DATA MODEL FOR OVERHEAT PREDICTION OF MEDIUM-VOLTAGE SWITCHGEAR

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ABSTRACT

In China, a detailed plan has been defined for building a more robust and reliable distribution network by utilizing smart grid features under the national development plan. By far this plan has driven many Chinese switchgear manufacturers to offer so-called smart switchgears.

Because of the different skill levels of the switchgear installers and operators in China, incorrect installation and operation accounts for a significant portion of the root causes of incidents caused by overheating of the connection points, such as the tulip contacts or cable connection points. So, one of the smart functions requested by customers is online monitoring of temperatures of the critical hotspots of components, and especially those withdrawable connection points. The traditional way of detecting overheating is through a viewing window and the use of a portable infrared device that is not always accurate and predictable due to the access and orientation of the switchgear components. In order to detect overheat situations more accurately and prior to an incident, an online temperature monitoring system can be applied. Normally such a system is set to give an alarm when a temperature limit is exceeded in the measuring points. Then actions need to be triggered to remove the risk of a developing failure. However, due to the fact that the alarm can't be activated unless the temperature limit is exceeded, this type of system can't protect components in a network from overheating before a defined temperature limit has been exceeded.

Therefore, in order to give an early warning before reaching a critical stage, a dynamic data model has been developed by ABB to judge and predict an imminent overheat situation. The data model has proven to be effective in predicting potential overheat situations by utilizing data collected in low load situations far away from a failure mode. The data model has been verified with physical tests and both the data model and verification tests will be discussed in detail in this paper.

INTRODUCTION

In the field of online monitoring of medium-voltage (Hereinafter called MV) switchgears, temperature rise in critical areas is a key item to be monitored. The present way of triggering an overheat alarm is to define a temperature limit, which triggers an alarm if the defined limit is exceeded in one of the measuring points. However, according to the long-term experience of practical use, this monitoring principle has two weak areas to be concerned with:

Firstly, the alarm will only be triggered when the temperature has already exceeded the defined alarm limit. So when the alarm has triggered, the switchgear is already in a potential failure mode with a high risk of failure unless immediate actions are taken to bring the temperature below the defined alarm level.

Secondly, by defining an alarm level, the switchgear is healthy as long as no alarm has been triggered and only has a problem when the alarm has been triggered. So this method is not suitable to detect a latent overheat fault. As low current passing through a weak area in the switchgear may not result in exceeding the alarm level defined, so the monitoring system will not be able to detect such a failure mode.

In Figure 1, a typical curve representing the actual temperature of a measured point is shown by the black curve with different load situations. Traditionally, a constant limit alarm has been defined as the red dotted line. This figure shows that the alarm level has been exceeded due to a high temperature in the 1250A period. Due to this incident, the load had to be reduced from 1250A to 1100A to reduce the temperature below the critical limit. Such action might have an impact on the feeding side of the switchgear. However, the constant limit method is unable to detect the fault until the fault has escalated to reach or exceed the limit and immediate actions need to be taken to prevent a severe failure of the switchgear or other assets.

A dynamic temperature limit model has been developed by ABB recently that is able to detect possible failures even at very low current levels and with a temperature below the alarm level. By offering this type of early warning alarm, a high temperature situation will be prevented before the temperature has exceeded the high temperature alarm level. Corrective actions can then be planned and executed in a controlled way without any risk of entering a failure mode.

MODEL CONCEPT

For the data model, two steps have been introduced to establish linkages between the dynamic temperature limit of hotspots and the real-time current and its acting time. The first step is based on the real-time current to establish

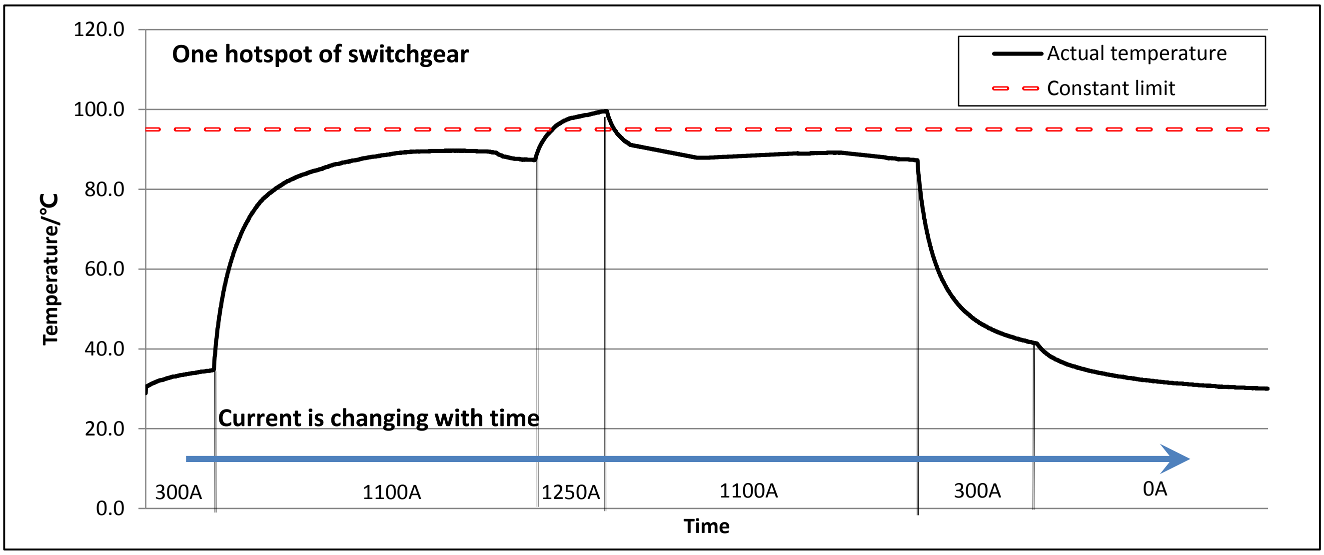

Figure 1: Constant limit method to trigger alarm

its appropriate stable temperature under which healthy switchgear should be assured. The second step is then based on the result of the first step as a safe limit to calculate the transition process from the present temperature to the stable temperature. Based on this concept, the dynamic temperature limit model consists of two calculations.

Stable temperature rise calculation

The stable temperature rise of the hotspot is calculated from the highest of the real-time three-phase currents according to equation 1:

$$T_{stable} = ({}^{I}/_{I_{ref}})^{1.6} * T_{ref} \qquad \text{Equation 1}$$

I	the real-time highest phase current
I_{ref}	the rated current of switchgear
T_{ref}	the stable temperature rise under rated current
T_{stable}	the stable temperature rise under real-time highest phase current

Equation 1 can be referenced from clause 5.4.3.2 of Reference [1]. Attention should be paid to the exponent 1.6. In this standard the exponent is a range from 1.6 to 2.0. This means the calculated result is a range rather than a single value. By using the exponent 1.6 the maximum value of this range will be calculated, while by using the exponent 2.0, the minimum range will be calculated. Given that the data model should allow for the worst condition, exponent 1.6 is used in Equation 1.

In addition, attention also should be paid to the parameter T_{ref} which is defined as the stable temperature rise under rated current. But there is no doubt that a series of different T_{ref} can be used when conducting a series of temperature rise tests on the same switchgear. However, these different T_{ref} are hovering around a value within a defined range. So it is necessary to pick out the single representative value as T_{ref} to put into Equation 1. The method to find out this value is described next:

In the field of temperature calculation, it is very hard to set up an accurate mathematic model to calculate the problem exactly, so the probability and statistics theory is often introduced to solve these difficult problems. Similarly, the probability and statistics theory also plays an important role in the process of defining the representative T_{ref}.

The valid temperature rise data of one special type of switchgear was collected from already available test reports and then used as known data to form a statistical sample. Then the distribution type (normal or other types) of this sample can be defined with a statistical method. Finally, the probability distribution curve can be drawn out and the scope of temperature rise can be extended subsequently as shown in Figure 2.

From the perspective of statistics, 75% is considered a default number representing a high probability event. As it is assumed that most of the MV switchgears are working at a healthy status, so therefore a value called X1 can be found on the curve to make the event P{X<X1} = 75%, which means the probability of the event "the temperature rise is under X1" is 75%. The remaining 25% are working at sub-health status as they are deteriorated from being in service for a long time. However, they are still able to continue serving for several more years. They should not be considered as switchgears which could soon lead to accidents and therefore must be taken out of service and examined immediately. In order to allow for these sub-health switchgears, the other value X2 of the event P{X<X2} = 99.99% (The X2 will be infinite if using 100%,

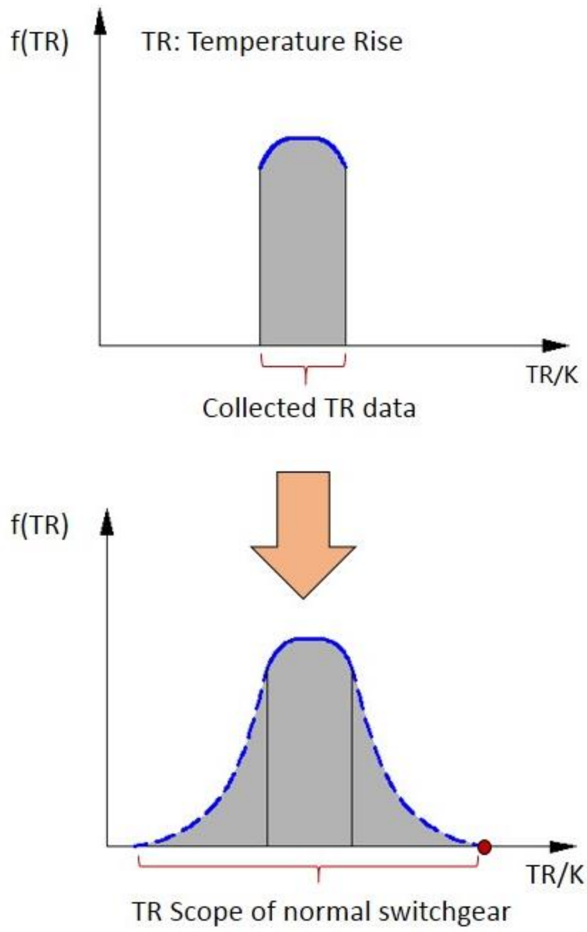

Figure 2: Use of known data to extend temperature rise scope by probability and statistics theory

so 99.99% is substituted here) has been used to cover these sub-health switchgears. Figure 3 on the right shows this method.

In the horizontal axis of the green chart, the values to the left of the red point X1 mean the stable temperature rise of switchgear is at a healthy status. The red point X1 on the horizontal axis makes the blue area equal to 75% (The whole area is 100%). This means that the probability of the event "stable temperature rise of hotspot of all switchgears at rated current is under the value X1" is 75%. Similarly, in the horizontal axis of the pink chart, the values to the left of the red point X2 indicate the stable temperature rise of switchgear is under healthy and sub-health status. And the red point X2 on the horizontal axis makes the blue area equal to 99.99%. This means that the probability of the event "stable temperature rise of hotspot of all switchgears at rated current is under the value X2" is 99.99%.

Thus the two values of T_{ref}, one with 75% probability representing healthy switchgears, and the other one with 99.99% probability representing both healthy and sub-health switchgears have been identified. According to the method, the T_{ref} of the hotspots of MV switchgears at risk has been established. Therefore, the value X1 and X2 can be put into Equation 1 to calculate T_{stable} respectively at real-time current which is essential for the subsequent calculation.

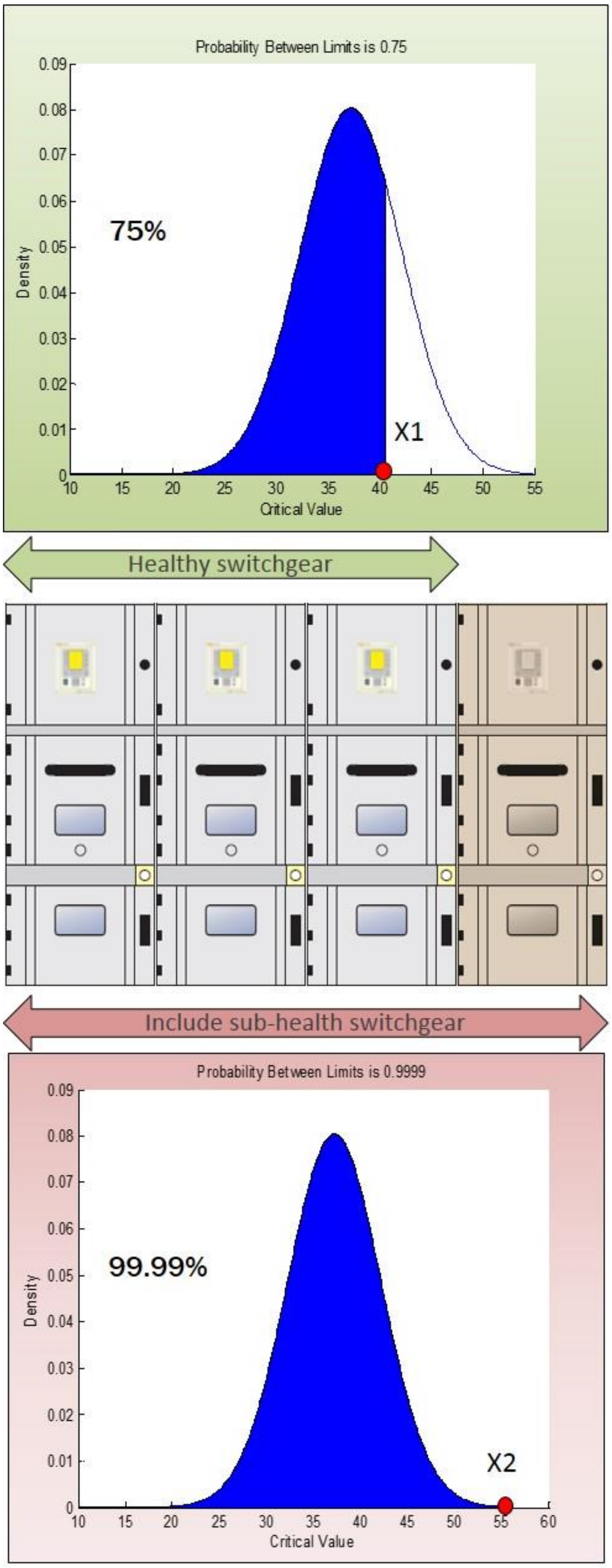

Figure 3: Method of defining representative T_{ref}

Dynamic temperature limit calculation

The dynamic temperature limit is calculated according to equation 2:

$$\theta_n = \theta_{n-1} + (\theta_{stable} - \theta_{n-1}) * (1 - e^{\frac{-t}{\tau}}) \qquad \text{Equation 2}$$

- θ_n the calculated real-time temperature limit
- θ_{n-1} the calculated real-time temperature limit at previous time step
- $\theta_{ambient}$ the real-time ambient temperature
- θ_{stable} the calculated stable temperature is equal to $T_{stable} + \theta_{ambient}$
- t time step between calculations
- τ thermal time constant for monitored MV switchgear

Time constant τ is used to describe the transient process. In fact, Equation 2 is not a new formula but rather another expression of the definition of thermal time constant. The definition of thermal time constant can be found in Reference [2]:

$$(\theta_n - \theta_{stable})/(\theta_{n-1} - \theta_{stable}) = e^{\frac{-t}{\tau}} \qquad \text{Equation 3}$$

The definition of Equation 3: When using a thermometer whose initial temperature is θ_{n-1} to measure a body whose temperature is θ_{stable}, the reading of the thermometer changed from θ_{n-1} to θ_n to make Equation 3 equal to e^{-1} after t. The duration t is defined as the thermal time constant of the thermometer. Thermal time constant is used to describe a body's transient process from one thermally stable status to another thermally stable status. Therefore, the thermal time constant can be used to describe the heat transient process of a switchgear, that is, the transition changing from one stable temperature rise to another stable temperature rise as a result of changes in current.

According to the above definition of thermal time constant, a large number of tests on some classical MV switchgears were performed to establish the thermal time constant of the hotspots whose positions are shown in Figure 4. It needs to be emphasised that MV switchgears with different current ratings and structures have different thermal time constants. Therefore, enough tests should be performed to establish special thermal time constant for the switchgear with special current rating and structure before applying this model.

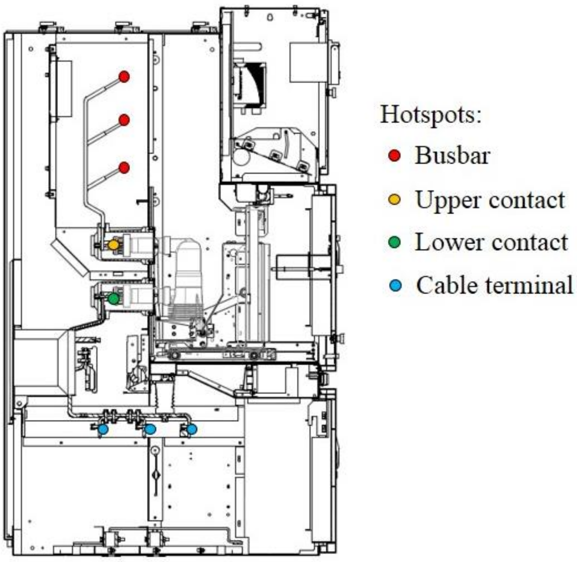

Figure 4: Hotspots of classical MV switchgear

VALIDATION BY TESTS

A large number of tests on some typical MV switchgears with changing reference current were performed to prove the validity of the dynamic temperature limit model. Due to space constraints only some classical test results are presented in this paper.

As shown in Figure 5, the yellow curve that is calculated

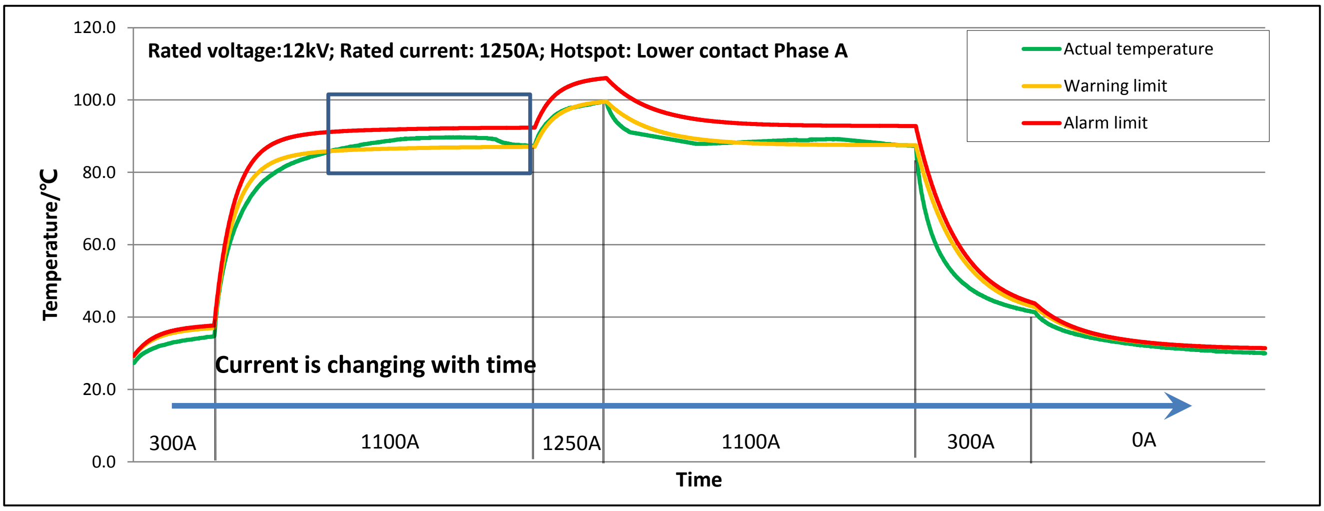

Figure 5: Example 1

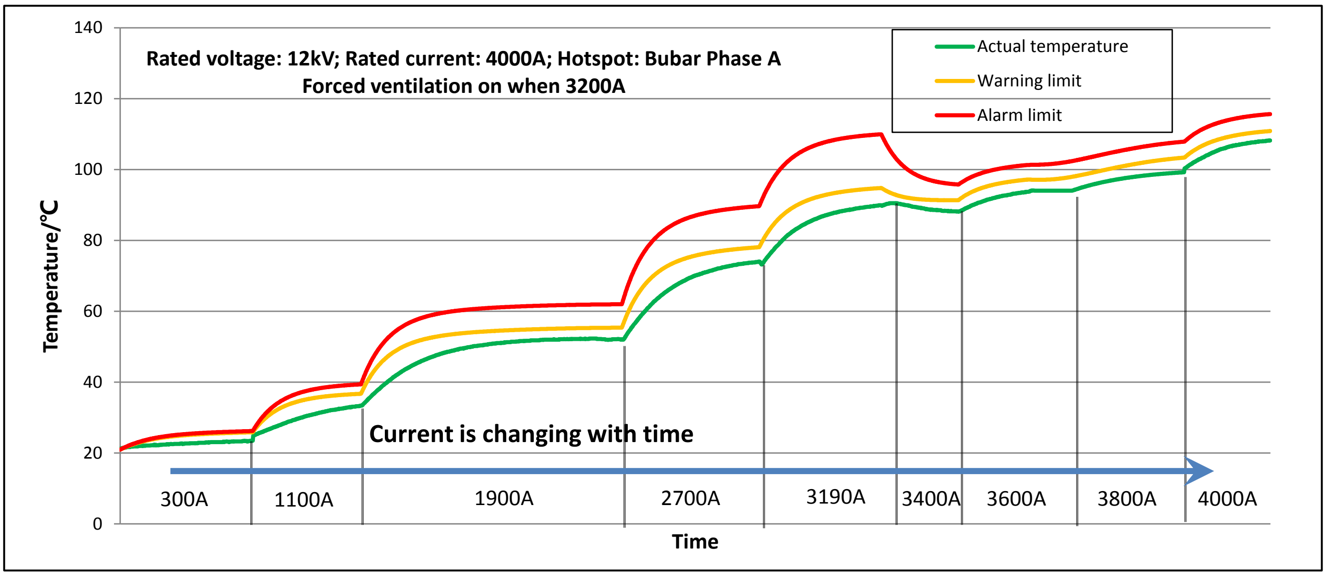

Figure 6: Example 2

from Equation 2 with 75% T_{ref} serves as a warning limit, while the red curve that is calculated with 99.99% T_{ref} serves as alarm limit. The figure shows that the actual temperature, the green line, has exceeded the warning line when the current is 1100A, so a warning signal will be triggered ahead of the actual temperature exceeding the safe limit. The final test result indicated that the stable temperature at 1250A was above the ambient temperature by 66.5°C, which slightly exceeded the safe limit 65°C stipulated by set standard. Obviously the slight excess would not lead to any immediate damage to the switchgear. Therefore, there is no need to disconnect the switchgear immediately, but instead to make a correction at the next planned maintenance. Since it was known already at 1100A that the switchgear had a problem, a better switching strategy would have been to rearrange the load in such a way that this specific switchgear avoided having a load of 1250A at all.

As shown in Figure 6, even if the current changes frequently or the switchgear is equipped with forced ventilation function, the model still is able to track the actual temperature curve closely and give the right prediction.

CONCLUSION

Performed tests proved that the dynamic temperature limit model is able to monitor the health of a switchgear when also carrying low currents. This gives an added value because corrective actions can be planned without being under time pressure and re-routing of loads can be done in such a way that the switchgear will never enter a risk zone without risk of high load failure modes. In comparison to the constant limit model, this dynamic temperature limit model provides much better and more valuable monitoring to the health of switchgears. This will again lead to a more reliable supply and higher quality of the MV network where load variations can be handled.

REFERENCES

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[2] S. Yang, W. Tao, 1998, *Heat Transfer*, Higher Education Press, Beijing, China, 52.