Transaction on Power System Distribution
ISSN: 2229-8711 Online Publication, June 2011
www.pcoglobal.com/gjto.htm
PS-M17 /GJTO

Global Journal of Technology & Optimization
Volume 2, 2011

SIMULATION OF SUBSTATION INTEGRATED MONITORING SYSTEM USING LABVIEW

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Received December 2010, Revised April 2011, Accepted May 2011

Abstract
This paper presents the new integrated monitoring system for high voltage electric power substation system. The substation has a crucial function to maintain the reliability and to keep the quality of an electric power transmission system. On the other hand, the exposure to high voltage environment may also be able to cause risk to human health. Therefore an integrated monitoring system is crucial to be implemented for easy monitoring and controlling the substation while minimizing interaction of human to the substation devices. All the substation devices conditions are displayed integratedly in Graphical User Interface (GUI) developed using LabVIEW software. The developed display contains several windows and said window display. As a result, the parameters of the substation devices such as: frequency, voltage, load impedance, reluctance, oil level, temperature, cooling condition, power and protection system are successful displayed and monitored.

Keyword: integrated monitoring system, high voltage, power substation, reliability, quality, human interaction, graphical user interface, window display, LabVIEW

1. Introduction

An electric power substation is a part of electric power transmission and distribution system. It has a necessary function in maintaining the reliability of the electric power supply. Therefore all the substation devices must be monitored.

Monitoring means acquiring significant parameters from the assets of interest [1-5]. The acquired data allow carrying out of analyses and diagnose the condition of the assets which is of great use for maintenance scheduling, failure management and controlling system [4, 5].

According to Bergman, in order to develop an effective, economic and efficient on-line condition monitoring system, the appropriate combination of parameters to be monitored, the appropriate monitor(s), and the appropriate degree of monitoring must be matched with the value provided by the specific substation power equipment in the overall power system [3].

Endesa Distribucion developed full substation monitoring project at one of its substations, namely, Sant Just Desvern (Barcelona). Five power transformers and all circuit-breakers belonging to Endesa are monitored. It used IEC 61850 standard [1].

Jin Hua developed a Support System for High Voltage Electric Equipment Condition-based Maintenance of Transformer Substation based on whole transformer substation. The system can helps to manage the data on the insulation state of high voltage as well as state of high electric equipment by using the computer database. It is also able to collect and analyze the information on high voltage electric equipment test data. The system can give the results of qualification judgment, according to rules of preventive experimentation of power equipment, and delivers states data and the data history curve of online monitoring equipments to remote terminal [5].

The integrated monitoring means all the device parameters are monitored integratedly in a displayer. A display is constructed by multi level windows. The first window display is a main window display and it has a function to show the primary device icon of substation. While the second level of window display contains of parameters and characteristic of each device displayed.

The window display is developed using Graphical User Interface (GUI) based on LabVIEW software. The devices and their parameters such as frequency, voltage, load impedance, reluctance, oil level, temperature, cooling condition and power can be monitored from the display.

This method helps the operator monitoring in real time the condition of each device easily. Furthermore, in the case of any failure, the operator will be acknowledged immediately that a specific device is experiencing some difficulty or failure. The blackout condition can be prevented and continuity power supply will be guaranteed.

Besides, the data from the monitoring system is feasible to be used for maintenance scheduling prediction and this method minimizes time contact between human and high voltage device. As it is known, most substation devices have high voltage and generate electromagnetic that can harm human health [6, 7].

2. Substation

Fig. 1 below represents the high voltage electric power substation, where voltage is step down or step up with regard to the load capacity. It is a part of a power electrical generation, transmission, and distribution.

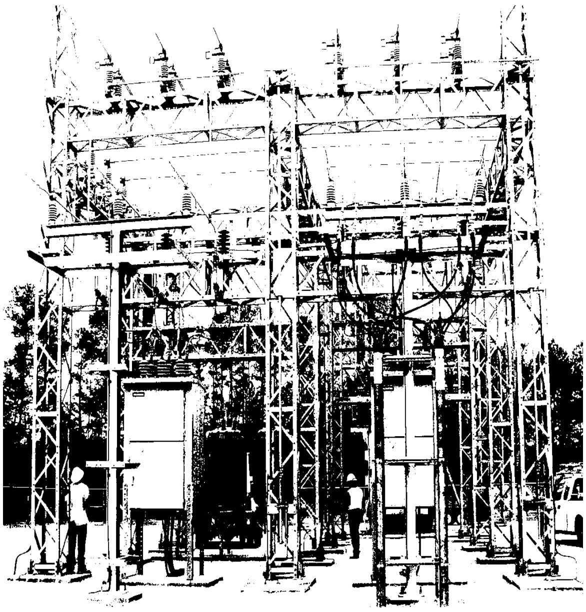


Fig.1: An electrical substation with 220 kV/66 kV 185 MVA (http://www.google.com.my/images?um=1&hl=en&client=firefox-a&rls=org.mozilla%3Aen)

There are several devices in substation, among them are power transformer, circuit breaker, isolator, metering and etc [8-15].

2.1. Transformer

Transformer is an electrical device used to transfer alternating currents or voltage from one electrical circuit to another by using electromagnetic induction [8-11,16-21]. Power transformers filled with a highly refined mineral oil that is used to insulate internal live parts of the transformer. The oil prevents corona and manages temperature control inside the transformer for the prevention of equipment and machinery overheating during the operation of large job applications. An oil filled transformer, like any other valuable equipment needs regular maintenance. Its condition has to be monitored frequently to make sure that the mechanical part works properly and the internal fluid performs its functions very well.

2.2. Circuit breaker

A circuit breaker is an automatically-operated electrical switch which is designed to protect an electrical circuit from damage caused by overload or short circuit.

Current interruption in a high-voltage circuit-breaker is obtained by separating two contacts in a medium having excellent dielectric properties and arc quenching properties [12-14,22,23]. After contacts separation, current is carried through an arc and is interrupted when this arc is cooled by a gas blast of sufficient intensity.

2.3. Isolator

The purpose of the isolator is to isolate sections of overhead line, small transformer substations and busbars [24,25]. The connection from the line to the moving contact must be a flexible conductor to allow the movement of the rocking pedestal between the open and closed positions.

2.4. Three phase measurement and single phase power factor correction

Since electric power is generated and distributed as sinusoidal voltages and currents, the analysis of electric circuits with sinusoidal sources is very important. The AC circuit analyses are regularly performed in power substation. This involves studying the performance of the system under both normal and abnormal conditions [26-30]. However, such analysis requires a good understanding of AC circuit theory. The instantaneous power delivered to a load can be expressed as

$$P(t) = i(t).v(t) \tag{1}$$

In the case of sine wave voltage and current, the instantaneous power may be expressed as the sum of two sinusoids, or as the sum of two sinusoids with twice the frequency as shown below:

$$\begin{aligned} P(t) &= V_m I_m \cos(\theta) + V_m I_m \cos(2\omega t + \theta) \\ &= (V_m I_m \cos(\theta))(1 + \cos 2\theta(t)) + \\ &\quad V_m I_m \sin(\theta).\cos(2\omega t + \pi/2) \end{aligned} \tag{2}$$

where, $v(t) = V_m \cos(\omega t)$ and $i(t) = I_m \cos(\omega t + \theta)$

Hence, the active power and the reactive power are given by

$$P = V_m I_m \cos(\theta) \tag{3}$$

$$Q = V_m I_m \sin(\theta) \tag{4}$$

The cosine of the phase angle (θ) between the voltage and the current is called the power factor. The apparent power (S) can be calculated from P and Q as

$$S = V_m I_m = \sqrt{P^2 + Q^2} \tag{5}$$

The power factor is determined with the following equation:

$$\theta = \cos^{-1}\left(P / \sqrt{P^2 + Q^2}\right) \tag{6}$$

The voltage across the load impedance and the current in the impedance can be used to compute the power-per-phase [25,26,31]. Assume that the angle between the voltage and the current is θ, which is equal to the angle of the impedance. Fig. 2 below represents the phase power and the total power, where the total active power is three times of the phase active power.

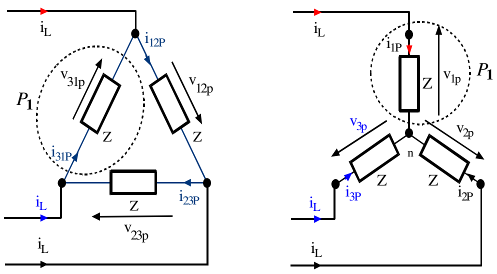
$$P_{total} = 3P_{line} = 3V_m I_m \cos(\theta) \tag{7}$$

Based on the balanced delta-connected loads, the line current is $I_{line} = \sqrt{3}\, I_{phase}$ and the voltage is the same. On the other hand, for the balanced star-connected loads, the current is the same but the voltage is $V_{phase} = V_{line} / \sqrt{3}$. Therefore equation (7) becomes

$$P_{total} = \sqrt{3}\, V_{line} I_{line} \cos(\theta) \tag{8}$$

3. Display development

Operators of the substation are used to handle physical instruments such as buttons, knobs, meters, indicators, chart recorders, lights etc. Therefore to make them still comfortable operating this system the display is developed in such a way to resemble the physical instruments.



(a) (b)

Fig. 2: (a). Delta-connected load and (b) star-connected load

The monitoring display is constructed using LabVIEW program which is called virtual instruments (VIs). VIs has both an interactive user interface-known as the front panel-and the source code-represented in graphical form on a block diagram [32]. VIs contains three main components which are the front panel, the block diagram, and the icon and connector pane.

Basically there are few steps to implement the display for monitoring:

1. At first, a user interface must be built by using a set of tools and objects. The user interface is known as the front panel.
2. Then the block diagram of primary equipment contains the source code is generated. In some ways, the block diagram resembles a flowchart.
3. The next step is to analyze the data from the block diagram. This will be done by the program automatically.
4. Indicators are used as outputs. Thermometers, lights, metering and other indicators display output values from the program.
5. Finally Master VI is created for calling VIs to run. The program opens a VI and shows it on the screen (if selected).

Fig. 3 represents the process to create the master front panel display or window display and calling the subVIs. Table 1 shows several devices and their related parameters that will be displayed in the monitor.

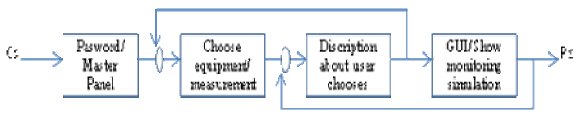


Fig.3: Block diagram window display development flow

Table 1: Equipment & measurement to monitor

Modeling	Monitor Parameters
Transformer	Oil tank level , Cooling System
Circuit Breaker	Temperature for Gas-blast
Isolator	Control Position Contact
Protective Relay	Fault & Overcurrent Limit
Measurement	3 Phase AC Power Measurement, Power Factor Correction

3.1. Transformer window display

The transformer window display is designed based on the number of the parameters of the transformer that are intended to be monitored. The arrangement or layout of the parameters in display is constructed by considering the readability and aesthetic value.

In this design, the transformer window display consists of two parts; the first is oil level and the second is temperature as represented by Fig. 4 and Fig. 5.

The transformer oil level window display will exhibit:

1. Description of the display.
2. Lamps to notify condition of the oil level.
3. Level of the tank in transformer.
4. Diagram of the oil tank level control system.
5. Graph showing input and output curves.

Whereas the transformer temperature window display will exhibit:

1. Description of the display.
2. Current temperature of the transformer.
3. Buttons to adjust temperature limits.
4. Graphs showing the temperature history and histogram.
5. Cooling fan status.

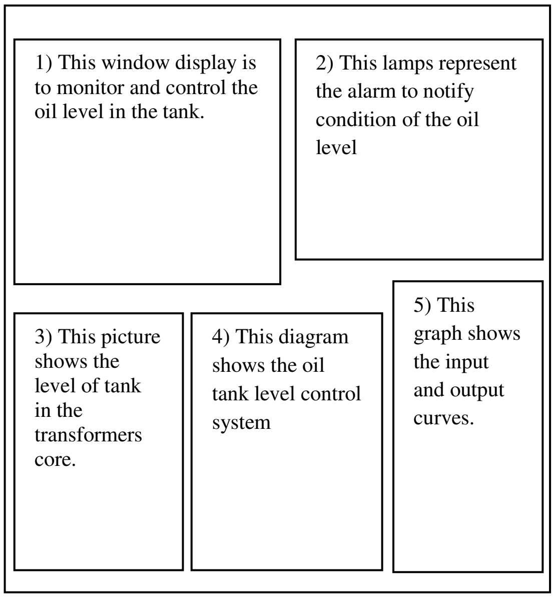


Fig.4: Layout of transformer oil level window display

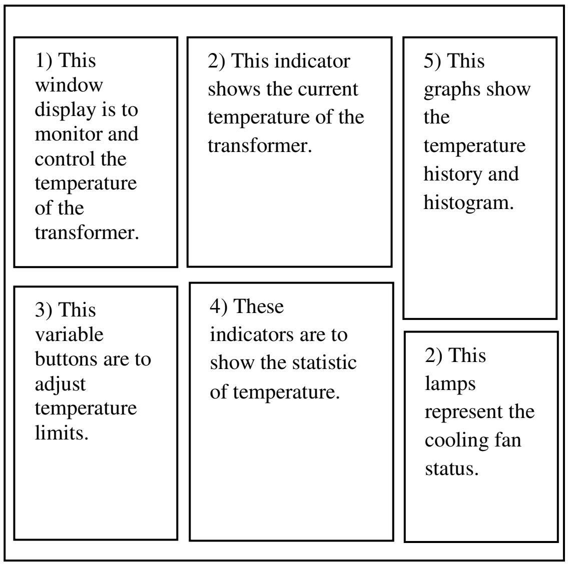


Fig.5: Layout of transformer temperature window display

In the implementation part, basically this system is a closed loop control system. The temperature of the transformer is continuously monitored by a temperature sensor. When the transformer is overheating the system will respond by activating the cooling fan. By this way the temperature of the transformer can be maintained in its operational range.

3.2. Circuit breaker window display

Circuit breaker window display will present six parts, they are:

1. Description of the display.

2. Notification.
3. Thermometer display.
4. The level of tank.
5. The cooling fan.
6. The temperature graph.

The layout of the circuit breaker window display is shown in Fig. 6.

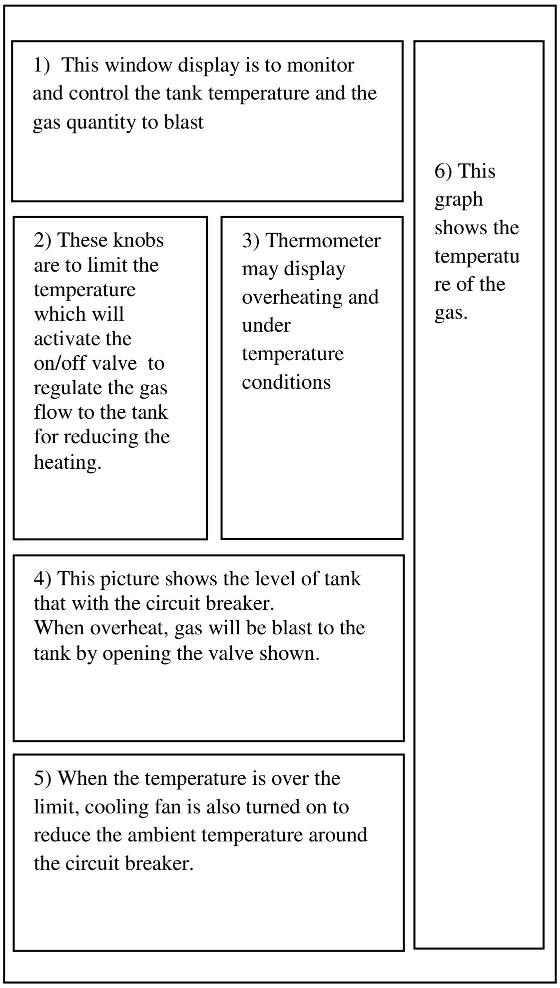


Fig.6: Layout of circuit breaker window display

Like in the transformer system, basically this system is also a closed loop temperature control system. In the operation there is a spark each time the circuit breaker opens or closes. This will increase the temperature and should be overcome. The temperature of the circuit breaker is continuously monitored by a temperature sensor. The reduction of the temperature is done by blowing gas to the contactor of the circuit breaker. Furthermore, when the temperature is still over the limit, cooling fan is also utilized to reduce the ambient temperature.

3.3. Isolator contact window display

The isolator contact window display shows the direction of the isolator contact movement whether in open or close position which is controlled using a stepper motor.
Parts of the isolator contact window display are:

1. Description of the display.
2. Setting of the motor driver
3. Voltage and current graphs.
4. Switching condition
5. Movement of the motor
6. Motor direction setting

The layout of the isolator contact window display is described in Fig. 7.

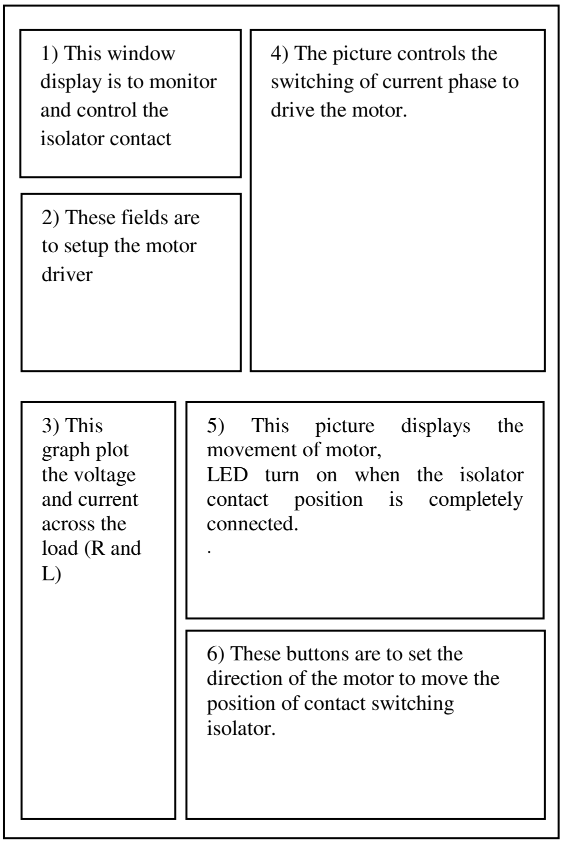


Fig.7: Layout of isolator contact window display

3.4. Three phases power measurement window display

Three phases power measurement window display is shown in Fig. 8. The window displays six components, i.e.:

1. Description of the display.
2. User choice.
3. The RMS value of measured variables.
4. The variables amplitude tuning
5. Circuit illustration
6. Total power

3.5. Single phase power and power factor correction window display

The single phase power and power factor correction window display will show the items below:

1. Description of the display.
2. Variables tuning.
3. Hide and show the wave form.
4. Power factor setting.
5. Phasor graph.
6. Circuit form.
7. Power factor correction.

Fig. 9 describes the window display for single phase power and power factor

4. Results and analysis

A. Circuit breaker display

The circuit breaker window display is designed to monitor the gas blast applied to the arc which must be able to cool it rapidly by referring to ambient temperature limitation from 45C/-45C [12-14,22]. When temperature rises, the valve is ready to blast

SF6 gas in tank to cool down the temperature inside and outside the tank and when it reaches over the limit, the gas will flow to the tank. This window display is shown in Fig.10.

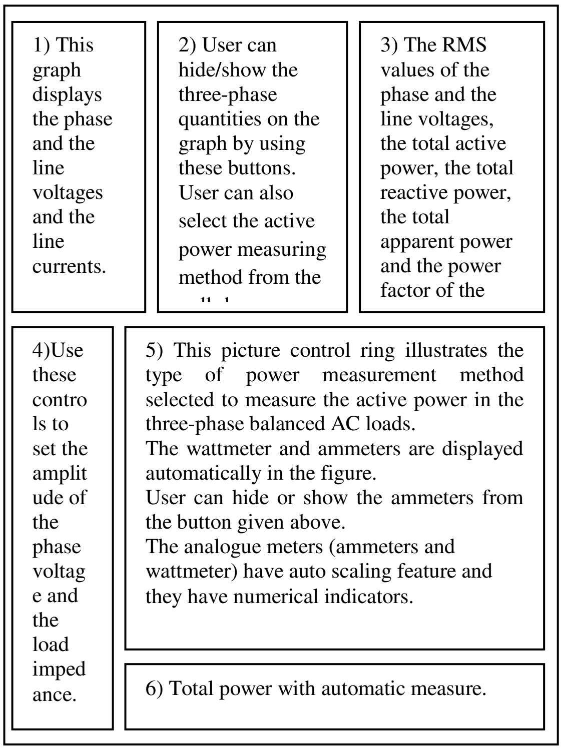


Fig.8: Layout of three phase measurement window display

B. Transformer display

As a primary substation device, more attention must be given to power transformer. Therefore, some of its parameters are closely monitored. Firstly is the oil transformer. The oil transformer has the function to maintain the transformer temperature and also reduce heat of transformer winding. Therefore the oil transformer level should be controlled [10, 18-21]. Fig. 11 represents the window display for monitoring the oil transformer condition, temperature and level.

Second is the power transformer temperature, which should be continuously monitored. When the temperature is over the limit by referring to the IEEE standard in Table 2 (Revision of IEEE Std 62-1978), cooling fan 1 and 2 will be enabled until the temperature decrease below the limit. After that, cooling fan 1 and 2 will turn off and cooling fan 3 and 4 will turn on as usual. Fig. 12 shows the window display for transformer temperature.

C. Isolator contact display

The direction of the isolator contact movement whether it's open or close position is control using stepper motor [24, 25]. When contact part in close position, the LED will light up and it shows that the isolator contact is connecting a line. The window display monitoring for isolator contact device is presented by Fig.13.

D Power Display

Total power from three-phase power systems can measure using one, two or three wattmeter. In this case, we consent applying two and three wattmeter with has more feasibility. A wattmeter considered as a voltmeter and an ammeter combined in the same box, which has a deflection proportional $VI\cos(\theta)$. A wattmeter has two voltage and two current terminals, which have + or – polarity signs [25, 27-29]. Three phases power measurement methods utilizing the wattmeters for a balanced three-phase AC load.

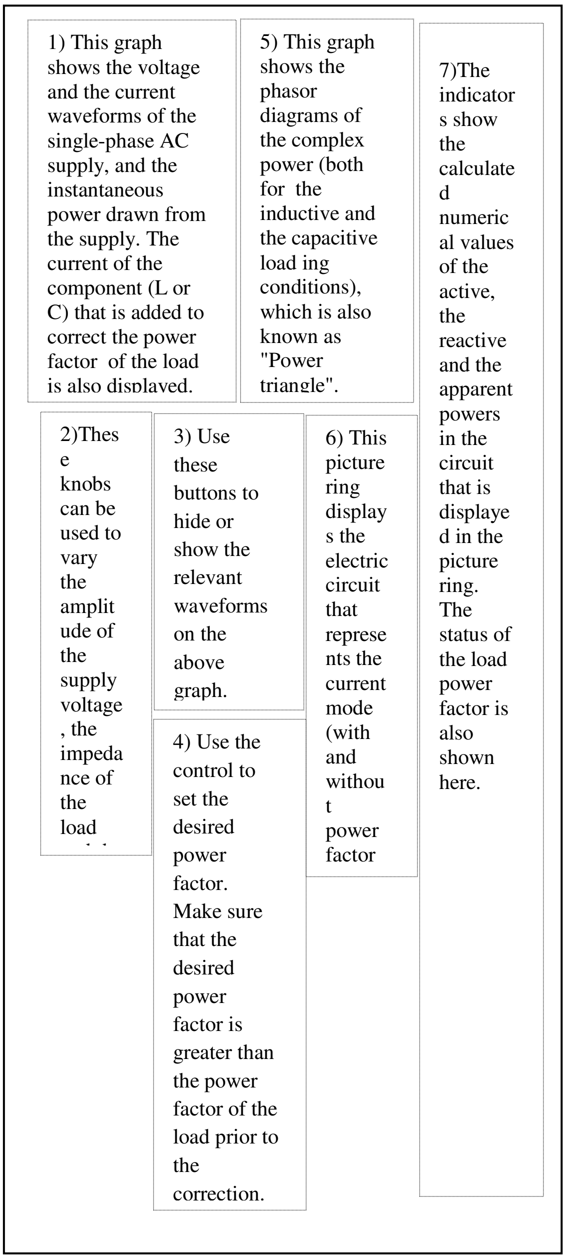


Fig.9: Layout of single phase power and power factor window display

1. Two Power meters Display
   This method can be used in a three-phase, three-wire balanced or unbalanced load system for Δ or Y connection. To perform the measurement, two wattmeter's are connected as shown in Fig. 14.
2. Three Powermeter Display
   This method is used in a three-phase, four-wire balanced or unbalanced load. The connections are made with one wattmeter in each line as represented in Fig. 15. The total active power supplied to the load is equal to the sum of the three wattmeter-readings [25, 28-29].

E. Single Phase Power and Power Factor Correction Display

The power factor approaches a value of 1.0. The process of making the power factor approach 1.0 (or below 1.0 but above

the existing power factor) is known as power factor correction (or compensation). The power factor correction is performed by placing a capacitor or an inductor across the existing load, that in it self, may be an inductive or a capacitive load, respectively. During the power factor correction process, the voltage across the load remains the same and the active power does not change. However, the current and the apparent power draw from the supply decreases. This means that the amount of decrease in supply current or power can be utilized by other loads without increasing the capacity of the supply [25, 28, 29].
The window display for single phase power and power factor correction is shown in Fig. 17. This window display provides a highly flexible virtual instrument known the power and power factor correction for single-phase ac circuits.

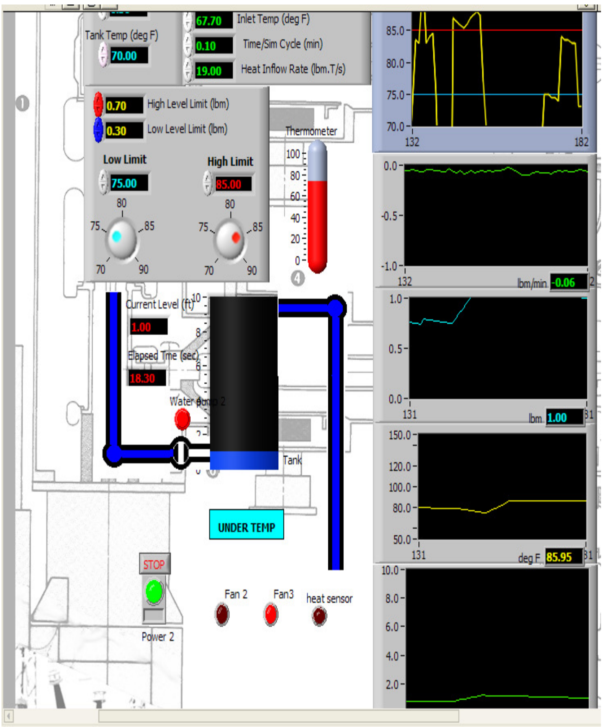


Fig.10: Circuit Breaker Gas window display

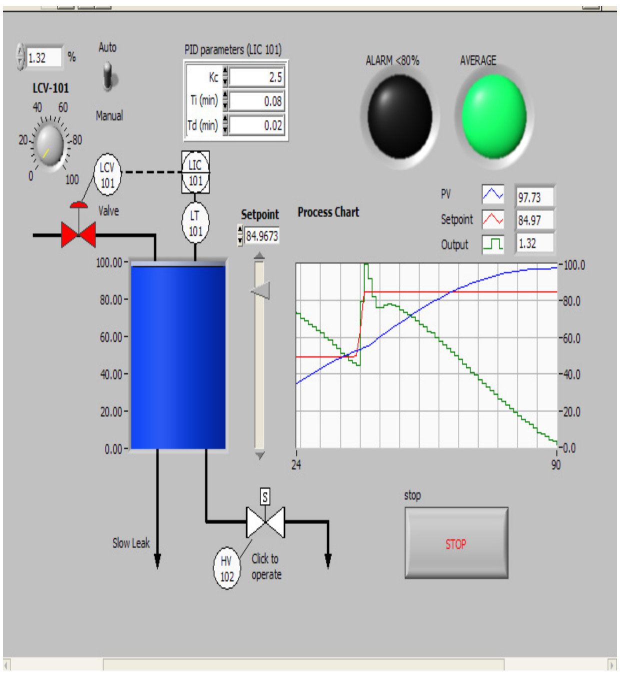


Fig.11: The window display for oil level in transformer tank

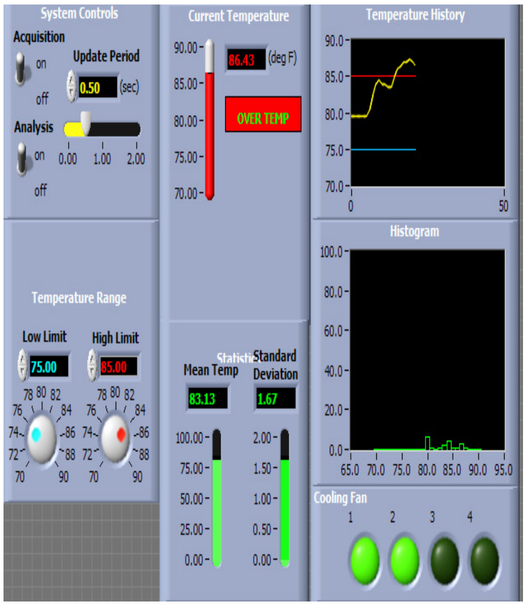


Fig.12: The window display for transformer temperature

Table 2: IEEE standard for monitoring ambient temperature

TEMPERATURE RISE AMBIENT (^{O}C)	RECOMMENDATION
0 - 10	Repair in regular maintenance schedule
11- 39	Repair in near future. Inspect for physical damage.
40 - 75	Repair in immediate future. Disassemble and check for probable damage
>76	Critical problem; repair immediately

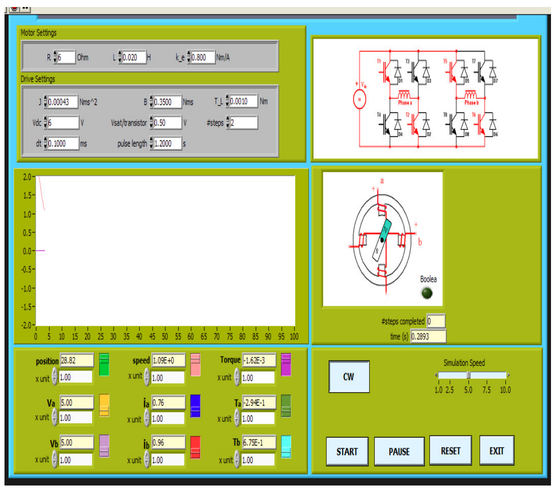


Fig.13: The Contact Isolator window display monitoring

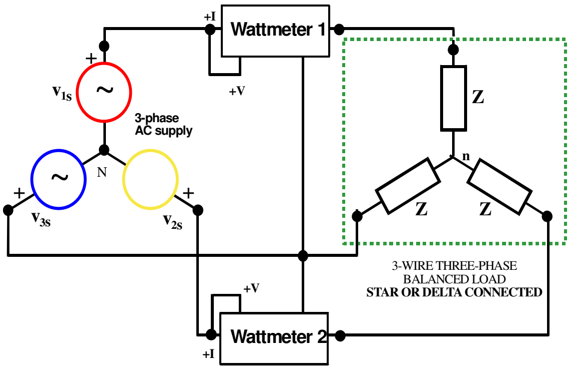


Fig.14: Power measurement with two wattmeters

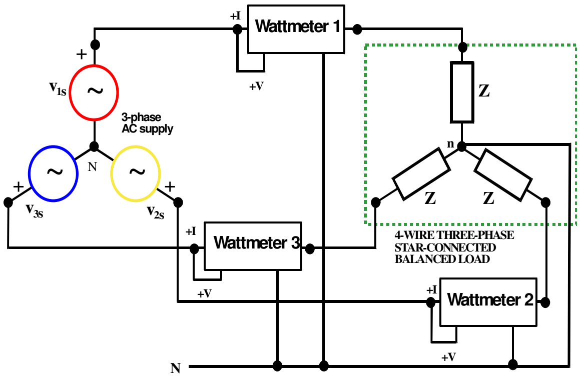


Fig. 15: Power measurement with three wattmeters

Fig. 16 shows three phase power measurement window display.

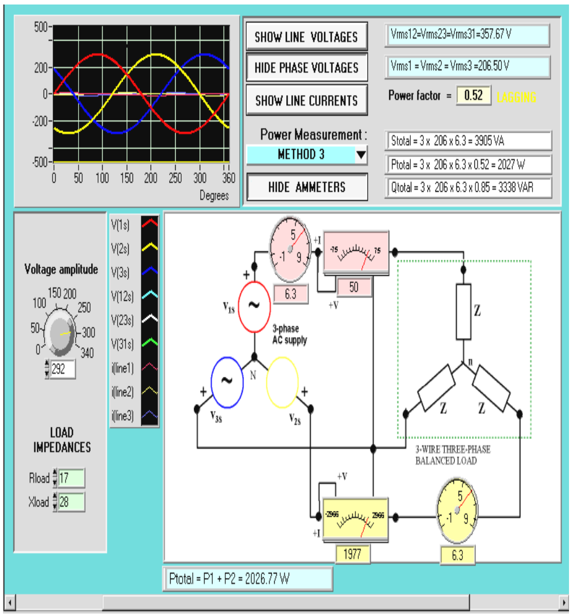


Fig. 16: Three phases power measurement window display

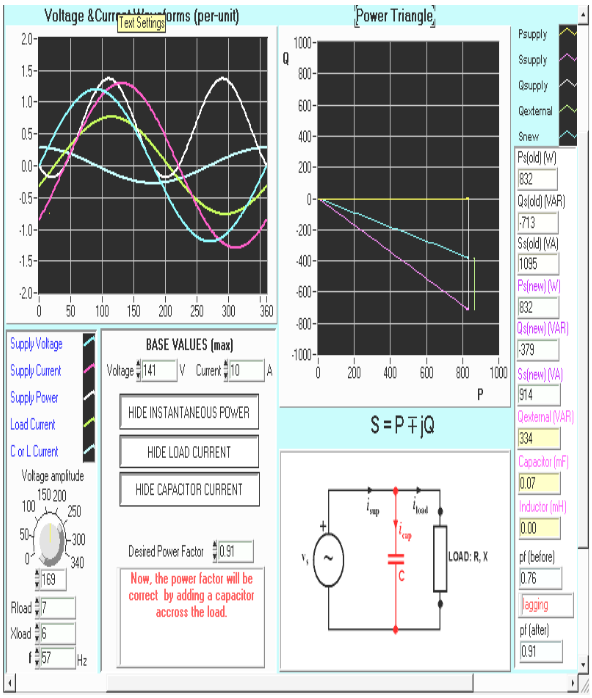


Fig. 17: Window display for single phase power and power factor correction

5. Discussion

The design of an electrical substation integrated monitoring has been presented. The integrated monitoring system shows the substation equipments condition using window displays. The window displays were developed using LabVIEW software. The displays consist of multi-windows display, where each window will shows particular substation equipments and conditions. They include the transformer, circuit breaker, isolator, three phase and single phase power measurement and power factor. The first step in window design is to determine the parameters that will be displayed and type of display. The second step is to place each parameters display position in window. The final is to implement using LabVIEW GUI software. A detailed description to perform the integrated monitoring, i.e. the LabVIEW GUI design for the window display and each window display contents, is given and the results are displayed.

This design is independent to the parameters monitored in the substation such as frequency, voltage, load impedance, reluctance, oil level, temperature, cooling condition, power and protection system. This is because the interface can acquire whichever values of the parameters without affecting those parameters.

The only limitation is the number of parameters monitored. It depends on the capacity of interface and the sensors installed.

6. Conclusion and Future Work

The window display for substation devices using LabVIEW programming for monitoring the devices condition has been successfully developed. The windows display the primary substation equipment parameters and conditions. Each display parameter is based on IEEE Standard guideline. The window display makes easy to monitor the equipment condition, reduce human contact with high voltage equipment and schedule the maintenance time. Besides, it also can reduce number of human resources. The simulation results show that the window can operate appropriately and display the parameters of the equipments.

In future research, an integrated monitoring system which has been designed will be applied directly to the electrical substation equipment. In this way, some weaknesses that still exist can be improved and the window as well as features that are deemed less can be added. For instance, the window for lightning arresters and busbar equipment that does not exist can be completed. Then the features of the load condition of the transformer secondary or primary that does not exist can be added. Furthermore, to make this integrated monitoring system to be an intelligent system, an advanced algorithm such as neural network can be added. The neural network will work as a decision maker in determining the condition of equipments.

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