International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 3 Issue 2, February-2014, pp: (174-182), Impact Factor: 1.252, Available online at: www.erpublications.com

Simulation of a three phase differential relay for transformer protection

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Abstract: One of the most important equipment in power system is the power transformer, which is used in different sizes, types, and connections. A power transformer functions as a node to connect 2 different voltage levels. Therefore, the continuity of its operation is of vital importance in maintaining the reliability of power supply. According to many years of experience, the differential protection provides the best overall protection for a power transformer. The variable percentage differential characteristic of differential relay provides fast, sensitive and reliable tripping for internal faults and security against operation on large external faults. This paper includes modeling and simulation of the differential relay by using MATLAB/SIMULINK and using this model to study all the environments affecting the operation of the protective relay for power transformer protection. Graphs show transformers fault currents and trip signal for different fault cases.

Keywords: Power transformer, Protective relays, Differential protection relay.

Introduction

Power transformer is one of the important constitution of the power system, therefore its protection against all types of faults becomes the point of interest of many researches . Since protection is accomplished by relays, and relays nowadays goes through many important changes from purely electromechanical type to a fully numerical relays based on microprocessor, therefore it is necessary to study the relay characteristic and environment which affect its operation.
There are various types of relays, the main types being over current relay, distance relay, and differential relay. The differential relay plays an important role in the protection of generator windings, bus bars, and transformers. This paper will concentrate specifically on the Differential Protection Relay.

Principle of differential relay operation

A differential relay can be defined as a device that operates when the phasor difference between two currents exceeds a predetermined value as shown in fig.(1).

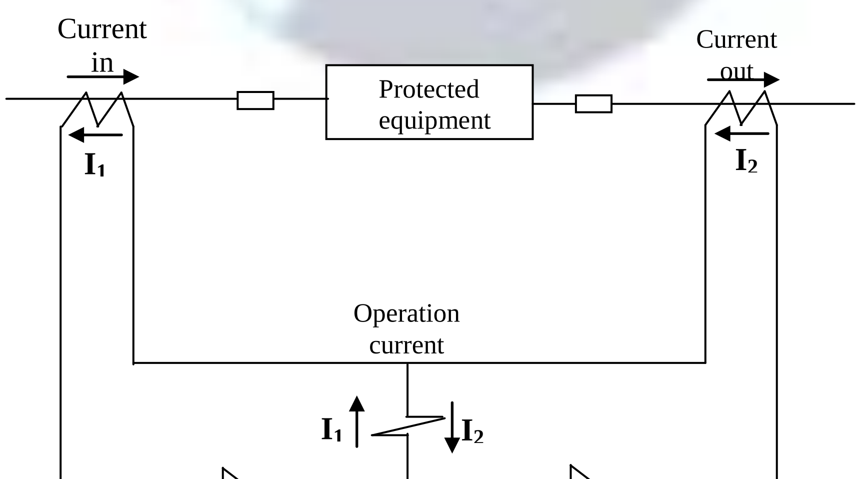


Fig. (1) General Differential Principle

The relay is design with two windings, called operating and restraining windings. The restraining winding is designed to prevent undesired relay operation, and a current flow should be in the operating winding due to a transformer error during an external fault. The differential current in the operating winding is proportional to (I_1-I_2), and the current in the restraining winding is proportional to ($1/2(I_1+I_2)$). The ratio of differential current of the operating winding to the average restraining current is fixed as percentage, hence the relay is called (Percentage differential relay). The relay is also called (Biased differential relay) because the restraining coil is also called biased coil. Differential protection principle is used in protection of large transformers, generators, motors, feeders and busbars [1].

Vector Group compensation in differential protection of transformers

iDfferential protection for a power transformer has been used for decades. In order to correctly apply transformer differential protection proper compensation for:

- Power transformer phase shift (i.e. vector group compensation)
- CT secondary currents magnitude difference on different sides of the protected transformer (i.e. ratio compensation).
- Zero sequence current elimination (i.e. zero sequence current reduction).

Shall be done. Previously this was performed with the help of interposing CTs or special connection of main CTs [2]. It is more efficient if the compensation is done by the relay itself. In order to perform the required compensations by the relay itself, the vector compensation matrix is required.

$$A= (2/3)\begin{vmatrix} Cos(k*30^0) & Cos((k+4)*30^0) & Cos((k-4)*30^0) \\ Cos((k-4)*30^0) & Cos(k*30^0) & Cos((k+4)*30^0) \\ Cos((k+4)*30^0) & Cos((k-4)*30^0) & Cos(k*30^0) \end{vmatrix} \quad .....(1)$$

Where k denotes the secondary winding vector group. This number is represented by the clock convention just like the windings on the transformer windings. For instance, Yd11 connection of the transformer represents that the secondary winding is delta connected with leading vector group by 30^o. Therefore if plug 11 in the above matrix and multiply the matrix that is produced with the readings of current transformers on the transformers secondary winding, the product will be in phase with the readings obtained from the current transformer on the primary side. This gives what is meant by vector compensation.

Using the vector compensation method, the relay must exclude the zero sequence components that exist in grounded windings, since the presence of zero sequence components with cause mal operation of the relay. The elimination of zero sequence components can be done by introducing another matrix dellac the (I_o) elimination matrix as given below:

$$(B)= (1/3)\begin{vmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{vmatrix} \quad .....(2)$$

The matrix will remove any zero sequence component that is presented in the current transformer reading if it is connected to ground. If the power transformer is ungrounded there is no zero sequence components, then the matrix (B) becomes as follow [3]:

$$(B)= \begin{vmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{vmatrix} \quad .....(3)$$

Simulation and Testing of Differential Protection Relay

In this paper a complete simulation model of the differential relay is presented, and testing of this model is done for 132kV system using Matlab/Simulink media as shown in Fig.(5). The block representing the relay is divided in to two blocks as shown in Fig (6), first block is the (compensating block) shown in fig.(7) which includes vector compensation matrix for phase shift angle and zero sequence current and calculation of the differential current (I_{diff}.) and bias current (I_{bias}) for the relay inputs, the current (I_{diff}) represents the difference between the input and output currents of the power transformer, and (I_{bias}) is the average of the input and output currents of the power transformer. While the second block shown in fig.(8) is the (Decision block), which includes the principle components parts for the relay function which are the logic circuits, The sequence of operation of the decision block can be illustrated by the chart shown in fig.(3)

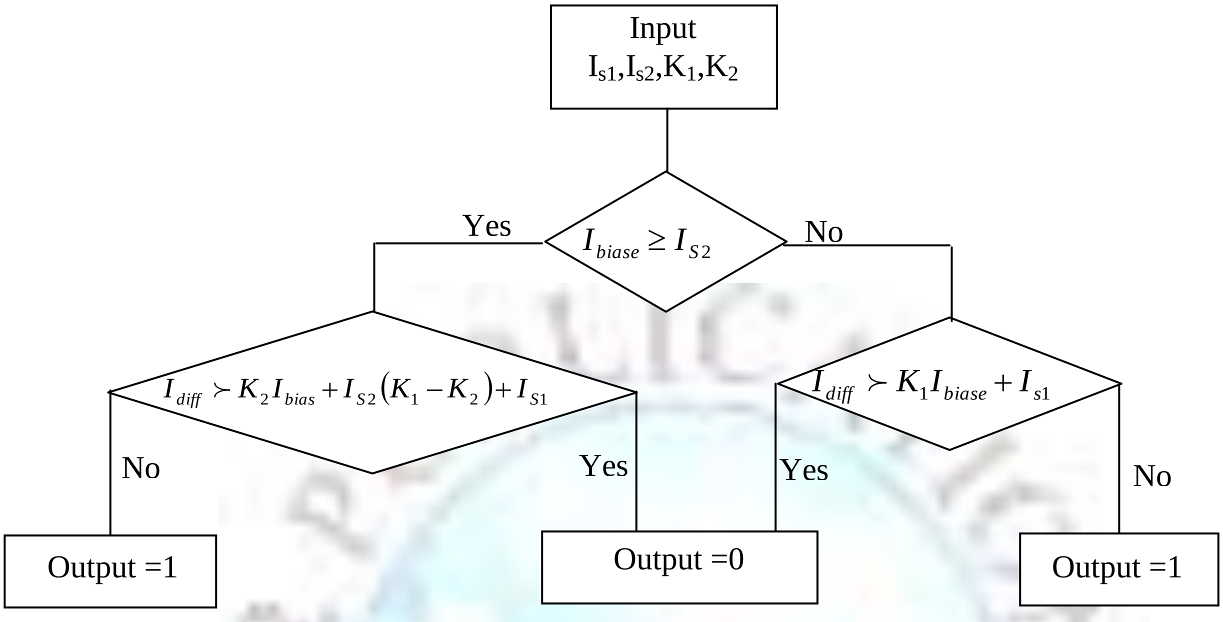


Fig. (3) Relays flow chart

Where I_{s1} is the differential current at zero bias current and Is_2 is the bias current when the relay characteristic starts to change and k_1 , k_2 are the percentage bias. These constants can be obtained from the relay characteristic shown in fig. (4) which is used in this work. The differential protection operating region is located above the slop characteristic and the restraining region is below the slop characteristic. A dual slope bias technique is used to enhance stability for through faults and provides further security for external faults with CT saturation. Atypical trip criterion is used as follows:

$$for \quad I_{bias} \langle I_{S2}$$
$$I_{differential} \rangle K_1 (I_{bias}) + I_{S1}$$

$$For \quad I_{bias} \rangle I_{S2}$$
$$I_{differential} \rangle K_2 (I_{bias}) - (K_2 - K_1) I_{S2} + I_{S1}$$

To arrive the correct settings, the characteristics of the relays to be applied must be considered. The recommended settings for three of the adjustable values (taken from the relay manual) are:

Differential current setting I_{S1}	(0.2-2.0 I_n)
Bias current threshold setting I_{s2}	(1-30 I_n)
Lower percentage bias setting K_1	(0.3-1.5)
Higher percentage bias setting K_2	(0.3-1.5)

Relay Setting Ranges

Where I_n is the rated secondary current of the current transformer. In this work I_n is taken to be 1A. According to this value of I_n the following constants are calculated:

I_{s1}=0.3, I_{s2}=2, K_1=0.35, K_2=1.2

The correction ratio must also be applied in order to ensure that the relays see currents from the primary and secondary sides of the transformer that are well balanced under full load condition. In this paper selection current transformers ratio at primary and secondary sides are (1/300) & (1/1000) respectively.

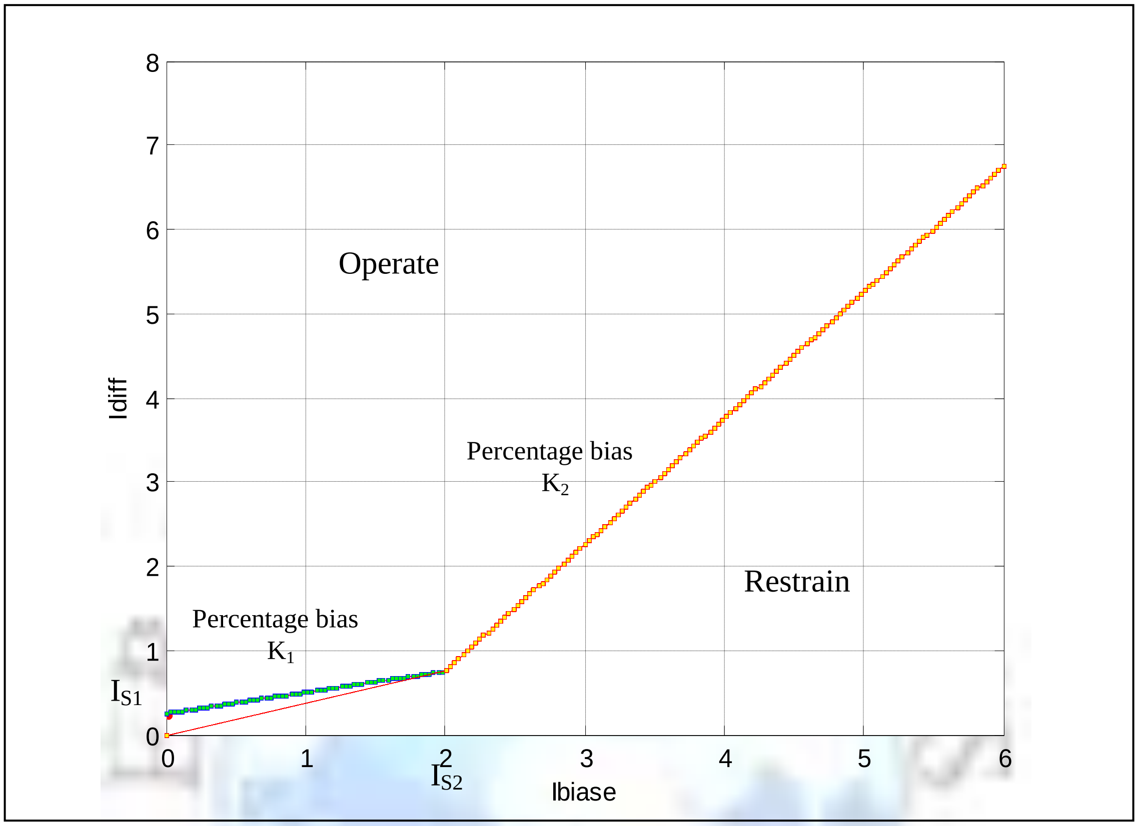


Fig.(4): Relay Characteristic

The output of the relay block (trip signal) will be an input to the breakers, if the relay trip signal equal to one will tell the breaker to keep closed (this in case when normal operation or external fault) while if the relay trip signal equal to zero will tell the breaker to open (this is the case of internal fault).

A simulation model of differential protection for 132/33kV transformer was studied for the following cases:

1-Interanal faults

2-Normal operating mode under rated values

3-External faults

The relay operated for the first case as shown in appendix (A_1) and did not operate in the cases of the normal operation & external fault as showing in appendix (A_2).

Conclusion

In this paper, an attempt has been made through the use of MATLAB/SIMULINK to test differential protection relay for a large power transformer. Tests have been carried out on a varity conditions (normal operating mode under rated values, Internal faults and external faults).It can be noted from simulation results that high sensitivity for internal faults and high stability for external faults & normal operation.

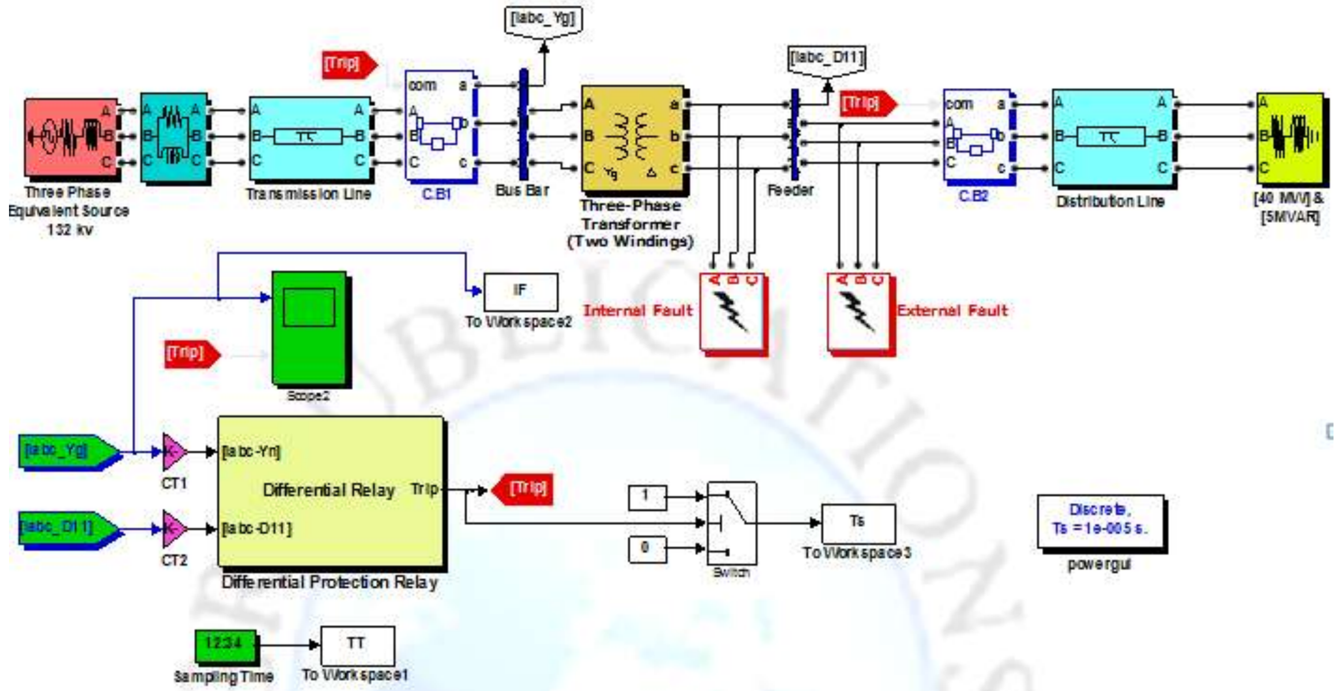
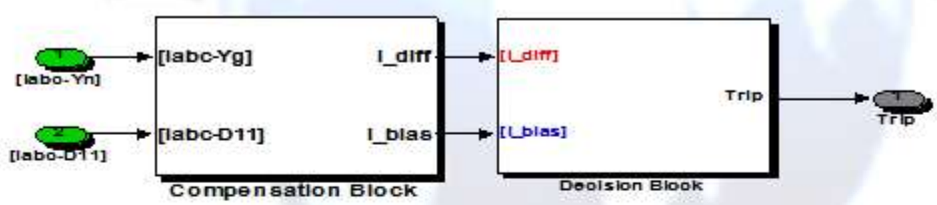


Fig.(5): Matlab/Simulink



F:ig.(6): Relay block diagram

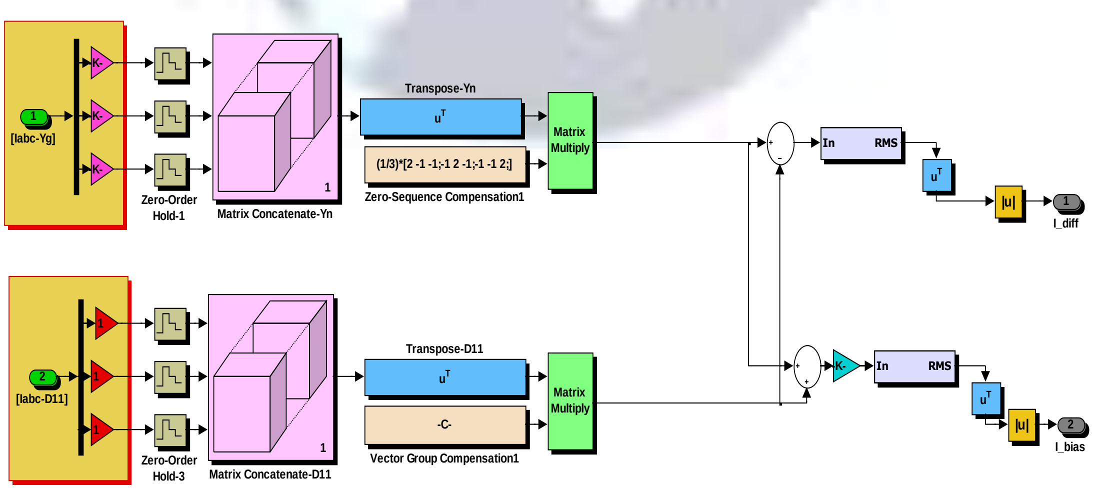


Fig. (7): Compensating block

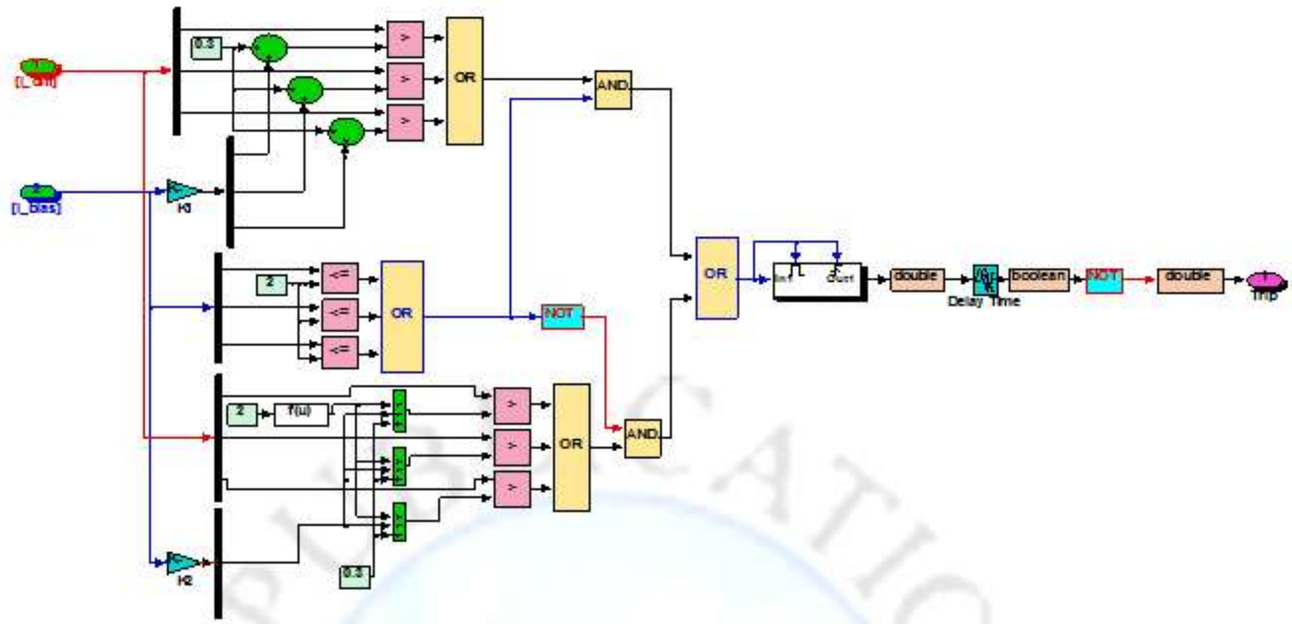
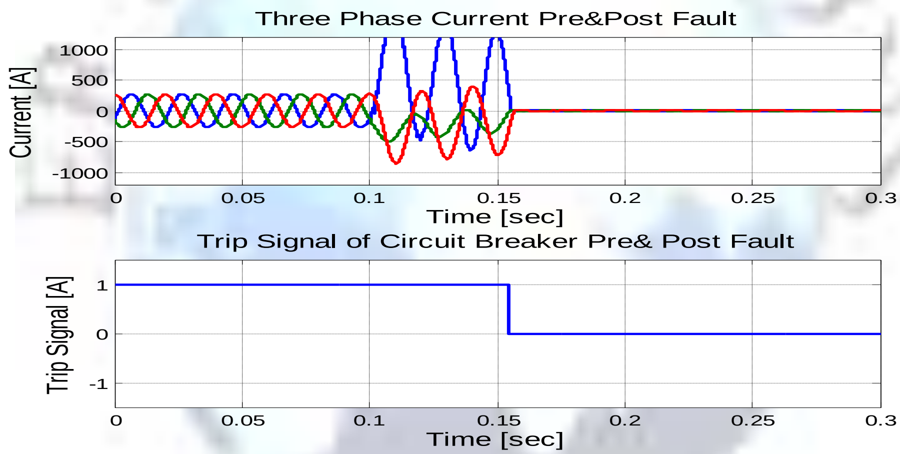
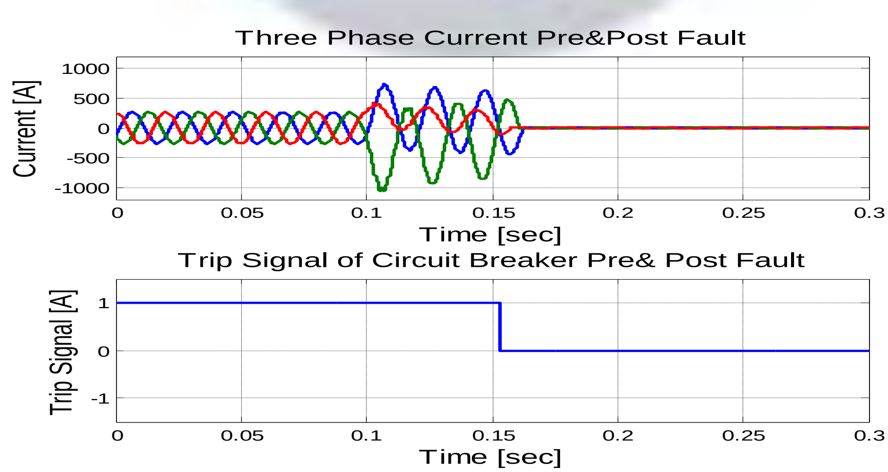


Fig.(8): Decision block

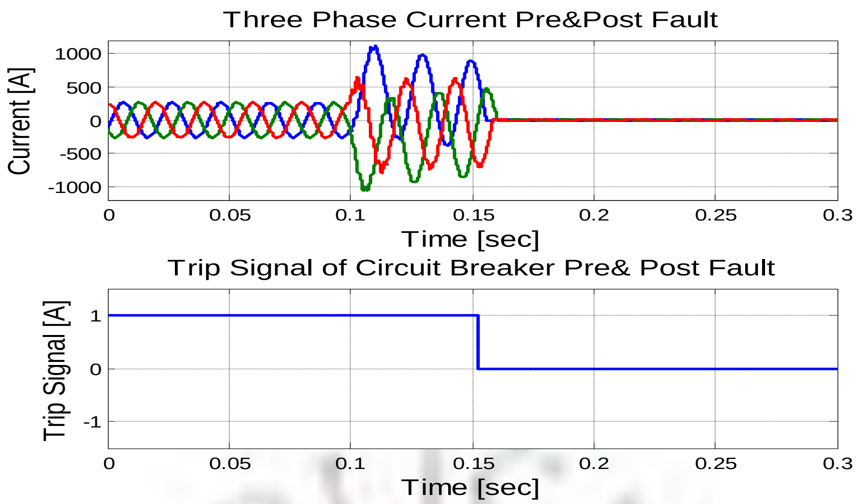
Appendix (A1) Internal faults:



Single Line to ground fault

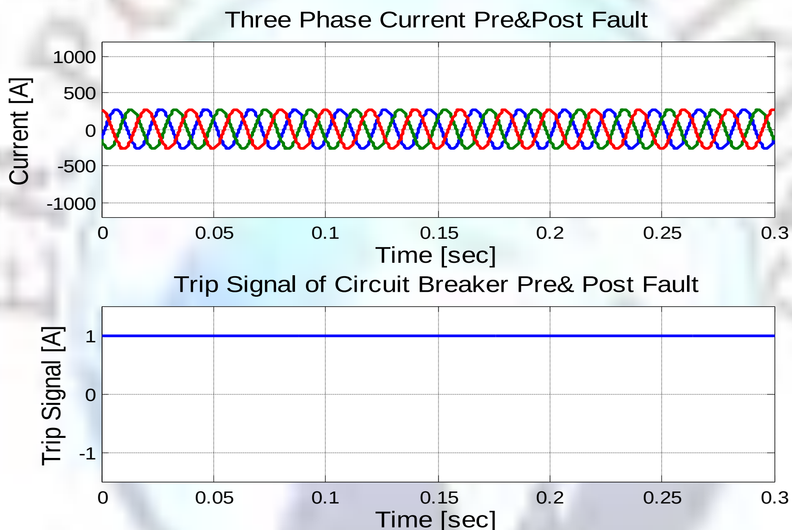


Line to Line to ground fault

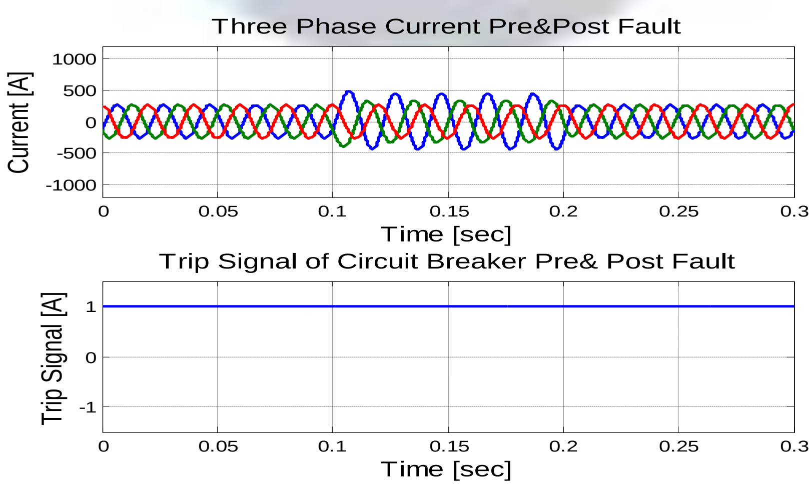


Three phase fault

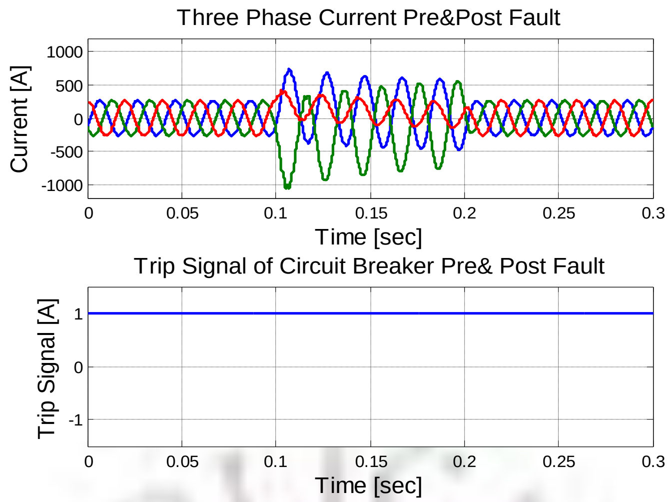
Appendix (A_2) Normal operation & external faults:



Normal operation

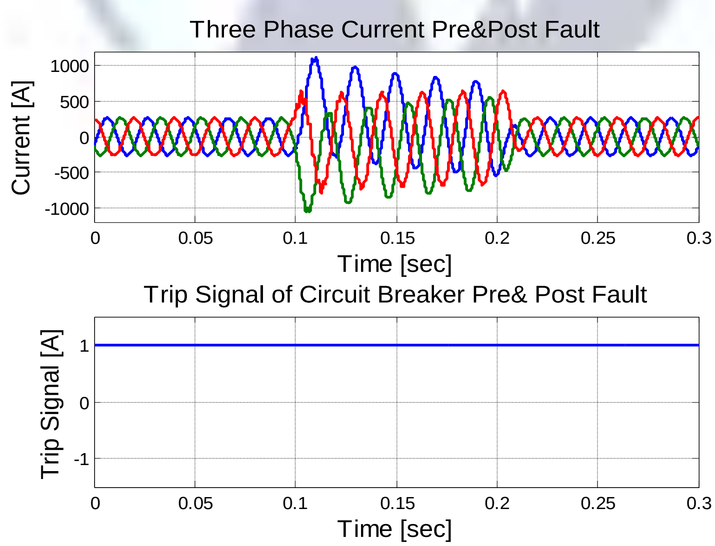


Single line to ground fault



Line To Line Fault

Line To Line to Ground Fault



Three phase Fault

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