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Monitoring of Distribution Transformer Faults using Power Line Communication

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Abstract

Distribution transformers of substation are one of the most important equipment in power system network. Because of the large number of transformers and various components over a wide area in power systems, the data acquisition, condition monitoring, automatic controlling are the important issues. This project presents design and implementation of automatic control circuits using power line communication to monitor as well as diagnose condition of transformers, like over voltage, over currents, temperature rise and oil level. The suggested power line communication monitoring system will help to detect internal faults as well as external faults of transformer and also diagnose these faults with the help of desired range of parameters which is setting by programmer.
Keyword- Distribution Transformer, Faults, PIC 16F877 Microcontroller

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I. INTRODUCTION

Transformers are considered as the backbone of the electrical power system. Its special characteristic features enable, flexible transmission of power i.e. from generating station to the distant loads. Chance of fault occur in transformers are rare as compared transmission lines, but the damage caused by the faults usually takes more time and money to repair. Fast clearing of faults, however, assist in reducing the damage to the equipment. It also diminishes the chances of interruption in power service caused by drop in voltage and instability of system.

Most of the transformers installed in the power system are designed for all time duty. Hence, it is required to ensure the life of the transformer is made as long as possible. This necessitates protection of the transformer from various causes that could lead to failure. Hence automatic protection of transformers against possible faults is essential and of at most importance.

Choice of the protective gear for a transformer depends upon several factors such as:

1) Type of transformer
2) Size of transformer
3) Type of cooling
4) System where it is used ie, its electrical location in the network

There are number of factors, which affect the life expectancy of the transformer and these should receive the careful consideration. Mainly failure of transformer occurs when it is operated for long time under the following condition.

A. High Temperature

The temperature rise can cause deterioration of insulation. At the winding temperature of 98%, insulation occurs at a normal rate. In a temperature zone extending upto 1400˚C, the rate of deterioration increases exponentially with temperature. Temperature rise cause an insulation failure and thereby the failure of the transformer.

Rise of temperature may be caused by the following reason:

1) External Fault

A line or a line to ground fault result in heavy current flow, which causes the rise of temperature at a drastic rate. This result in decomposition of insulating oil to form bubbles there by sinking the oil and also it cause the deterioration of the winding insulation.

2) Internal Faults

If an internal fault such as a inter turn fault of coolant, bad load sharing, core fault, poor electrical contact etc. occur by any chance, it is also results in rise of temperature leading to the same consequences as mentioned above.

3) Continuous Operation under Heavy Load

Continuous Operation under Heavy Load: Continuous operation under load can also cause high temperature. Normally transformers are designed to withstand an over load of about 50% for a short duration (with rated power up to 100MVA). The temperature rise during this duration may not exceed the limit. But if the transformer is made to operate under heavy load for duration more than the specified, the associated temperature rise may exceed the permitted limit and may lead to the circumstances mentioned before. The overloading occurs when the utility slowly increases the load in small increments over time. The capacity of the transformer is exceeded, resulting in excessive a temperature that prematurely ages the insulation. As the transformer's paper insulation ages, the strength of the paper is reduced. Then forces from an outside fault may cause a deterioration of the insulation, leading to failure.

B. Over Current

A transformer build in accordance with the IS standards may be operated at its KVA at any current with + or – 10% of the voltage. If the transformer is subjected to over currents beyond this limit it may lead to failure of transformer. Over current in transformers may be caused due to external short circuit and is also cause damage to transformer winding because they create massive electromechanical forces and currents that subject the winding assemblies to incredible forces. This type of short circuit is always on the downstream side or secondary of the transformer. But the main reason that causes over current in a transformer is due to overloading of the device.

C. Over Voltage

Each winding of the transformer will be assigned a value of highest voltage for equipment which the maximum value of the highest voltage of a system to winding may be connected with respect to its insulation. The line surge (line disturbance) is the number one cause for all types of transformer failures. This category includes switching surge, voltage spikes, line faults/flashover, and other transmission and distribution (T&D) abnormalities. This significant portion of transformer losses indicates that more attention should give to providing surge protection, or testing the adequacy of surge protection.

D. Sinking of Oil Level

The transformer oil provided in the tank is mainly intended for two purpose:

1) To provide necessary insulation
2) To facilitate cooling

Therefore it is very important that required amount of oil to be always available in the tank. If not, adverse effects on both the insulation and cooling system can be observed. The non-visibility of the oil level due to accumulated dust may not show the exact level in the tank. The oil is likely to go below the core level, this leads to excessive temperature rise and failure of inter turn insulation and flash over the windings. The sinking oil level in the transformer tank occurs due currents and other such factors.

E. Methods to Overcome Failure

Several methods are adopted for the protection transformers, some of the common methods are mentioned below.

1) Over current protection can be achieved by providing fuses, on both primary and secondary sides of the transformer.
2) For over voltage protection lightning arrestors can be provided on both sides of transformer.
3) Reduction in oil level can be controlled beyond exceeding the permanent limits by providing sufficient volume of reserve oil an additional tank.

The first two methods is already employed in the distribution level of power system. In case of over voltage protection, lighting arrestor is provided only on the primary side as its uneconomical to be provided also on the secondary. The next method is uneconomical to adopted in a distribution transformer. The last method mentioned is usually employed in the protection scheme of power transformers. As it's economical and can be easily employed in the distribution transformer system. Power Line Communication (PLC) is a communication technology that enables sending data over existing power cables.

The system will monitor various parameters such as over voltage, over current, temperature rise and oil level reduction and indicate to substation if there is any fault in the system. The fault indication will be sent through the power line to the substation. A relay system is provided to trip the circuit during fault condition.

II. DESIGN OF PROPOSED SYSTEM

The overall aim of the project is to build a microcontroller based transformer protection with transformer parameters monitoring capabilities. This protection is based on the transformer parameters fed into the ADC of the microcontroller and monitoring the transformer parameters. Immediately a fault is detected the microcontroller taking necessary action through power line communication.

The entire project is divided into two. First part of the project is to design and build the hardware of the entire system. Here we use 11kVA/415V distribution transformer, voltage sensor, current sensor, temperature sensor, oil level sensor, PIC 16F877 microcontroller, LCD display, alarm and indicator. The second part is the development of a program in microcontroller that will indicate the fault of the distribution transformer algorithm.

The highest priority is given to the software design and implementation in order to develop a suitable algorithm that will promptly interact with the microcontrollers through power line communication.

III. PROPOSED SYSTEM

The proposed system will monitor the various parameters such as voltage, current, temperature and oil level and will indicate to the substation if there is any fault. The fault signal will be send to the substation through the power line for fault indication.

The fig1 shows the block diagram of proposed system. It consists of distribution transformer, sensors, microcontroller, LCD display, alarm and indicator. Here we use different types of sensors for sensing voltage, current, and temperature and oil level. The output of the sensors is fed to the ADC port of PIC 16F877 microcontroller. It reads the value and display on LCD. And also compare with set value if any condition will be satisfied it produce a signal send to the PIC 16F877 microcontroller which is placed in the substation for indicating corresponding fault.

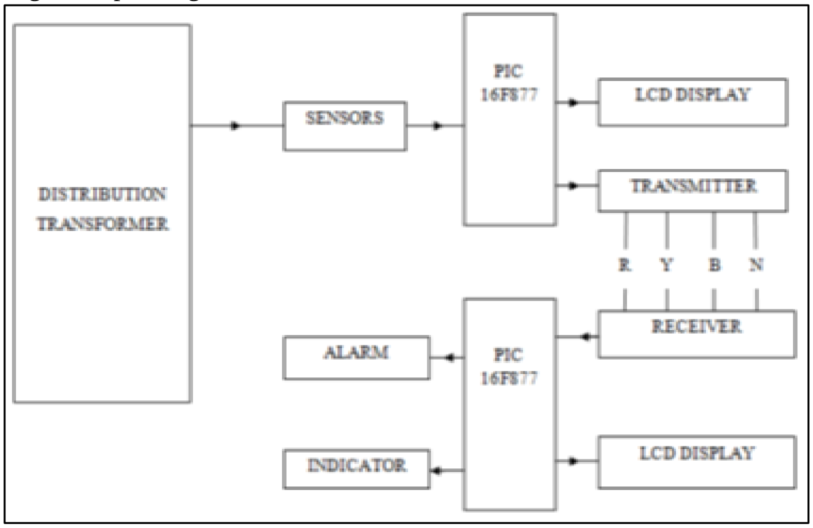

Fig. 1: Block Diagram of Proposed System

A. Distribution Transformer

Distribution transformers normally have ratings up to 250 kVA, although some national standards can describe units up to 5000 kVA as distribution transformers. Since distribution transformers are energized for 24 hours a day (even when they don't carry any load), reducing iron losses has an important role in their design. As they usually don't operate at full load, they are designed to have maximum efficiency at lower loads. To have a better efficiency, voltage regulation in these transformers should be kept to a minimum. Hence they are designed to have small leakage reactance.

Distribution transformers are used in the distribution system in order to step down voltage (11kV/415V). It is costly and critical equipment in electricity distribution network which feeds different types of loads such as domestic, commercial, agriculture, industrial etc. Hence distribution transformers form the essential link between power utility grid and large number of consumers.

B. Sensors

Here four types of sensors are used. They are voltage sensors, current sensors, temperature sensors and oil level sensors.

1) Voltage Sensors

In voltage sensor, potential transformer is used for sensing the voltage. Potential transformer is an instrument transformer. This transformer step down the voltage to a safe value. The potential transformer is mainly classified into two, i.e. the conventional wound types (electromagnetic types) and the capacitor voltage potential transformers. Conventional wound type transformer is very expensive because of the requirements of the insulation. So we use capacitor voltage transformer.

a) Capacitor Voltage Transformer (CVT)

Capacitor potential transformer is a combination of capacitor voltage divider and magnetic potential transformer is relatively small ratio. The circuit diagram of the capacitor potential transformer is shown below.

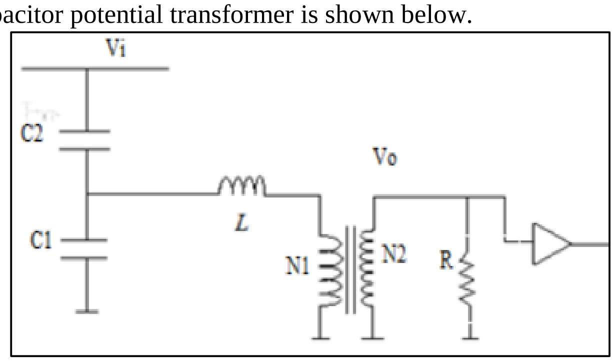

Fig. 2: Circuit diagram of Capacitor Voltage Transformer

When we have major the voltage are very high voltage lying then we require a transformer with high insulation, this transformer become very expensive. To solve this problem we use capacitor type potential transformer or capacitor voltage transformer (CVT). Capacitor 1C is much greater than 2 C so the impedance is very low. Therefore voltage across 1C is very low. This low voltage is fed to the transformer. When a load is connected across the secondary side of the transformer there is a phase shift between load resistor and capacitor 1C . So we use an inductor for compensating the phase shift.

$$\frac{V_0}{V_I} = \frac{C_1}{C_2 + C_1} * \frac{N_2}{N_1}$$

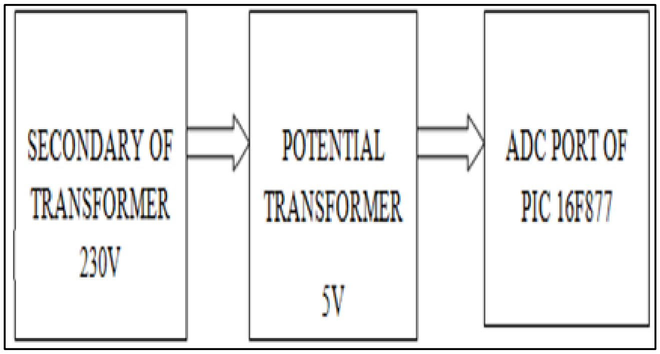

Fig. 3: Block diagram of voltage sensor

The phase voltage from the secondary side of the distribution transformer is supplied as input to the capacitor voltage transformer. The stepping down of phase voltage is done using the capacitor voltage transformer having a transformation ratio 230/5V. The received voltage clamped to a reference of 2.5V to include negative cycle also. The output voltage is fed as input to the ADC port of PIC 16F877 microcontroller. The above explanation is for a single phase. Similarly the same can be applied to the other two phases.

2) Current Sensor

In current sensor current transformer is used for sensing the current. Current transformer is an instrument transformer that is designed to produce an alternating current in its secondary winding which is proportional to the current being measured in its primary. Current transformer is used for the transformation of current from a higher value into a proportionate current to a lower value. It provides a convenient way of safely monitoring the actual electrical current flowing through in a transformer.

The current sensor ACS756 was used because the current sensor IC provides economical and precise solution for AC or DC current. The current sensor is capable of measuring upto 50amps. The monitored current value is displayed on the LCD display and as soon the voltage transformer is overloaded if current transformer sends the information through the ADC port of microcontroller.

The current from the secondary side of the distribution transformer is supplied as the input to the current transformer. The stepping down of the current is done using the current transformer having a transformation ratio 50/5A. This is converted to proportional voltage drop through a resistor. The received voltage is clamped to a reference of 2.5V to include negative cycle. This is amplified using an Op-amp and fed as input to the microcontroller. The above explanation is for single phase. Similarly the same is applied to the other two phases.

3) Temperature sensor

LM 35 was chosen to be the temperature sensing devices in this project. The LM 35 series are integrated circuits, temperature sensors, whose output linearly proportional to the Celsius temperature. The LM 35 thus has advantage over linear temperature sensors calibrated in degree Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient centigrade scaling with a rated operating temperature range of over -55ºC to +150ºC.

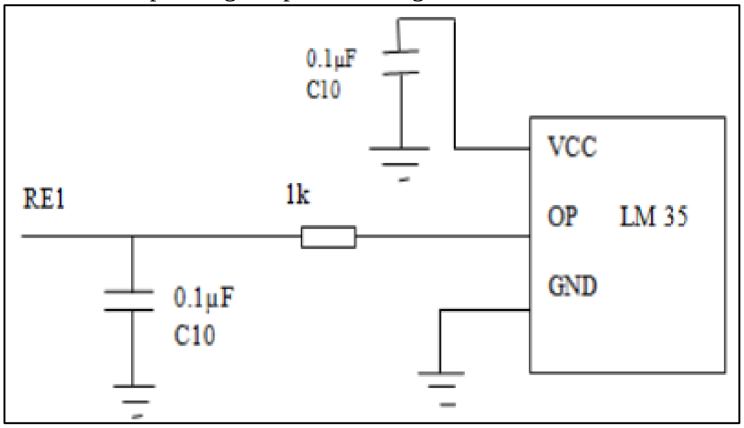

Fig. 4: Temperature sensing circuit

4) Oil Level Sensors

Here potentiometer is used for sensing oil level of the distribution transformer. The measuring instrument called a potentiometer is essentially. A voltage divider used for measuring electric potentiometer. Potentiometers are commonly used to control audio equipment. Potentiometers operated by a mechanism can be used as position transducers.

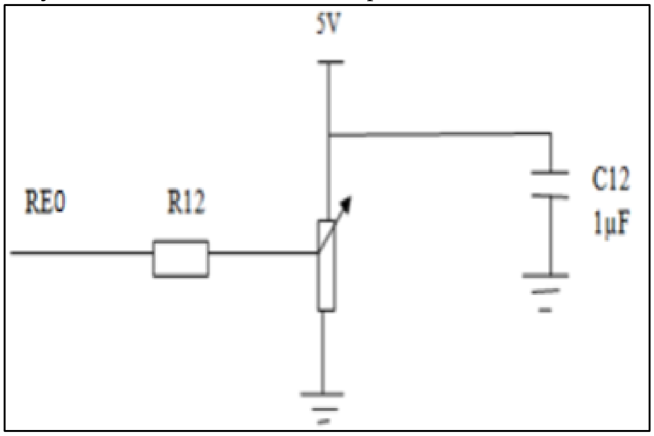

Fig. 5: oil level sensing circuit

Sensing of oil is done using a float. The movement of float will cause a proportional movement of the variable terminal of a potentiometer, which changes the resistance. By the variation in the value of resistance, position of floats transducer to a corresponding voltage signal. Thus the resistance offered by POT determines the magnitude of voltage at input terminals of PIC.

C. PIC 16F877 Microcontroller

The PIC microcontroller PIC 16F877 is an most useful microcontrollers in the industry. This controller is very convenient to use the coding or programming of this controller is also easier. One of the main advantage is that it can be right arise as many times as possible because it use FLASH memory technology. It has a total number of 40 pins and there are 33 pins for input and output.

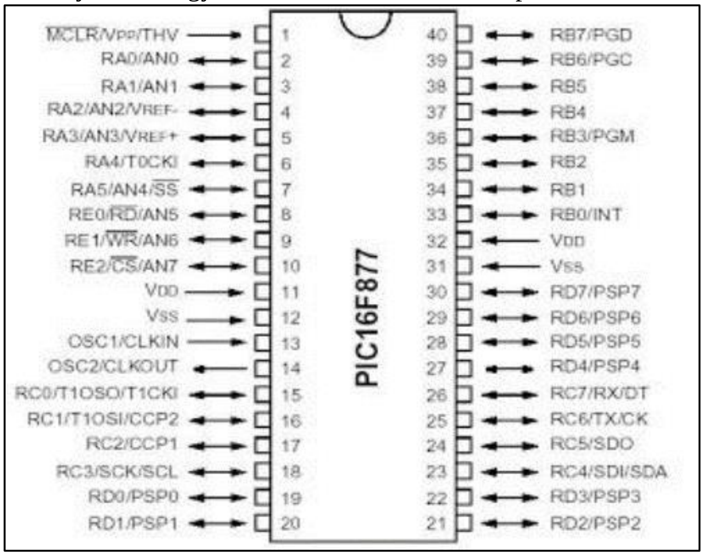

Fig. 6: PIC 16F877 microcontroller

a) Pin Configuration and Description of PIC 16F877

There are 40 pin microcontroller IC. It consist of two 8 bit and one 16 bit timer. Capture and compare modules, serial ports, parallel ports and 5 input output ports and also present in it.

Pin 1: MCLR

The first pin is the master clear pin of the IC. It resets the microcontroller and is active low, meaning that it should constantly be give a voltage of 5V and if 0V are given than the controller is reset. Resetting the controller bring it pack to the first line of the program.

Pin 2: RA0/AN0

PORT A consist of 6 pins, from pin 2 to pin 7, all of this are bidirectional input/output pins. Pin 2 is the first pin of this port. This pin also can be use an analog pin ANO. It is built in analog to digital converter. The out from oil level sensor.

Pin 3: RA1/AN1

This can be analog input 1.

Pin 4: AN2/Vref
It can also act as analog input 2 or negative analog reference voltage given to it.
Pin 5 RA3/AN3
It act as as analog input 3 or can act as analog positive reference voltage.
Pin 6: RA0/T0CKI
To time 0 this pin can act as the clock input pin.
Pin 7: RA5/AN4/SS
This can be analog input 4. There is synchronous serial port in the controller.
Pin 8: RE0/RD/AN5
PORT E start from pin 8 to pin 9 and this also a bidirectional input output ports. It can act as read control pin.
Pin 9: RE1/WR/AN6
It can be analog input 6. The output of temperature sensor is fed to the pin number 9. It act as right control.
Pin 10: RE2/CS/AN7
It can be analog input 7 and also it act as control select.
Pin 11 and 32: VDD
These two pins are positive supply for the input or output and logic pins. It should be connected to 5V.
Pin 12 and 3: VSS
This pins are ground reference for input/output and logic pins. They should be connected to zero potential.
Pin 13: OSC/CLKIN
This is the oscillator input or the external clock input pin. This pin is fed to the 120 kHz carrier generator.
Pin 40: OSC2/CLKOUT
This oscillator output pin. A crystal resonator is connected between pin 13 and 14 to provide external clock to the microcontroller.
Pin 15: RC0/T1OCO/T1CK1
PORT C consists of 8 pins. It is also a bidirectional input output port. It can be clock input of timer 1 or the oscillator output of timer 2.
Pin 16: RC1/T1OCI/CCP2
It can be the oscillator input of timer 1.
Pin 17: RC2/CCP1
The transmitter of X-10 is connected across RC2 and RB0.
Pin 18: RC3SCKSCL
It can be input/ output for synchronous serial clock.
Pin 23: RC4/SDI/SDA
It can be SPI (Serial Port Input) data.
Pin 25 : RC6/TX/CK
It can be synchronous clock or USART asynchronous transmit pin.
Pin 26: RC7/RX/DT
It can be synchronous data pin or the USART receive pin.
Pin 19, 20,21,22,27,28,29,30:
All of this pins belongs to PORT D which is again a bidirectional input and output port.
Pin 33 -40: PORT B
All this pins belongs to PORT B. Out of which RB0 can be used as the external interrupt pin and RB6 and RB7 can be used as in circuit debugger. The LCD are connected to this pin.

The proposed system is based on microcontroller for monitoring transformer parameters like voltage, current, temperature and oil level for the protection of distribution transformer. The transformer parameters fed into the ADC port of the microcontroller and comparing the transformer voltage, current, and temperature and oil level with its set up value. When a fault occurs microcontroller will send a signal to the substation microcontroller for indicating fault. The signal will transmit through the power line with the help of X-10 technology.

D. Transmitter

The transmitter section is used to send various parameter values such as voltage, current, temperature and oil level to the receiving station through power line. The values are send during each zero crossing of the sinusoidal 50Hz signal. The values are send at 120 kHz as Pulse Width Modulation (PWM).

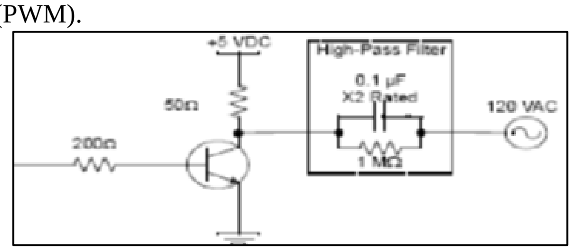

Fig. 7: Transmitter circuit

The above figure shows the block diagram of transmitter section. The output from the microcontroller is fed to the X-10 transmitter. Transmitter consists of a bipolar NPN transister and high pass filter. NPN transistor amplify the signal from microcontroller. The amplified signal is pass through the high pass filter to remove an wanted signal. Then the signal transmitted through the 120 kHz generator. Already above mention the data signal transmitted in 120 kHz frequency because of the signal does not interfere with other signal.

a) 120 kHz Carrier Generator

X-10 uses 120 kHz modulation to transmit information over 50Hz power lines. It is possible to generate the 120 kHz carrier with an external oscillator circuit. A single I/O pin would be used to enable or disable the oscillator circuit output. However, an external oscillator circuit can be avoided by using one of the PIC microcontroller Capture/Compare/PWM (CCP) module. The CCP1 module is used in PWM mode to produce a 120 kHz square wave with a duty cycle of 50%.

The fig 8 shows the circuit diagram of 120 kHz carrier generator. The high pass filter allows the 120 kHz signal to be safely coupled to the 50 Hz power line, and it doubles as the first stage of the 120 kHz carrier detector. To be compatible with other X-10 receivers, the maximum delay from the zero crossing to the beginning of the X-10 envelope should be about 300µs. Since the zero crossing detector has a maximum delay of approximately 64µs.

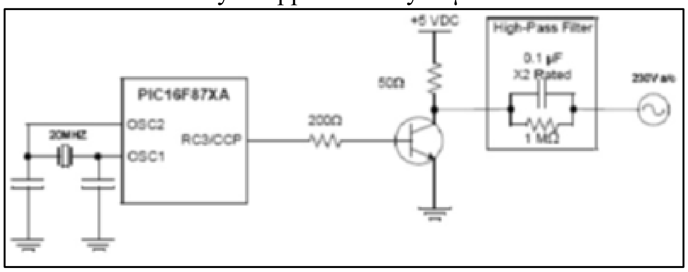

Fig. 8: 120 kHz Carrier Generator

E. Receiver

To receive X-10 signals, it is necessary to detect the presence of 120 kHz signal on ac power line. It consists of decoupling capacitor, high pass filter, tuned amplifier and envelop detector. These are shown in figure below.

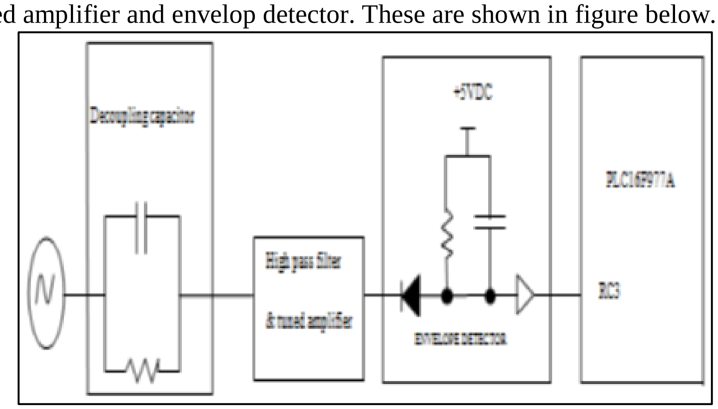

Fig. 9: Signal isolation module and envelope detector

IV. FLOW CHART

The flow chart diagram developed with given an initial description of the system. The programs are divided in to two parts which are main program and interrupt program (receiver program).The microcontroller will always loop the main program until an interrupt occurred. When the controller receives an interrupt flag, then it will jump to interrupt the process.

The flow chart gives a diagram representation of the program. The system flow chart is designed as shown below. The flow chart above shows the initial description of the system program. The first thing the program will do initialize input, output ports and read ADC. Then the transformer parameters which fed to the microcontroller and the status of transformer display on LCD. The microcontroller continuously capturing the transformer parameter and compare with predetermined value.

When the transformer voltage is greater than predetermined value a signal passes through the power line. It also sends an alarm signal to the alarm circuit and also displays the transformer voltage on LCD. And also transformer current is greater than predetermined value a signal passes through the power line. It also sends an alarm signal to the alarm circuit and also display the transformer current on LCD. Then the microcontrollers compare the temperature of transformer greater than predetermined value a signal passes through the power line. It also sends an alarm signal to the alarm circuit and also displays the temperature status on LCD.

Microcontroller compare oil level of a transformer with a predetermined value .if it is less than the predetermined value a signal flow through the power line, it also send an alarm signal to an alarm circuit. When a condition is failure on each check the control pass to the monitoring of transformer parameters or it act as a loop.

Fig. 10: Flow Chart

V. FUTURE SCOPE

X-10 technology offers a solution that was initially developed to integrate with low cost lighting and appliance control devices. It is now trying to innovate into higher speed with regard to establishing the communication between home PCs and controlled appliances.

In a substation may implement a backhaul connection. Which connect to a PLC unit that connect to the medium voltage grid. Repeater units or similar head end units are placed on the medium voltage grid at intervals to connect substation together and back to the backhaul connection. Signalling could use Digital Spread Spectrum (DSS) where signals pass through line equipment as this less expensive.

In future we can implement two way communications simultaneously using power line. In airport the signal light can be controlled by sending control signals through power line. There is wide application in railways with power line communication. We can use this techniques for knowing the status of train through power line.

VI. CONCLUSION

In this paper we have presented a design of a system based on PLC that is used to monitor and control the voltage, current, temperature and Oil level of a distribution transformer in both sides. The proposed PLC system which has been designed to monitor the transformers essential parameters continuously monitors the parameters throughout its operation. When the PLC recognize any increase or decrease in the level of voltage, current, oil level or temperature values. The unit has been made shut down in order to prevent it from further damages with the help of relays in three phase system. This claims that the proposed design of the PLC system makes the distribution transformer more robust against some key power quality issues which make the voltage, current or temperature to peak. Hence the distribution is make more secure, reliable and highly efficient by means of the proposed system.

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