 6	Figure 7	Figure 8	Figure 9

Table 4. When the fault occurred at load bus side

Bus	Source side bus		Load side bus	
Fault type	Symmetrical fault	Asymmetrical fault	Symmetrical fault	Asymmetrical fault
Figure	Figure 10	Figure 11	Figure 12	Figure 13

4.3. Comparison with existing approaches

The following Table 5 provides the comparison results of the proposed fault allocation and fault type classification approach with some existing approaches. This comparison table helps us to understand how the proposed approach how differs from existing approaches.

Table 5. Comparison of the proposed approach with existing approaches

Approach name	Calculation required	Required measurements	Special requirement	features
Proposed approach	No	frequency	PMU and frequency characteristics observation	Capable to fault location detection and fault type classification
Traveling wave based	Yes	Pulse wave traveling and reflection time period	GPS, Waveform capturing sensors	Fault location detection
Impedance based	Yes	Voltage variation	Frequently data recording instrument	Fault location detection
Neural network	Yes	Phase voltage and angle	Separate artificial neural network for each subdivision of line length	Capable to fault location detection and fault type classification

5. CONCLUSION

This paper describes an approach for fault allocation and fault classification, this approach comprises the study of the frequency characteristic of voltage and current during normal and abnormal conditions. The presented approach confirms the source side and load side fault location and also gives fault identification of faults in two categories symmetrical and asymmetrical. On the basis of the above-described method and experiment outcome, we can say that if the source side and load side voltage and current frequency characteristics have the same behavior, then we can assume that the fault occurs on the source bus side. If the source side and load side voltage and current frequency characteristics have opposite behavior, then we can assume that the fault occurs on the load bus side. The given approach is tested on two models at the MATLAB/Simulink platform and also gives an assurance of good quality results. The major outcomes of this paper are: i) Here we firstly find that there is no frequency deviation of voltage and current in case of no-fault; ii) The frequency characteristic of voltage and current draws the same behavior in case of source side bus fault; iii) The frequency characteristic of voltage and current draw opposite behavior in case of load side bus fault; iv) The frequency characteristics of voltage and current approximate same for symmetrical faults; v) Similarly, the frequency characteristics of voltage and current approximate same for Asymmetrical faults, and vi). On the basis of the similarity of frequency characteristics, we become able to classify the faults occurrence identity into two categories namely symmetrical and asymmetrical.

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