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Comparison of Rationalised Haar Transform and Block Pulse Function based algorithms for Transformer Protection

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Abstract

This paper describes application of Rationalized Haar Transform and Block Pulse Function for digital protection of power transformers. Digital relay algorithms are developed to extract fundamental, second harmonic and fifth harmonic components. These components are then used for harmonic restraint differential protection of power transformers. The Block Pulse Function based method is computationally simple and flexible to use with any sampling frequency with respect to Rationalized Haar Transform. In Rationalized Haar Transform method one extra step of computation of Haar co-efficient is involved. Different graphs of Rationalized Haar Transform and Block Pulse Function based methods for Inrush, Over-excitation and Internal fault conditions have been plotted and compared. Off-line testing of the method with simulated inrush, over-excitation and internal fault current data clearly indicate that the Block Pulse Function method can provide fast and reliable trip decision.

***Key* Words- Rationalized Haar Transform, Block Pulse Functions, Power Transformer Protection And Digital Differential Relay.**

I.INTRODUCTION

The differential relaying principle is commonly used for the protection of power transformers [1]. This is based on comparison of the fundamental, second and fifth harmonic currents. A differential protection scheme with harmonic restraint is the usual way of protecting a power transformeragainst internal faults and restraining the tripping operation during non fault conditions, such as magnetizing inrush currents and over-excitation currents [2-9].

Several algorithms have been proposed for digital protection of power transformers. Among these algorithms, Discrete Fourier Transform based algorithm has been used for a very long time and it is still being used but there have been developments which provided better algorithms such as HAAR function and Block Pulse Function based algorithms. Schemes using Rationalized Haar Transform and BPF have been compared for differential protection of power transformers.

II.RATIONALISED HAAR TRANSFORM

The Rationalized Haar Transform (RHT) is the rationalized version of Haar transform (HT).The RHT coefficients Crhk, k =0, 1,2,…N-1 are obtained by using the rationalized Haar transform on the incoming data samples, i.e. voltage and current samples acquired over a full cycle data window or a half-cycle data window at a sampling rate of 16 samples per cycle. These coefficients are obtained by mere addition and subtraction of data sampleThe RHT coefficients are calculated by the given formula:-

$C_{rh0}=(x_0+x_1+x_2+x_3+x_4+x_5+x_6+x_7+x_8+x_9+x_{10}+x_{11}+x_{12}+x_{13}+x_{14}+x_{15})$

$C_{rh1}=(x_0+x_1+x_2+x_3+x_4+x_5+x_6+x_7)-(x_8+x_9+x_{10}+x_{11}+x_{12}+x_{13}+x_{14}+x_{15})$

$C_{rh2}=(x_0+x_1+x_2+x_3)-(x_4+x_5+x_6+x_7)$

$C_{rh3}=(x_8+x_9+x_{10}+x_{11})-(x_{12}+x_{13}+x_{14}+x_{15})$

$C_{rh4}=(x_0+x_1)-(x_2+x_3)$

$C_{rh5}=(x_4+x_5)-(x_6+x_7)$

$C_{rh6}=(x_8+x_9)-(x_{10}+x_{11})$

$C_{rh7}=(x_{12}+x_{13})-(x_{14}+x_{15})$

$C_{rh8}=(x_0+x_1)$

$C_{rh9}=(x_2-x_3)$

$C_{rh10}=(x_4-x_5)$

$C_{rh11}=(x_6-x_7)$

$C_{rh12}=(x_8-x_9)$

$C_{rh13}=(x_{10}-x_{11})$

$C_{rh14}=(x_{12}-x_{13})$

$C_{rh15}=(x_{14}-x_{15})$

Current $i(t)$ which is given by time function can be expressed in terms of Fourier coefficients as:

$$i(t) = A_0 + \sqrt{2}\,A_1 \sin(2\pi t) + \sqrt{2}\,B_1 \cos(2\pi t) + \sqrt{2}\,A_2 \sin(4\pi t) + \sqrt{2}\,B_2 \cos(4\pi t) + \ldots\ldots \ldots + \sqrt{2}\,A_5 \sin(10\pi t) + \sqrt{2}\,B_5 \cos(10\pi t) \qquad (1)$$

In terms of RHT coefficients:

A_1=0.0555C_{rh1}-0.011C_{rh2}+0.011C_{rh3}-0.0276C_{rh4}+0.0184C_{rh5}+0.0276C_{rh6}-0.0184C_{rh7}-0.0169C_{rh8}-0.0096C_{rh9}+0.0033C_{rh10}+0.0143C_{rh11}+0.0169C_{rh12}+0.0096C_{rh13}-0.0033C_{rh14}-0.0143C_{rh15} .... (2)

B_1=0.011C_{rh1}+0.0555C_{rh2}-0.0555C_{rh3}+0.0184C_{rh4}+0.0276C_{rh5}-0.0184C_{rh6}-0.0276C_{rh7}+0.0033C_{rh8}+0.00143C_{rh9}+0.0169C_{rh10}+0.0096C_{rh11}-0.0033C_{12}-0.0143C_{rh13}-0.0169C_{rh14}-0.0096C_{rh15} .... (3)

Similarly 2nd harmonic is calculated as follows:-

A_2=0.0533C_{rh2}+0.0533C_{rh3}-0.022C_{rh4}+0.022C_{rh5}-0.022C_{rh6}+0.022C_{rh7}-0.0312C_{rh8}-0.0129C_{rh9}+0.0312C_{rh10}-0.0129C_{rh11}-0.0312C_{rh12}+0.0129C_{rh13}-0.0312C_{rh14}-0.0129C_{rh15} .... (4)

B_2=0.022C_{rh2}+.022C_{rh3}+0.0533C_{rh4}-0.0533C_{rh5}+0.533C_{rh6}-0.0533C_{rh7}+0.0129C_{rh8}+0.0312C_{rh9}-0.0129C_{rh10}-0.0312C_{rh11}+0.0129C_{12}+0.0312C_{rh13}-0.0129C_{rh14}-0.0312C_{rh15} .... (5)

Likewise 5th harmonic is also calculated as:--

A_5=0.0074C_{rh1}-0.011C_{rh2}+0.011C_{rh3}-0.044C_{rh4}+0.0088C_{rh5}-0.044C_{rh6}-0.0088C_{rh7}-0.040C_{rh8}-0.014C_{rh9}+0.061C_{rh10}-0.072C_{rh11}+0.040C_{rh12}+0.014C_{rh13}-0.061C_{rh14}+0.072C_{rh15} .....(6)

B_5=0.011C_{rh1}+0.0074C_{rh2}-0.0074C_{rh3}+0.0088C_{rh4}-0.044C_{rh5}-0.0088C_{rh6}-0.044C_{rh7}+0.061C_{rh8}-0.072C_{rh9}+0.040C_{rh10}+0.014C_{rh11}-0.061C_{12}-0.072C_{rh13}-0.040C_{rh14}-0.014C_{rh15} .... (7)

III.BLOCK PULSE FUNCTIONS

The algorithm based on BPF is computationally simple and flexible to use with any sampling frequency [11].The BPF coefficients are obtained by merely calculatingthe values of current samples.The current samples are acquired over a full cycle data window at the sampling rate of 12samples per cycle.
Relationship between Fourier and BPF coefficients has been established. Current $i(t)$ which is given by time function can be expressed in terms of Fourier coefficients as:

$$i(t) = A_0 + \sqrt{2}\,A_1 \sin(2\pi t) + \sqrt{2}\,B_1 \cos(2\pi t) + \sqrt{2}\,A_2 \sin(4\pi t) + \sqrt{2}\,B_2 \cos(4\pi t) + \ldots\ldots$$
$$\ldots + \sqrt{2}\,A_5 \sin(10\pi t) + \sqrt{2}\,B_5 \cos(10\pi t) \quad \ldots\ldots.. (1)$$

In terms of BPF coefficient a_n:

$$A_1 = 0.0302(a_1 + a_6 - a_7 - a_{12}) + 0.0824(a_2 + a_5 - a_8 - a_{11}) + 0.1125(a_3 + a_4 - a_9 - a_{10}) \quad \ldots\ldots..(8)$$

$$B_1 = 0.1125(a_1 - a_6 - a_7 + a_{12}) + 0.0824(a_2 - a_5 - a_8 + a_{11}) + 0.0302(a_3 - a_4 - a_9 + a_{10}) \ldots.. (9)$$

$$A_2 = 0.05626(a_1 + a_3 - a_4 - a_6 + a_7 + a_9 - a_{10} - a_{12}) + 0.1125(a_2 - a_5 + a_8 - a_{11}) \quad \ldots\ldots (10)$$

$$B_2 = 0.09746(a_1 - a_3 - a_4 + a_6 + a_7 - a_9 - a_{10} + a_{12}) \quad \ldots\ldots.... (11)$$

$$A_5 = 0.0225(a_3 + a_4 - a_9 - a_{10}) + 0.06149(-a_2 - a_5 + a_8 + a_{11}) + 0.084(a_1 + a_6 - a_7 - a_{12}) \quad ..(12)$$

And

$$B_5 = 0.0225(a_1 - a_6 - a_7 + a_{12}) + 0.06149(-a_2 + a_5 + a_8 - a_{11}) + 0.084(a_3 - a_4 - a_9 + a_{10}) \quad (13)$$

IV.APPLICATION OF DIFFERENTIAL PROTECTION OF TRANSFORMERS

In these schemes, the trip decision is based on the relative amplitude of the fundamental component compared to the second-harmonic and fifth harmonic components in the differential current. Two indices are used to obtain the relative amplitudes. The first index is defined as

$K2= ((A_2)^2+ (B_2)^2)^{1/2}/ ((A_1)^2+ (B_1)^2)^{1/2}$ .... (14)

The second index is defined as

$K5= ((A_5)^2+ (B_5)^2)^{1/2}/ ((A_1)^2+ (B_1)^2)^{1/2}$ .... (15)

Pre defined value for K2 is 0.15 and for K5 is 0.08 for restraining relay action.

Testing of the schemes

A 132kv/11kv three phase wye-wyetransformer system has been simulatedduring present work. **Table 1** gives the value of transformerparameters in present simulation and **table 2** gives the value of transmission lineparameters. Fig 13 shows basic simpowersystem model of transformer.

TABLE 1 Transformer parameters

Transformer nominal frequency and power	10 MVA and 50Hz
Transformer winding parameters	R=.002 pu, L=.08 pu
Transformer core loss resistance	500 pu

TABLE 2 Transmission line parameters

Length	300 km
Frequency used for RLC specification	50 Hz
Positive and zero sequence resistances (Ohms/km)	0.01273 and 0.3864
Positive and zero sequence inductances (H/km)	0.9337e-3 and 4.1264e-3
Positive and zero sequence capacitance (F/km)	12.74e-9 and 7.751e-9

V. RESULTS

INRUSH CONDITION

The plots below provide values of indices K2 and K5 for phase A. Similar results have been obtained for other phases as well

RESULT FROM RHT

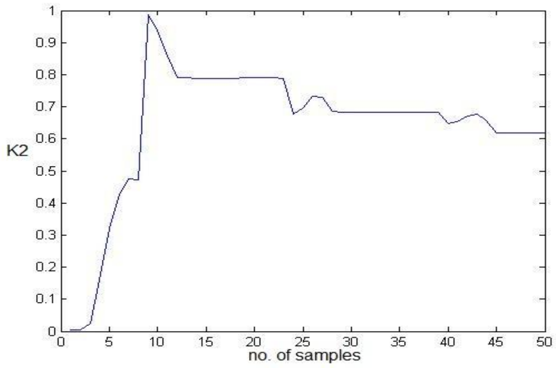

Fig. 1

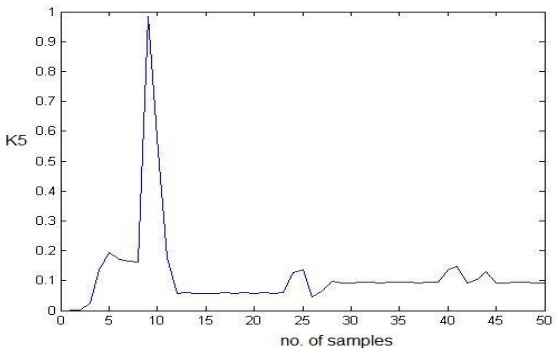

Fig. 2

RESULTS FROM BPF

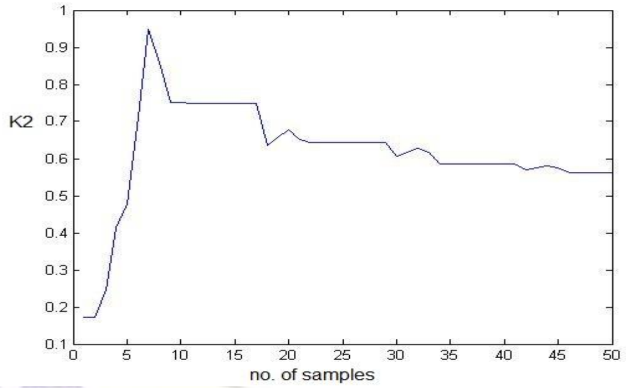

Fig. 3

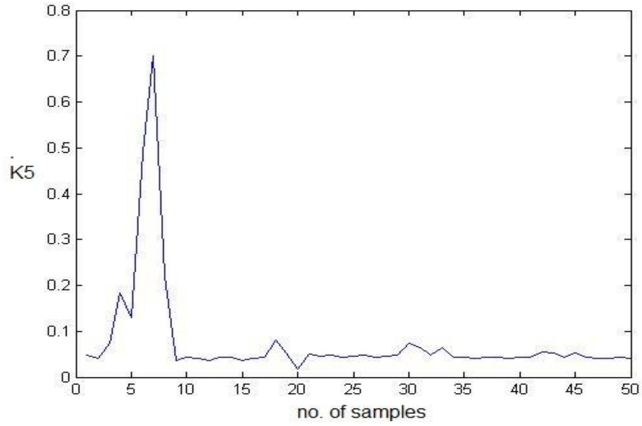

Fig.4

OVEREXCITATION CONDITION

Plots below show values of indices K2 and K5 for phase A. Similar results have been obtained for other phases as well

RESULTS FROM RHT

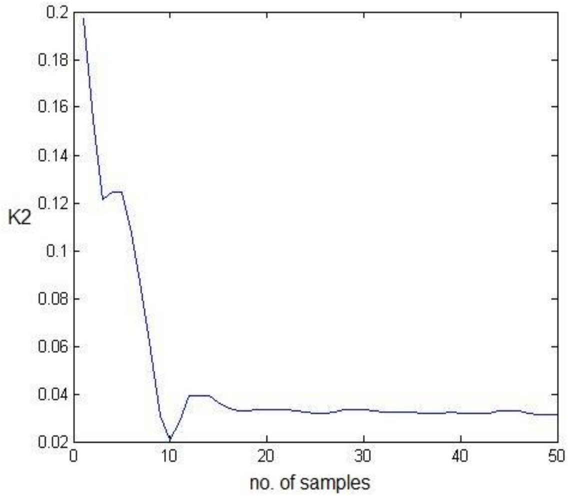

Fig. 5

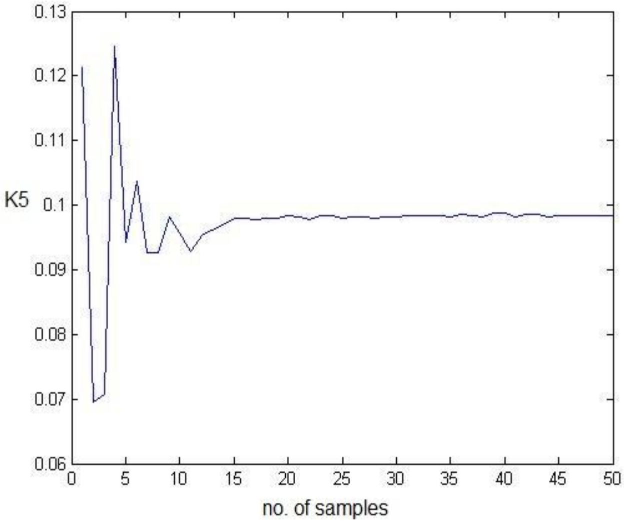

Fig. 6

RESULTS FROM BPF

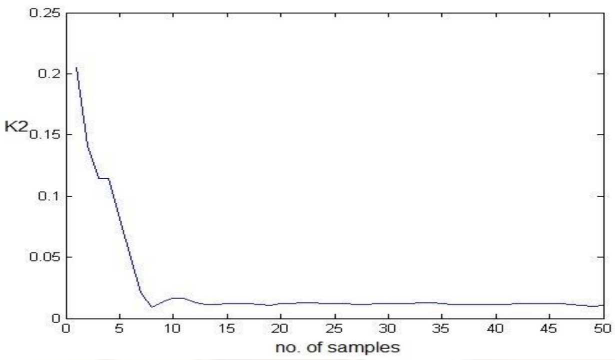

Fig. 7

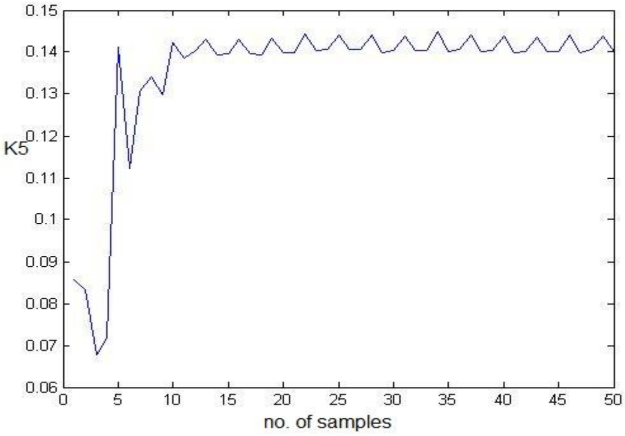

Fig. 8

INTERNAL FAULT CONDITION

Plots below show values of indices K2 and K5 for phase A. Similar results have been obtained for other phases as well

RESULT FROM RHT

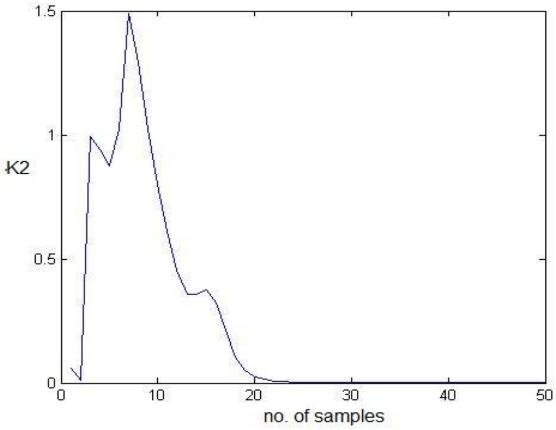

Fig.9

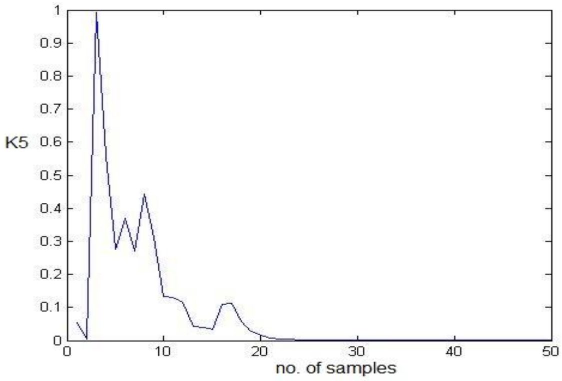

Fig. 10

RESULTS FROM BPF

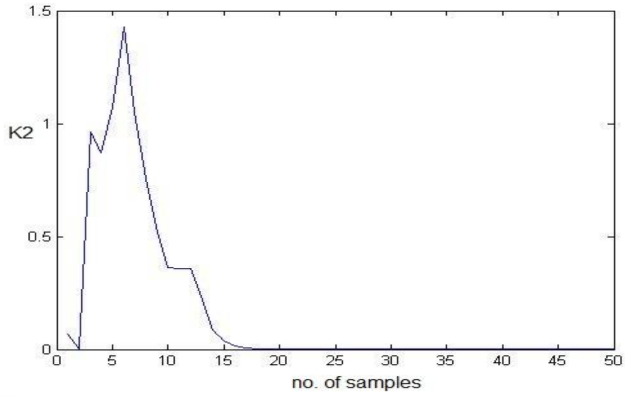

Fig. 11

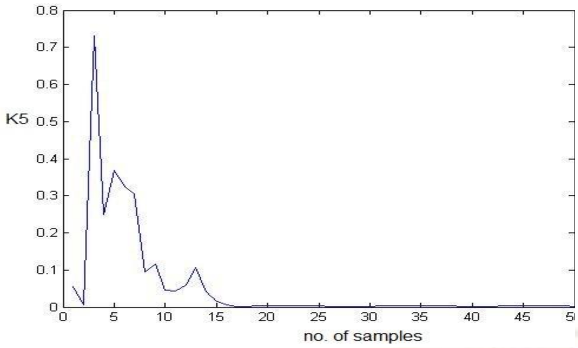

Fig. 12

VI. CONCLUSION

i) Simulation results from MATLAB sim power system reveal that differential current is negligible in case of normal condition and external fault condition.

ii) The differential current is high in case of inrush current, over excitation and internal fault current.

iii) The post fault current for all the cases have been processed with two algorithms. The coding has been done for RHT and Block Pulse Functionbased methods.

iv) Fault conditions can be distinguished from non fault conditions within a cycle in both algorithms. In non fault conditions either K2nd or K5th are above their respective threshold values, restraining trip action of protective relay. In internal fault condition, none of the indices are above the threshold value and tripping action takes place.

v) Processing time in case of Block Pulse Function algorithm is least.

vi) Block Pulse Function requires fewer samples per cycle. It gives satisfactory result at sampling rate of 12 samples per cycle whereas RHT require at least 16 samples per cycle to provide appropriate result

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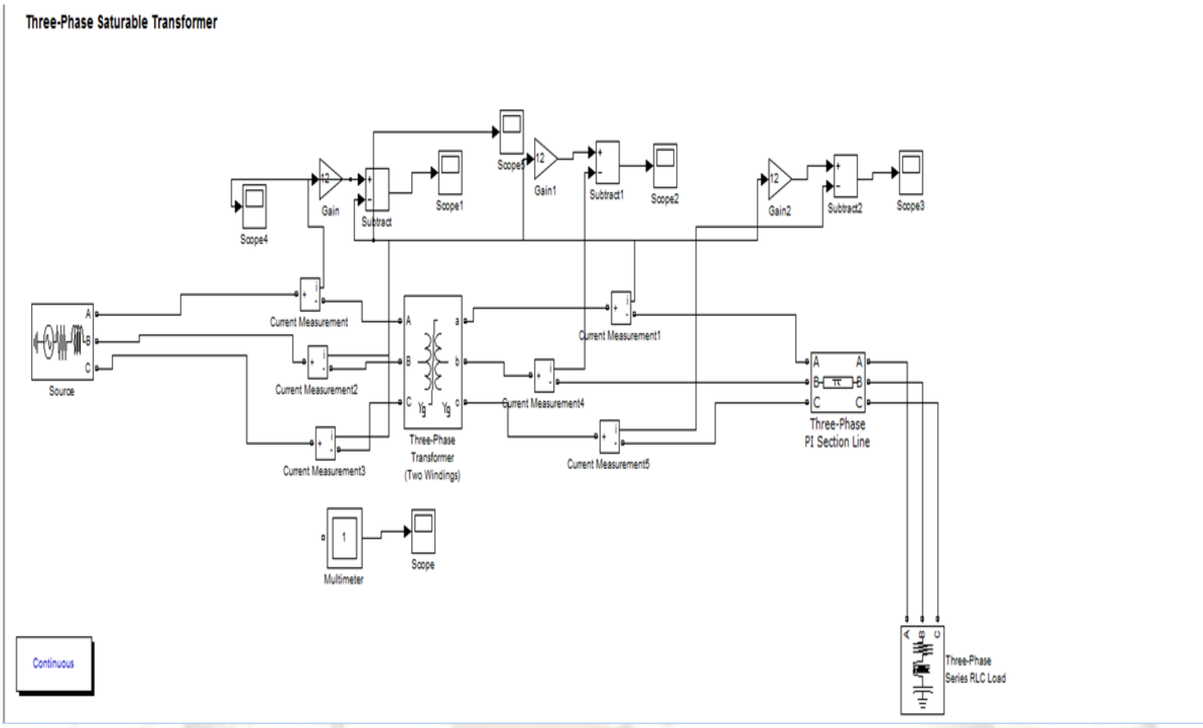
Three-Phase Saturable Transformer
Scope4
Gain
Subtract
Scope1
Scope5
Gain1
Subtract1
Scope2
Gain2
Subtract2
Scope3
Source
Current Measurement
Current Measurement2
Current Measurement3
Three-Phase Transformer (Two Windings)
Current Measurement1
Current Measurement4
Current Measurement5
Three-Phase PI Section Line
Multimeter
Scope
Continuous
Three-Phase Series RLC Load

Fig 13