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Algorithm Based on Harmonic Wavelet Transform and Rule Based Decision Tree for Detection and Classification of Transmission Line Faults

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Abstract- This paper presents an algorithm based on harmonic wavelet transform (HWT) and rule-based decision tree for detection and classification of transmission line faults. Proposed algorithm has been implemented to provide voltage-based protection scheme to transmission line. Voltage recorded at both ends of transmission line has been decomposed using harmonic wavelet transform. Absolute values of output of harmonic wavelet transform based decomposition of voltage signal is taken as fault index and plotted for recognition of faults. Peak values of fault indexes are given as input to rule-based decision tree for classification of faults. Proposed voltage-based scheme proved to be effective in detection and classification of transmission line faults.

Keyword: **Faults, harmonic wavelet transforms, power system, rule-based decision tree, transmission line.**

1.INTRODUCTION

The power system network is used to transmit and distribute electrical power generated at large generating stations to load centres and consumers. A transmission line is one of the important elements of this electric power system network which is used to supply bulk power from central generating stations to load centres. As a result, power transmission lines have been rapidly developed in number and length. One important factor of an electrical power transmission system is to continuously deliver electrical power to consumers. Sustained fault on these lines may lead to disturbances of power supply in large area.

Hence, isolation of faulty line helps to maintain uninterrupted power supply in large area. This requires effective protection schemes for transmission lines [1]. Commonly occurred faults on transmission lines include line to ground (LG), double line (LL), double line to ground (LLG), three phase faults without involvement of the ground (LLL), three-phase fault with involvement of ground (LLLG) and inter-circuit faults [2]. Signal processing and mathematical techniques have been deployed for detection of transmission line faults. A novel approach for detecting, classifying and locating short-circuit faults in power transmission lines has been reported in [3]. A low cost, fast and reliable microcontroller-based protection scheme using wavelet transform and artificial neural network has been proposed by authors in [4] and its effectiveness has been evaluated in real time. Hussain *et al.* [5], proposed a simple fault location algorithm for multi-terminal transmission lines using unsynchronized measurements. Developed data synchronization procedure is employed to identify faulted leg before fault location is calculated. Fault location algorithm is independent of fault resistance and source impedance variations.

In [6], authors presented a methodology for fault location based on theory of state estimation in order to determine location of faults more accurately by considering realistic systematic errors that may be present in measurements of voltage and current. In this methodology besides calculating most likely fault distance obtained from measurement errors, variance associated with distance found is also determined using the errors theory. Obtained results are relevant to show that proposed estimation approach works even adopting realistic variances. He *et al.* [7], proposed a novel technique for fault detection and classification in extremely high-voltage transmission line using fault transients. Proposed technique, called wavelet singular entropy (WSE), incorporates advantages of wavelet transform, singular value decomposition and Shannon entropy.

WSE is capable of being immune to noise in fault transient and not being affected by transient magnitude so it can be used to extract features automatically from fault transients and express fault features intuitively and quantitatively even in case of high-noise and low-magnitude fault transients.

Research work proposed in this paper is mainly focussed on detection and classification of power system faults to provide voltage based protection schemes with the help of harmonic wavelet transform and ruled decision tree.

2.PROPOSED TEST SYSTEM

An overhead transmission line rated at 765 kV and having a line length equal to 200 km is used for proposed study of detection of transmission line faults as shown in Fig. 1. This line is connected to two large area power system networks simulated by two power source blocks of MATLAB/Simulink. Technical information of proposed test system is provided in Table I. Different types of power system faults have been simulated at middle of transmission line. Voltages and currents have been recorded at both ends of transmission line. Voltage signals recorded at both ends of transmission line are used to design voltage based protection scheme.

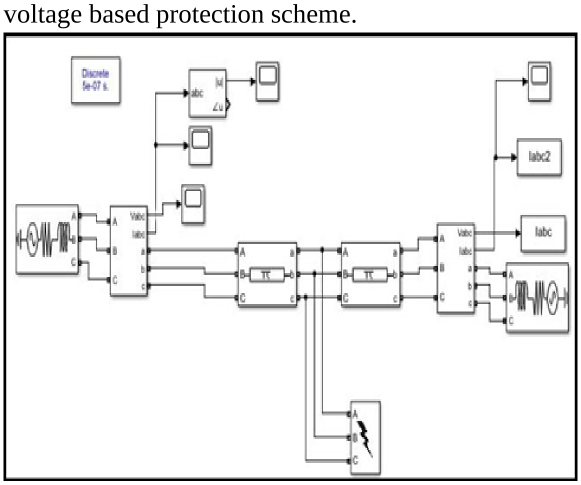

Fig.1. Proposed test system used for investigation of faults

TABLE I. TECHNICAL DATA OF THE PROPOSED TEST SYSTEM

Element	Parameter	Value
Sending end source (Generator 1)	Voltage (line)	765 kV
	Phase angle of phase-A	20°
	Source impedance	17.177+j45.917
Receiving end source (Generator 2)	Voltage (line)	765 kV
	Phase angle of phase-A	0°
	Source impedance	15.31+j45.917
Transmission Line	Line length	200 km
	Positive sequence impedance	0.01273+j0.3520 /km
	Zero sequence impedance	0.3864+1.5556 /km

simulation results are presented in following sections. Indexes are found to be effective in detection and discrimination of various types of transmission line faults. Detailed simulation results are presented in following sections.

2.1LINE TO GROUND FAULT

Line to ground (LG) fault is simulated on phase-A of transmission line at middle of transmission line at 6th cycle from start of simulation. Results are taken for 12 cycles with 6 cycles for pre-fault and 6 cycles for post fault conditions. Voltage of phase-A is recorded at first end of transmission line and decomposed using harmonic wavelet transform with sampling frequency of 1.92 kHz. Absolute values of output of harmonic wavelet transform of voltage is calculated and designated as fault index. Proposed fault index pertaining to voltage of phase-A on first end of transmission line during LG fault is shown in Fig. 3.

1.PROPOSED ALGORITH

Algorithm using harmonic wavelet transforms and rule-based decision tree for detection and classification of power system faults to provide transmission line protection is illustrated in the Fig. 2. Various types of faults are created at middle of test transmission line using a three- phase fault MATLAB simulation block. Voltage current

It is observed from Fig. 3 that values of fault index are very low during pre-fault condition. These values exceeds to a very high value of 6x10^4 just after occurrence of fault indicating LG fault on phase-A. It is also observed that values of fault index during post fault condition decreases to low value in duration of 0.06 s. Low values in pre-fault condition and high value just after fault occurrence clearly indicate presence of LG fault. Hence, proposed fault index based on harmonic wavelet transform is found to be effective in detection of transmission line faults. Signals are recorded at both ends of transmission line. Voltage signal is decomposed using harmonic wavelet transform. Absolute values of output matrix of harmonic wavelet transform has been obtained for voltages recorded at both ends of transmission line and these values are multiplied to obtain proposed fault index. Peak values of this fault index are given as input to rule based decision tree for classification purpose.

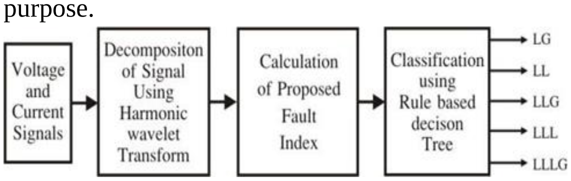

Fig. 2.Proposed algorithm for detection and classification of the transmission line fault.

2.SIMULATION RESULTS AND DISCUSSION

This section presents simulation results related to analysis of power system faults using a proposed fault index based on harmonic wavelet transform. Voltage signal recorded at both ends of transmission line are decomposed using harmonic wavelet transform with sampling frequency of 1.92 kHz. Absolute value of output of harmonic wavelet transform is designated as fault index. Peak values of fault various types of transmission line faults. Detailed

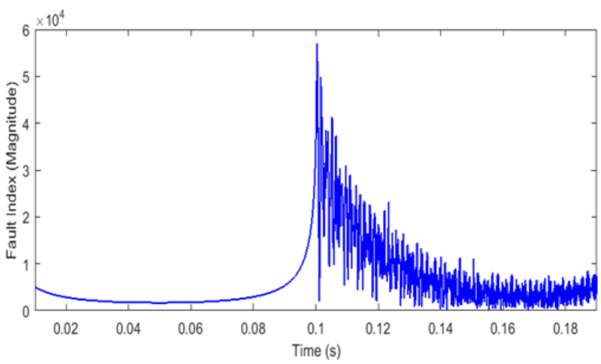

Fig. 3.Voltage based fault index for phase-A on first end of the transmission line during LG fault on phase-A.

Line to ground (LG) fault has been simulated on phase-A of transmission line at middle of transmission line at 6th cycle from start of simulation. Results are taken for 12 cycles including 6 cycles of pre-fault condition and 6 cycles for post fault condition. Voltage of phase-A is recorded at second end of transmission line and decomposed using harmonic wavelet transform with sampling frequency of 1.92 kHz. Absolute values of output of harmonic wavelet transform of voltage is calculated and designated as fault index. Proposed fault index pertaining to voltage of phase-A on second end of transmission line during LG fault is shown in Fig. 4.

It is observed from Fig. 4 that values of fault index are very low during pre-fault condition. These values exceeds to very high values of $6x10^4$ just after occurrence of fault indicating LG fault on phase-A. It is also observed that values of fault index during post fault conditions decreases to low values in duration of 0.06 s. Low values in pre-fault condition and high value just after fault occurrence clearly indicate presence of LG fault. Hence, proposed fault index based on harmonic wavelet transform is found to be effective in detection of transmission line faults based on voltages measured at both ends of transmission line.

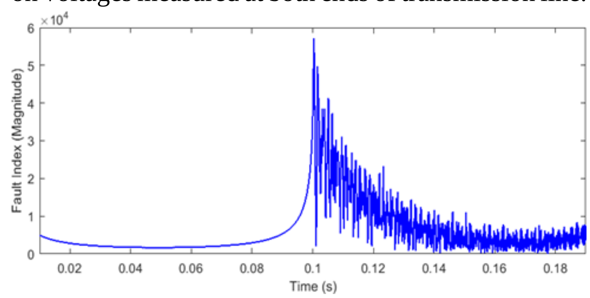

Fig. 4.Voltage based fault index for phase-A on second end of transmission line during LG fault on phase-A.

Line to ground (LG) fault has been simulated on phase-A of transmission line at middle of transmission line at 6th cycle from start of simulation. Results are taken for 12 cycles including 6 cycles of pre-fault condition and 6 cycles for post fault condition. Voltage of phase-A is recorded at both ends of transmission line and decomposed using harmonic wavelet transform with sampling frequency of 1.92 kHz. Absolute values of output of harmonic wavelet transform of voltages at both ends are calculated. Multiplication of these values is designated as fault index. Proposed fault index pertaining to voltage of phase-A recorded on both ends of transmission line during LG fault is shown in Fig. 5.

It is observed from Fig. 5 that values of fault index are zero during pre-fault condition. These values exceeds to very high values of $3.4x10^9$ just after occurrence of fault indicating LG fault on phase-A. It is also observed that values of fault index during post fault conditions decreases to low values in a duration of 0.04s. Low values in prefault condition and high values just after fault occurrence clearly indicate presence of LG fault. Hence, proposed fault index using harmonic wavelet transform based decomposition of voltage on both ends is found to be effective in detection of transmission line faults.

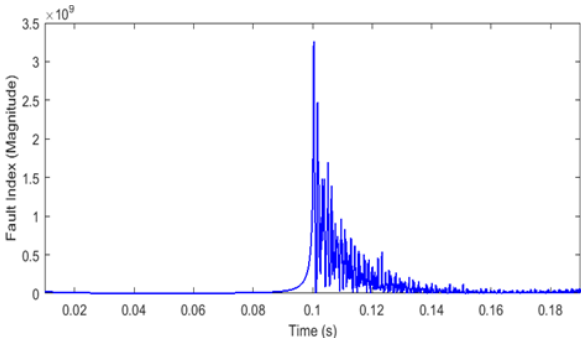

Fig. 5. Fault index for phase-A based voltages measured at both ends of transmission line during LG fault on phase-A.

2.2 DOUBLE LINE FAULT

The double line (LL) fault has been simulated by short circuiting phases-A&B at middle of transmission line at 6th cycle from start of simulation. Results are taken for 12 cycles including 6 cycles of pre-fault condition and 6 cycles for post fault condition. Voltage of phase-A is recorded at first end of transmission line and decomposed using harmonic wavelet transform with sampling frequency of 1.92 kHz. Absolute values of output of harmonic wavelet transform of voltage is calculated and designated as fault index. Proposed fault index pertaining to voltage of phase-A on first end of transmission line during LG fault is shown in Fig. 6.

It is observed from Fig. 6 that values of fault index are very low during pre-fault condition. These values exceeds to very high values of 2.5x10^5 just after occurrence of fault indicating LL fault on phases-A&B. It is also observed that values of fault index during post fault conditions decreases to low values in a duration of 0.08s. Low values in pre-fault condition and high value just after fault occurrence clearly indicate presence of LL fault. Hence, proposed fault index based on harmonic wavelet transform is found to be effective in detection of transmission line LL fault.

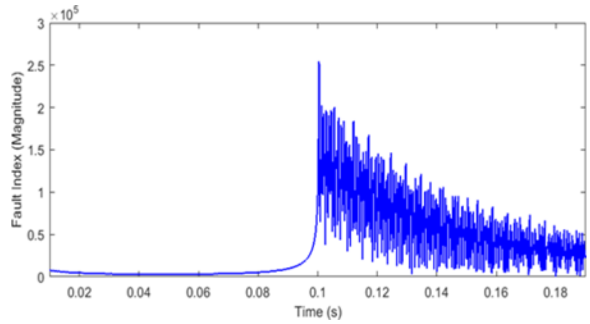

Fig. 6. Voltage based fault index for phase-A on first end of transmission line during LL fault on phases-A & B.

The double line (LL) fault has been simulated by short circuiting phases-A&B of at middle of transmission line at 6th cycle from start of simulation. Results are taken for 12 cycles including 6 cycle of pre-fault condition and 6 cycles for post fault conditions. Voltage of phase-A is recorded at second end of transmission line and decomposed using harmonic wavelet transform with sampling frequency of 1.92 kHz. Absolute values of output of harmonic wavelet transform of voltage is calculated and designated as fault index. Proposed fault index pertaining to voltage of phase-A on second end of transmission line during LL fault is shown in Fig. 7.

It is observed from Fig. 7 that values of fault index are very low during pre-fault condition. These values exceeds to very high values of 2.5x10^5 just after occurrence of fault indicating LL fault on the phases-A&B. It is also observed that values of fault index during post fault conditions decreases to low values in duration of 0.08 s. Low values in pre-fault condition and high value just after fault occurrence clearly indicate presence of LL fault. Hence, proposed fault index based on harmonic wavelet transform is found to be effective in detection of transmission line LL fault.

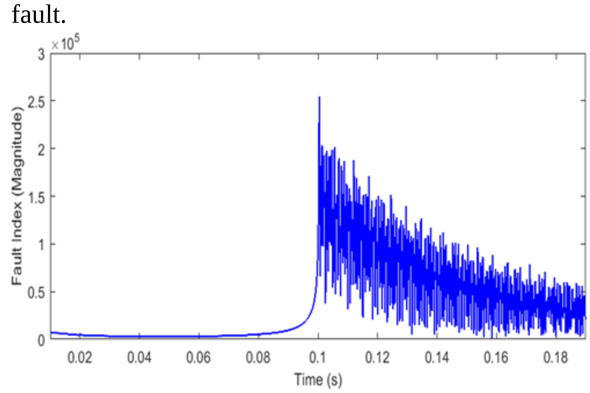

Fig. 7. Voltage based fault index for phase-A on

second end of transmission line during LL fault on phases-A & B.

The double line (LL) fault has been simulated by short circuiting phases-A &B of transmission line at middle of the transmission line at 6th cycle from start of the simulation.

Results are taken for 12 cycles including 6 cycle of pre- fault condition and 6 cycles for post fault conditions. Voltage of phase-A is recorded at both ends of transmission line and decomposed using harmonic wavelet transform with sampling frequency of 1.92 kHz. Absolute values of output of harmonic wavelet transform of voltages at both ends are calculated. Multiplication of these values is designated as fault index. Proposed fault index pertaining to voltage of phase-A recorded on both ends of transmission line during LL fault is shown in Fig. 8.

It is observed from Fig. 8 that values of fault index are zero during pre-fault condition. These values exceeds to a very high values of $6.5x10^{10}$ just after occurrence of fault indicating LL fault on phases-A&B. It is also observed that values of fault index during post conditions decreases to low values in a duration of the 0.06s. Zero values in pre-fault condition and high values just after fault occurrence clearly indicate presence of LL fault. Hence, proposed fault index using harmonic wavelet transform based decomposition of voltage on both ends is found to be effective in detection of transmission line LL faults.

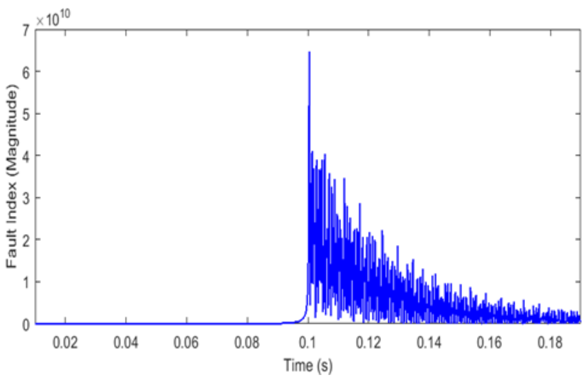

Fig. 8. Fault index for phase-A based voltages measured at both ends of transmission line during LL fault on phases-A & B.

2.3DOUBLE LINE TO GROUND FAULT

The double line to ground (LLG) fault has been simulated by simultaneously grounding phases-A&B of at middle of transmission line at 6th cycle from start of simulation. Results are taken for 12 cycles including 6 cycles of pre-fault condition and 6 cycles for post fault conditions. Voltage of phase-A is recorded at first end of transmission line and decomposed using harmonic wavelet transform with sampling frequency of 1.92 kHz. Absolute values of output of harmonic wavelet transform of voltage is calculated and designated as fault index. Proposed fault index pertaining to voltage of phase-A on first end of transmission line during LLG fault is shown in Fig. 9.

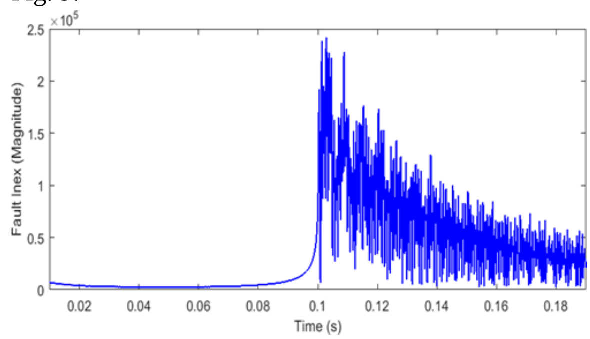

Fig. 9.Voltage based fault index for phase-A on first end of the transmission line during LLG fault on phases- A & B.

It is observed from Fig. 9 that values of fault index are very low during pre-fault condition. These values exceeds to very high values of $2.5x10^5$ just after occurrence of fault indicating LL fault on phases-A&B. It is also observed that values of fault index during post fault condition decreases to low values in a duration of 0.08s. Low values in pre-fault condition and high value just after fault occurrence clearly indicate presence of LLG fault. Hence, proposed fault index based on harmonic wavelet transform is found to be effective in detection of transmission line LLG fault.

Double line to ground (LLG) fault has been simulated by simultaneously grounding phases-A&B of at middle of transmission line at 6th cycle from start of simulation. Results are taken for 12 cycles including 6 cycles of pre- fault condition and 6 cycles for post fault conditions. Voltage of phase-A is recorded at second end of transmission line and decomposed using harmonic wavelet transform with sampling frequency of 1.92 kHz. Absolute values of output of harmonic wavelet transform of voltage is calculated and designated as fault index. Proposed fault index pertaining to voltage of phase-A on second end of transmission line during LLG fault is shown in Fig. 10.

It is observed from Fig. 10 that values of fault index are very low during pre-fault condition. These values exceeds to very high values of $2.5x10^5$ just after occurrence of fault indicating LL fault on phases-A&B. It is also observed that values of fault index during post fault conditions decreases to low values in duration of 0.08 s. Low values in the pre-fault condition and high value just after fault occurrence clearly indicate presence of LLG fault. Hence, proposed fault index based on harmonic wavelet transform is found to be effective in detection of transmission line LLG fault.

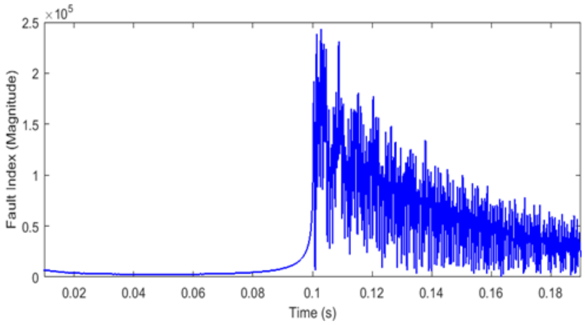

Fig.10.Voltage based fault index for phase-A on second end of transmission line during LLG fault on phases-A & B.

Double line to ground (LLG) fault has been simulated by short circuiting phases-A &B of transmission line at middle of transmission line at 6^{th} cycle from start of simulation. Results are taken for 12 cycles including 6 cycles of pre-fault condition and 6 cycles for post fault conditions. Voltage of phase-A is recorded at both ends of the transmission line and decomposed using harmonic wavelet transform with sampling frequency of 1.92 kHz. Absolute values of output of harmonic wavelet transform of voltages at both ends are calculated. Multiplication of these values is designated as fault index. Proposed fault index pertaining to voltage of phase-A recorded on both ends of transmission line during LLG fault is shown in Fig. 11. It is observed from Fig. 11 that values of fault index are zero during pre-fault condition. These values exceeds to a very high value of $6x10^{10}$ just after occurrence of fault indicating LLG fault on phases-A&B. It is also observed that values of fault index during post conditions decreases to low values in a duration of 0.06s. Zero values in pre-fault condition and high values just after fault occurrence clearly indicate presence of LLG fault. Hence, proposed fault index using harmonic wavelet transform based decomposition of voltage on both ends is found to be effective in detection of transmission line LLG faults.

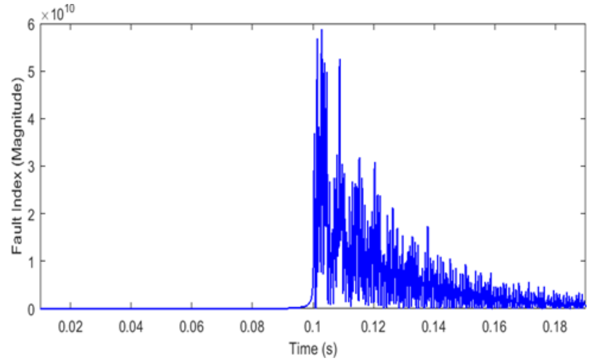

Fig. 11. Fault index for phase-A based voltages measured at both ends of transmission line during LLG fault on phases-A & B.

2.4THREE PHASE FAULT WITH THE INVOLVEMENT OF GROUND

Three phase fault with involvement of fault (LLLG) is simultaneously grounding all three phases at middle of transmission line at 6^{th} cycle from start of simulation. Results are taken for 12 cycles including 6 cycles of pre- fault condition and 6 cycles for post fault conditions. Since, three phases is symmetrical in nature, behaviour of all three phases will be similar. However, results related to all three phases have been presented in this section.

Voltage of phase-A is recorded at first end of transmission line and decomposed using harmonic wavelet transform with sampling frequency of 1.92 kHz. Absolute values of output of harmonic wavelet transform of voltage is calculated and designated as fault index. Proposed fault index pertaining to voltage of phase-A on first end of the transmission line during LLLG fault is shown in Fig. 12.

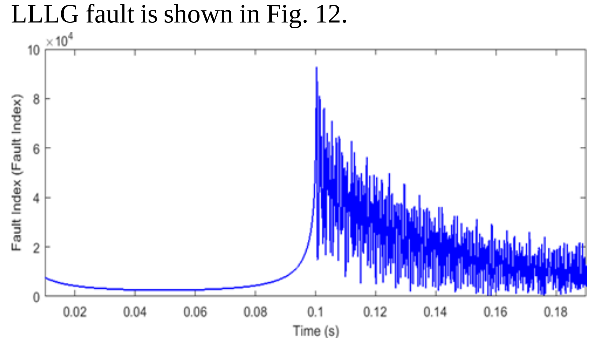

Fig. 12. Voltage based fault index for phase-A on first end of transmission line during LLLG fault.

It is observed from Fig. 12 that values of fault index are very low during pre-fault condition. These values exceeds to very high values of $9.5x10^4$ just after occurrence of fault indicating LLLG fault. It is also observed that values of fault index during post fault conditions decreases to low values in duration of 0.08 s. Low values in the pre-fault condition and high value just after fault occurrence clearly indicate presence of LLLG fault. Hence, proposed fault index based on harmonic wavelet transform is found to be effective in detection of transmission line LLLG fault.

Voltage of phase-A is recorded at second end of transmission line and decomposed using harmonic wavelet transform with sampling frequency of 1.92 kHz. Absolute values of output of harmonic wavelet transform of voltage is calculated and designated as fault index. Proposed fault index pertaining to voltage of phase-A on second end of transmission line during LLLG fault is shown in Fig. 13.

It is observed from Fig. 13 that values of fault index are very low during pre-fault condition. These values exceeds to very high values of $9.5\text{x}10^4$ just after occurrence of fault indicating LLLG fault. It is also observed that values of fault index during post fault condition decreases to low values in duration of 0.08 s. Low values in pre-fault condition and high value just after fault occurrence clearly indicate presence of LLLG fault. Hence, proposed fault index based on harmonic wavelet transform is found to be effective in detection of transmission line LLLG fault.

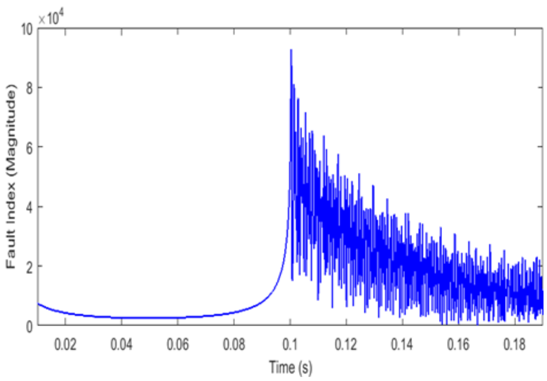

Fig. 13. Voltage based fault index for phase-A on second end of transmission line during LLLG fault.

Three phase fault with involvement of ground (LLLG) has been simulated by short circuiting all three phases at middle of transmission line at 6^{th} cycle from start of simulation. Results are taken for 12 cycles including 6 cycles of pre-fault condition and 6 cycles for post fault conditions. Voltage of phase-A is recorded at both ends of transmission line and decomposed using harmonic wavelet transform with sampling frequency of 1.92 kHz. Absolute values of output of harmonic wavelet transform of voltages at both ends are calculated. Multiplication of these values is designated as fault index. Proposed fault index pertaining to voltage of phase-A recorded on both ends of transmission line during LLLG fault is shown in Fig. 14.

It is observed from Fig. 14 that values of fault index are zero during pre-fault condition. These values exceeds to a very high values of $9.5\text{x}10^9$ just after occurrence of fault indicating LLLG fault. It is also observed that values of fault index during post fault condition decreases to low values in a duration of 0.06s. Zero values in pre-fault condition and high values just after fault occurrence clearly indicate presence of LLLG fault. Hence, proposed fault index using harmonic wavelet transform based decomposition of voltage on both ends is found to be effective in detection of transmission line LLLG faults.

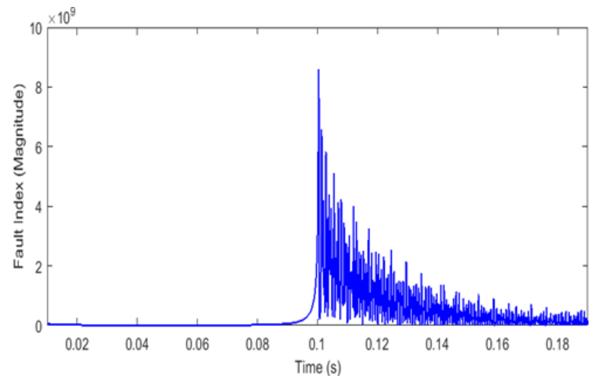

Fig. 14. Fault index for phase-A based voltages measured at both ends of transmission line during LLLG fault.

2.5CLASSIFICATION OF TRANSMISSION LINE FAULTS

Peak values of proposed fault index observed during various types of power system faults on transmission line are provided in Table I. These peak values help to detect and discriminate the various types of faults. These peak values are given as input to rule based decision tree for detection and discrimination of different types of faults based on decision rules. Classification using rule based decision tree along with different decision rules used for classification purpose are shown in Fig. 15.

It is observed that fault index calculated using voltage at both ends of transmission line is found to be more effective in detection and classification of transmission line faults. Fault index corresponding to phase-A is found to be more effective in classification of faults into groups of similar nature. However, fault index corresponding to phase-C is found to be more effective in discrimination of LL and LLG faults. There is no need to classify faults LLL and LLLG from each other because behavior of these faults is same and these are considered identical to each other in power system studies. Hence, protection scheme using harmonic wavelet transform based decomposition of voltage recorded at both ends of transmission line rule based decision tree is found to be effective in detection and discrimination of transmission line faults.

TABLE I. PEAK VALUE OF THE VOLTAGE BASED FAULT INDEXES

Type of Faults	LG	LL	LLG	LLL	LLLG
Fault index based on voltage at first end of transmission line					
Phase-A	$6x10^4$	$2.5x10^5$	$2.5x10^5$	$9.5x10^4$	$9.5x10^4$
Phase-B	$2.3x10^4$	$2.5x10^5$	$3.4x10^5$	$4.5x10^5$	$4.5x10^5$
Phase-C	$2.3x10^4$	200	$6.5x10^4$	$3.8x10^5$	$4.5x10^5$
Fault index based on voltage at second end of transmission line					
Phase-A	$6x10^4$	$2.5x10^5$	$2.5x10^5$	$9.5x10^4$	$9.5x10^4$
Phase-B	$2.3x10^4$	$2.5x10^5$	$3.4x10^5$	$4.2x10^5$	$4.2x10^5$
Phase-C	$2.3x10^4$	200	$6.5x10^4$	$3.8x10^5$	$3.8x10^5$
Fault index based on voltages at both ends of transmission line					
Phase-A	$3.4x10^9$	$6.5x10^{10}$	$6x10^{10}$	$9x10^9$	$9x10^9$
Phase-B	$9.5x10^8$	$6.5x10^{10}$	$10x10^{10}$	$2x10^{11}$	$2x10^{11}$
Phase-C	$5.5x10^8$	$2 x10^4$	$4x10^9$	$14x10^{10}$	$14x10^{10}$

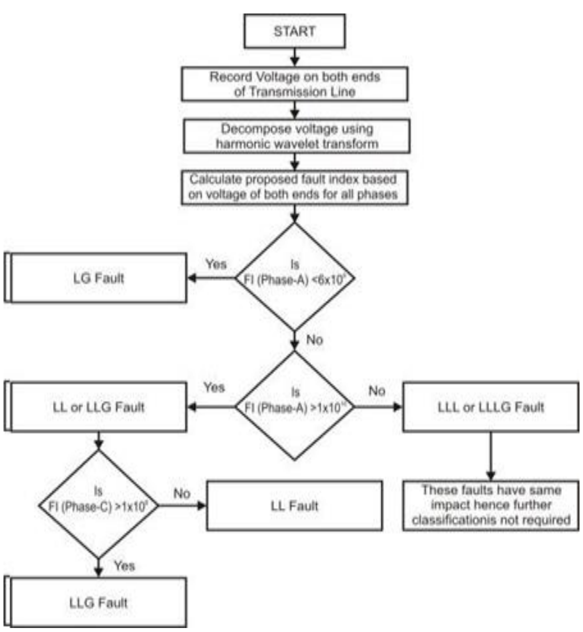

Fig. 15. Ruled decision tree-based flow chart for classification of transmission line faults using voltage based fault index.

3.CONCLUSION

This research work presents a method for detection and classification of transmission line faults. Proposed method is based on harmonic wavelet transform and rule based decision tree. Voltage signal recorded at both ends of transmission line is decomposed using harmonic wavelet transform and proposed fault index is calculated. Peak values of proposed fault index are given as input to rule based decision tree for classification purpose. It is concluded that fault index calculated from voltage recorded at both ends of transmission line is found to be more effective in detection and classification of transmission line faults.

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