Protection of Distribution Transformer using PLC and SCADA based System

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***Abstract*— The online monitoring of distribution transformer is required for automation as well as protection of transformer. In this paper, the automation of distribution transformer has been done by using Programmable Logic Controller (PLC) based system. In this system, various types of sensors and transducers are required for sensing various input parameters of transformer. The various special protection systems are available which is based on volume of power distributed and often the load changes without prediction required modified and a special communication based systems to control the various electrical parameters. In electrical environment have lots of disturbance in nature, due to natural disasters like as storms, cyclones or heavy rains transmission and distribution lines may lead to damage. Most of the existing systems are reliable on various applications but not perfect for electrical applications. A Supervisory Control and Data Acquisition (SCADA) based system is also required for real time operation and online monitoring of transformer. The combination of PLC and SCADA is given the reliable real time operation and proper online monitoring of present state of distribution transformer.**

Keywords- PLC; SCADA; Distribution Transformer; Sensors; Transducers; Modbus driver; RSVIEW32

I. INTRODUCTION

Distribution transformer is an electrical transformer that is used to carry electrical energy from a primary distribution circuit to a secondary distribution circuit. This can also be used to transfer the current within a secondary distribution circuit or to the service circuit. In this paper, the various types of faults, which are related to distribution transformer, is discussed. A fault in electrical equipment is defined as a defect in its electrical circuit due to which the current is diverted from the intended path. The paper of Rohan Perera & Bogdan Kasztenny presents practical solutions to protect transmission lines with multiple taps [7]. If the fault impedance is being low then the fault currents are relatively high. At the fault conditions duration, the power flow is diverted towards the fault and supply to the neighboring zone which is affected [6]. Voltages become unbalanced. It is necessary to detect the fault as early as possible that is why a kit is being made using microcontroller to make a fast processor. This phenomenon will detect following four major faults and will give trip signal to relay.

The research work of ref. 2 has been done in designing and developing a Novel Distribution Automation System (DAS) in an open loop customer side distribution system [2].

In this project, it will be done to eliminate transient response after fault occurring on distribution transformer. Since it is not considering all types of fault on transformer, here, this is interested in only the fault analysis of transformer due to over/under voltage fault, over/under current fault and over temperature fault on both sides of transformer by using PLC. Basically, the main objectives of this paper are following as below:

- Firstly, the transformer protection system will be fully automated by using PLC based system.
- Secondly, the Supervisory Control and online monitoring of transformer protection system will be implemented by using SCADA based system.

II. MAJOR FAULTS IN DISTRIBUTION TRANSFORMER

The faults in distribution transformer are mainly classified as two types which are external faults and internal faults. The internal incipient transformer faults usually develop very slowly in the form of a gradual deterioration of the insulation due to some causes [1]. This is essential to protect the high values of variables in transformer against external and internal electrical faults.

A. External Faults in Distribution Transformer

1) External Short Circuit of Distribution Transformer:

The short circuit may occur in two or three phases of power system. The fault current level is always high. This depends upon the voltage at phase which has been short circuited and upon the impedance of the circuit up to the fault point margin. The winding loss or resistance loss or copper loss of the fault feeding transformer is abruptly increased. This increasing copper loss causes internal heating in the transformer.

2) High Voltage Disturbance in Distribution Transformer

High voltage disturbance in distribution transformer are of two kinds which are transient surge voltage and power frequency over voltage.

Transient Surge Voltage: The transient high voltage and high frequency surge may arise in the power system due to any of the following causes,

- To occur the arcing ground if neutral point is isolated.
- To occur switching operation of different electrical equipment.
- To occur atmospheric lightening impulse.

It is after all a traveling wave having high and steep wave form and also having high frequency in transmission line network. The transmission line wave travels in the electrical power system upon reaching in the power transformer of substation, it leads to breakdown the insulation between turns adjacent to line terminal which may create short circuit between turns.

Power Frequency Over Voltage: There may be always a chance of system over voltage due to sudden disconnection of large load in transformer. The amplitude of this voltage is higher than its normal level but frequency is same as it was in normal condition. Ali Kazemi & Casper Labuschagne's paper presents to provide over excitation protection for power transformers through a Volts/Hz element that calculates the ratio of the measured voltage to frequency in p.u. of the nominal quantities [8]. Over voltage in the system causes an increase in stress on the insulation of transformer. When the AC line frequency reduces in a power system network then the magnetic flux in the core increases then the effect are more or less similar to that of the over voltage.

B. Internal Earth Faults in Distribution Transformer

1) Internal Earth Faults in a Star Connected Winding with Earthed to Neutral Point through an Impedance

In this case the fault current is dependent on the value of earthing impedance and is also proportional to the distance of the fault point from neutral point as the voltage at the point depends upon the number of core winding turns come under across neutral and fault point limit. When the distance between fault point and neutral point is more than certain limit then the number of turns come under this distance is also more, therefore voltage across the neutral point and fault point is high which causes higher fault current.

2) Internal Earth Faults in a Star Connected Winding with Neutral Point Solidly Earthed

In this case, earthing impedance is zero ideally. That means the fault current is dependent up on leakage reactance of the portion of winding comes across faulty point and neutral point of transformer and also the fault current is dependent on the distance between neutral point and fault point in the transformer side. In previous case the voltage across these two points depends upon the number of winding turn comes across faulty point and neutral point. Therefore, in star connected winding with neutral point solidly earthed due to the fault current depends upon two main factors, one the leakage reactance of the winding comes across faulty point and neutral point and other is the distance between faulty point and neutral point.

3) Internal Phase to Phase Faults in Distribution Transformer

Phase to phase fault in the transformer are rare. When such a fault does occur, it will give rise to substantial current to operate instantaneous over current relay on the primary side as well as the differential relay.

4) Core Inter Turns Fault in Distribution Transformer

Distribution Transformer connected with electrical extra high voltage transmission line system, is very likely to be subjected to high magnitude of voltage, steep fronted as well as high frequency impulse voltage due to lightening surge on the transmission line network. The developed voltage stresses between winding turns become so large. Due to this, it cannot sustain the stress and causing insulation failure between inter turns in some points and also LV winding is stressed because of the transferred surge voltage on transformer. A very large number of distribution transformer failures arise from fault between turns. The inter turn fault may also be occurred due to mechanical forces between turns originated by external short circuit.

C. Core Fault in Distribution Transformer

In any portion of the core lamination is damaged or the core lamination is bridged by any conducting material cause's sufficient eddy current to flow. Therefore, this part of the core becomes over heated. Operational stresses can cause failure of the transformer winding, insulation, and core [4].Sometimes, insulation of bolts (Used for tightening the core lamination together) fails which also permits sufficient eddy current to flow through the bolt and causing overheating. This insulation failure in lamination and core bolts cause severe local heating. These local heating causes additional core loss but cannot create any noticeable change in input and output current in the transformer. So these faults cannot be detected by normal electrical protection scheme. This scheme is desirable to detect the local over heating condition of the transformer core before any major fault occurs. The excessive load current alone may not result in damage to the transformer if the absolute temperature of the windings and transformer oil remains within specified limits [5]. The excessive over heating leads to breakdown of transformer insulating oil with evolution of gases surrounded here. These surrounded gases are accumulated in Buchholz relay and actuating Buchholz Alarm.

The paper of Vinay Barhate starts with conventional methods like 2nd harmonic restraint and harmonic blocking under differential protection and proceeds to the DFT method, WT method, WPT method and then most recent techniques using Artificial Neural Networks, Fuzzy logic and Fuzzy Neuro techniques [9]. A Frequency response analysis (FRA)

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consists of measuring the impedance of a transformer winding over a wide range of frequencies and comparing results with a reference set [10]. The paper of R. Prudhvi Raj presents that the thermo couple is placed inside the transformer, temperature sensor is placed outside the transformer to overcome the over temperature fault [11].

III. SENSORS AND TRANSDUCERS

In this model, three transducers are used which are followed as Voltage transducer, Current transducer and Temperature transducer. The diagram of snapshot of used transducers is shown in fig. 1.

Figure 1. Snapshot of transducers

These transducers are analog transducers. The analog sensors produce a continuous output signal or voltage which is generally proportional to the measuring quantity. Any sensor is based on a simple concept that physical property of a sensor must be altered by an external stimulus to cause that property either to produce an electric signal or to modulate (to modify) an external electric signal.

A. Voltage Transducer

A voltage transducer is an element of electrical circuitry that both measures and monitors the levels of current and voltage dispersed and dispensed through the network depending on whether the current is AC or DC.

When the power supplied to the circuit is AC, a voltage transducer will monitor and measure the current more readily than the voltage while voltage transducers work mainly in conjunction with DC power sources and the measurement capabilities of different voltage transducers differ widely due to the many ranges of their application, from computer circuitry to large transformer circuits.

B. Current Transducer

A current sensor is a device that detects electrical current (AC or DC) in a wire and generates a signal proportional to its variable parameters. The generated signal could be analog voltage or current or even digital output. This can be then utilized to display the measured current in an ammeter or can be stored for further analysis in a data acquisition system or can be utilized for control purposes. An input current signal is scaled down through interposing current transformer (CT). The scaled down signal is fed to a precision rectifier stage then this output is processed to provide DC Voltage/ Current output signal proportional to input AC Current and the output signal is calibrated for RMS value.

C. Temperature Transducer

A temperature transducer is an electrical device usually used in automated air-temperature control sequences. Generally this purpose is to take a measurement of the air temperature and relay the information after translating it into a readable form to a power source for the mechanical part of the system. If once the information has been taken by the temperature transducer and relayed, then the information is sent to the unit power source. If the unit power source reveals the information from the temperature transducer, this either tells the system to stand idle or engage depending on the temperature that has been measured. When the temperature reads lower than the setting input to the system by the user requirement, the heating unit is told to engage until the air is measured by the temperature transducer to be as high in temperature as the user requirements. As the same principle is applied to cooling systems, in this condition the temperature is read to be higher than the setting input before the cooling system is engaged.

IV. INTERFACING WITH PLC SYSTEM

A PLC is primarily used to control machinery system. The programs written for PLCs consist in simple terms on instructions to turn on and off outputs based on input conditions and the internal program of PLC. One designed to be programmed once and run repeatedly as needed. If a process is controlled by a PLC it uses inputs from sensors to make decisions and update outputs to drive actuators as shown in fig. 2. The PLC based model process is a real process that will change over time. The actuators will drive the system to new states (or modes of operation). It means that the controller is limited by the sensors available. If an input of PLC is not available then the controller will have no way to detect conditions.

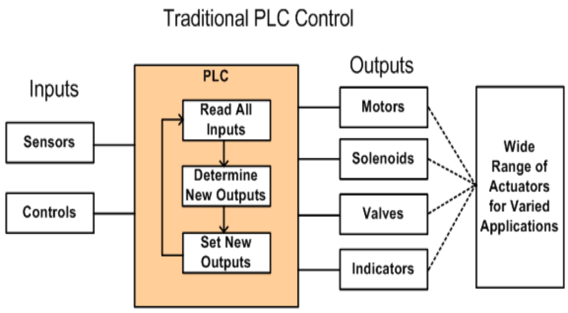

Figure 2. Basic functional diagram of PLC system

In this model, the five inputs and four outputs of PLC are used for interfacing with actual prototype model. The snapshot of working model is shown in fig.3.

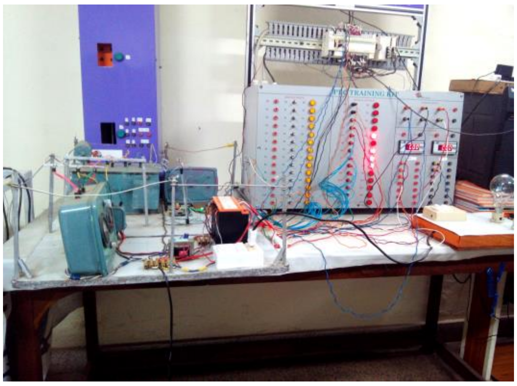

Figure 3. Snapshot of working model

The inputs are configured as:-

- I0 – Switching input
- I1 – Push Button
- I2– A Under voltage phase fault relay in primary side of transformer
- I3 – A over voltage phase fault relay in primary side of transformer
- I4 – A Overload or over current fault relay in primary side of transformer

The outputs are configured as:-

- Q0 – R Phase Relay
- Q1 – Y Phase Relay
- Q2 – B Phase Relay
- Q3 – Output for LED light

V. SCADA SYSTEM AND MODBUS COMMUNICATION

SCADA is a system operating with coded signals over communication channels so as to provide control of remote equipment (using typically one communication channel per remote station). The use of PLC has greatly reduced the cost of implementing new control circuits on the plant floor and has reduced the time needed to make various changes to the relay circuit as demanded by a given process and SCADA is used to make the system more accurate [3].This proposed system is an industrial control system where a computer system monitoring and controlling a process.

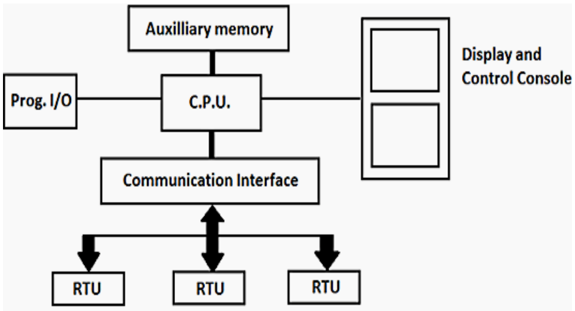

Figure 4. Functional block diagram of SCADA

Remote terminal units (RTUs) connect to sensors in the process and convert sensor signals to digital data. These have telemetry hardware capable of sending digital data to the supervisory system as well as receiving digital commands from the supervisory system or SCADA. A functional block diagram of SCADA is shown in fig. 4.

In this study, SCADA software used for Schneider PLC is RSView32 which helps to visualize different parameters of induction motor which are to be controlled. PLCs (programmable logic controllers) are the most commonly used controllers in today's industrial environment. The numbers of processes and machine control applications are controlled by the PLCs and their RS Logix software. A controlling the logical operation of a machine or a process is only half the solution.

VI. IMPLEMENTATION OF ACTUAL PROTOTYPE MODEL

The schematic block diagram of proposed project consists of different blocks which are following as below and this is shown in fig. 5.

A. Three Phase or Single Phase AC Power Supply

In this model, it can be used as a single phase or three phases. In this section, voltage controller (used for voltage variation), voltmeter (to measure voltage) and ammeter (to measure current) have been used. And also here, it has been used ON/OFF switch and push button which are connected with inputs of PLC (I0, I1).

B. Electromagnetic Relay (Output)

The three EM relays are used as a main circuit breaker of substation and the power supplies of relays are directly connected to the outputs of PLC (Q0, Q1 and Q2) and NO (Normally Open) terminals of these three relays are connected to main line.

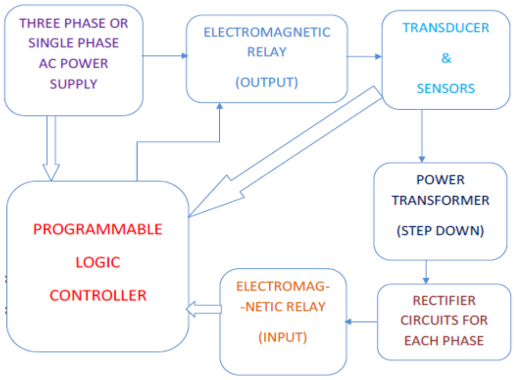

Figure 5. Schematic block diagram of proposed model

C. Transducer & Sensors

The voltage, current and temperature transducers are used. Its output side are connected with PLC and its input side are connected with actual model and these transducers are analog type.

D. Programmable Logic Controller

This PLC connection is made by five inputs and four outputs which is discussed in section-IV.

E. Distribution Transformer (Step Down)

In this model, a 12VA (Volt-Ampere), 230/12 V step down transformer is used.

F. Rectifier and Filtering Circuits for Each Phase

The secondary voltage of transformer is 12V AC. Because of LED light load works on DC, rectification is required to fulfil the necessary condition of load. And also filtering is required for pure dc output voltage at secondary side of transformer. The filtering process made by connecting capacitor between phase and neutral terminal. The rectification and filtering is made in all three phases and all are identical connection.

G. Electromagnetic Relay (Input Fault Sensing Relay)

The predefined three faults of secondary side of transformer are sensed which are following as an over current fault, under voltage fault and over voltage fault.

VII. RESULTS

In this model, PLC has been properly worked that means it can find the various faults which are over & under voltage, over & under current, and over temperature faults at primary side of transformer(HV) as well as under & over voltage and over current faults at secondary side of transformer(LV). At faulty condition, these LED lights do not glow. At normal condition of model, all 8 LED lights connected across the substation's boundary glow which is shown in fig. 6.

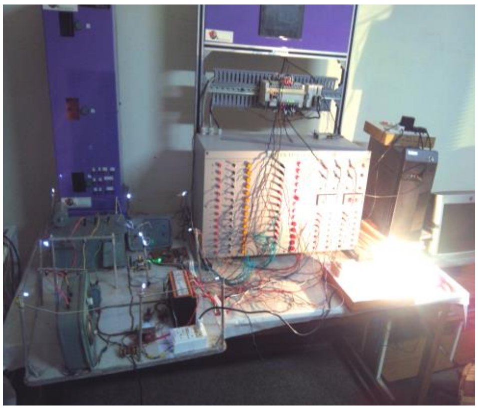

Figure 6. No-fault condition of running model

It has been given two different form of monitoring data which are following as below:

- Continuous Graphical Representation
- Bar Graph Representation

The values of voltage, current and temperature recorded at a particular time t1 is shown graphically in fig. 7. From fig.7, the red color graph represents voltage parameter, green represents current parameter and yellow represents temperature parameter.

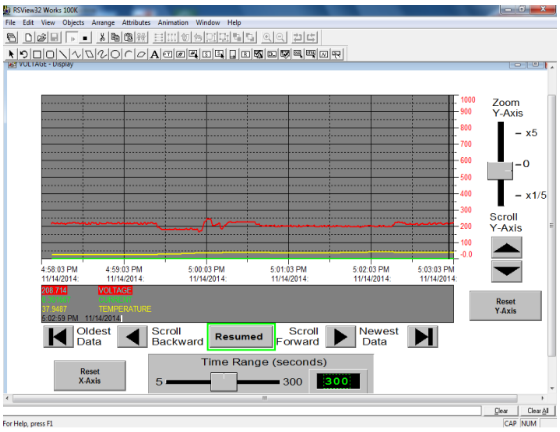

Figure 7. Screenshot of different parameters recorded at time t1

VIII. CONCLUSIONS

In this model, the proposed PLC based controlled protective relay deals with the most important types of these failures, which are summarized as the phase lost, the over/under current, the over/under voltage, the unbalance of supply voltages, the overload, the unbalance of phase currents and the ground fault.

If any fault is observed during online operation of the transformer, a warning message appears on computer and then the transformer is automatically OFF. The test has been found successful in detecting the faults and in recovering them. The voltage, current, winding temperatures of transformer are then directly being displayed on the computer screen with the help of the software developed. After having all these data these are controlled considering their tolerance values.

SCADA is used to monitor the real time information of transformers' variables voltage, current and temperature and also to give the statistical data record at different time intervals which is used to analyze the response time.

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