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# Implementation of Power Transformer Differential Protection Based on Clarke's Transform and Fuzzy Systems

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## Abstract

*Transformer differential protection is generally exposed to faulty operation related to abnormal operating conditions (inrush, over excitation, etc.). This paper presents a method for protecting and monitoring power transformers based on fuzzy logic and the application of Clarke's transform. The fuzzy logic allowed us to analyze the operating condition of power transformers such as energization, inrush, and over excitation. Decision making is performed by fuzzy logic after the pre-processing of the input signals through Clarke's transformation. An electrical power system was modelled using MATLAB software to obtain the operational conditions and fault situations needed to test the algorithm developed. The objective of these tests was to generate data for distinct situations for the verification and the analysis of the proposed methodology.*

*The fuzzy logic relay analyses the operating regime for the equipment and eliminates the abnormal work situations which generate failures. The system has been implemented using AT89S52, PIC16F877A. These were employed for developing the prototype relay, with all the coding done using microcontroller C and PIC basic languages. Kiel uVision3 and PIC Simulator IDE, these two software been used for loading the programs on chip. A special terminal program, developed in C language was used to apply the current input signals to the prototype relay in real-time by using of MAX232 serial data communication. The logic is deterministic, computationally efficient, secure and highly reliable. The validity of the proposed logic was exhaustively tested by simulating various types of fault, energisation conditions and sympathetic inrush on a 13.8 kV system modelled in MATLAB with a 2100MVA, 13.8KV/735KV, Star –star connected transformer. The relay was able to correctly discriminate between inrush, internal faults and no fault disturbances.*

***Keywords:*** *Clarke's transform, differential protection, fuzzy system, power transformer, MATLAB, Kiel uVision3 and PIC18 Simulator IDE.*

## 1. Introduction

### 1.1 General

The function of power system protective relaying is to initiate the prompt removal of abnormal conditions from service of elements of power system. Since the appearance of microprocessor in the mid-1970s, digital protective relaying has attracted much attention [1]. The power transformer is one of the important elements in power system. The power transformer is a piece of electrical equipment that needs continuous monitoring and fast protection since it is very expensive and an essential element for a power system to perform effectively. Power transformer internal faults may cause extensive damage or power system instability. Thus, different transformer protection schemes are used to avoid interruptions of the power supply and catastrophic losses. Electrical protective relaying of power transformer is based on a percentage differential relaying technique [2]. This is the most common protection technique, which provides discrimination between an internal fault and an external fault or a normal operating condition. Usually, differential relays compare the currents from all terminals to a predetermined threshold and in the case of an internal fault; the equipment is disconnected from the power supply as it reaches beyond the predetermined threshold. The literature shows that the method based on the harmonic restraint has been commonly used to solve this problem. Harmonic-restrained differential relay is based on the fact that magnetizing inrush current has a large second harmonic component, and nowadays the above technique is widely applied. But this technique must be replaced because harmonics occur in a normal state of power system and quantity of second frequency component in inrush state has been decreased because of the improvement in core steel [1]-[6].

There are cases in which the presence of differential currents cannot make a clear distinction between fault and inrush. Some other operation conditions can cause differential currents and they deserve special attention. Some examples of these are energization, Over-excitation. In order to prevent the relay misoperation in these cases, it is necessary to differentiate inrush current from fault current.

In order to improve power transformer protection, various methods were developed for accurate and efficient discrimination of the situations described previously. Recently, to advance the conventional approaches, several new AI (artificial-Intelligence) features for protective relaying have been developed. In 1983, Phadke and Thorp proposed an algorithm based on the flux-restraint principle to discriminate between internal faults and other operating conditions [12]. In 1993, Wiszniewski and Kasztenny presented a fuzzy set for power transformer differential relaying [13]. In 2003, shin et al. reported improved power transformer protection using fuzzy logic with flux-differential current and harmonic restraint [14]. In [7], the differential power method was proposed to recognize faults from inrush currents using an optimal probabilistic neural network. Although other methods which detect faults were shown in the literature, the harmonic restraint has been extensively [8].

Despite progress in differential protection techniques, faults near the end of the winding and inter-turn faults are also a challenge for engineers and researchers since these types of faults are difficult to protect properly (either with the differential protection or mechanical protection, such as the Buchholz relay) [2].

This paper presents an efficient method based on Clarke's transform with fuzzy sets for differential protection of power transformers. In the proposed technique, the input variables of the fuzzy-based relay are differential currents resulting from Clarke's transform and data windowing process. The fuzzy system is designed to distinguish internal faults from other operating conditions of the power transformer, even for faults near the neutral.

It should also be highlighted that in order to test the proposed algorithm, computing simulations were performed using "MATLAB" [11]. A power system was implemented, where its dynamic behaviour could be observed. The simulation includes: A.C source voltage, frequency dependent parameters, and a power transformers. Extreme operational situations were used in order to observe the behaviour of the proposed technique.

## 1.2 Objective

1) To develop new differential based relaying algorithm using Clarke's transform and fuzzy system.
2) This new algorithm employs the Clarke's transform for obtaining the differential current components from the primary and secondary winding of the power transformer.
3) It also employs the fuzzy system which produces a trip signal if a fault is recognised.

## 2. Differential Protection

Fig. 1 shows a typical differential relay connection diagram for the protection of power transformers. In this figure, the connection of current transformers (CTs), coupled with the primary and secondary branches, are shown. $N_p : N_s$ is the turn ratio between the primary and secondary windings of the transformer, and $1{:}n_1$ and $1{:}n_2$ are the turn ratios between the branches and CTs, selected to make $N_p n_1 = N_s n_2$. In normal conditions and external faults for a single-phase transformer, currents

$i_{ps}$ and $i_{ss}$ (secondary currents of CTs) are equal.

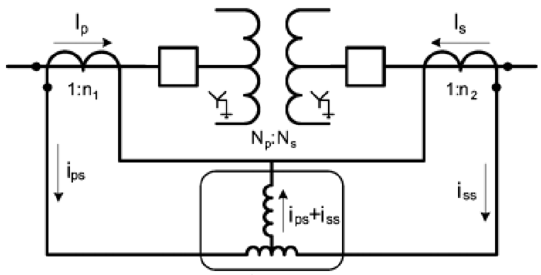



Fig. 1. Differential relay connection diagram.

However, in the case of internal faults, the difference between these currents becomes significant, causing the differential relay [2] to trip. The differential current (also called operating current) $i_d$ can be obtained as the sum of currents entering and leaving the protected zone, according to

$$i_d = [i_{ps} + i_{ss}] \qquad (1)$$

And it provides a sensitive measure of the fault current. The restraint current $i_{rt}$ =k $[i_{ps} - i_{ss}]$ should also be considered. The relay sends a trip signal to the circuit breaker (CB) when the differential current is greater than a percentage of the restraint current. As mentioned before, certain phenomena can cause a substantial differential current to flow when there is no fault, and then this false differential current is

## 3. Proposed method

### 3.1 General description

In this project, an efficient method based on Clarke's transform with fuzzy set [9], [10] is employed for differential protection of power transformers. Here the input variables of the fuzzy-based relay are differential currents resulting from Clarke's transform. After acquiring the data from both primary and secondary of power transformer, the signals are processed using Clarke's transform and differential currents are calculated. Then these currents are further processed by data-windowing process. These currents are the inputs of the fuzzy system. The fuzzy system is designed to distinguish internal faults from other operating conditions of power transformer. If the output of the fuzzy system is greater than the threshold value, i.e., when it exceeded the threshold value, the relay sends a trip signal to the C.B. It is important to emphasize that the proposed Fuzzy system computes each differential α-β-γ component independently. The following sections will describe each block individually. The block diagram of proposed method is shown in Fig.2.

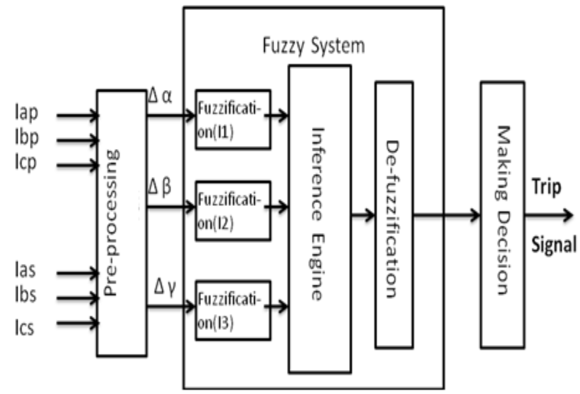



Fig.2. Block diagram of proposed system

### 3.2 Pre-processing

After acquiring the data, a pre-processing stage was executed, obtaining the uncoupled signals for the fuzzy system. This pre-processing can be carried out by two stages are Clarke's transform and another one is data windowing process.

### 3.2.1 Clarke's Transform

Since Clarke's transform is a widely used computational tool, standing researchers in various fields of knowledge such as engineering, physics, mathematics, computer graphics and digital signal processing. In this context, the Clarke's transform is presented as alternative methods. A pre-processing stage was executed for obtaining the uncoupled signals. This stage was executed for obtaining the uncoupled signals for data-windowing process This was obtained by applying Clarke's transformation to the three-phase currents in the both transformer ends, as represented in the following equation:[15]

$$\begin{bmatrix} I_{\alpha p h} \\ I_{\beta p h} \\ I_{\gamma p h} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} [I''_{ph}] \qquad (2)$$

Where, $I''_{ph} = [\ I'_{ph}\ I'_{ph+120}\quad I'_{ph+240}\ ]$, *ph* is the phase of current reference. It is important to emphasize that Clarke's transform could be applied to both instantaneous values as well as the phasors. The main idea of using Clarke's transformation is to carried out in a pattern-recognition process to discriminate certain conditions of transformers, such as internal faults, over excitation, magnetizing inrush, and energization. The proposed method uses the differential $\alpha - \beta - \gamma$ components of the current, such as,

$$\Delta\alpha_{ph} = I_{\alpha p\,h} + i_{\alpha p\,h} \tag{3}$$

$$\Delta\beta_{ph} = I_{\beta p\,h} + i_{\beta p\,h} \tag{4}$$

$$\Delta\gamma_{ph} = I_{\gamma p\,h} + i_{\gamma p\,h} \tag{5}$$

Where, $I_\alpha$, $I_\beta$, $I_\gamma$, $i_\alpha$, $i_\beta$, and $i_\gamma$ are α-β-γ-components of the primary and secondary currents of a transformer.

### 3.2.2 Data windowing

After Clarke's transform those alpha, beta and Gama current components need to be organized into data window of 200 samples. The 200-sample data windows were obtained as shown in the Fig.3.

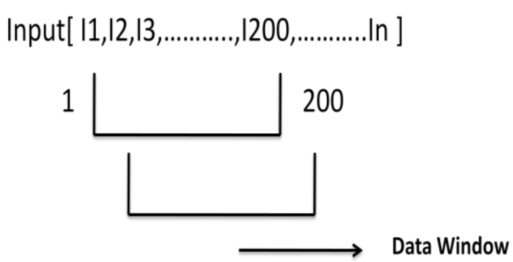



Fig.3. Forming window data

The sample data window is formed by reading 200 data starting at a certain index. The next data window is obtained by shifting the index. The main idea adopted here is based on interpolation method with Fast Fourier Transformation (FFT).

The start and stop of the window can be adjusted by adjusting start and end function parameters. The Output data of this process is used as input to the fuzzy system.

### 3.2.3 Fuzzy system

The fuzzy system is used to deal with the input imprecision without data loss during processing and to determine the fault condition more accurately than conventional differential protection methods. Steps involved in fuzzy system are:[16]

#### 3.2.3.1 Fuzzification:

Fuzzy logic uses linguistic variables instead of numerical variables. In the real world, measured quantities are real numbers (crisp). The process of converting a numerical variable (real number) into a linguistic variable (fuzzy number) is called fuzzification. It is the classification of input data into suitable linguistic values or sets. In this proposed scheme the fuzzy system applied to the proposed relay uses the fuzzy inputs: 1) Δ α ;2) Δβ ; and 3) Δγ . These variables are obtained from (3)-(5). Figs. 4(a)–(d) show the membership functions of the inputs and the output fuzzy set. For fuzzification of a defined input variable from (3), a range is set between 0 and 150 and the membership values range from 0 to 1. The input variable from (4), a range is set between 0 and 100. The other input variable from (5) in the range from 0 to 15. The output variable is shown in Fig. 4(d) ranging from 0 to 1 for two membership functions that determine block or trip signals.

#### 3.2.3.2 Inference method:

The proposed relay uses robust rules to discriminate two operating conditions: steady state or internal faults. For this paper, in order to perform a mathematical operation, the Mamdani method was chosen [10]. 27 rule bases were used in this proposed scheme.

#### 3.2.3.3 Defuzzification:

#### 3.2.3.4

The method needed a crisp value for control purposes. The technique applied a centroid in accordance with [10]

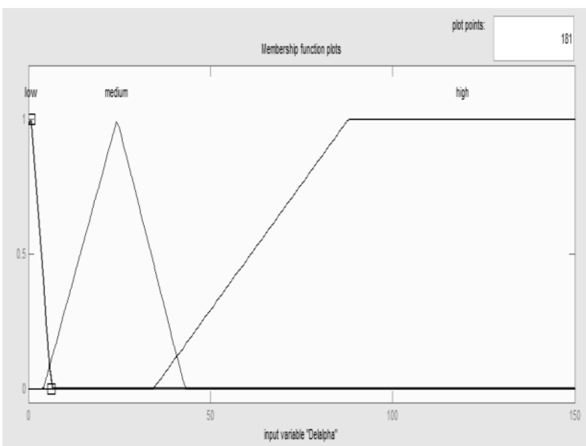
$$\text{Output}=\frac{\sum_{j=0}^{N} y_j\ \ \mu_F(y_j)}{\sum_{j=0}^{N} \mu_F\ (y_j)} \tag{6}$$

Where, $y_j$ is the value of each point on a domain of a final output fuzzy set and $\mu_F(y_j)$ is the membership value at each point. The specification for the proposed relay is given in table-I.

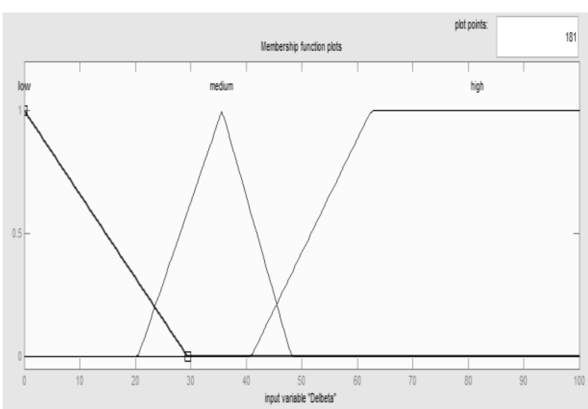
### Table I

### Specification of the proposed relay

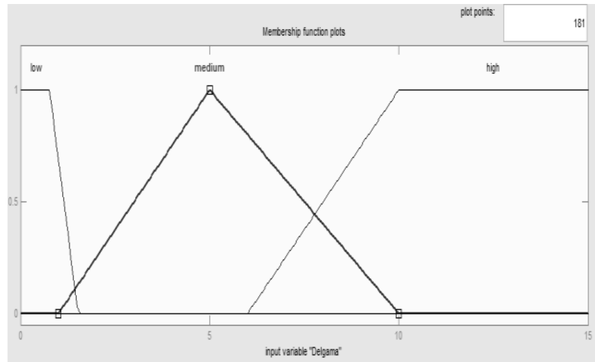
| | |
|---|---|
| **Measurements** | Transformer primary and secondary current |
| **Relay output** | Trip or no trip |
| **Threshold of operation** | 0.57 |



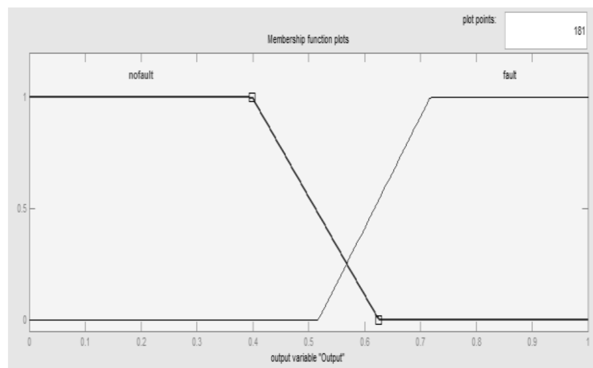

(a)




(b)




(c)




(d)

Fig.4. Fuzzy membership functions.(a) input fuzzy set $\Delta\alpha$ (b) input fuzzy set$\Delta\beta$ (c) input fuzzy set $\Delta\gamma$. (d) output fuzzy set.

## 4. Simulated electrical system

### 4.1 MATLAB Models For Fault studies

The validity of the proposed logic was exhaustively tested by simulating various types of fault, energisation conditions and sympathetic inrush on a 13.8 kV system modelled in MATLAB with a 2100MVA, 13.8KV/735KV, Star – star connected transformer. The relay was able to correctly discriminate between sympathetic inrush, internal faults, and non-fault disturbances.

The parameters used by the transformer are shown in table II. And fig.5. shows the simulated electrical power system.

ISSN: 2278-0181
Vol. 1 Issue 7, September - 2012

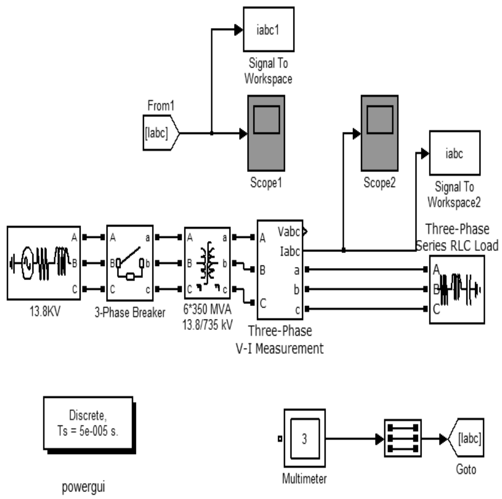



Fig.5. simulated electric power system

**Table II**

**Transformer parameters under no-fault condition**

| S.No | Specification | Value |
|---|---|---|
| 1. | Primary voltage | 13.8KV |
| 2. | Secondary Voltage | 735KV |
| 3. | Primary resistance (p.u) | 0.002 |
| 4. | Secondary resistance(p.u) | 0.002 |
| 5. | Primary inductance (p.u) | 0.08 |
| 6. | Secondary inductance (p.u) | 0.08 |
| 7. | Nominal power of transformer | 2100MVA |
| 8. | Transformer Frequency | 50 |
| 9. | Magnetization resistance | 500 |
| 10. | Winding type | Star –star |

## 5. Hardware implementation

### 5.1 Hardware description

The main purpose of this section is to explain how to design the fuzzy based differential proto type relay for the protection of power transformer including hardware and software implementation.

The system has been implemented using AT89S52, PIC16F877A. These were employed for developing the prototype relay, with all the coding done using microcontroller C and PIC basic languages. Kiel uVision3 and PIC Simulator IDE, these two software been used for loading the programs on chip. A special terminal program, developed in C language was used to apply the current input signals to the prototype relay in real-time by using of MAX232 serial data communication. The logic is deterministic, computationally efficient, secure and highly reliable.

Before looking the details of designing this project, it is best to start with brief review of the system design. Figure.6 shows the complete system design of the proposed proto type relay.

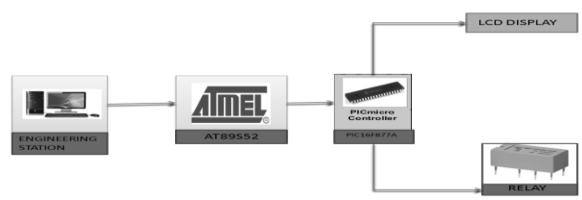



Fig.6. Block diagram of the system

#### 5.1.1 Circuit diagram for the proto type relay

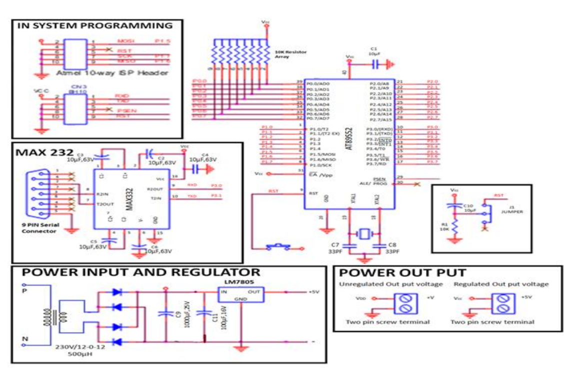



Fig.7. Interfacing of MAX232 and AT89S52

ISSN: 2278-0181
Vol. 1 Issue 7, September - 2012

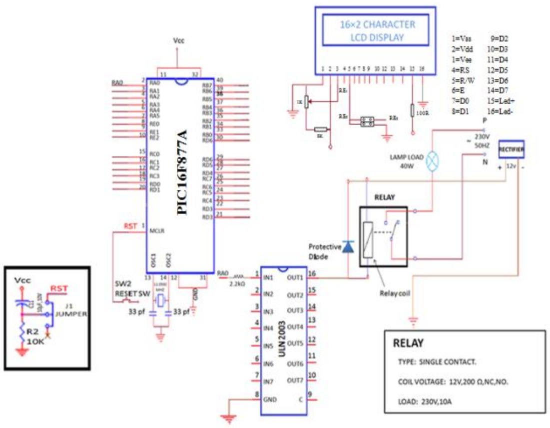


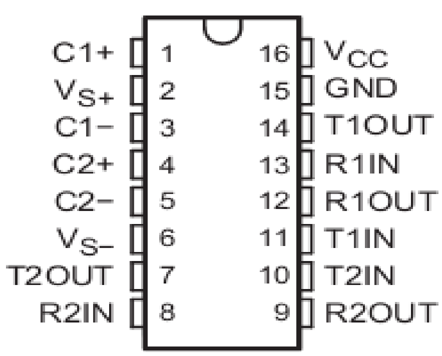

Fig.8. Interfacing facing of AT89S52,PIC16F877A,LCD and relay

### 5.1.2 MAX232

### Features

1) Operates From a Single 5-V Power Supply
2) With 1.0-µF Charge-Pump Capacitors.
3) It is very much useful for serial data communication.
4) Two Drivers and Two Receivers
5) ±30-V Input Levels
6) Low Supply Current ...8 mA Typical.

### Pin configuration



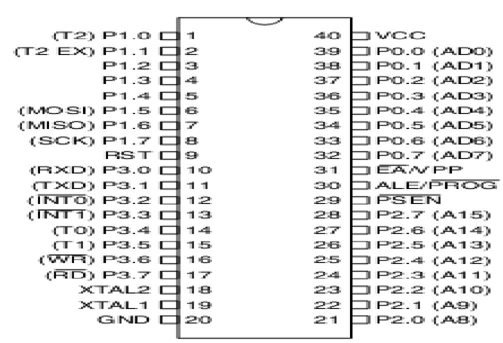

### 5.1.3 AT89S52

The AT89S52 is a low-power, high-performance CMOS 8-bit microcontroller with 8K bytes of in-system programmable Flash memory. The device is manufactured using Atmel's high-density non-volatile memory technology and is compatible with the industry standard 80C51 instruction set and pin Out. The on-chip Flash allows the program memory to be reprogrammed in-system or by a conventional non-volatile memory programmer. By combining a versatile 8-bit CPU with in-system programmable Flash on a monolithic chip, the Atmel AT89S52 is a powerful microcontroller which provides a highly flexible and cost effective solution many embedded control applications.

### Features

1) Compatible with MCS®-51 Products
2) 8K Bytes of In-System Programmable (ISP) FlashMemory-Endurance:10,000 Write/Erase Cycles
3) 4.0V to 5.5V Operating Range
4) Fully Static Operation: 0 Hz to 33 MHz
5) Three-level Program Memory Lock
6) 256 x 8-bit Internal RAM
7) 32 Programmable I/O Lines
8) Three 16-bit Timer/Counters
9) Eight Interrupt Sources
10) Full Duplex UART Serial Channel
11) Low-power Idle and Power-down Modes
12) Interrupt Recovery from Power-down Mode
13) Watchdog Timer
14) Dual Data Pointer
15) Power-off Flag
16) Fast Programming Time
17) Flexible ISP Programming (Byte and Page Mode)

### Pin Configuration

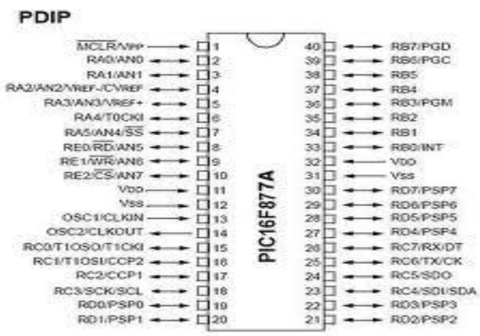


ISSN: 2278-0181
Vol. 1 Issue 7, September - 2012

### 5.1.4 PIC16F877A

The PIC16x84 is a microcontroller in the PIC family of controllers produced by Microchip Technology. The PIC16x84 became popular in many hobbyist applications because it uses a serial programming algorithm that lends itself to very simple programmers. Additionally, it uses EEPROM memory, so it's easy to erase and requires no special tools to do so. It also has a 64 byte EEPROM for storage of user data. The PIC16x84 was easily tweaked to allow crackers to Then produce the source assembly files.

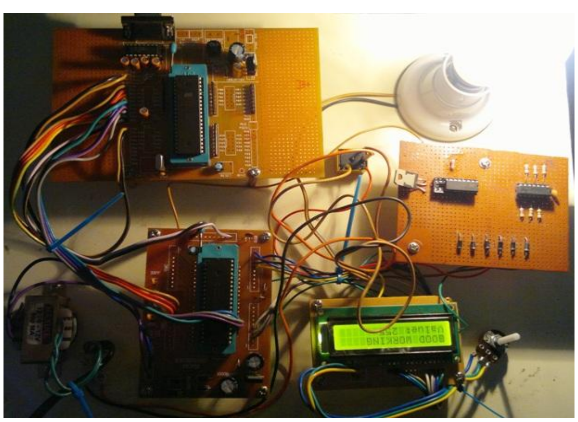
### Pin configuration




### 5.1.5 16 x 2 Character LCD FEATURES

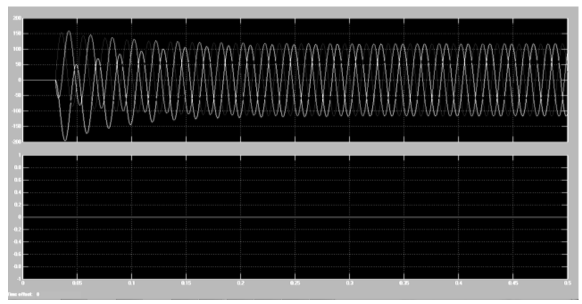
1) 5 x 8 dots with cursor
2) Built-in controller (KS 0066 or Equivalent)
3) + 5V power supply (Also available for + 3V)
4) 1/16 duty cycle
5) B/L to be driven by pin 1, pin 2 or pin 15, pin 16 or A.K (LED)
6) N.V. optional for + 3V power supply

## 6. hardware pictures

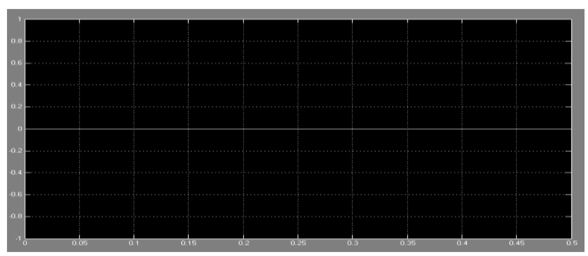


## 7. Result and discussion

The main purpose of this section is to present some results regarding the proposed algorithm. Various different tests were simulated for distinct operating conditions of power transformer shown in bellow. For brevity, only few cases were taken here.



**(a)**

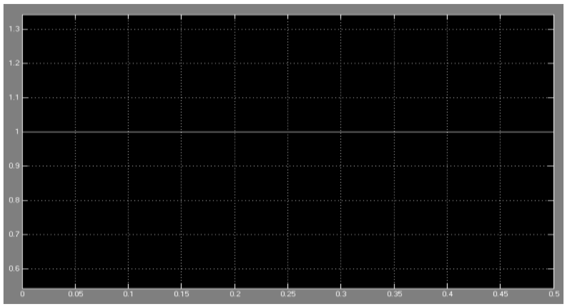


**(b)**

Fig.8.(a) Transformer primary and secondary current for the inrush condition.(b) Relay output.

The figure 8.(a) shows the transformer inrush currents transients in the primary side during energization of the transformer without any load. And the 8. (b) Shows the relay output. From the figure it is observed that the proposed technique is deterministic. The value zero Conclude that in case inrush current the proposed relay is not giving any trip signal to the circuit breaker.

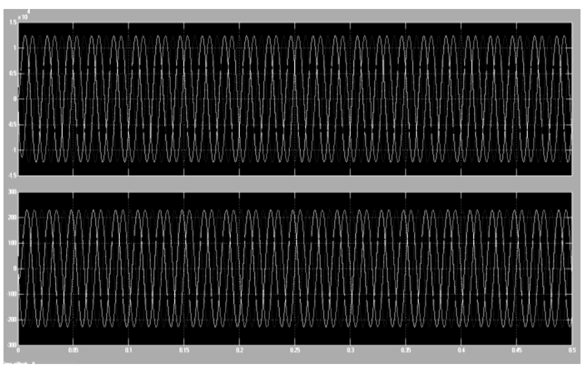
**(a)**



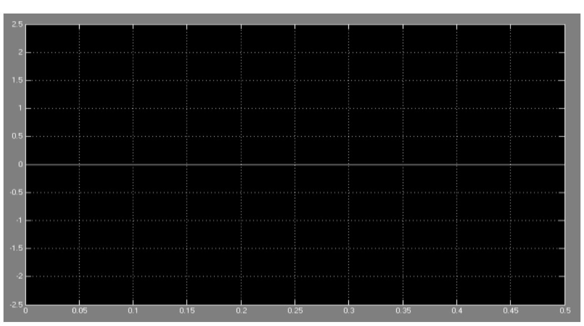
**(b)**

Fig.9(a) Transformer secondary and primary current for energisation under fault condition.(b) Relay output.

Fig-9.(a) shows the transformer primary and secondary side during energization of the transformer under fault condition. And the 9.(b) shows the relay output. It can be observed that in the energization under fault condition it attains the value above the threshold value, so it gives the trip signal to the circuit breaker.



**(a)**



**(b)**

Fig.10(a) Transformer secondary and primary current for no fault condition.(b) Relay output.

Fig-10.(a) shows the primary and secondary current of the transformer during normal operating condition. And from the fig-10(b) shows the relay output, which can conclude that at the normal condition the proposed method sent no trip signal.

The proposed relay was able to discriminate between inrush, fault and no-fault conditions. Thus the proposed technique is deterministic, secure and highly reliable in both simulation environments as well as in laboratory test. **Table-III** shows the experimental results for the proposed prototype relay. These are given bellow.

## Table-III Experimental results for relay

| Various cases | Relay output |
|---|---|
| Inrush current | No trip |
| Energization under fault | Trip |
| No-fault | No trip |

## 8.conclusion

The paper presents a new algorithm differential protection power transformer based on fuzzy logic and application of Clarke's transform shows a vastly improved performance over conventional techniques. The obtained result shows that the proposed fuzzy based differential relay represents a proper action. It can operate with proper sensitivity and even without tap changing effect using fuzzy logic with Clarke's transform that is proposed here solves this problem. Thus the use of fuzzy logic with Clarke's transform can make it possible to extend reliability and sensitivity of differential relays for power transformer.

## Acknowledgment

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