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Discrete Fourier Transform Algorithm Based Digital Multifunction Relay for Transmission Line Protection

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Abstract*: In this Paper, an innovative busbar protection system with advanced zone selection that provides security for external faults and fast to detect external-to-internal evolving faults. It also present test results showing the fast response for the relay of busbar faults, security for external faults, and minimum time delay for evolving faults. It is further implemented in MATLAB as a simulation for multiple bus bar transmission system and output waveforms for highly corrupt voltage and current signals. The proposed algorithm has the ability to detect all types of in-zone faults and remains stable during out of zone faults. An average tripping time for most of the internal faults is within 50 ms. this work proposes a new real-time digital filtering method for removing faulty current and voltage signal and hence improving DFT algorithm. The obtained simulation results are satisfactory.

***Keywords:* Include Asymmetrical faults, Digital relay, Power system Protection, Fourier filtering algorithms,**

I. INTRODUCTION

Primary purpose of Power System is to ensure continuous delivery of power supply despite of various faults like Overcurrent, Earth faults, and Phase faults etc. Thus different protection devices are used for Power System Protection out of which numerical relays embedded with digital signal processor (DSP) are able to improve the protection operations significantly. Various DSP techniques such as Fast Fourier Transform (FFT), Discrete Fourier Transform (DFT) and Wavelet Transform along with Artificial Neural Networks (ANNs) can be used to detect spurious signals and faults. The main purpose of Power System is to generate, transmit and distribute electric energy to customers without interruptions in the most economical and safe manner. Power System suffers through many faults such as Phase and Earth Faults [1].

Most of these faults result into sudden and significant increase in current. Thus, overcurrent protection is essential in order to minimize the disturbances caused by any failure in the system and to ensure continuous power delivery. Therefore, it is a common practice to interconnect major elements of Power System such as generators, power transformers, transmission lines, etc. by using protection devices such as fuses, switchgears and circuit breakers along with various types of relays [2].

The major disturbances that occur in the power system are classified into different types, line to ground (LG) fault, line to line to ground (LLG) fault, line to line (LL) fault, three phases (LLL) fault, and three phases to ground (LLLG) fault. Positive, negative, and zero sequence current components are present in LG, LLG, LL faults, so they are called asymmetrical faults, whereas in LLL and LLLG fault only positive sequence component is present and so they are called as symmetrical faults.

When the faults occur in such power system, protection systems are required to isolate faulted part of the power system, and leave the healthy parts of the system connected to the power supply. The operational security of the power system depends upon the successful performance of the thousands of relays that protect equipments and hence protect the whole system from cascading failures. Thus, the failure of a relay to operate as intended may jeopardize the stability of the entire system and equipment in it. The mal-operation of this relay is generally due to unnecessary tripping that reduces the security of such system and hence its reliability. In order to avoid the unnecessary tripping, many techniques have been developed such as digital filter or blinder.

Accurate and fast measurement of the voltage and current phasers of the fundamental components is very important in three-phase distance relay that may be investigated by an integrated Phasor measurement unit (PMU). In digital relaying system, discrete Fourier transform (DFT) is the most widely used filtering algorithm [1-3] for computing the fundamental phasers and their symmetrical components.

Some transient disturbance currents of a transmission line may contain a DC offset which decays exponentially with time (time constant of the line inductance to resistance ratio L/R), or a large number of unwanted harmonics or decaying DC components due to the thyristor-controlled switched capacitor (TCSC) compensated lines [4]. This latter always needs few cycles for decaying DC component or 10– 20 cycles for harmonics component to obtain the accurate fundamental phasers by discrete Fourier transform DFT algorithm.

The present work focuses on presenting a novel digital multifunction relay based on Discrete Fourier Transform

(DFT) algorithm capable of removing integer harmonics using simple computation. However, the voltage and current signals include serious harmonics and decaying dc during the fault period. The decaying dc and higher order harmonics severely inhibit the search for an accurate fundamental frequency signal and delay the convergence time. When a fault occurs, it is desired that the relay used for protection has to respond quickly. The fundamental frequency phasor estimation of the DFT algorithm is within time limit.[5]

II. OBJECTIVE

- To analyse the condition of unbalanced in the voltage of three phases.
- To avoid undesirable operation of the relay.
- To prevent the propagation of these faults.
- To safeguard the system against the abnormal operation resulting from it.
- To analyze the generated incremental waveform for fault condition in which trip signal is generated about 50 ms after the inception of the fault.
- Consideration of various asymmetrical faults (LG , LL LLG faults).
- 4 bus bar systems is design in MATLAB/Simulink using electrical aerospace library (Sim power system).
- To simulate the 4 bus bar system with fault and to observe the behaviour under fault conditions.

III. METHODOLOGY

Modern digital relays are widely employed in protection systems nowadays. Designing and modelling of digital relay require establishing a generalized relay structure which is composed of more relevant and common internal modules employed for typical relays. The functionality of each of the internal modules of the generalized numerical relay, namely signal conditioning and sampling module, analog anti-aliasing filtering module, analog-to-digital conversion module, DFT algorithm and relay trip logic, are the essential step adopted .

A. Discrete Fourier transform algorithm (DFT)

The main concept of the Fourier algorithm is that any signal can be regarded as a combination of periodic components, provided that it meets the Dirichlet conditions, i.e. finite discontinuous points, limited extremes and limited integration value within any period [4]. The deduction of the Fourier algorithm is based on the following two assumptions:

1. Measurement errors have constant covariance and are independent from sample to sample.
2. Any dc offset term is eliminated (e.g. by an analog filter or by means of software)

The second requirement is in particular needed for the short-window Fourier Algorithms. The input signal to be sampled can be written as,

$$Y(t) = \sum_{n=1}^{N} Y_n\, S_n(t) + \mathcal{E}(t) \qquad (1)$$

Where the coefficients Y_n are unknown while the signals $S_n(t)$ are pre-selected as follows :

$S1(t) = \cos(\omega 0t)$	Fundamental Component
$S2(t) = \sin(\omega 0t)$	Fundamental Component
$S3(t) = \cos(2\omega 0t)$	Second Harmonic
$S4(t) = \sin(2\omega 0t)$	Second Harmonic
$SN1(t) = \cos(\frac{N}{2}\omega 0t)$	$\frac{N}{2}$ th Harmonic
$SN(t) = \sin(\frac{N}{2}\omega 0t)$	$\frac{N}{2}$ th Harmonic

N/2 is the highest harmonic order contained in the signal, assuming N is an even number; ε(t) stands for the noise in the measurement. The choice of S_n (t) above is in accordance with the form of the Discrete Fourier Transform. The component at a certain harmonic order n is split into two orthogonal terms, sin(nω0t) and cos(nω0t). Equation (1) can be expressed in matrix form as follows:

$$\begin{bmatrix} Y1 \\ \vdots \\ Yk \end{bmatrix} = \begin{bmatrix} S1(\Delta t) & \cdots & SN(\Delta t) \\ \vdots & \ddots & \vdots \\ S1(K\Delta t) & \cdots & SN(K\Delta t) \end{bmatrix} \begin{bmatrix} Y1 \\ \vdots \\ YN \end{bmatrix} + \begin{bmatrix} \mathcal{E}1 \\ \vdots \\ \mathcal{E}N \end{bmatrix}$$

Or

$$y = SY + \mathcal{E} \qquad (2)$$

Where K is the number of samples in one sampling window, and Δt represents the time interval between two neighbouring sample points. To estimate all N parameters, K ≥ N is required. If the error vector ε is assumed to have zero mean, and a covariance matrix

$$E\{ \mathcal{E}\, \mathcal{E}T \} = W \qquad (3)$$

Then the solution to (2) using least square technique yields

$$Y= (ST\ W\text{-}1\ S)\text{-}1\ ST\ W\text{-}1\ y \qquad (4)$$

With the assumption that the errors are uncorrelated and independent from sample to sample and have a constant covariance, W is a multiple of the unit matrix. Therefore the least square solution (when εTW-1ε is minimized) is

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$Y=(S^T S)^{-1} S^T y$ (5)

Substituting the orthogonal expressions of sine and cosine terms in (5), the ijth entry of the matrix STS is

$(S^T S)_{ij} = \sum_{K=1}^{K} S_i(K\Delta t) S_j(K\Delta t) = \{K/2 : i = j \quad \{0 : i \neq j$ (6)

The fundamental frequency components are given by

$Y_c = \frac{2}{k}\sum_{k-1}^{k} y_k \cos(k\Theta)$ (7)

$Y_c = \frac{2}{k}\sum_{k-1}^{k} y_k \sin(k\Theta)$ (8)

Where è = 2ð/K. The magnitude of the fundamental component can be calculated by

$|Y| = \sqrt{Y_c^{\,2} + Y_s^2}$ (9)

The results for fundamental frequency, in (7) and (8), are independent of the number of parameters N. The fundamental component obtained from the Fourier algorithm, is the optimal solution in the least square sense, under the assumption that the noise samples are uncorrelated.

B. *Relay Trip Logic*

1. *Fail to Trip*

In a transmission system, fail-to-trip may or may not lead to loss of more primary components than needed, depending on whether the fault is finally cleared by remote back-up protection, or just by local back-up protection. A mal-trip will always lead to loss of at least one component in the system. In such a viewpoint, a mal-trip results in more severe damage to the system than a fail-to-trip does. But when a fail-to-trip leads to tripping of the remote backup this constitutes the loss of at least two components. In transmission systems this greatly endangers the operation of the system.

To deal with fail-to-trip, a redundant protection is applied. Basics of relay protection operation are described here on fig.1.

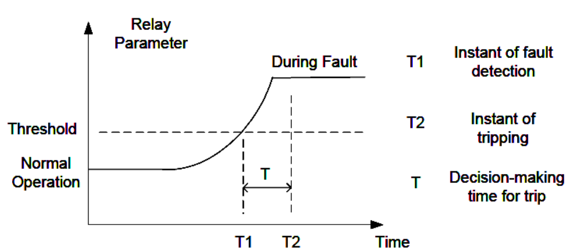

Fig. 1 Basics of Relay Protection Operation

A relay trip signal is sent out only when the measured value exceeds the threshold and holds for a preset decision-making time T.

2. *Trip logic*

Protection scheme uses the zone selection algorithm to determine the terminals in the affected bus-zone. The purpose of the bus differential trip algorithm is to send trip signals to the circuit breakers according to the differential element operation. To send the correct trip signals, the differential trip algorithm uses differential element information and zone selection information to determine which breakers to trip. The concept of digital protection system that must be able to limit the fault current before the first current peak and the fault has to be detected in at least 50 ms after fault initiation.

C. *Analytical model*

To show the minimum delay time to trip signal for protection of transmission line, a part of a transmission system of 11 KV, 4 buses shown in Fig.2 is modeled using the MATLAB/Simulink [6].. Several non-fault events are applied to this system along with unsymmetrical faults i.e., single line to ground, line to line and double line to ground events at different times. The simulation results shows that, the proposed algorithm could help the relay to minimize the time required to trip signal . It is verify that algorithm helps to isolate the faulty bus from healthy system in very short duration.

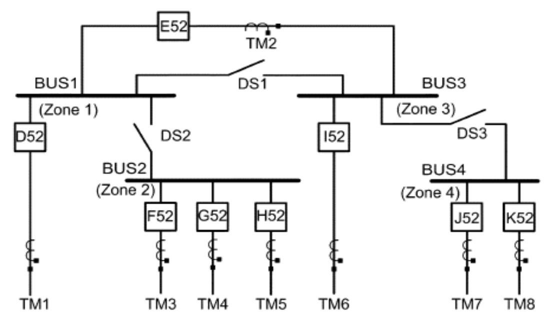

Fig.2:- Bus 11 Kv Simulated Transmission System

IV. SIMULATION RESULTS ON 4 BUS SYSTEM

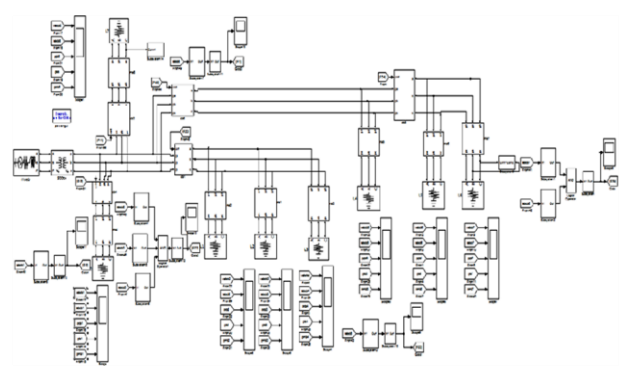

Fig. 3 Simulink Model for 4 Bus System

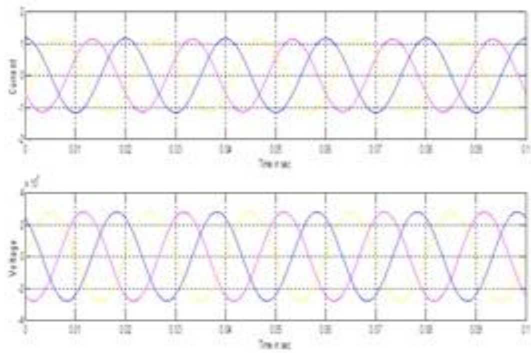

Fig.4 Three Phase Current & Voltage Output Waveforms

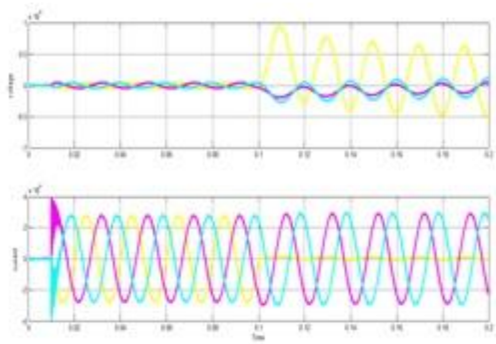

Fig. 5 Three Phase Current & Voltage Output Waveforms Due to LG Fault

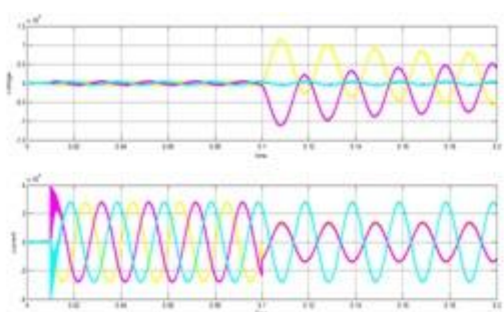

Fig. 6 Three Phase Current & Voltage Output Waveforms When LL Fault

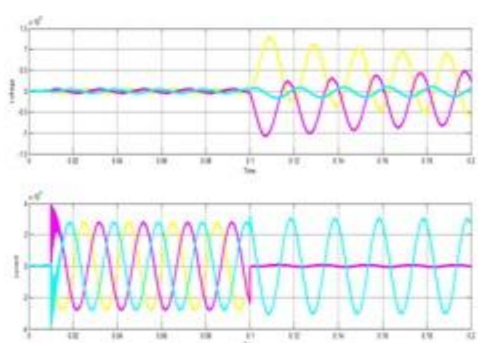

Fig. 7 Three Phase Current & Voltage Output Waveforms When LLG Fault

These models along with their corresponding voltage and current waveform without fault condition and with fault condition (LG, LL, and LLG) are shown in fig. (4) to (7). Unsymmetrical fault occurs in the transmission line are detected and isolated from the 4 bus system within short period is as given below.

Case I: Trip Signal Generated for Bus 1

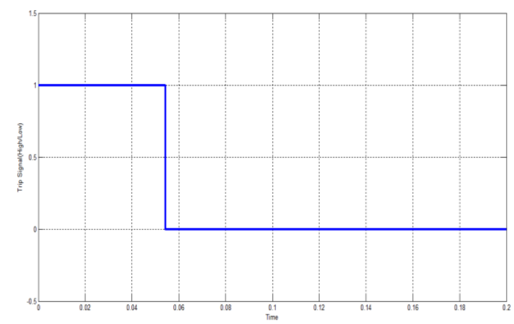

Fig.8 The Output Trip Signal of the Digital Relay (LG Fault) for Bus 1

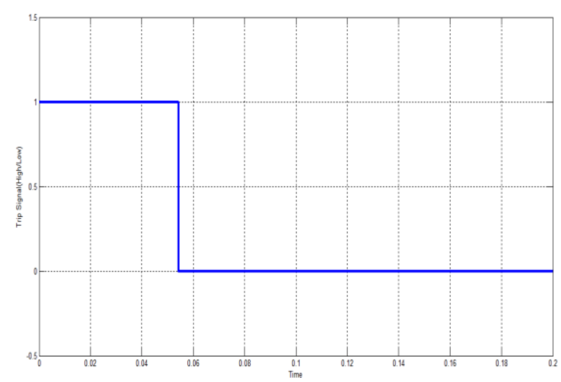

Fig.9 The Output Trip Signal of the Digital Relay (LL Fault) for Bus 1

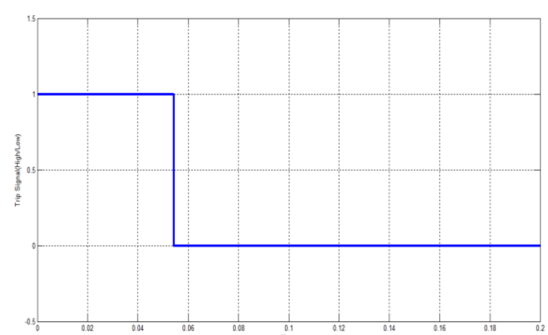

Fig.10 The Output Trip Signal of the Digital Relay (LLG Fault) for Bus 1

Case II: Trip Signal Generated for Bus 2

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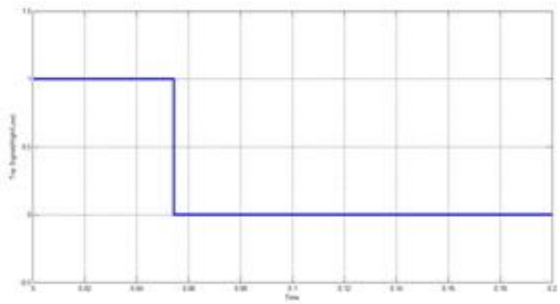

Fig.11 The Output Trip Signal of the Digital Relay (LG Fault) for Bus 2

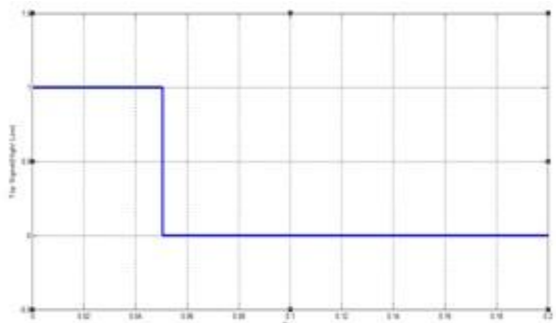

Fig.12 The Output Trip Signal of the Digital Relay (LL Fault) for Bus 2

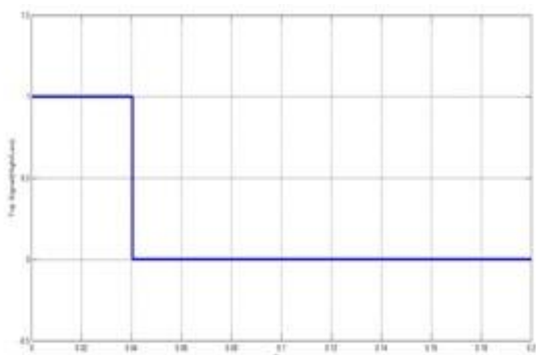

Fig. 13 The Output Trip Signal of the Digital Relay (LLG Fault) for Bus 2

Case III: Trip Signal Generated for Bus 3

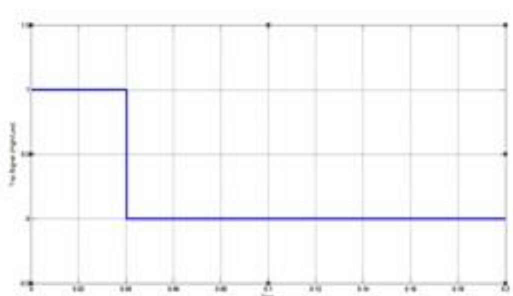

Fig. 14 The Output Trip Signal of the Digital Relay (LG Fault) for Bus 3

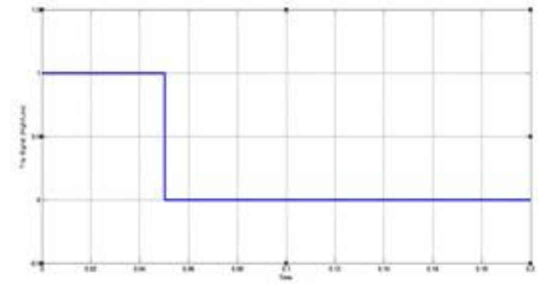

Fig. 15 The Output Trip Signal of the Digital Relay (LL Fault) for Bus 3

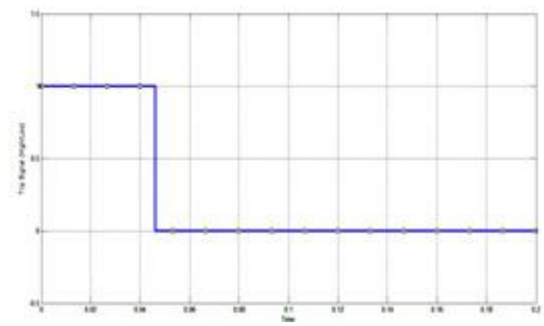

Fig. 16 The Output Trip Signal Of The Digital Relay (LLG Fault) for Bus 3

Case IV: Trip Signal Generated forBbus 4

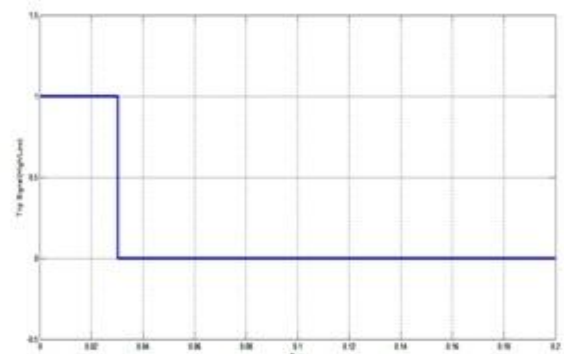

Fig. 17 The Output Trip Signal of the Digital Relay (LG Fault) for Bus 4

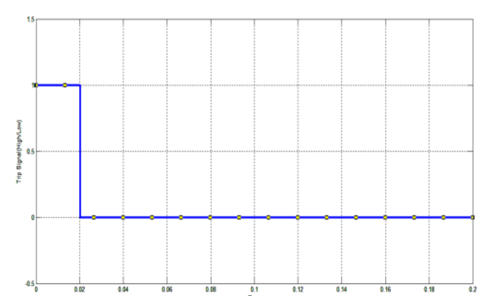

Fig. 18 The Output Trip Signal of the Digital Relay (LL Fault) for Bus 4

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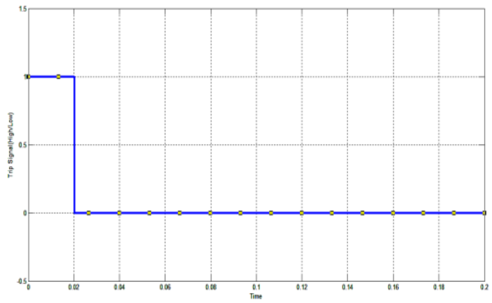

Fig. 19 The Output Trip Signal of the Digital Relay (LLG Fault) for Bus 4

The results of the simulation and testing of the developed digital relay model for a simple transmission line model built in Simulink. Fig.(8) to (19) shows output trip signal generated when LG,LL,LLG fault applied to the system .The time required to generate trip signal is less than 50 millisecond .LL and LLG fault appear in bus 4 required less time to trip the signal (to isolate the signal.) is 20 milliseconds .

V. CONCLUSIONS

The results of the simulation and testing of the developed digital relay model for a simple transmission line model built in Simulink are presented. The simulation result shows that the method is capable of completely eliminating the faulty signal and hence greatly improving the reliability of the full-cycle DFT algorithm. Generated incremental current and voltage signal due to faulty condition, proposed relay trip signal is about 50 ms after the inception of the fault.

Innovative differential protection switches the relay to a high-security mode during through-fault conditions. While in the high-security mode, the algorithm does not block the differential elements, thus avoiding unnecessary time delays for clearing faults evolving from external to internal faults.

VI. FUTURE WORK

The work done on the digital protection system for protecting multiple busbar system has been carried out successfully using DFT algorithm.

Time required to trip the faulty signal is minimized approximately up to 50 milliseconds. However, there is a lot of scope to design and implement the protection system using artificial Intelligence which consists of neural network, Fuzzy logic and Wavelet transform.

This technique can detect the correct nature of internal and external fault in the equipment and the system as a whole. Further reduction in the fault detection time can also be done by using these methods.

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