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Transmission Line Fault Analysis using Synchronized Phasor Measurements

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Abstract

The modern power system is expanding from all directions due to the exponential increase in load and integration of renewable energy sources. It must be protected by smart sensors called synchronized phasor measuring units that provide the power system's dynamic state by placing them at the sstrategic positions of the power system. In this paper, a smart sensor called as NI based phasor measurement unit was used to detect the faults and classify the faults on transmission line. The complete analysis has been carried out on the experimental set up containing three phase AC source as three phase generator, a 400 KV, 200 km, three-phase transmission line having same per unit values and three phase balanced load along with a NI based PMU to extract the real-time information at a very faster speed

Index Terms: Phasor Measurement Unit, Fuzzy Logic, Symmetrical Component, Situational Awareness, cRIO based PMU.

I. INTRODUCTION

Lack of adequate situational awareness leads to unforeseen power system problems such as blackouts affecting the country's economy and various losses in different forms. Therefore, there is a need for effective situational awareness (SA) that will enable the operator to make decisions in good time and take appropriate protective action against power system disturbances in transmission and distribution lines [1]. Mathaios et.al. [2] Presented a review of SA with different tools, methods, and its impact on the decision making.Supervisory Control and Data Acquisition (SCADA) has traditionally being the technology used to capture the power system disturbances. Yoshio Ebata [3] presented the application of internet technology to SCADA for power system monitoring using wide area network (WAN). Chen-Ching Liu et.al., [4] presented an application for acquisition system is much faster than the SCADA. Although SCADA can prevent the failures to some degree, but it is limited because of its slower sampling rate. The transmission line is exposed to atmosphere and hence at any point of time, faults can take place. Since they transport power from restoration of distribution system for restoration planner and loss minimization to provide service to consumers.Mangapathira et.al [5] presented about the SCADA system and wide-area monitoring system (WAMS) to monitor time synchronized data. It has been observed that the modern data generation to distribution and used for various purposes, any type of fault on transmission line needs immediate attention and action to reduce the power interruptions. In order to avoid and minimize the frequency of power interruptions, the operator should be aware of the dynamic state of the power system. The need for effective and efficient real time situational awareness can be fulfilled by employing phasor measurement units (PMUs), which provide the synchronized phasor data at a speed more than 60 samples per cycle. It is more reliable, faster and robust [6].

Fault analysis on a transmission line is essential to improve the efficiency of the power system and hence the effective SA [7]. The protective relay plays a great role for the protection of the power system. There are many techniques reported in the literatures for identifying and

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classifying the faults on the transmission line [8]-[11].

This paper presents a real time system for detecting the transmission line fault , classify the type of fault and protect the transmission line by actuating the circuit breaker at high speed expresses in terms of microsecond speed. The proposed algorithm uses the concept of fuzzy logic which is based on the symmetrical component of three phase current values. The rest of the paper is organised as follows. The second section gives the detail system description and components used in the suggested system. Section III describes the working of the system for different fault detection and classification. Conclusions are presented in section IV.

II. SYSTEM ARCHITECTURE

The proposed system consists of an artificial transmission line of 200 km, a NI Based PMU (cRIO) as shown in Fig. 1. The NI based PMU (cRIO) contains a high performance reconfigurable controller (NI cRIO 9066) along with NI 9242, 250 Vrms, 24-Bit, 50 kS/s/ch, 3-Ch, AI C Series Module, NI 9246, 20 A, 24-Bit, 50 kS/s/ch, 3-Ch, AI C Series Module, NI 9467, GPS Time Synchronization Module, NI 9401 8-Channel, 100 ns, TTL Digital Input/ Output Module, a relay module to protect the line at fault condition and a Dell Precision Tower 3620 work station along with LabVIEW 2016 software. The cRIO based.

Table 1 Component specification

Components	Specification			
Transmission line	4-π section each 50Km	Resistance	0.2Ω	
		Inductance	8.4mH	
		Capacitance (C/2)	2 μF	
	Scale factor	Current Transformer (CT) Ratio	Potential transformer(PT) Ratio	
		1:1	1:4	
NI cRIO (9066) based PMU	Current Transformer	Potential transformer	GPS	Relay Driver
	NI-9246-20Arms, 30A peak to peak, and 24 bit	**NI-9242**-250V rms , L-N, 400Vrms L-L, 24-bit, 3-channel	**NI-9467** -GPS C series synchronization module.	**NI 9401**-5V/TTL, 8 channels, 100ns C series digital module
3-Ø Load	3 phase Resistive load	1KΩ,300V,1.2A		
	3 phase Lamp load	230V, 200W		

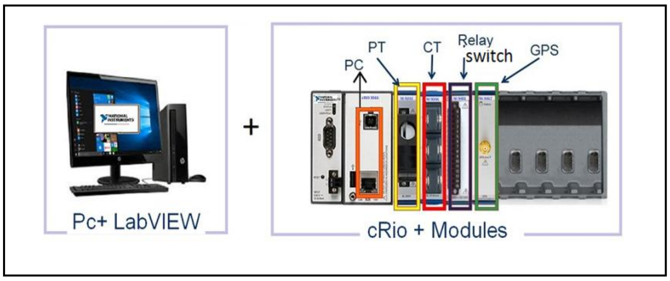

Fig. 1 NI Based PMU

PMU is placed before the pi-section of the transmission line as shown in Fig. 2.Whenever a fault occurs, it detects the fault and triggers the breaker for tripping action, such that the power supply is disconnected from the transmission line. The NI based PMU is programmed on the LabVIEW platform. The block diagram of NI based PMU is shown in Fig .3. PMU continuously measures voltage and current phasor and serves as an input to the fault detection algorithm. NI based PMU having high sampling rate typically 60 samples per cycle enables to switch the breaker almost in real time at microsecond speed to protect against the fault. The component specification is given in the table 1. The voltage and the current module acts as potential transformer and current transformer, GPS module provides the synchronous clock and pulse per second (PPS) signal and the relay driver digital I/O module provides the switching signal to the circuit breaker of transmission line. Fig. 2 shows the schematic diagram of the experimental setup. It contains three phase AC source, three phase transmission line of

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200 km and a three phase resistive load. Different types of faults are applied at the three phase resistive load. Current and voltage phasors are obtained from NI based PMU. A LabVIEW based fuzzy algorithm is developed using the current phasor from NI based PMU and then detection and classification of faults are carried out based on symmetrical components of voltages and currents. Circuit breaker receives a trip signal from the relay in order to protect the transmission line from different types of faults. The experimental setup for the proposed work is presented in Fig. 3.

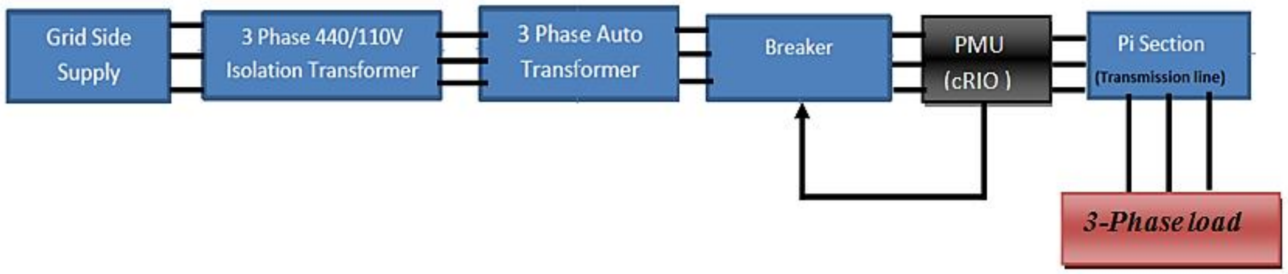

Fig. 2 Schematic diagram of the proposed system

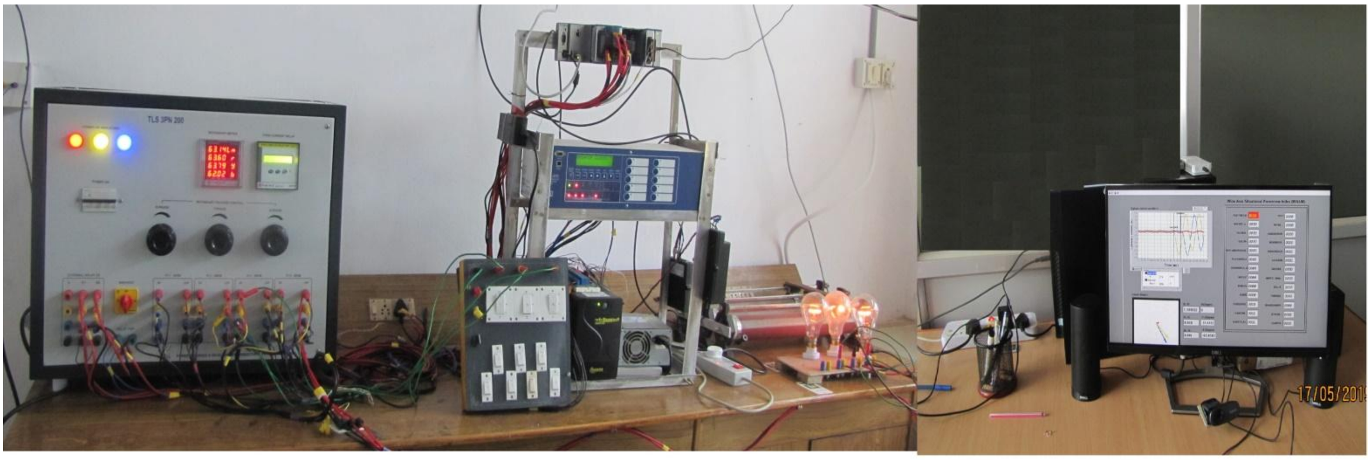

Fig. 3 Experimental setup of proposed work

III. FAULT DETECTION AND CLASSIFICATION ALGORITHM

The algorithm is based on fuzzy logic which has been developed based on the symmetrical components of three phase current values. The symmetrical components of currents are taken from the NI based PMU. Equation (1) shows the symmetrical component of currents. These currents aprovided to LabVIEW based Multi Input Single Output (MISO) Fuzzy system. The Fuzzy rules are formulated based on the positive sequence current (Ia_1), negative sequence current (Ia_2) and zero sequence current (Ia_0)[12][13]. A triangular membership function has been chosen based on the offline fault data obtained from the National Instrument cRIO-9066, current and voltage acquisition modules with LabVIEW software, forming NI based PMU. The algorithm is tested online for real time fault detection, classification and appropriate decision making. The rule based fuzzy logic algorithm is shown in the Fig.5 which has been used for the transmission line fault detection and classification. The triangular membership function has been employed for both input and output variable membership function. The symmetrical components (zero sequence, positive sequence and negative sequence[Ia_0, Ia_1 and Ia_2])and the current (I_R, I_Y, I_B) values are taken as input variable to the fuzzy rule based and the output obtained from the fuzzy rule based system is class of fault (fault type). The rules of fuzzy knowledge based system are framed and are as follows:

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$$Ia_0 = \frac{I_R + I_Y + I_B}{3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1a)$$

$$Ia_1 = \frac{I_R + \alpha I_Y + \alpha^2 I_B}{3} \ldots\ldots\ldots\ldots\ldots(1b)$$

$$Ia_2 = \frac{I_R + \alpha^2 I_Y + \alpha I_B}{3} \ldots\ldots\ldots\ldots\ldots(1c)$$

Rule 1: If $I_{a0} = I_{a1} = I_{a2}$ is finite, then output is L-G fault.
Rule 2: If $I_{a0} = 0$ and I_{a1} is negative of I_{a2}, then output is L-L fault.
Rule 3: If $Ia_0 = I_{a2} = 0$ and I_{a1} is finite and I_R, I_Y, I_B are high, then output is L-L-L fault.
Rule 4: If Ia_0, I_{a1}, and Ia_2 are finite and sum of I_{a0} and Ia_1 is negative of Ia_2, then output is L-L-G fault.
Rule 5: If $Ia_0 = I_{a2} = 0$ and I_{a1} is finite and I_R, I_Y and I_B are low, then output is L-L-L fault

Where Ia_0, Ia_1 and Ia_2 are zero sequence, positive sequence and negative sequence components of currents. $I_R, I_Y,$ and I_B are the phase currents and α is $1\angle 120$ respectively α^2 is $1\angle 240$ respectively. "F" in the table 2 stands for finite value. The algorithm is developed in LabVIEW platform FPGA based cRIO controller. LabVIEW with 667 MHz Dual-Core CPU cRIO acquires the current and voltage data at 50 kS/s/channel. When fault occurs on the transmission line, the fuzzy logic algorithm detects the fault online, classify the type of fault by suitable indication and trigger the circuit breaker to protect the transmission line.

Fig. 6 to Fig. 10 shows the LabVIEW front panel for different fault conditions which are based on the output of the fuzzy logic. Each front panel shows the three phase current wave.

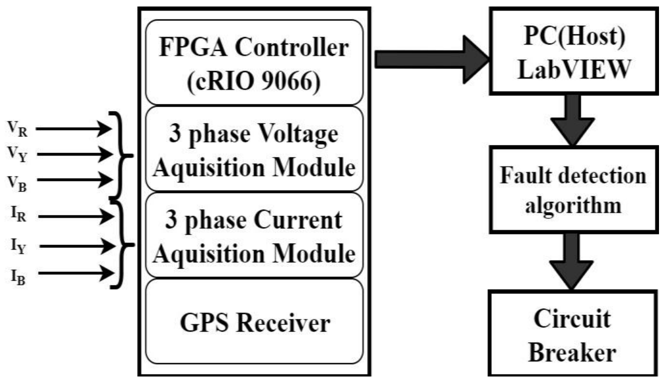

Fig. 4 PMU (cRIO) block diagram

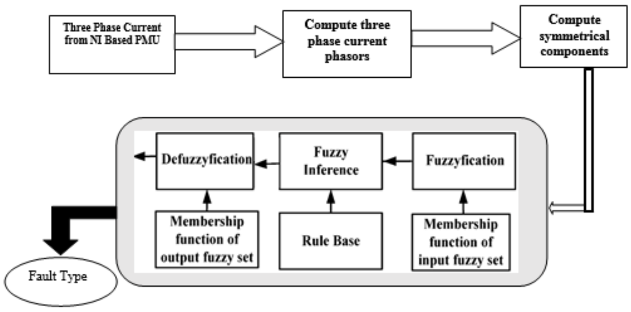

Fig. 5 Fault detection algorithm (using symmetrical component)

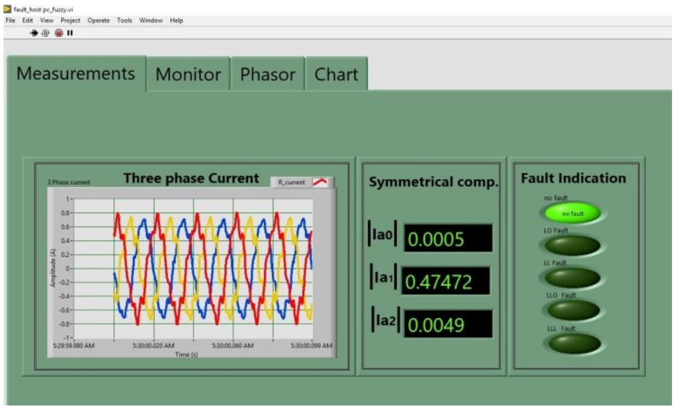

Fig.6 LabVIEW front panel under no fault condition

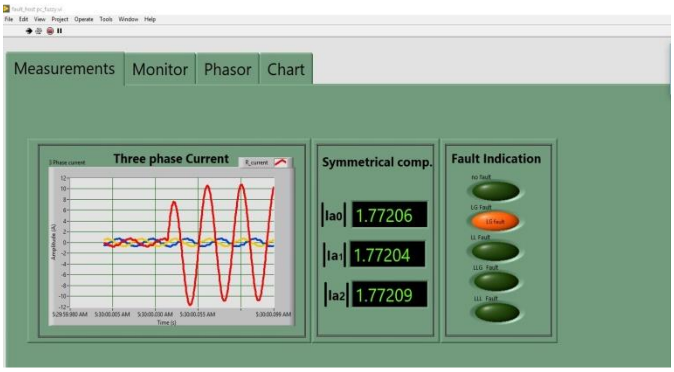

Fig. 7 LabVIEW front panel under LG fault

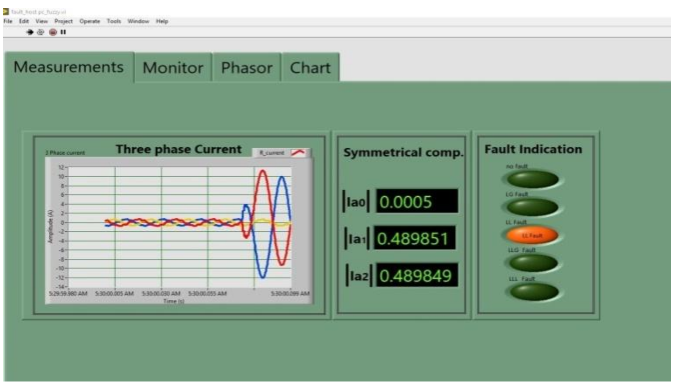

Fig.8 LabVIEW front panel under LL fault condition

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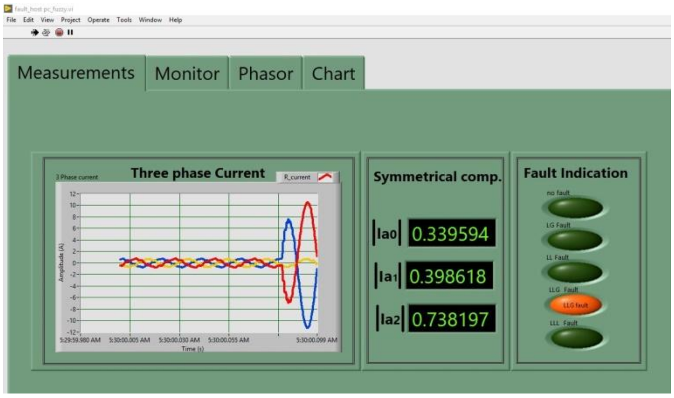

Fig. 9 LabVIEW front panel under LLG fault condition

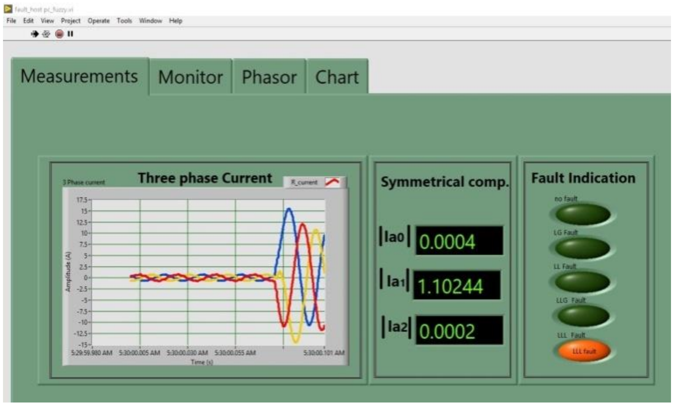

Fig. 10 LabVIEW front panel under LLL fault condition

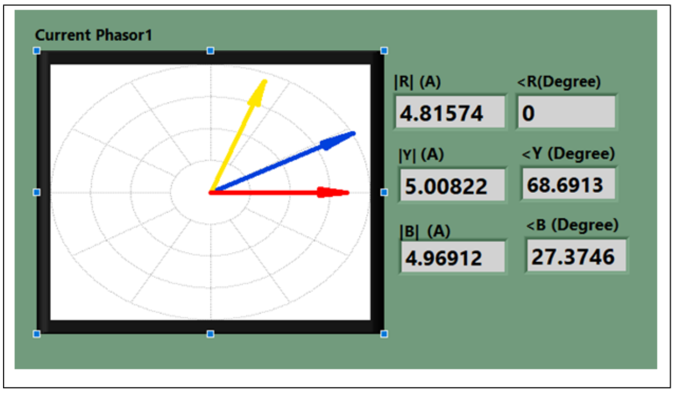

Fig.11 LabVIEW Phasor diagram under LLL fault condition

Table 2: Relationship between sequence currents for different types of faults

Fault Type	Ia_0	Ia_1	Ia_2	Remarks
LG	F	F	F	$Ia_0 = Ia_1 = Ia_2$
LL	0	F	F	$Ia_2 = - Ia_1$
LLL	0	F	0	$Ia_0 = 0$
LLG	F	F	F	$Ia_0 + Ia_1 = - Ia_2$

Form, the symmetrical component magnitude at fault instance and the respective fault indication. Fig. 11 shows the front panel of the LabVIEW program presenting distorted phasor from its balanced position, under the LLL fault condition and the respective phasor magnitude and angle of each phase. Fig. 12 shows the LabVIEW block diagram of the fuzzy logic-based LabVIEW host program employed for fault detection in this work.

IV. CONCLUSION

A multiple input single output fuzzy system is implemented using the symmetrical components of currents derived from NI based PMU for detecting different types of faults on transmission line. The proposed system is able to detect the fault precisely and able to take the decision for protecting the transmission line. The real time analysis confirms the most important requirement for restoring the fault on transmission line to be robust, faster and more efficient. LabVIEW is equipped with interactive visualization presentations to be used for quick decision by the power system operators. Compared to conventional instrumentation systems, LabVIEW based virtual- instrumentation has economic and computational benefits.

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