MODELING OF INTEGRATED MONITORING ON POWER TRANSFORMER USING LABVIEW^{TM}

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Abstract: A power transformer has important role in a substation, for transmission and distribution of electric energy to customers. Its performance of reliability should be maintained. Therefore, it is necessary to be monitored in integrated approach continuously. This manuscript presents an integrated monitoring system simulation of power transformer using Labview^{TM} software, as a description in real condition. On this simulation, it is necessary some inputs, such as frequency, transformer capacity, primary and secondary voltages, load and its power factor. The simulating design needs sensings as sensor or transducer representations. The results are primary and secondary currents and voltages waves, oil and winding temperature charts, frequency, cooling conditions and protection system. They are operated and displayed integratedly.

Keywords: Monitoring, Power Transformer, Labview, Temperature, Charts, Frequency

A power transformer on a substation in electrical system is the most important role for transmission or distribution of electric energy to customers. There are many parameters of quantities to be paid attention and monitored in order to be proper in its function. The main parameters those necessary to be monitored are voltages, currents, tap changer position, protection systems, oil and winding temperatures, and cooling systems (Wilson, 1997).

The indications of quantities are sent to a control room, then to control center to be further processed and analyzed. The obtained data are sent in real-time. As additional information, the obtained data are inputs for controlling the transformer. For example, the secondary voltage is used as input of automatic voltage regulator, that regulates the tap changer position automatically, which it ultimately maintains the secondary voltage in constant condition (Wilson, 1997). Other example, oil and/or winding temperatures are inputs of relay those control cooling system automatically if they reach a certain temperature value, so that the overheating in power transfomer can be avoided (Manometerfabrik, 1986).

Whereas Laboratory Virtual Instrument (VI) Engineering Workbench (Labview) is a program of application, like as C or BASIC. However, Labview uses graphics or drawings, instead of texts or writings. Labview program is called as Virtual Instruments (VIs), because the displays and operations resemble real conditions, such as oscilloscope and multimeter. Every VI uses function that manipulate the input from user interface or other sources, and display or move the information to a file or other computer. The VIs consist of three display components, i.e. interactive user interface, equivalent source code and accept parameter. Interactive user interface is called as front panel, because it indicates simulating panel from real instrument. This panel consist of knobs, push button, graphics and other control, including indicators. Front panel is a combination of various control and indicator, where control is input data and supply for block diagrams, and further to be done execution to control devices. Whereas indicators are displays of run results (National Instruments, 2001).

The VIs receive instructions from source code, that called block diagram, display the commands, done by a program. When placed an indicator or control on the front panel, Labview will present icons of block diagram from the indicator or control on VI automatically. Whereas the accepting parameter is sub routine that displayed in other VIs, forms front panel and block diagram that used in main VI program (National Instruments, 2001).

The use of Labview is similar to basic of logic applied in the program. The main point of Labview program is block diagram, as source code from a front panel. If understood the block diagram, the programming of Labview will be easier. After designed a system, for execution the program can push the run button. Whereas for execution the porgram repeatedly, we can push run button continuously. Otherwise, for stopping the execution, can push stop button. The palletes on Labview gives an that necessary ways for creating and editing front panel and block diagram. The palletes are Tools Pallete, Control Pallete and Function Pallete. Tool Palletes are available on front panel and block diagram, consist of Operate Value, Position/Size/Select, Edit Text, Connect wire, Object Popup, Scroll window, Set/Clear Breakpoint, Probe data, Get Color and Set Color. Whereas Control Palette is only available on front panel, that consist of control and indicator for creating. Function Palette is available on block diagram, consist of VIs and function to create block diagram. Labview follows data flow models for running of VI. The nodes of block diagram is for execution, if all inputs are available. When fulfill for execution, the nodes will supply data to output terminals and pass output data to further nodes in the paths of data flow (Wells, 1995).

This purpose of simulation is modeling of integrated monitoring on a power transformer using Labview, explanation of main parameters of power transformer and reveal of results those as far resemble as real conditions. Thus, the results will be more interesting rather than those with other software.

METHOD
Input Data

On a power transformer, it is necessary main quantities or parameters to be known as main data or usually called rating. These parameters or quantities become inputs for simulation, i.e. frequency, power, capacity, primary and secondary voltages of transformer, load and its power factor, and actual

primary voltage. These input data are as far represent as the actual quantities.

Sensings

In this simulation, it is presented by a diagram component of Demo Voltage Read as input sensing interpretation of quantities on site in real condition. It is shown on Figure 1. The quantities those be sensed in this case are frequency, voltages, currents and temperatures.
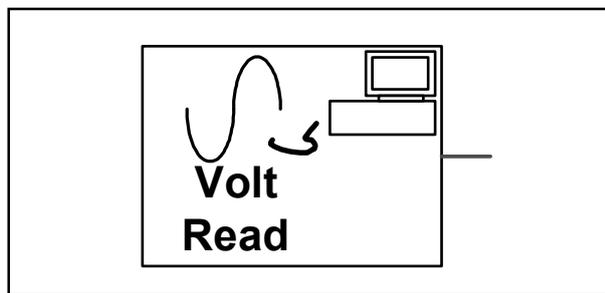

Figure 1 Diagram Component of Demo Voltage Read

Creating and Displaying of Sinusoidal Waves

As the real condition, the voltage and current are in three phase sinusoidal waveforms. Thus, this simulation was designed in such condition. Generally, the voltage waveforms are (Saadat, 1999):

$$V_a = V_{ma} \; sin(\omega t) \qquad (1a)$$

$$V_b = V_{mb} \; sin\left(\omega t - \tfrac{2\pi}{3}\right) \qquad (1b)$$

$$V_c = V_{mc} \; sin\left(\omega t - \tfrac{4\pi}{3}\right) \qquad (1c)$$

where subscribe a, b, c represent phase a, b, c respectively, and subscribe m reveals the maximum value. The current waves are presented by:

$$I_a = I_{ma} \; sin(\omega t - \theta) \qquad (2a)$$

$$I_b = I_{mb} \; sin\left(\omega t - \tfrac{2\pi}{3} - \theta\right) \qquad (2b)$$

$$I_c = I_{mc} \; sin\left(\omega t - \tfrac{4\pi}{3} - \theta\right) \qquad (2c)$$

where q is arcus of cosine of power factor. The current values depend upon the transformer loading.

Such three phases are revealed in one display, by facility bundled component diagram. Period of sinusoidal waves, of course, is considered to input frequency. The component diagram for creating sinusoidal waves and bundling are shown on Figure 2.
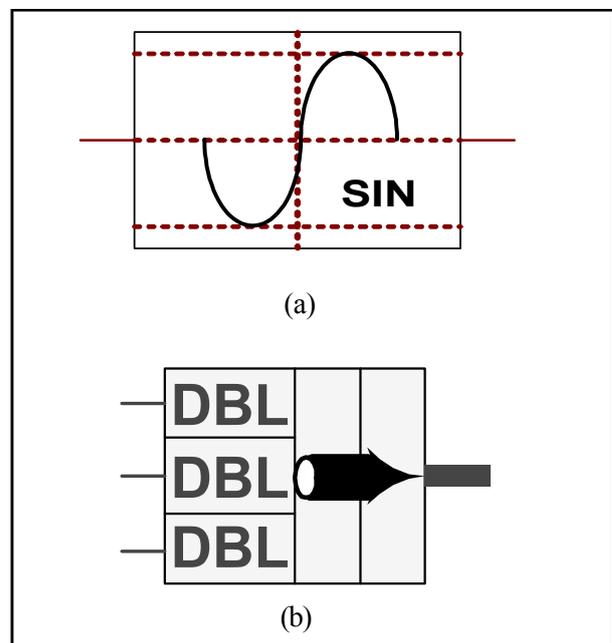

(a)

(b)

Figure 2 Component Diagram of
   (a) Sinusoidal Wave Creating and
   (b) Bundling

Temperature and Current Relation

Temperature of power transformer, either oil or winding, determines to performance of transformer. The oil temperature depend on environmental condition, transformer capacity and loading. If the loading of power transformer is small enough, the oil and winding temperatures will be low. However, if the loading of power transformer

is high anough, their temperatures are high enough too. Thus, the loading is limited by temperature, that indicated by alarm and trip indications. Nevertheless, if the oil and/or winding temperatures are high enough, while the loading is small enough, it is concluded that there is some not proper or normal operation inside the power transformer. Further-more, the protective devices will operate. Because very complex, it is assumed the range of oil temperature lain on 50 until 60°C normally. The mean of very complex is the flow of heat inside and outside of power transformer is very complicated. The heat flow from the winding to the core and to the oil, from the core to the oil, and from the oil to outside of power transformer through radiator by the aid of blowers. Sometimes, the heat is originated from the environment if the tempera-ture of outside power transformer is higher than that inside of power transformer. Thus, the oil and winding temperatures are influenced by many parameters.

Whereas the winding temperature rise to oil, based on (Manometerfabrik, 1986), follows the curve of Figure 3.
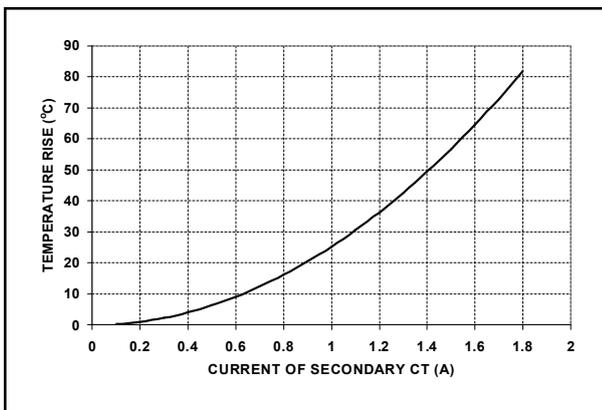

Figure 3   Curve of Temperature Rise to Secondary Current of Current Transformer

Figure 3 shows the temperature rise will increase quadratically as the current rises. The mean current is secondary current of current transformer with rating of 2 Ampere, as IEC (International Electrotechnical Commission) standard. Thus, it is necessary a ratio the current rating of power transformer windings to secondary of current transformer. In this instance, the power transformer rating is 60 MVA, as usually existence in sites, the maximum current of 150 kV primary winding is 231 Ampere. For be safe, it is used current transformer of 300/2 Ampere. The numeric of 300 is the nearest value higher than 231 and according to IEC standard.

Above curve can be approached by equation is

$$\Delta T = 25,23 \ I^2 \qquad (3)$$

where DT is in °C and I is in Ampere. Whereas the winding temperature is

$$T_w = T_o + \Delta T \qquad (4)$$

where T_o is oil temperature.

Output Displays

The outputs of simulation result are indicated by some displays. If data are suitable, they will further be processed. The sensings of data are frequency, voltage, current and temperature. Usually, the displays are in chart, in order to know the history of previous condition, not in instantaneously. Other displays are presented in panel meter, such powers, currents and voltages. Also it is presented by numerical measurements, indications and protective facility.

Programming

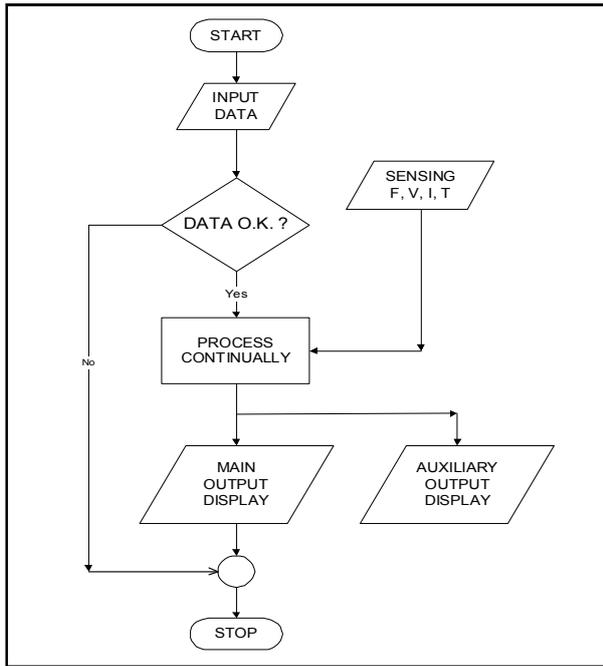The flow chart of programming is shown on Figure 4.

Figure 4 Flow Chart of Programmatic Design

The sensings are as interpretation of data acquisition. If the data do not conform to transformer capacity, then the program will not run.

The complete programming is shown on Figure 5. It is needed input data of frequency, capacity, actual primary voltage, load and its power factor and nominal primary voltage. With the sensing, such data will be processed. The voltage and current waves are three phase, where each phase is shifted by 120º. The current and voltage waves in each phase is shifted by cosinus arcus of load power factor. It is also necessary of temperature calculation process. Finally, the results of programming are shown in some displays as outputs. These indications are as representation of actual condition.
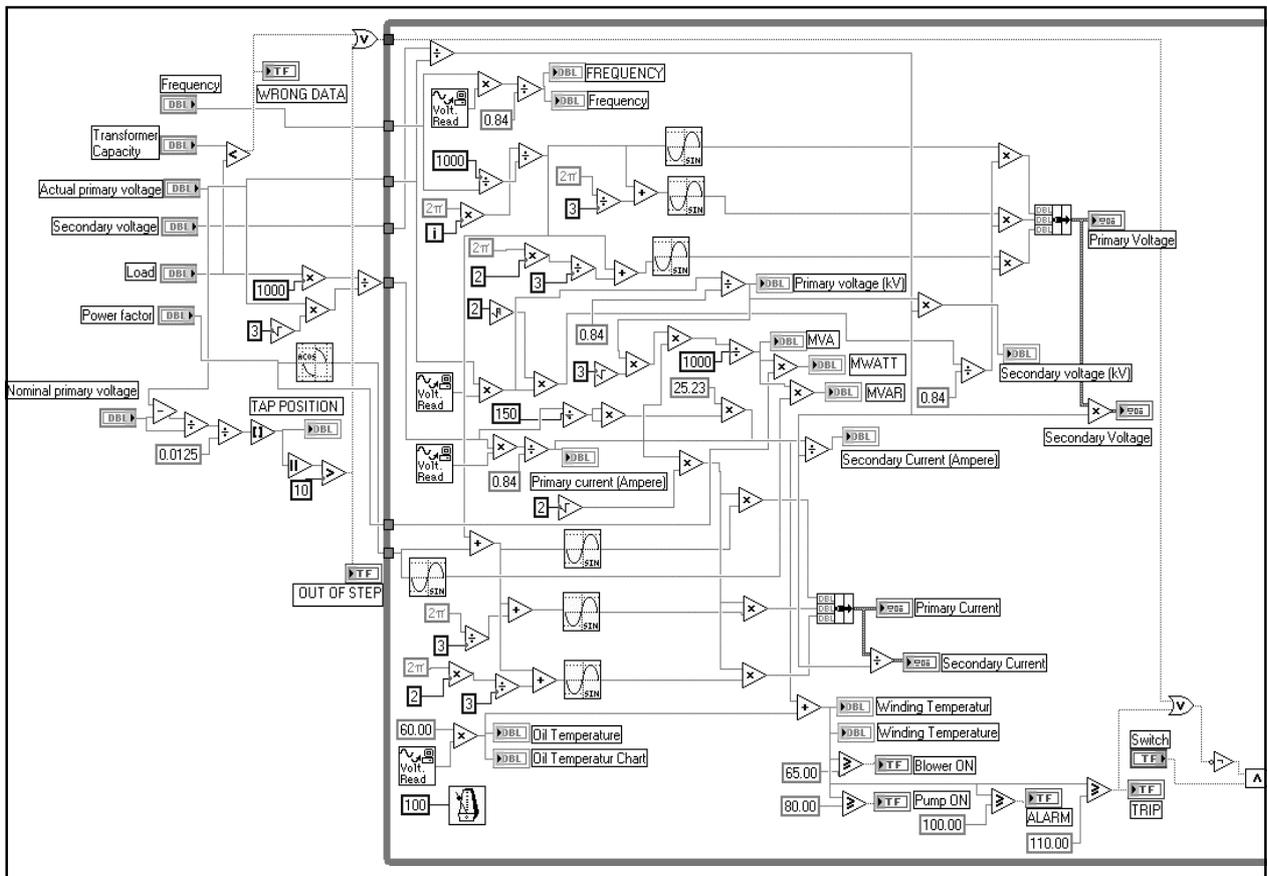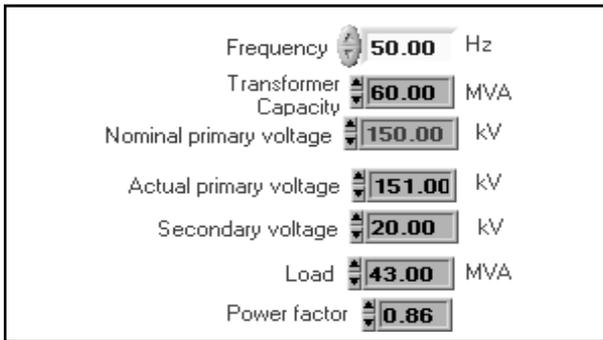

Figure 5 Layout of Programming Diagram

RESULTS AND DISCUSSION

Input Data

In order to the program runs properly, the input data have to conform to the design. The input forms are shown on Figure 6, as an example.


Figure 6 The Typical of Input Data

The input quantities and data as sample, for this case, are Frequency (50 Hz), Transformer Capacity (60 MVA), Nominal Primary Voltage (150kV), Actual Primary Voltage (151 kV), Secondary Voltage (20 kV), Load (43 MVA) and Power Factor (0.86) lagging.

Switch

This switch, shown on Figure 7, is used for turning on and off of running process. It is also necessary to push the run button on toolbar.
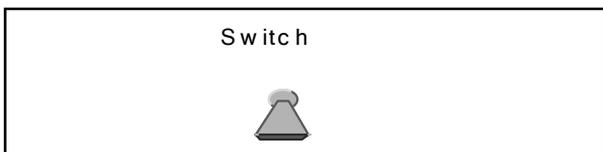
Figure 7 Switch Button

Fault Indication

Faults are indicated by turning lamp on. The faults in this simulation are wrong input data, out of step of tap changer position and trip, as shown on Figure 8. Three faults cause the program can not run, that mean the power transformer do not be energized.
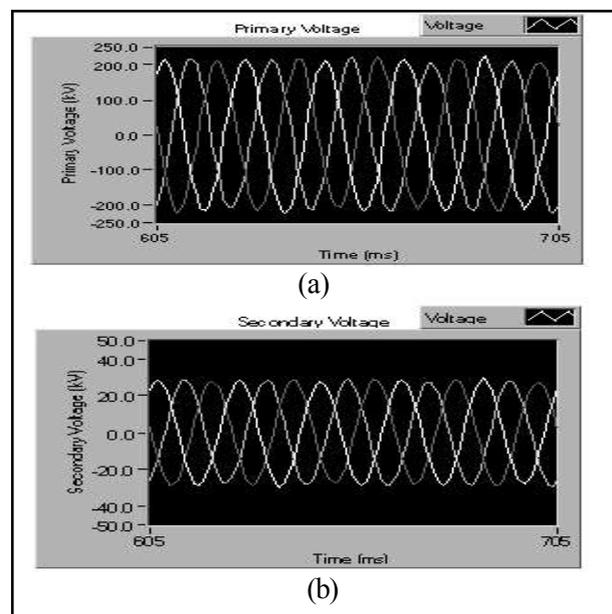

Figure 8 The Kind of Fault Indication

The lamp will be on according to the kind of fault, that is WRONG DATA, OUT OF STEP and TRIP. As an example, on Figure 8, the trip lamp is ON when the trip occur.

Primary and Secondary Voltage Waves

The results of primary and secondary voltage waves are shown on Figure 9, those are in three phase.
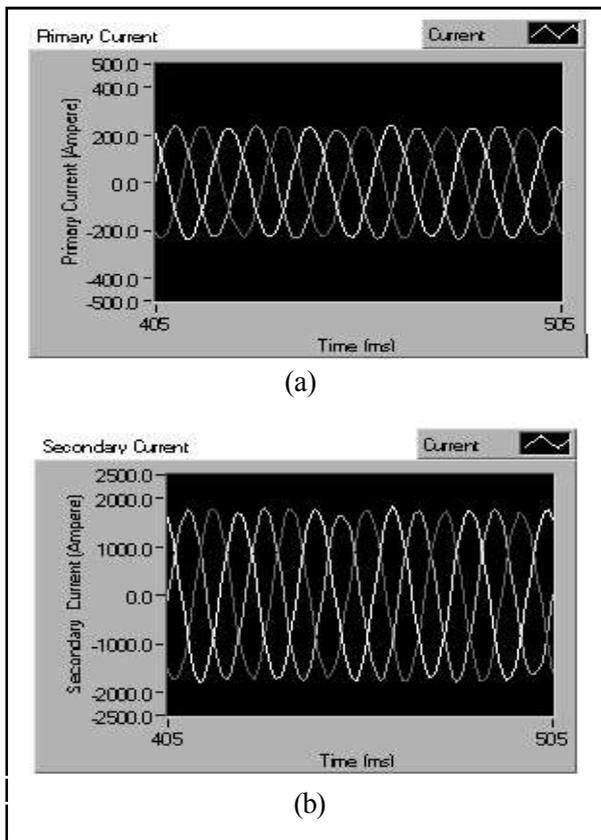

Figure 9 Primary and Secondary Voltage Waves
(a) Primary Voltage
(b) Secondary Voltage

The effective values of primary voltages are around 150 kV, suitable with the input voltage, whereas the secondary ones are around 20 kV. Each phase, in same sides, is shifted by 120°.

Primary and Secondary Current Waves

The results of primary and secondary current waves are shown on Figure 10, where the primary current is shown on Figure 10(a) and the secondary voltage is shown on Figure 10(b).

(a)

(b)

**Figure 10   Primary and Secondary Current Waves of Po-
        wer Transformer
        (a) Primary Current
   (b) Secondary current**

The current waves are similar to the voltage ones, i.e. the forms are sinusoid and each phase is shifted by 120° each other. However the primary currents are less than the secondary ones. The primary currents are proportional inversely to the ratio of primary and secondary voltages, compared to the secondary ones. The shifting of phase angles will rise as the power factor decreases, and vice versa.

Oil and Winding Temperature

Figure 11 shows the chart from simulation results of power transformer oil temperature (a) and winding temperature (b) measurements. In this particular case, it is assumed that the value of oil temperature is 60°C x 0,84 = 50,4°C, as usual in site. The display of oil temperature is also in thermometer form.

The winding temperature is higher than the oil one, because of heating addition due to flowing current. This temperature will rise as the current increase due to loading from the input of program. It is also revealed in digital numerical form.

(a)

Winding Temperature

80.99   (b)
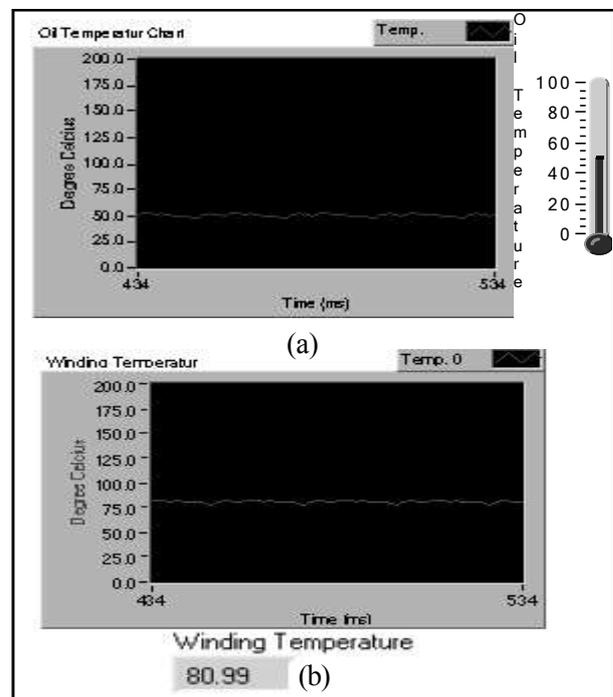
**Figure 11 The Temperature Display Results
        (a) Oil Temperature
        (b) Winding Temperature**

Frequency

Although the frequency input is constant, but in real condition, it experiences small variation, due to electric generation, loading or other factors. Thus, it is necessary to involve sensing parameter in the simulation, in order to approach the real condition. The display of frequency is indicated in both chart and digital numerical form, as shown on Figure 12.
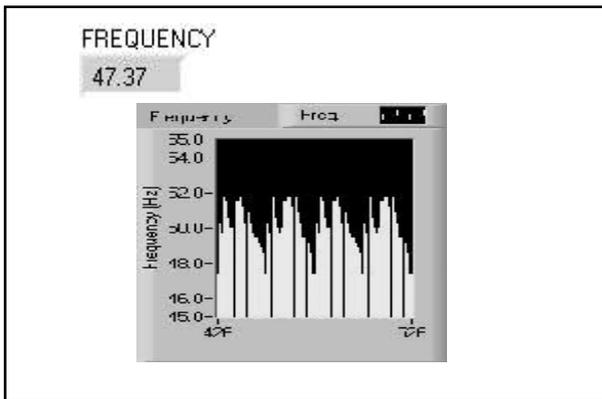

Figure 12 The Frequency Display Result

Cooling and Alarm System Indications

Figure 13 shows the cooling and alarm system indications, consist of blower on, pump on and alarm.
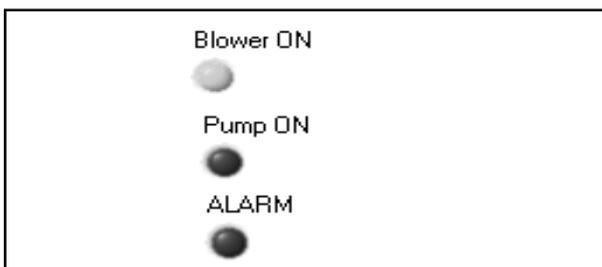

**Figure 13   The Display Results of Cooling and Alarm Sys-
tem Indications**

The cooling and alarm system indications are indicators of temperature, i.e. BLOWER and PUMP will be ON on 65°C and on 80°C respectively. ALARM indicates that the transformer operates in a critical threshold, so that it need a warning. The alarm was set on 100°C. Above this value, i.e. 110°C, the transformer will experience TRIP, not operate due to be protected.

Power, Voltage and Current Meter Panels

The magnitudes of power, either active, reactive or complex powers, are displayed on meter panels. The active power is proportional to the load power factor. Whereas the reactive power is proportional to the cosinus arcus of load power factor. The meter panels are shown on Figure 14.

The primary and secondary voltages and currents are also displayed on the meter panels. The voltage values depend on the input voltages, whereas the currents depend on both the input voltages and the loads.
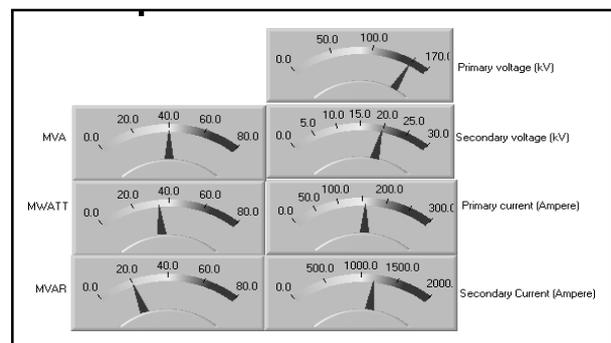

**Figure 14 The Meter Panel Displays of Powers, Voltages
and Currents**

All input data influence to the outputs. Frequency determines the density of waves and read frequency. Transformer capacity determines WRONG DATA of fault indication, if this input not enough against to the load. Nominal primary voltage and Actual primary voltage determine OUT OF STEP indication. Nominal primary voltage itself determines the amplitude of primary voltage and primary current.

The Secondary voltage determines the amplitudes of secondary voltage and secondary current. Whereas Load determines the amplitudes of primary current and secondary current, winding temperature indicator, cooling and alarm system indications (Blower ON, Pump ON, ALARM), and the meter panels of powers. Winding temperature indicator is also determined by oil temperature.

Power factor determines the shifting of angle between voltage and current on corresponding phases, currents and the meter panel of powers. Thus, the parameters of inputs and/or outputs are correlated or integrated each other. One parameter influences to other parameter and vice versa.

CONCLUSIONS

(1) With Labview software, it was obtained a preliminary design of power transformer integrated monitoring automatically. This is one of important considerations to design in the real condition, (2) the parameters or quantities in power transformer monitoring system are correlated each other, not be separated, (3) this monitoring system operates automatically, due to available of protective system. This means the program can not run in certain conditions, depend on the input data.

REFERENCES

Manometerfabrik.,A.B.K. 1986. *AKM Winding Temperature Indicator,* Bulletin 35E, Sweden: AKM, Stockolm.

National Instruments. 2001. *Labview : Getting Started with Labview, Part Number 321527E-01.*Texas:National Instruments™.

National Instruments. 2001. *Labview : User manual, Part Number 320999D-01.* Texas: National Instruments™.

Saadat, H. 1999. *Power System Analysis.* Singapore: McGraw-Hill.

Wells, L.,K.1995. *The Labview Student Edition User's Guide.* New Jersey: Prentice-Hall, Inc.

Wilson Transformer. 1997. *Wilson Transformer Management System.*Pty., Ltd, Victoria: Wilson Transformer Co.