

# Application Note

## Increasing Power Transformer Life Using Through-Fault-Monitoring and Thermal Management



Figure 1 - BE1-FLEX Protection, Automation and Control System

**This application note is designed to inform and educate protection engineers on thermal protection features available in modern multifunction transformer protection products, and how these features can be used to prevent thermal related failures in power transformers.**

Protection schemes for power transformers typically use measured currents and voltages. Likewise, the Basler BE1-FLEX utility grade multifunction relay system includes percentage restrained current differential, a large selection of overcurrent, voltage, and frequency elements for primary and backup applications, and is easily programmed with an industry best BESTCOMSPi<sup>us</sup>® interface software. However, life expectancy for liquid-immersed power transformers is also influenced by winding temperature and the number of “Through-Fault” (TF) operations, both of which are monitored in the modern BE1-FLEX system. Monitoring TF operations, the various real time thermal parameters of the power transformer, and communicating the information to a manned location can allow for safe transformer overload without loss of life.

In many transformers, the winding hot-spot temperature is not readily available. Very large transformers may have embedded RTDs at the winding hot-spot, but they are not easily installed and can cause problems. Alternatively, the winding hot-spot temperature can be derived by measuring the top (or insulating) oil temperature. This is done by referencing the manufacturer supplied data for insulating oil temperature to calculate the winding hot-spot temperature. Operating the transformer closer to its maximum design temperature rise without damaging or causing loss of life to the insulation can result in

significant savings by deferring capital investments required to purchase additional transformer capacity. In addition, through-faults can damage transformer insulation, so having a way to actively monitor and report this information will allow for “just in time” maintenance, preventing what may otherwise have been an insulation failure. In addition to temperature, other parameters can be utilized for more complete transformer protection and operation. Some of these are: sudden pressure (gas or oil), ambient temperature, oil flow and air flow.

The BE1-FLEX system can gather information about transformer temperatures, ambient temperature, oil flow, air flow, and through faults to assist in optimizing transformer loading. Because this type of information has only recently become available as technology has evolved, many protection engineers have not previously utilized this information. Many operations attempt to reduce expenditures on new transformers by maximizing the MVA flow of their current power transformers. This, combined with a general lack of thermal application knowledge by Protection Engineers, may result in increased transformer thermal related damage or failures. Using temperature based protection functions will help mitigate the risk of transformer failure as a result of accelerated thermal and through fault insulation aging.

### Power Transformer Basics

Power transformers are built with a laminated steel core to reduce eddy current losses. The windings are usually copper, but occasionally aluminum is used, and refined paper is used for insulation. Highly refined mineral oil provides additional insulation and serves as the winding heat transfer and cooling medium. The steel core, copper windings, paper insulation and mineral oil all have specific thermal limits. Power losses in the transformer cause the temperature to rise. This excess heat energy is transferred to the insulating oil and, if the temperature rises beyond the designed capability, it can cause premature failure of the transformer.

Transformers are rated based on their maximum designed temperature rise when delivering rated voltage and frequency. The maximum temperature rise is based on the thermal limitations of all parts of the transformer. The MVA rating of the transformer is primarily based on the weakest link. In a transformer, the weakest link is the paper insulation because it deteriorates with heat and time. Published standards for power transformers usually express these limits in temperature rise above ambient temperature. Using “rise above ambient temperature” helps to ensure the transformer has enough capacity independent of the daily surrounding temperatures.

There are two operating characteristics of a transformer that create heat. The first is called no load losses. This source of heat consists of hysteresis and eddy currents caused by the transformer charging current. The second is related to the load current flowing in the transformer and is caused by  $I^2R$  energy lost in the winding and by additional load induced eddy currents.

As the transformer loading rises, thermal energy in the transformer winding increases at a rate of the current squared ( $I^2R$ ). This thermal energy is then transferred to the transformer oil, causing the temperature to rise. Loading above the design limits of the transformer can create immediate and future problems for the transformer. The insulating and heat transfer capability of the transformer oil decreases when the oil begins to break down and form gas bubbles. The steel structure of the transformer can lose mechanical strength with heat and become permanently deformed. Tap changers, bushings and/or current transformers also can be damaged or deformed by excessive heat. The insulating oil temperature can be utilized to calculate the transformer winding hot-spot temperature and build a protection function with the BEI-FLEX that will provide sensitivity to the many heat related problems that can occur with a power transformer.

Modern power transformer temperature limits are listed in the “IEEE Guide for Loading Mineral-Oil Immersed Power Transformers” [1]. This Guide provides useful information about what to expect when transformers are operated in an over-temperature condition. The Guide uses 65,000 hours (7.4 years) of operation at the maximum 65° C rise above ambient as the normal life expectancy of a transformer. This is the point where 50% of the strength in the paper insulation has been lost. This loss of insulating capacity greatly increases the probability of an insulation failure during a through

fault. The relationship between oil temperature and transformer life is defined in the guide as the aging factor FAA. Consult IEEE Std C57.91, “IEEE Guide for Loading Mineral-Oil-Immersed Transformers and Step-Voltage Regulators” for further details.

## Using the Basler BEI-FLEX for IEEE Transformer Thermal Management

The Basler BEI-FLEX relay gathers thermal information and provides analog inputs for control signals and annunciation signals. The BEI-FLEX can provide information for temperature, pressure, flow rate, oil level, tap changer position, SF6 gas and other useful inputs.

The BEI-FLEX can be configured with a variety of circuit boards that include RTD inputs, analog inputs, several communications options and power supplies. Circuit boards can be added and removed to configure the product in any manner the user deems necessary to accommodate the application. This can be done at the Basler factory or in the field.

Circuit board option A2 provides up to 7 RTD inputs. Each of the 7 RTD inputs may be connected to a 3-wire type RTD. The characteristic of each RTD is user selectable from standard 100 ohm platinum, 100 ohm nickel, 120 ohm nickel, or 10 ohm copper materials. A selection of RTD elements may be defined and utilized in the thermal protection of the transformer. The measured temperature associated with each RTD element may be displayed through the metering functions within BESTCOMSPi.us. The BEI-FLEX monitors each input for the status of the connected RTD and alarms if necessary.

Circuit board option U4 provides 7 analog inputs. Each analog input is user-selectable for 4 to 20 ma or 0 to 10 Vdc. BESTCOMSPi.us provides the user with pickup level, time delay and over or under comparison settings for the specific parameter and allows the user to incorporate these inputs into BESTlogicPi.us as desired. These analog inputs can be utilized to measure critical information about the transformer and surrounding equipment such as oil pressure, oil flow, nitrogen pressure, SF6 gas pressure and tap changer position. This information can be utilized locally, stored or transmitted remotely to make operating, maintenance and protection decisions.

## 5ITF Through Fault Monitor

The BEI-FLEX Protection, Automation and Control System features 5ITF through fault monitoring capability. External close-in faults can cause extensive wear on the transformer. The 5ITF function monitors the current flowing through the transformer and gives warning and control signals based on the current magnitude and time duration compared to a user defined withstand capability curve. In Figure 2, M is the magnitude of the through-fault current in the multiples of transformer base current setting. M is sensed and input to the transformer monitor system.

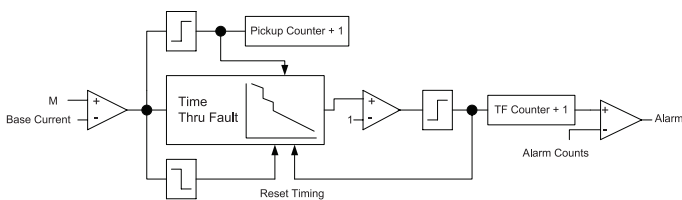


Figure 2 - Block Diagram of Transformer Monitor Function

5ITF monitors the current flowing through the transformer and gives warning and control signals based on the current magnitude and time duration compared to a user-defined withstand capability curve. As shown in Figure 3, the user defined withstand capability curve is a combination of up to three inverse time overcurrent curves.

Each of the three curves is defined by the following equation.

$$TF = \frac{K}{(M - 1)^N}$$

Where:

TF represents the transformer withstand capability time when a through fault current is M times the transformer base current setting.

M represents the magnitude of through-fault current in multiples of transformer base current setting.

K and N are user-selectable constants.

One of the three inverse time overcurrent curves is chosen based on the through fault magnitude (M). Let  $M_1$ ,  $M_2$  and  $M_3$  represent the threshold setting of through fault current for the three inverse time overcurrent curves. The curve selection criteria is as follows:

- If  $M_1 \leq M \leq M_2$ , Curve 1 is selected
- If  $M_2 < M \leq M_3$ , Curve 2 is selected
- If  $M > M_3$ , Curve 3 is selected

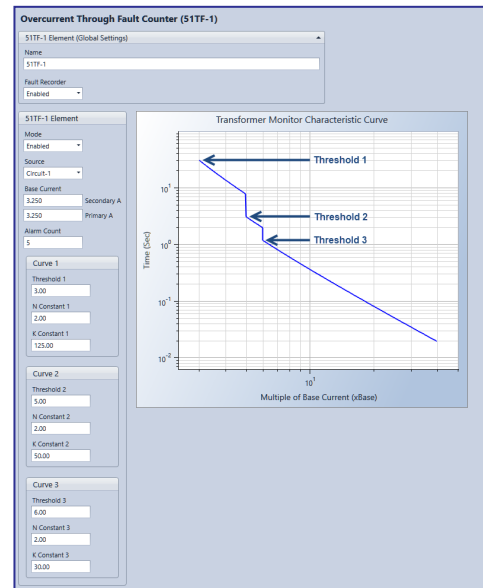


Figure 3 - Overcurrent Through Fault Counter User Setting Screen

When current is above M1, pickup will be set and pickup counts will be increased by 1. At this condition, 5ITF is timing toward trip using the Transformer Monitor Characteristic Curve.

When the Transformer Monitor Characteristic Curve time is reached, the Trip output will be set and the Through Fault Counter will be increased by 1. The Through Fault Counter indicates the number of events that have lasted long enough to exceed the transformer withstand capability and, thus, can predict the remaining life of the transformer. A user setting Alarm Counter is provided. When the Through Fault Counter exceeds the user defined alarm counter setting, an alarm is signaled. The Pickup Counter and the Through Fault Counter can be preset and reset by the user.

## Better Programming via Easy Graphical Interface

A national reliability study shows that a significant majority of all multifunction relay misoperations are caused by incorrect programming. Basler's intuitive settings software helps solve this problem. All BEI-FLEX relays can be programmed using any Boolean function with drag-and-drop elements, inputs, outputs and many other elements from the BESTlogicPlus programmable logic. These views or templates can be customized and saved according to your company's standard. Logic documentation is provided, as well as logic printing, settings export capabilities and settings difference analysis. Figure 4 shows the 5ITF Summary Screen displaying the enabled 5ITF function discussed earlier.

Figure 5 is part of the Transformer Application Template available at [www.basler.com](http://www.basler.com). To modify the logic, use the drag-and-drop method to add elements, then click and hold to connect a line between two elements. Users can

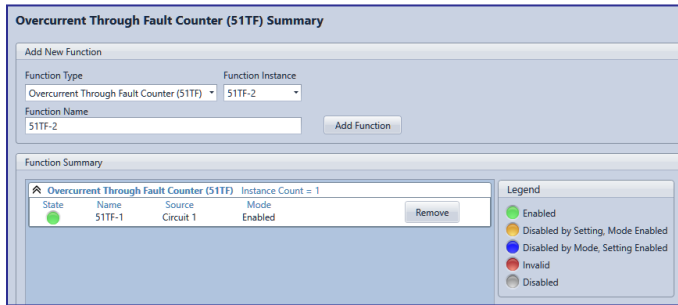


Figure 4 - Overcurrent Through Fault Counter (51TF) Summary Screen

access the Comment Box located in the Toolbox to add a comment. The new logic can be saved as an integral part of the BESTCOMSPPlus file, and it can be saved in the logic library for later use in similar applications. When complete, upload the new logic and settings to the BEI-FLEX via the BESTCOMSPPlus program.

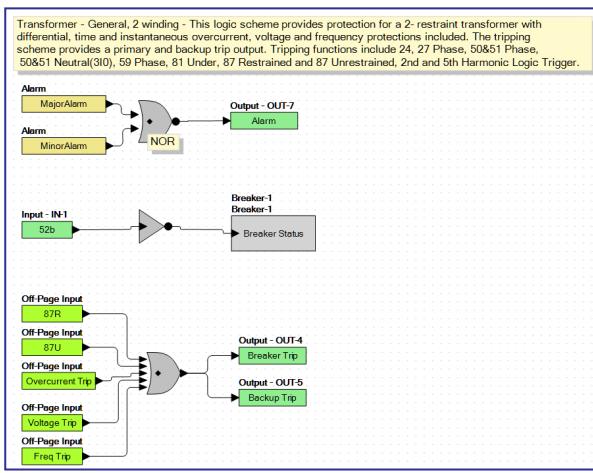


Figure 5 - Sample of Transformer Logic in BESTspace

## Conclusions

Monitoring, measuring, predicting and controlling transformer temperatures and through faults can add life to this critical part of the electrical system. Monitoring and measuring through faults, which can cause transformer insulation damage, can predict when preventive maintenance needs to be done before catastrophic failures occur. Measuring and controlling transformer temperatures can add years of useful life to the transformer while allowing the operator to increase loading on the transformer. This can reduce or eliminate the need for additional capital spending for capacity increases. The BEI-FLEX relay provides this added protection and control capability.

## References

- [1] IEEE Guide for Loading Mineral-Oil Immersed Power Transformers, IEEE Standard C57.91, Institute of Electrical and Electronic Engineers, New York NY, 2011.
- [2] Hunt, Rich, M.S., P.E., and Michael L. Giordano, B.S., P.E. "Thermal Overload Protection of Power Transformers – Operating Theory and Practical Experience." Georgia Tech Protective Relaying Conference (2005).

## More Information

For more information on Basler BEI-FLEX Protection, Automation and Control System, see [www.basler.com](http://www.basler.com) or contact Technical Support at 618-654-2341.