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Analysis of Inrush Current For Transformer Protection Using FFT Algorithm

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***Abstract*— This study deals with measurement of different harmonics of current in primary current ofa power transformer at different conditions by FFT (Fast Fourier Transform), THD (TotalHarmonic Distortion) based technique to assess the inrush condition of a powertransformer. It is observed that the second harmonic components are dominant under inrush condition byassessing FFT and THD of primary current of the transformer. Significant differences havebeen noted between the parameters which are found during inrush condition and that of normalcondition and fault condition which may be useful in detection of such inrush condition ofpower transformer. Same results which are obtained from the simulation are verified by hardware analysis on the basis of second harmonic component by using FFT algorithm in C language.**

Keywords: Inrush current; FFT; THD; Power Transformer

I. INTRODUCTION

In power system power transformer is an important part.The transient inrush current can be observed in the transformer initially when it is energized.

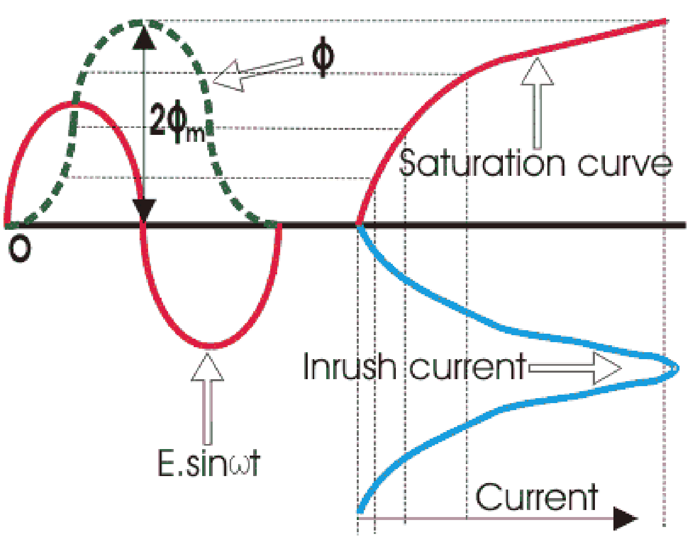

Figure 1. Inrush phenomenon

Core of the transformer is saturated just above the maximum steady state value of flux. But in this example, at the switching of the transformer the maximum value of flux will jump to double of its steady state maximum value. After steady state it gives maximum value of flux, the core becomes saturated, the current required to produced rest of flux will be very high. So primary of transformer will draw a very high peaky current from the source which is called magnetizing inrush current in or simply inrush current in transformer. Normally, inrush current is the maximum and peaky, instantaneous input current drawn by an electrical device when first turned on. Transformers several times may draw their normal full-load current when energized at first, for a few cycles of the input waveform.

Inrush current is a problem, because when inrush occur it interferes the normal operation of circuits as they have been designed to function. When there is inrush present in the system differential relay should not operate for it.When anunloaded or lightly loaded transformer is connected to a supply, then a large amount of transient current is produced due to flux asymmetries and saturation occurs in the core of the transformer. This current is called as transient inrush current. Inrush currents possesses a high DC-component which is decaying and has the several harmonics. Inrush currents magnitude depend upon the circuit condition and voltage at the instant of switching. For first few input cycles inrush current decays rapidly and then vary slowly. Sometimes, it will take 4 to 6Seconds to subside. Following factors affect the magnitude and duration of magnetizing inrush current:

- Size of transformer.
- Size of power system.
- Type of magnetic material in the core.
- Residual flux in the transformer.
- Switching instant of energization of the transformer.

In this paper, an attempt has been made to analyse and assess the inrush condition of a three phase transformer.

FFT is used here to detect the presence of harmonics in one of the three phase primary current at differentconditions after that total harmonic distortion (THD) has been calculated to detect and assess the inrush condition. This analysis will be helpful to generate the tripping signal for differential relay for protection of three phase power transformer.

The inrush current is very much asymmetrical in nature. This simply means that the odd harmonics are negligible in this inrush current and even harmonics are more. The 2^{nd} harmonic component, as the lower order harmonic, it is more prevalent. Other even harmonic components are also present in the inrush current but their percentage is very less and therefore, other harmonic components cannot be used as deciding factor for differentiating between the inrush current and fault current. The fault current is sinusoidal in nature. The percentage of harmonic content present in the fault current is very less. Therefore, 2nd harmonic becomes one of the deciding factors for inrush.MATLAB environment is used to simulate different

MVA rated power transformers which are energized by three phase 220 KV source feeding three phase load.Block diagram of the model simulated in MATLAB/Simulink tool shown in Fig. 2 which shows a transformer connected to the three phase supply along with a circuit breaker and load.

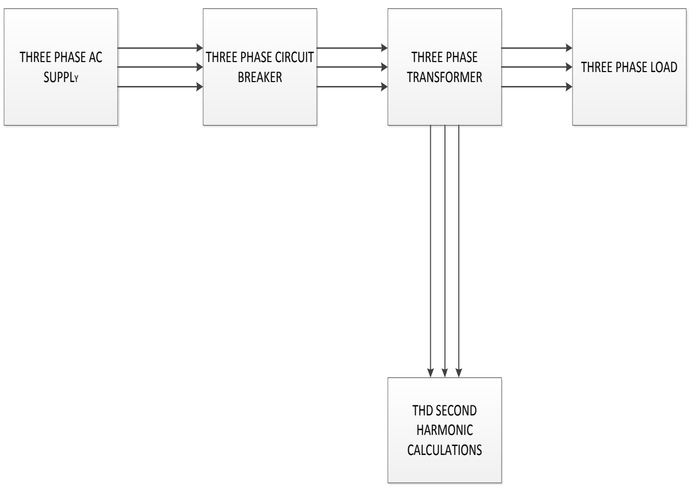

Figure 2. Block diagram of MATLAB model

The second harmonic component magnitude and Total Harmonic Distortion (THD) of primary currents of the three phases can be calculated by this arrangement.

II. MATERIALS &METHODS

Power system is a set of interactive components which are used for the generation, transmission, distribution and utilization. These work as a complete unit system to supply electricity to the consumer from generation side. To study practical aspects of power system, SIMULINK toolbar of MATLAB is used. MATLAB provides variety of built-in components that could be easily connected with each other to form a complete desired system. The set of monitoring blocks provide simplicity to visualize the behavior of system at any time of simulation.A MATLAB model of the power transformer to access inrush current analysis is required to generate.

The following components make up the fault simulation model:

A. Three-Phase Breaker
B. Three-Phase Source
C. Three-Phase Transformer
D. Three-Phase Fault
E. Three- Phase V-I Measurement
F. Three-Phase Series RLC Load
G. Scope
H. Current Measurement

Methods

At first, FFT based techniques have been used to detect the transient inrush current and normal current condition of a three phase power transformer. The fast Fourier Transform gives frequency information of stationary and periodic waveform. The fast Fourier transform is used to convert a signal from time domain (or space) to frequency domain. The important difference between FFT and DFT is that, the FFT technique is much faster and less error thanthe DFT. This implementation is done using Matlab/Simulink environment. Figure 3 shows the simulated model for inrush current analysis using FFT.As the 2nd harmonic content is dominantly present during inrush, total harmonic distortion (THD) also comes into picture. THDis present in the inrush current mainly because of the 2nd harmonic content in it. This helps us in differentiating between inrush current and fault current condition.

Magnitude of 2nd harmonic and THD as inputs

The magnitude of any harmonic component and its total harmonic distortion can becalculated using FFT analysis.

$$Fn = \sqrt{an^2 + bn^2)} \text{.....................(1)}$$

$$an = \frac{2}{T}\int_0^T f(t)\cos(n\,w1t) \text{.........(2)}$$

$$bn = \frac{2}{T}\int_0^T f(t)\sin(nw1t) \text{...........(3)}$$

Where,
Fn– Amplitude of nth order harmonic
n – Order of the harmonic
an and bn – Fourier coefficients
THD is the extent up to which harmonics are present in the signal.
THD is given by

$$THD = \sqrt{\left(\frac{I_{rms}}{I_1}\right)^2 - 1} \text{.................4)}$$

Where,
Irms – RMS value of current
I1 – fundamental current
The inrush current magnitude is normally very high whenever a powertransformer is energized initially at no load. The magnitude of 2nd harmoniccontent and THD content is calculated for any one the three phases.

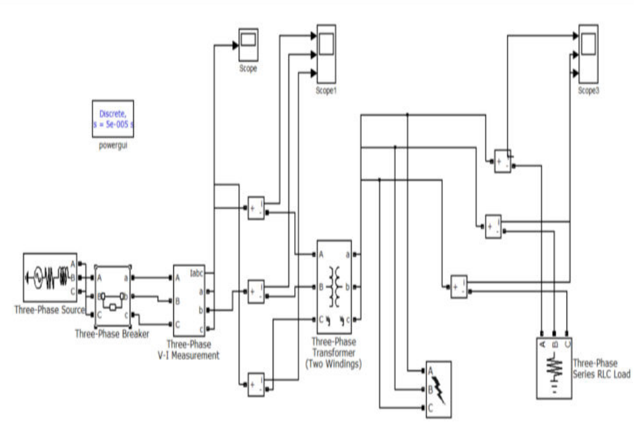

Figure 3. Matlab/Simulink model for Inrush Currrent analysis using FFT

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A test on 100 MVA transformer is first considered and it is applied with inrush condition along with 3 possible faults conditions at no load. The table shows the magnitude of calculated % 2nd harmonic contents and % total harmonic distortion (THD) of all three phases of the transformer. From the table we can observedthat the contents of 2nd harmonic % and THD % under inrush condition is above some threshold/cut off point i.e. say above 12%. It can be also observed that under any one of the fault condition, the respective phase, where the fault occur , have the 2nd harmonic % and THD % is less than 5% and under inrush condition it is having more than 12%. This is also true for other phases having no fault and it is found to be more than 12% so from this it can be concluded that the 2nd harmonics are predominant only under inrush current and also the THD % is much more under inrush conditions.

CONDITION	2ND HARMONIC% IN RESP PHASES			THD% IN RESP PHASES		
	A	b	c	A	b	c
INRUSH CURRENT	14.00	37.92	27.86	16.49	38.99	29.40
a-b-c-G	3.00	0.63	2.80	4.59	1.77	3.46
a-b-G	3.62	0.64	27.86	4.60	1.76	29.40
a-G	3.01	37.93	27.86	4.61	39.00	29.40

Now the test is conducted under different ratings of transformer that is for 100 MVA, 200 MVA, 400 MVA & under load, no load, fault & no fault condition, as shown in the table below.

III. RESULTS AND DISCUSSON

RATING	LOAD	FAULT TYPE	2ND HARMONIC	THD	INRUSH OR WITHPOT INRUSH
100 MVA	100%	L-L-L-G	2.79	4.48	W/O INRUSH
	100%	NO FAULT	12.72	14.48	INRUSH
	NO LOAD	NO FAULT	14.00	16.49	INRUSH
200 MVA	100%	L-L-L-G	4.43	5.55	W/O INRUSH
	100%	NO FAULT	13.34	15.34	INRUSH
	NO LOAD	NO FAULT	13.43	17.22	INRUSH
400 MVA	100%	L-L-L-G	5.10	8.27	W/O INRUSH
	100%	NO FAULT	14.34	16.77	INRUSH
	NO LOAD	NO FAULT	14.43	16.90	INRUSH
500 MVA	100%	L-L-LG	4.46	7.32	W/O INRUSH
	100%	NO FAULT	14.54	15.53	INRUSH
	NO LOAD	NO FAULT	16.76	19.03	INRUSH

It is concluded that for distinguishing between inrush and fault current , the analysis of %2nd harmonic component and THD% plays an important role being dominant in nature only under inrush condition.

Simulation Results

Under normal condition-

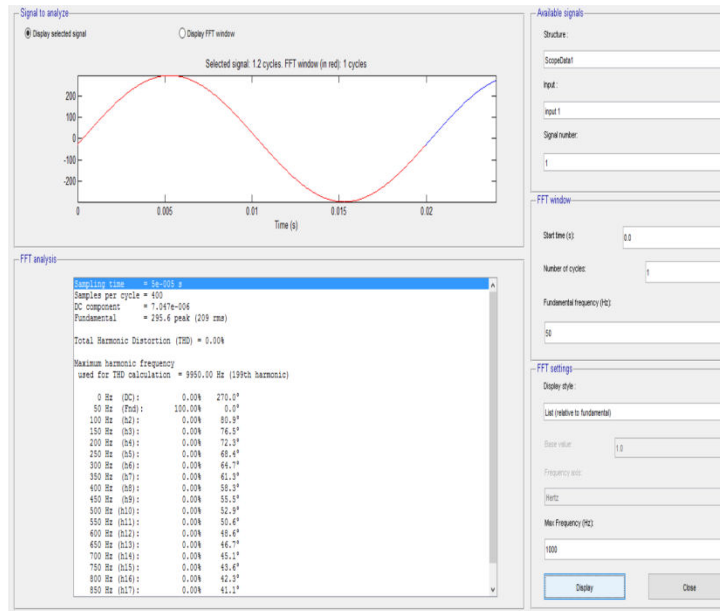


Figure 4. THD and 2nd harmonic under normal condition

Under fault condition[L-L-L-G]-

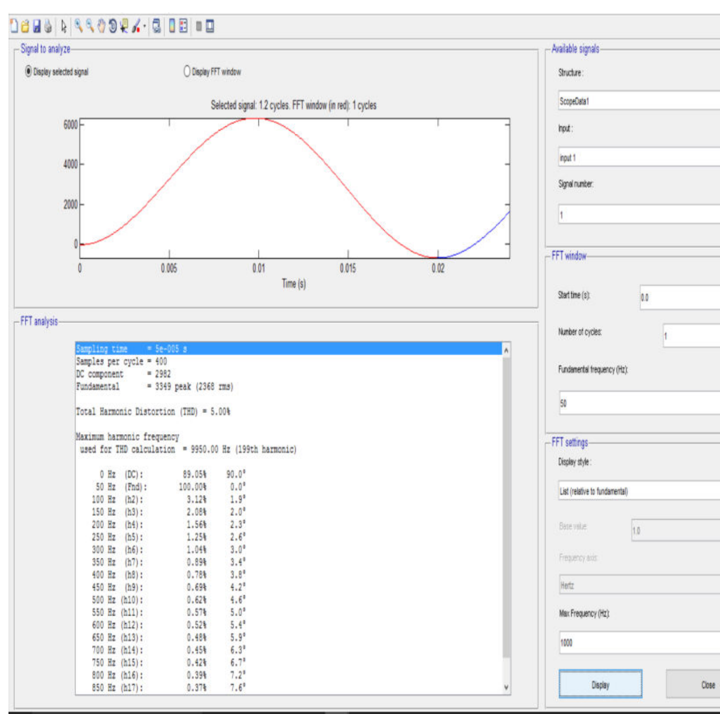


Figure 5. THD and 2nd harmonic under fault condition

Under Inrush Condition-

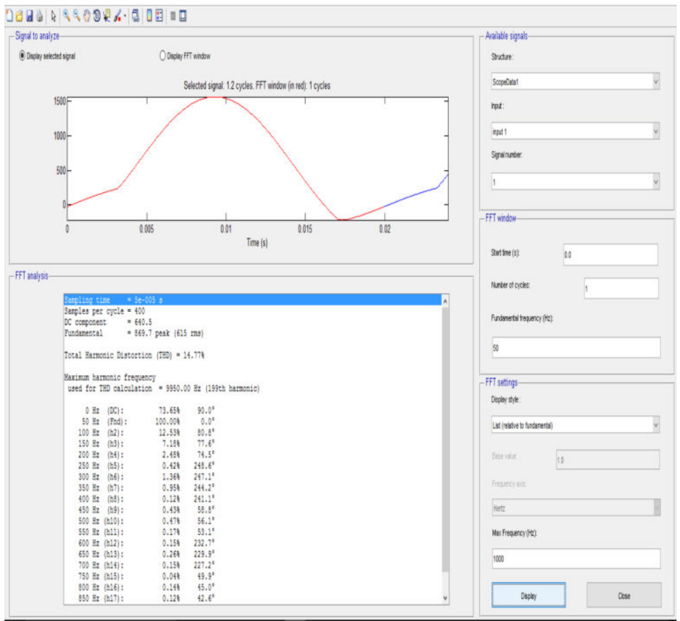


Figure 6. THD and 2nd harmonic under inrush condition

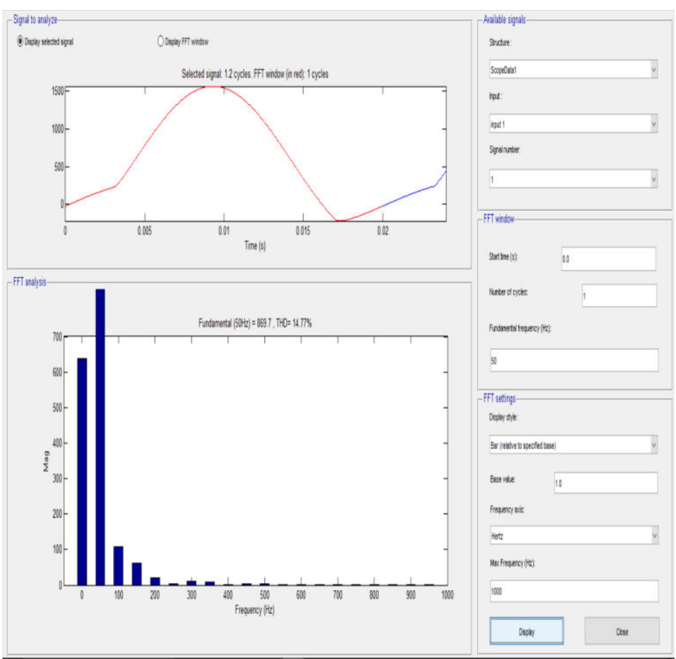


Figure 7. THD and 2nd harmonic under inrush condition

Discussion-

This test is conducted on transformers by considering different ratings like 100,200,400 and 500 MVA under different load condition that is load & no load conditions for LLL-G fault &inrush. The % of 2nd harmonic contents and % total harmonic distortion (THD) is calculated and tabulated in the table above. Observation of the table shows that the contents of 2nd harmonic % and THD% under fault condition are below 9%. So it can be observed again that irrespective of ratings and size of transformer, under LLL-G fault condition, the 2nd harmonic % and THD % are less than 9 % and inrush condition it is more than 12%. Thus it can be concluded that the 2nd harmonics are predominant only under inrush current and also the THD % is much more under inrush conditions. Therefore we can distinguish between inrush current and fault current on the basis of second harmonic threshold. For the fault condition the threshold id found to be less than 9% and for inrush condition it is more than 12%. So it is easier to prevent the faulty operation of differential relay during inrush.

IV. CONCLUSION

In this paper, an attempt has been made through the use of MATLAB/SIMULINK to analyze different conditions using FFT. The obtained result illustrate that the proposed MATLAB model represents an appropriate action. The model gives discrimination between inrush current and fault current on the basis of second harmonic threshold. Hence it is very simplest and convenient method for inrush detection and to avoid the faulty operation of differential relay during inrush. The proposed model was able to discriminate between inrush, fault and no-fault conditions.

HARDWARE DETAILS:
MICROCONTROLLER dsPIC33EP512MU810

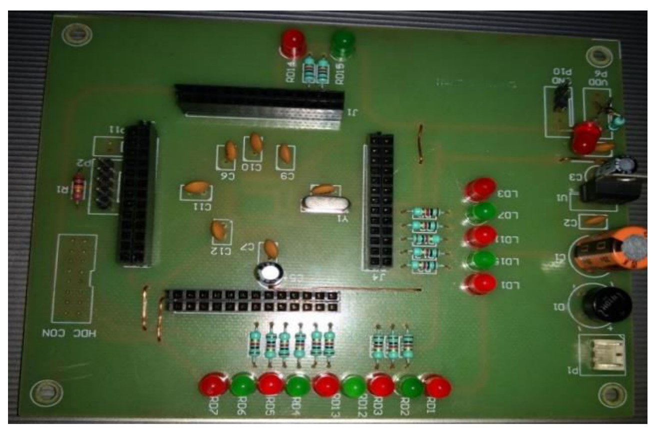
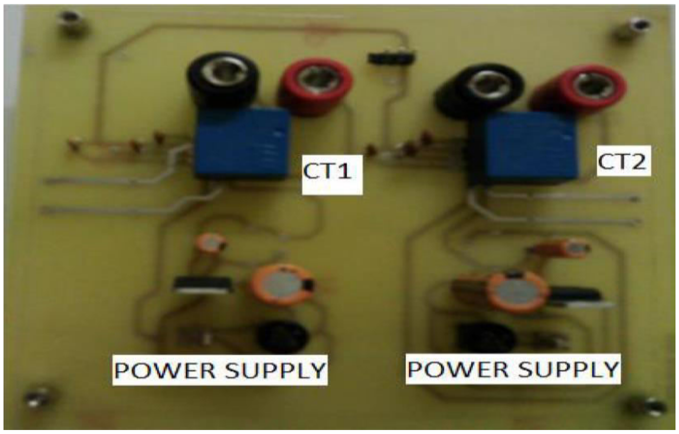


Figure 8.Microcontroller dsPIC33EP512MU810 circuitry**.**

CURRENT TRANSDUCER LEM HXS 10 – NP/SP3
The current transducer (CT) gives voltage as output. The nominal output voltage of the CT is 2.5 V. The 2 coils of the transducer are connected in series so as to have a nominal current of 10 A. CT can sustain a maximum current of 30 A.
The output voltage of the CT is given below:
VOUT = VOE + 0.625 ∗ I/ INP (5.1)
Where, VOUT - Output voltage, VOE – 2.5 V, I – Incoming current, INP – 10 A.



9. HARDWARE IMPLEMENTATION

The scheme of differential relay is tested on the transformer of the following rating: 2 KVA, 230/115 V, 50 Hz

This scheme is shown in Figure 5.6.

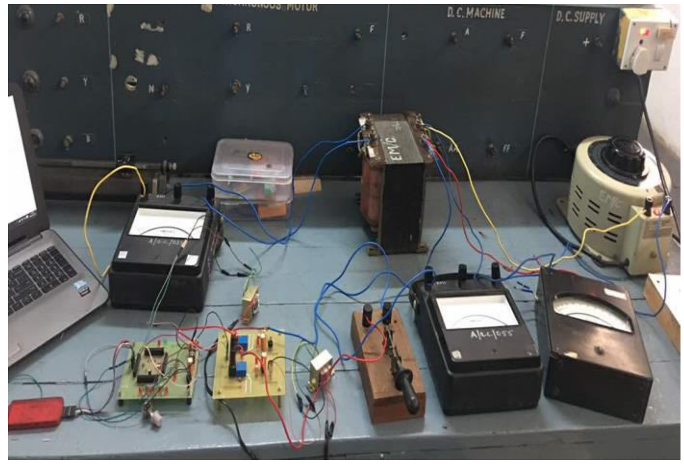
Components used:

1.Ammeter

2.Voltmeter
3.Rheostat [350Ω, 1.2 A]
4.Microcontroller disPIC33EP512MU810
5.Current Transducer LEM-HXS 10np/sp3
6.SPDT [Single pole double throw]
7.Dimmerstat
8.Pickit3
9.Transformer

Procedure:

The inrush current has been taken by using single pole single throw in which the voltage is set at maximum value at no load and then the sudden switching is provided by using SPDT. This is how the different samples of inrush has been taken. Then the short circuit current samples has been taken at load condition at different values considering threshold for short circuit current. After that the samples of inrush current and short circuit current is given to the disPIC program of FFT in which it gives the result in terms of test flag.



10.HARDWARE RESULTS EXPERIMENTAL DETAILS

The block diagram of the experimental set up is shown in Figure 6.1. The testing of the differential protection scheme is done on single phase. The CTs are connected in series with one phase of the transformer on primary as well as secondary side. The CTs can sustain a maximum current of 30 A. This is because the two coils of theCTs are connected in series. Had they been connected in parallel, CTs would have sustain a maximum current of 60 A.

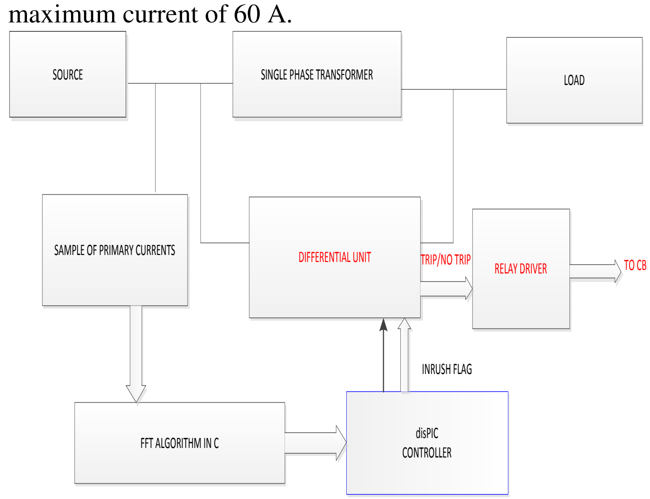


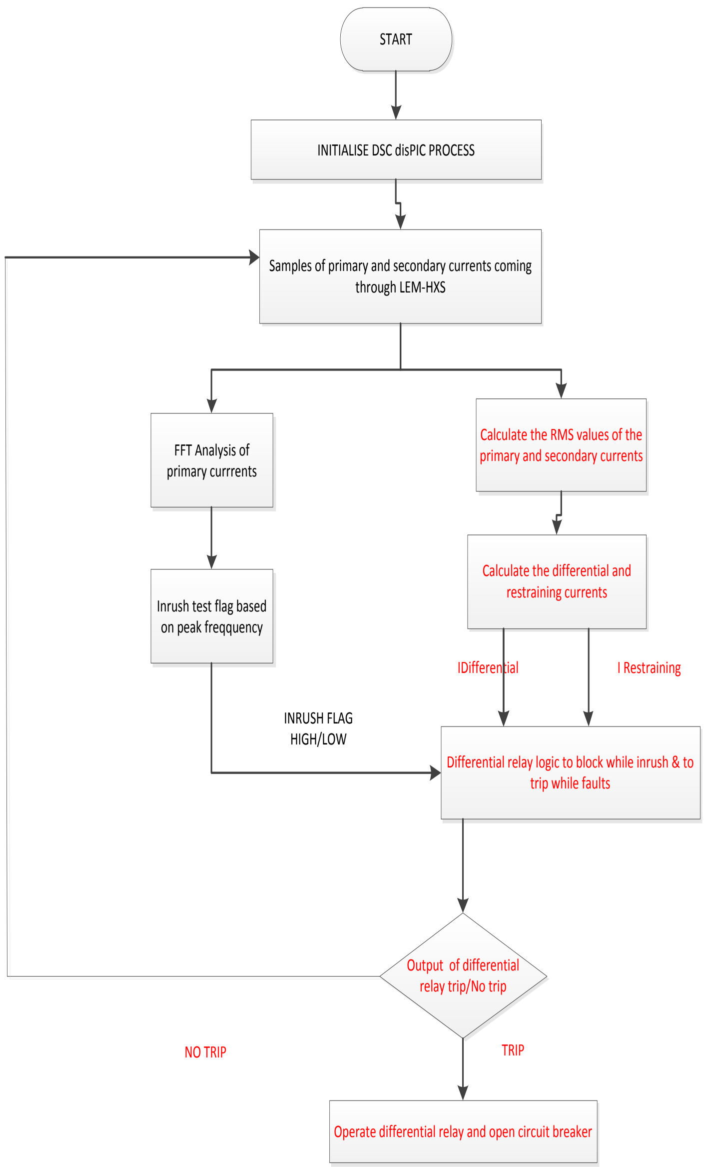
Figure 11: Block diagram of experimental set up

Procedure:

First the initialisation of disPIC has been carried out. The dsPIC process is initialized by programming.
The of primary and secondary current is taken by using the current transducer LEM-HXS from the transformer.
Out of which only the samples of primary current is used for FFT analysis.
The FFT algorithm used these current samples to detect the presence of inrush current in the primary current sample.

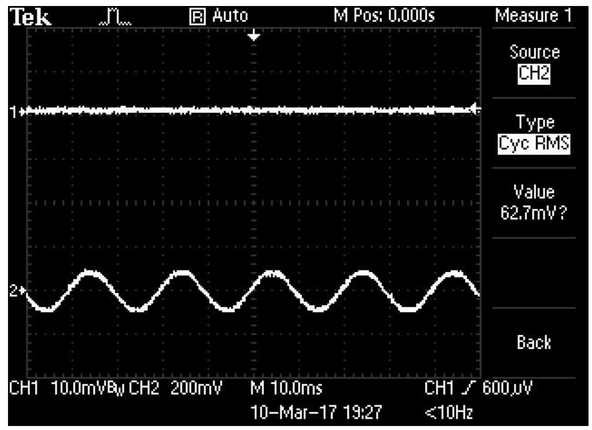
The FFT algorithm uses this current sample and process it by FFT algorithm and the output has been given by the algorithm in terms of peak frequency.
The inrush flag becomes high if there is presence of inrush in the current samples.
Here the inrush flag has been set. The path of block diagram and the flowchart has been followed. The differential protection scheme is not interfaced here as this module is implemented previously as you can see in the block diagram and the flowchart.

FLOWCHART OF THE PROCEDURE

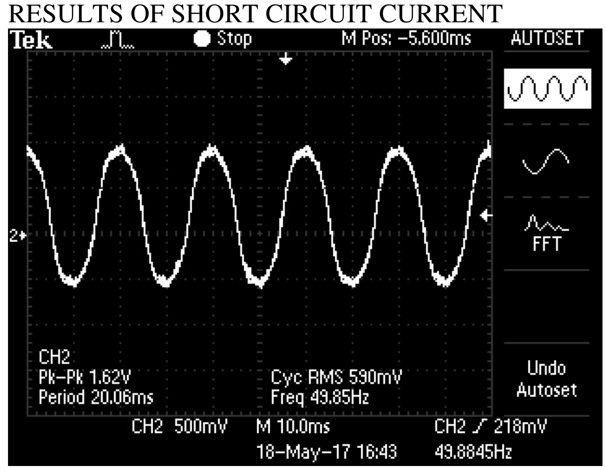


VERIFICATION OF OUTPUT OF CURRENT TRANSDUCER

Output of CT for I=1.0032A [Refer Channel2]



RESULTS OF SHORT CIRCUIT CURRENT



RESULT OF INRUSH OBTAINED FROM SUDDEN SWITCHING AT NO LOAD

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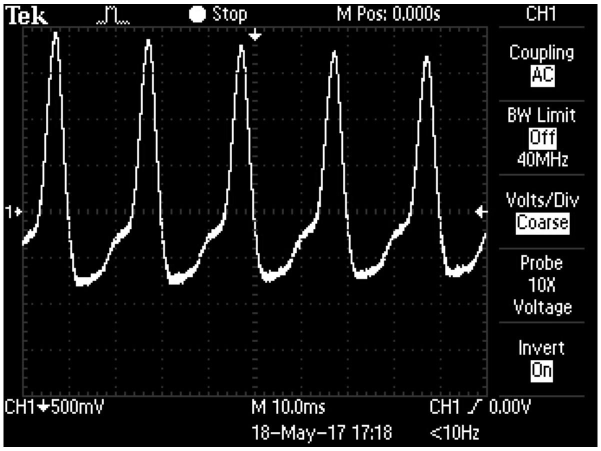
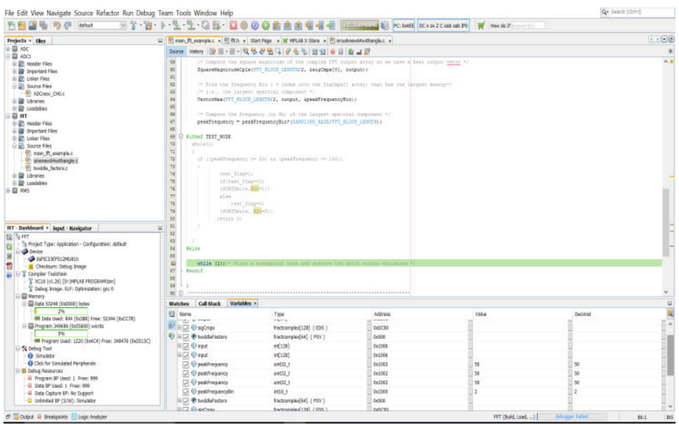


OUTPUT OF THE FAULT CURRENT SAMPLE



RESULT- Peak Frequency=50

OUTPUT OF THE FFT PROGRAM IN MICROCONTROLLER disPIC33EP512MU810

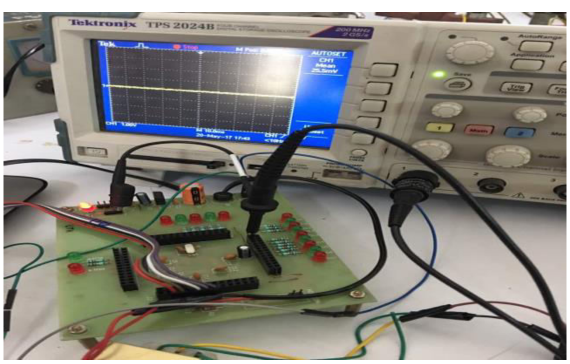
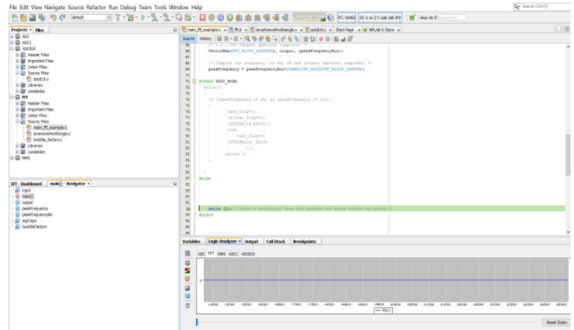
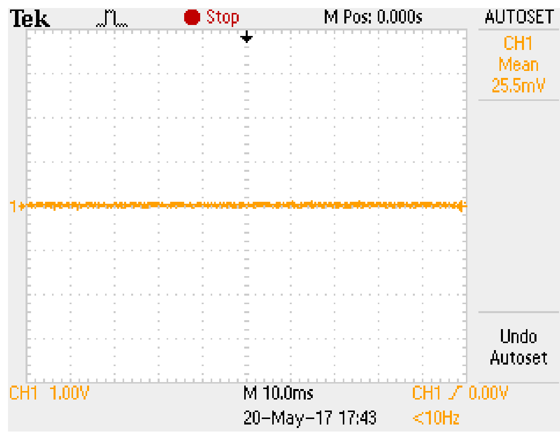


Figure 12.Output of FFT program in microcontroller

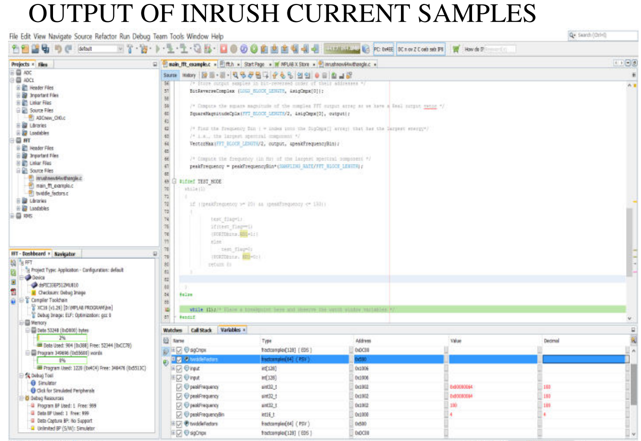
STATUS OF THE FLAG



OUTPUT OF THE FAULT CURRENT SAMPLES IN DSO

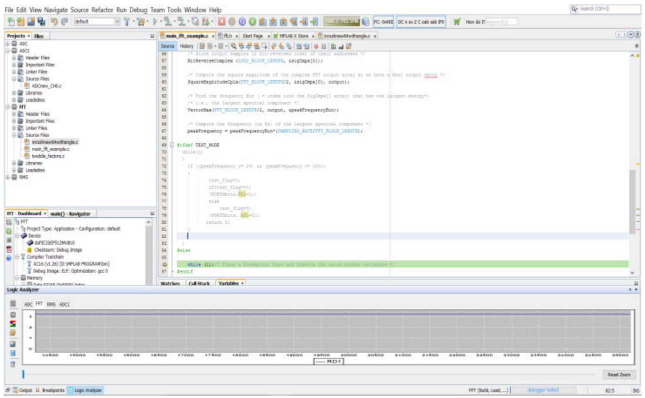


OUTPUT OF INRUSH CURRENT SAMPLES

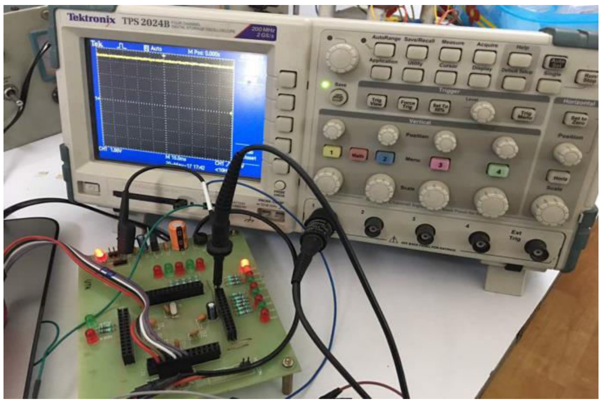


RESULT- Peak frequency=100

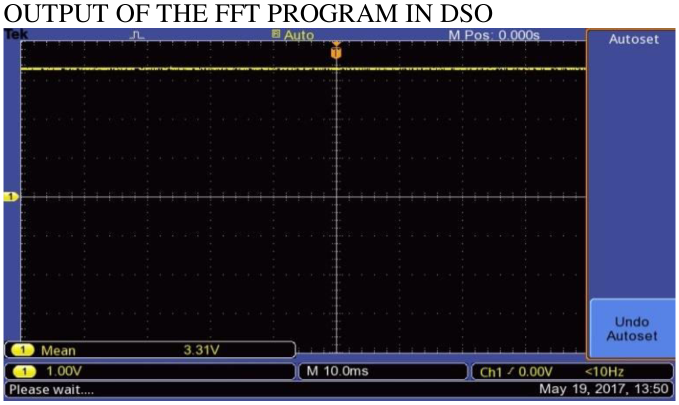
STATUS OF THE TEST FLAG



OUTPUT OF THE FFT PROGRAM IN MICROCONTROLLER disPIC33EP512MU810



OUTPUT OF THE FFT PROGRAM IN DSO



CONCLUSION

The project is implemented only for enabling of Inrush Flag once it detects using FFT algorithm whenever there is inrush current. The FFT algorithm is used to differentiate between inrush and fault current. It differentiates i fault and inrush current in the terms of peak frequency. The threshold is obtained by studying different fault current and inrush current samples. The peak frequency is found to be high and the dominancy of second harmonics is observed during inrush current. Thus proposed algorithm shows high accuracy for inrush analysis. The protection scheme is implemented using microcontroller dsPIC33EP512MU810.The scheme is implemented such that it samples the incoming signal from the primary side of Transformer using current Transducer . This On line input data is then converted to HEX and given as an input file to program of FFT Algorithm. The dsPIC33EP512MU810 microcontroller detects the inrush current based on peak frequency and enables the Inrush Flag. This part of Module of detection of inrush current is successfully implemented. The Differential relay module is not interfaced with the module of detection of inrush current since it was already executed in the previous project

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