Design and implementation of transformer static differential relay with harmonic blocking for transformer protection

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***ABSTRACT*-Transformer plays an important role in the supply of AC power. Protection of such transformer is the need and the basic protection system used for the transformer protection is differential protection. Differential protection based on the comparison of the transformer primary and secondary currents is one of the most important means of protecting a power transformer. When these currents deviate from a predefined relationship, an internal fault is assumed and the transformer is de-energized. The transformer can carry very high primary current and no secondary current during transient primary magnetizing inrush conditions. Use of second harmonic restraint is the most common technique used for preventing false tripping during the above condition. If the second harmonic content of the differential current exceeds a pre-defined percentage of the fundamental, inrush is indicated and the relay is prevented from tripping. Similarly the scenario with the third harmonics present in the supply system. 3rd harmonic blocking filters needs to be used for the treatment of high neutral currents caused by non-linear loads.**

In this paper a transformer static/electronic differential relay is implemented using second order active band-pass filter for detecting second harmonic ratio. Thus enabling a relay blocking signal during transformer inrush current, also the relay allows for a fine adjustment of the differential characteristic curve to facilitate its use in variety of transformer ratings.

***Index Terms*—Differential static relay, Hall Effect transducer, harmonic blocking.**

I. INTRODUCTION

Protective relaying is one of the several features of power system design. Every part of the power system is protected. It is used to give an alarm or to cause prompt removal of any element of power system from service when that element behaves abnormally. The abnormal behaviour of an element might cause damage or interference within effective operation of the rest of the system. The protective relaying minimizes the damage to the equipment and interruptions to the service when electrical failure occurs.

The important means of protecting a power transformer is differential protection based on the comparison of the transformer primary and secondary currents. However during transient primary magnetizing inrush conditions, the transformer can carry very high primary current and no secondary current.. The most common technique used for preventing false tripping during the above condition is the use of second harmonic restraint.

The proposed static differential relay avoids the dependence on the current waveform pattern in which it is not always guaranteed that the current waveform will maintain certain specifications under various loading or even inrush conditions. The present relay allows for second harmonic ratio detection using active band pass filters by which mal-operation due to inrush condition is avoided. Furthermore, it is possible to adjust the slope of the characteristic curve electronically

The objective of this paper is implementation of more developed scheme of an electronic differential relay with 2^{nd} harmonic blocking along with circuit for 3rd harmonic detection circuit for an AC power supply system wherein the circuit should not operate during power up time for the presence of 2^{nd} harmonic signals.

Several conditions can cause differential relay false tripping. These conditions can cause false trips from external faults, or simply increased transformer loading. Some indication is needed that the relay is not operating as desired before an incorrect operate happens. A potential problem can be identified by monitoring the operating condition of the differential relay. Indications provided by this monitoring can serve as a warning if the settings or connections are not correct [1]. The differential relay must detect energization inrush current and inhibit operation. Otherwise, the relay must be temporarily taken out of service to permit placing the transformer in service. In most instances this is not an option. The harmonics in faults are generally small. In contrast, the second harmonic is a major component of the inrush current. Thus, the second harmonic provides an effective means to distinguish between faults and inrush. [1]

A Hall Effect Current Sensor is a current transformer, which utilizes the Hall Effect. This effect was first observed by Edwin Hall in 1879. When a current-carrying conductor is placed into a magnetic field, a voltage will be generated perpendicular to both the current and the field. This principle is known as the Hall Effect. Hall Effect sensors can be applied in many types of sensing devices. If the quantity (parameter) to be sensed incorporates or can incorporate a magnetic field, a Hall sensor will perform the task [2].

Inrush current waveform is similar to a half-wave rectifier waveform, with very big amplitude up to 3000 ampere and stop after 3 second. This has always been a concern in the transformer and load power quality [3]. During the period of transient inrush current, the transformer's core normally enters a state of saturation. At this time, the primary winding is changed into a hollow winding, as if the iron core is removed from the coil. The flux lines extend into the area outside the iron core[4].Static relays with no or few moving parts became practical with the introduction of the transistor. Static relays offer the advantage of higher sensitivity than purely electro-mechanical relays, because power to operate output contacts is derived from a separate supply, not from the signal circuits. Static relays eliminated or reduced contact bounce, and could provide fast operation, long life and low maintenance [5].

II. FUNCTIONAL BLOCK DIAGRAM

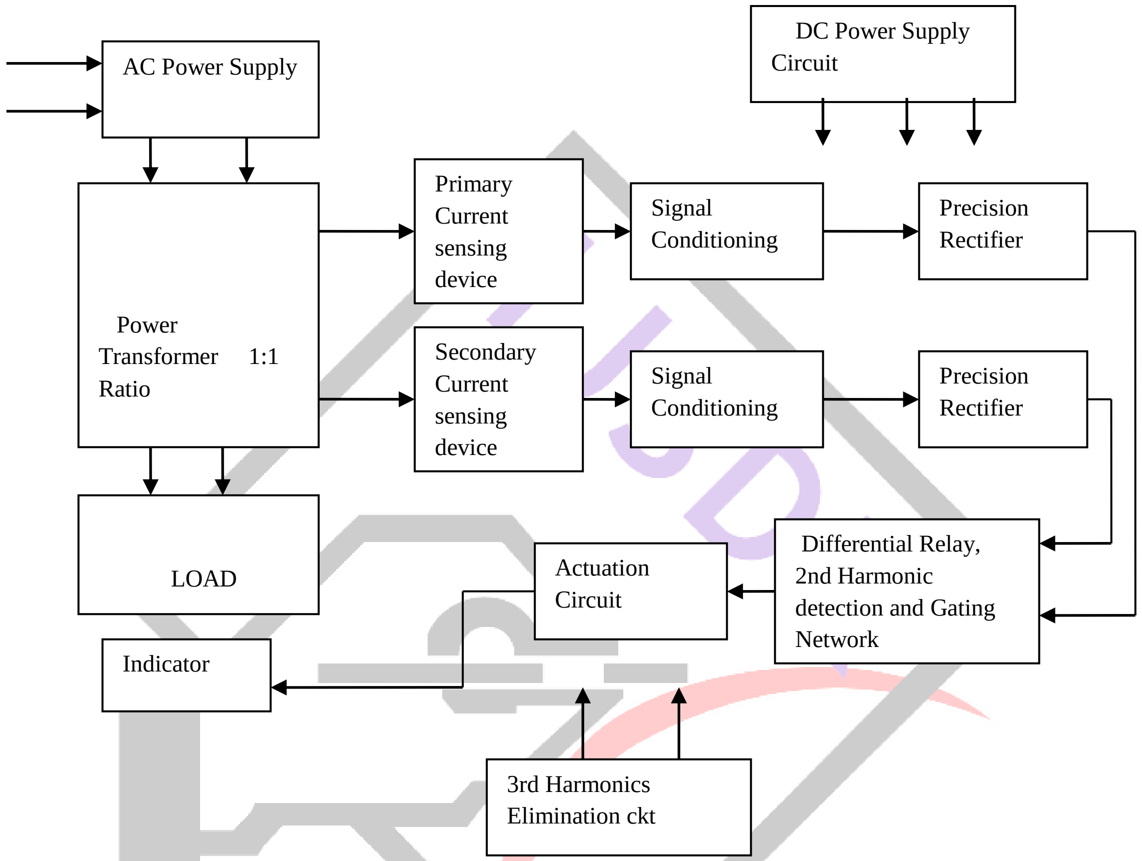


Fig1.1 Functional block diagram

Static relays technology is a preeminent choice of protection. The application of these relays is in many ways simpler than that of EM relays, although there has no significant change in the principles of system protection and coordination. Here the implementation is for an inrush activated blocking scheme for a static electronic differential relay based on an instantaneous level of differential current and its rate of change.

Present scheme is based on the waveform approach. They mentioned that the current magnitude and rate of change of current (di/dt) are low simultaneously for inrush for about 40-45 degrees from zero crossing of the positive rise of the rectified current wave, compared to normal fault current and load current. Here a more developed scheme of an electronic differential relay is implemented. The relay avoids the dependence on the current waveform pattern in which case it is not always guaranteed that the current waveform will maintain certain specifications under various loading or even inrush conditions. The present relay allows for second harmonic ratio detection using active band pass filters by which mal-operation due to inrush condition is avoided. Furthermore, it is possible to adjust the slope of the characteristic curve electronically.

III. POWER SUPPLY CIRCUIT

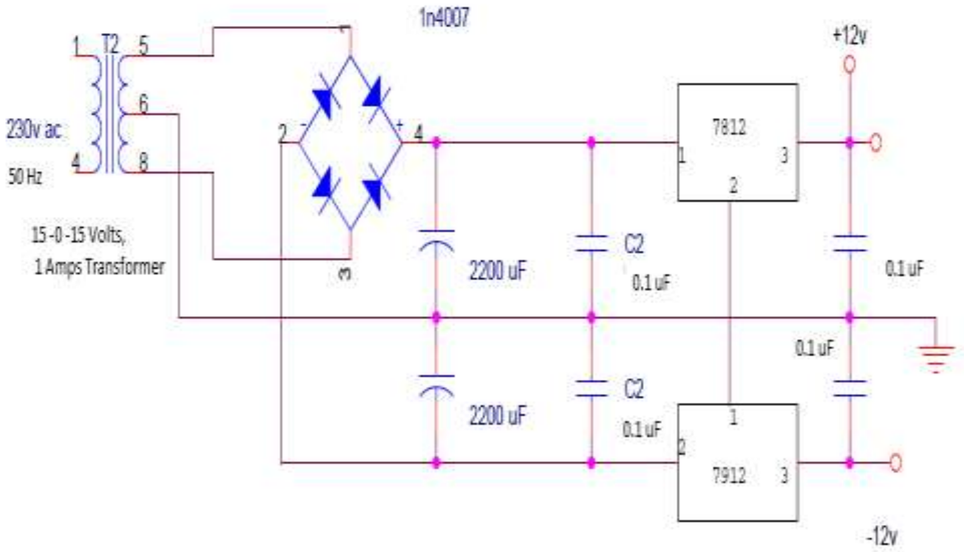


Fig 1.2 +12 /-12 Volts 500 mA Regulated Power Supply

Transformer selected is 15-0-15 volts , 1 Amps.
Peak Secondary voltage = 1.4142 * 15 = 21.21 volts
Filter capacitor voltage = 21.21 – 0.7-0.7 = 19.81 volts
The value of the capacitor is selected in such a way that for the designed circuit the ripple of the rectified , filtered dc voltage should have a minimum value;
C = 5 I / FV for a 10% ripple factor.
where I= load current
F= Supply frequency,
V= Peak secondary supply voltage of transformer
The ripple factor must be as much as low as possible for the proper operation of the circuit.
Capacitor C2 is used as High frequency filter, bypass all high frequency signals coming on the DC line.
IC 7812 is a +ve voltage regulator needs an input voltage minimum of
12 + 2.5 = 14.5 volts for providing regulated voltage.
Similarly IC 7912 is a -ve voltage regulator needs an input voltage minimum of
12 + 2.5 = 14.5 volts for providing regulated voltage.
IC 7805 is a positive voltage regulator gives a related output voltage of 5 Volts which needs a minimum voltage of 5+2.5 = 7.5 volts as minimum input for its operations.

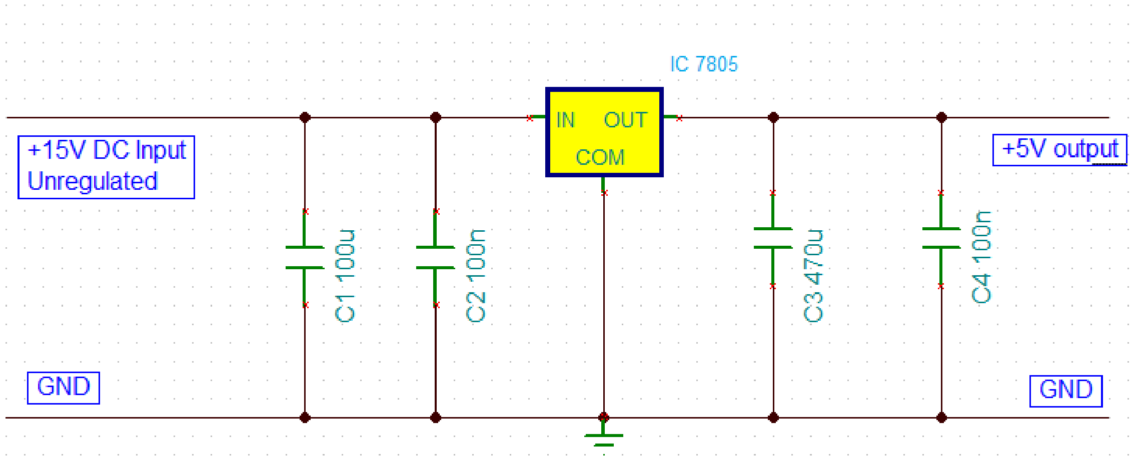


Fig 1.3 5 Volts, 1.0 Amp Regulated DC Power Supply

IV. HALL EFFECT CURRENT TRANSDUCER (HECT)

Theory of Hall Effect

The Hall Effect can be explained by the Lorentz force principle. When a charge moves in a direction perpendicular to an applied magnetic field, it experiences a force defined by the Lorentz Law. The direction of this force is perpendicular to the direction of propagation of the charge and that of the external magnetic field.

Operation of Hall Current Sensor

A Hall Current Sensor utilizes the principle of the Hall Effect to detect the current levels. These sensors monitor the gauss level created by a flow of current; they do not measure the actual current flow. The current being measured (through the primary conductor) is passed through a flux-collecting core (which is generally a slotted toroid) that concentrates the magnetic field on the Hall element. The Hall element is a piece of semiconductor material, which produces the Hall voltage proportional to the current flow. The Hall voltage is a low level signal, so generally a low noise high gain amplifier is used to regulate the output of the Hall element. The Hall Element along with the evaluation and regulation circuitry is generally fabricated into a single IC (Integrated Circuit).

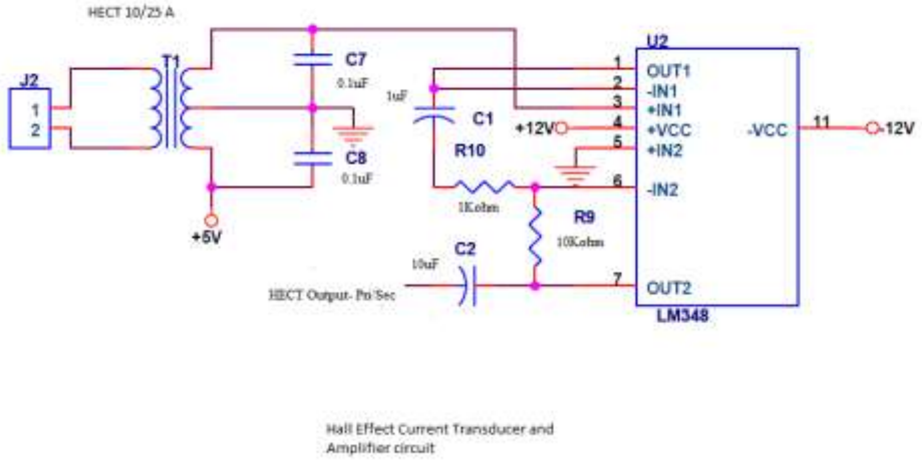
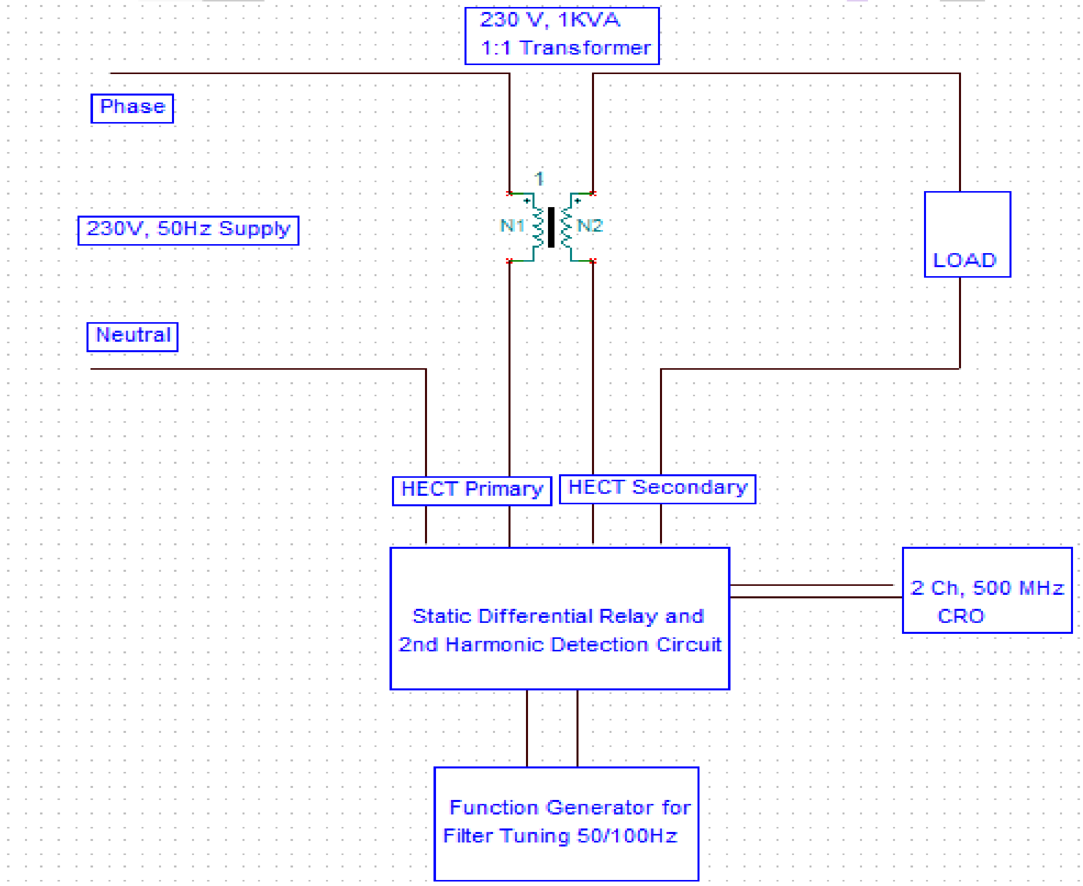


Fig 1.4 Hall Effect Transducer and Amplifier circuit.

V. TEST SET UP AND WORKING PRINCIPLE



A transformer static/electronic differential relay is implemented using second order active band-pass filter for detecting second harmonic ratio. Thus enabling a relay blocking signal during transformer inrush current, also the relay allows for a fine adjustment of the differential characteristic curve to facilitate its use in variety of transformer

In the implementation, 2 current sensors are used to sense the current flowing through the primary and secondary of the transformer. Later the signals are passed through the signal conditioning network and precision rectifiers. The Harmonic detection network detects the amount of 2^{nd} Harmonic present in the transformer and sends a tripping signal to a tripping network once it goes above the set limit.

The proposed relay avoids the dependence on the current waveform pattern in which it is not always guaranteed that the current waveform will maintain certain specifications under various loading or even inrush conditions. The present relay allows for second harmonic ratio detection using active band-pass filters by which mal-operation due to inrush condition is avoided. Furthermore, it is possible to adjust the slope of the characteristic curve electronically.

The relay's characteristics are defined according to the following set of equations:

Idiff = (Ip - Is)
Irest = (Ip + Is)/2
Idiff > k * Irest

Where:
Idiff: Differential Current
Ip: Primary current
Is: Secondary current
Irest: restraint current
Idiff: differential current
K: Constant in percentage

The dc levels corresponding to the primary and secondary currents are modified to give an output relevant to the restraining and differential currents using differential and adding amplifiers. A precision potentiometer resistor is used to adjust the required percentage (K).

The primary and secondary currents of the power transformer are passed through current transformers then transformed to voltage signals by the Hall Effect current transformers. To create signals corresponding to the primary and secondary currents for use in calculating differential and restraining currents of the characteristic curve, both signals are passed through amplifier circuits with gain with which both the primary and secondary currents signals are sufficient for the next stage. The buffer amplifier at the end enhances the current levels of both primary and secondary current signals.

The differential relay characteristic I differential > K * I restraint current is implemented through differential amplifier and summing amplifier circuits built on operational amplifiers where in user is able to set the relay characteristics with a potentiometer.

The ac primary signal corresponding to the primary current is passed through a second order active band pass filter tuned to give high gain for the 100 Hz signal to detect the second harmonic. The signal is also passed through another active band pass filter tuned to give high gain for the 50 Hz signal to detect the fundamental frequency. To calculate the second harmonic constraint percentage (ε), the 50 Hz filter output is passed through a precision variable resistor by which we can select any percentage (ε) from the 50 Hz signal (e.g. 0.12) to be compared to the 2nd harmonic signal. Finally our target is to send the tripping signal when the point of the characteristic curve is located in the operating zone in which Idiff > Irest.

VI. EXPERIMENTAL RESULTS

A digital storage oscilloscope was applied to measure the primary and secondary currents of the transformer during various operating conditions. The figures were captured using a digital camera. The inrush current signal captured by the relay in no-load condition is shown in Fig: 1.5. A light emitting diode is used to indicate this condition.

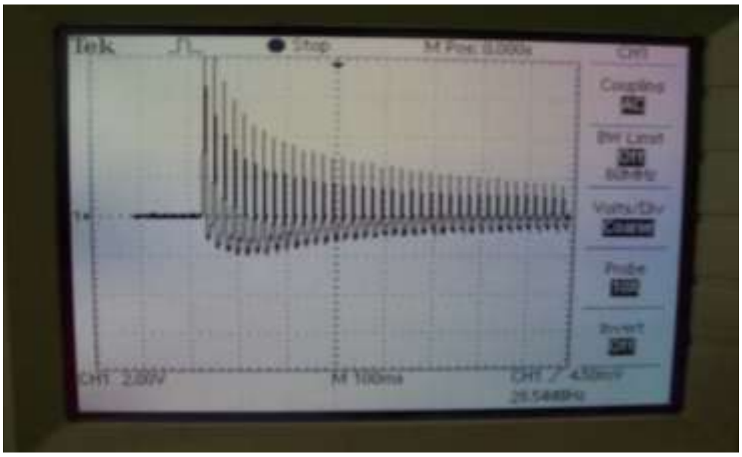


Fig: 1.5 Inrush current in no-load.

The inrush current signal in load condition is captured in Fig: 1.6 in which case also the 2nd harmonic LED remains on.

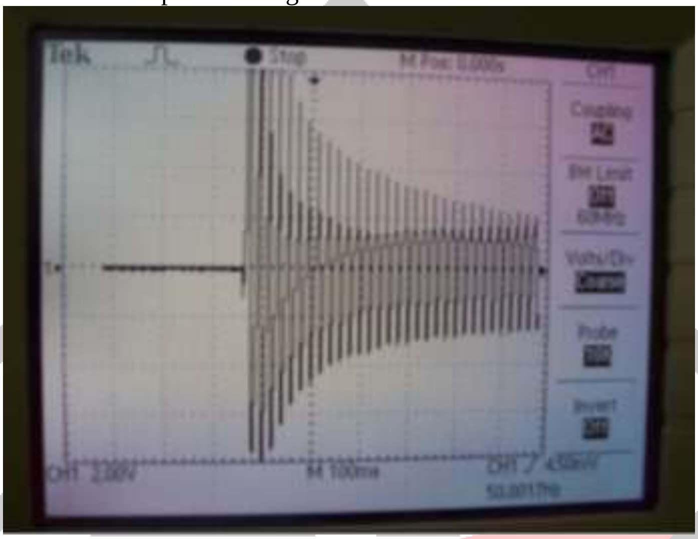


Fig: 1.6 Inrush current during load

The primary and secondary current captured signals in normal conditions are shown in Fig: 1.7. During the normal operation all LEDs are not activated, while during the internal fault condition the differential current LED and the tripping LED is activated.

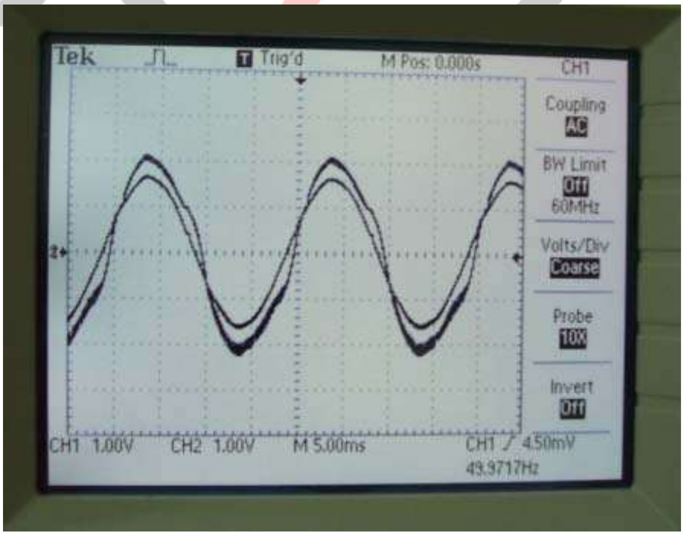


Fig: 1.7 Primary and secondary currents in normal operation

Load: RL Load (Lamp Load 100 watts)

Sl No	AC Supply Voltage	AC Supply Current (Primary)	AC Supply Current (Secondary)	Load	K Value setting	Trip signal
1	230 v	0.71 A	0.48 A	RL	0.9	Absent
2	229 v	0.71 A	0.48 A	RL	0.7	Absent
3	229 v	0.71 A	0.48 A	RL	0.5	Absent
4	230 v	0.71 A	0.48 A	RL	0.3	Absent
5	230 v	0.71 A	0.48 A	RL	0.1	Present
6	230 v	0	0.48 A	RL	0.23	Present

VII. CONCLUSION

A developed static differential relay is implemented and tested under various operating conditions. The relay allows for harmonic blocking using second order active band-pass filters; furthermore the shape of characteristic curve is adjustable, making it applicable to the protection of transformers with different ratings.

The relay is advantageous over electromagnetic differential relay as it is very compact, highly sensitive for internal faults and has absolute stability for heavy through faults, extremely short tripping times (20-50 ms), inrush current proof characteristic even during high starting currents, inrush currents. Static relays offer the advantage of higher sensitivity than purely electro mechanical relays, because power to operate output contacts is derived from a separate supply, not from the signal circuits. Static relays eliminated or reduced contact bounce, and could provide fast operation, long life and low maintenance.

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