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IR trend analysis for HV/MV equipment diagnostics.

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Abstract

In this paper the problem of varying load/ambient compensation is considered. The concrete application area is the trend analysis for HV/MV disconnectors condition assessment. As neither the direct temperature comparison nor thermograms subtraction is possiblle a new approach is proposed. A set of characteristic invariant factors with a rule-based reasoning algorithm are defined as a patent pending method for diagnosing possible defect development. The proposed approach allows for both trending and defect localisation. An experimental example demonstrates the feasibility of the proposed approach.

1. Introduction

Thermographic monitoring of electrical substation equipment gains increasing popularity for its being a non-destructive and primarily non-contact diagnostic technique thus allowing for testing under high potential. There are numerous defects that become apparent in infrared well before they become critical. The most common are: bad contacts (loose, corroded cable connections, defective sliding or tulip contact), inductive heating (bolted connections), current leakage, inter-winding short circuits, clogged transformer radiators, tap changer malfunction, oil ageing by-products deposit on instrument trafos winding and many other [1,4]. A precondition to study any of these defects is to run the object at minimum 30% the rated load.

The scope of the following paper covers the issue of thermographic inspections of HV/MV equipment with particular focus on compensation of varying operating and measurement conditions. Most thermographic inspection techniques in use nowadays allow for in-service condition assessment without referencing though to the past measurements. The current state is evaluated from single or multiple thermograms of the object in question all taken however at the same time. This is due to the fact that the actual surface temperature distribution is considerably affected by a number of factors unrelated to any defect development. Hence a direct temperature comparison between thermograms of the same objects but taken at different operating conditions is not possible. The temperature as measured by the camera reflects not only the object's internal condition but just as much the operating conditions (i.e. current load) and environment – sun irradiation, air temperature, wind-forced cooling and others. Thence an object with no developing defect may in fact yield a very different camera readings when inspected at different times. On the other hand many of these factors (e.g. wind) are not quantifiable to the extent allowing for straightforward analytical compensation. Some authors propose analytical or experimental methods to compensate for e.g. load variations [2, 3] but these are not general enough.

Another technical problem with processing of thermal sequences is variable camera positioning during off-hand in-the-field measurements. Even minor differences in the viewing angle with respect to the inspected object yield different object framing (shifted, rotated) thus making pixel-to-pixel automatic comparison (e.g. subtraction) impossible. The proposed way to circumvent this is to pre-select the target regions thereby disregarding their actual positioning in the consecutive frames.

A widely used method in thermographic condition assessment is to consider the temperature difference (delta) between a problem area and another identically loaded object or its part (appearing to be in the correct state) as a reference. This procedure is commonly used for electrical 3-phase devices. A different approach is the subject of this paper.

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2. Research goal and tools

The objective is to develop an approach allowing circumventing the inherent thermal picture dependence on changes in load and external conditions. This becomes an issue particularly for thermal trend analysis where establishment of common reference level is of the primary importance.

All thermographic measurements were performed with the use of Inframetrics IR camera model PM280E which is a cooled, SW FPA detector unit. The in-the-field inspection data were collected at a number of locations including industrial and state-run (electrical utilities) substations. At all times current load and ambient conditions were noted. Most measurements were made at early morning hours to eliminate the sun pre-heating influence. The inspections were repeatedly run over the period of 5 months.

The software tools (Thermal Trend Analysis Package) have been developed under MATLAB 5.1 environment. They are specifically dedicated to process sequences of thermal images rather than one image at a time only. Among its many features, apart from the trend analysis algorithms, there are 3D visualisation, temperature profiling (also 3D) and local emissivity adjustments.

3. Research scope

The investigation of thermal behaviour was performed on selected types of HV/MV equipment. In particular HV/MV disconnectors were chosen as they contribute the major part of defects occurring at substation equipment. Due to different operational and constructional individual properties each distinguished object features certain potential problem-areas that should be first taken under a "magnifying glass" while performing the thermal trend analysis. To localise such areas a statistical analysis was carried out on numerous population of equipment samples and a relevant thermographic database was set-up.

4. Proposed solution

Nearly all HV/MV disconnector failures are located at either of the heads (cable terminals) or the connector zone. It seems fully justified then to focus on these areas to pinpoint a possibly developing defect.

The proposed solution exploits the fact that, as a disconnector construction features full symmetry, its thermal behaviour should follow similar pattern. Due to basic electrical laws the same current flows along the whole path including the heads and disconnector arms. In its correct state both heads should yield the same surface temperature distribution and any load-dependent internal heat production variations should result in similar thermal responses unless the electrical resistance would change which would indicate a defect. The same applies to varying ambient conditions as both parts are subjected to the very same environmental conditions. It is proposed then to consider mutual relations between the predefined "problem areas" within a given object. In the case of HV/MV disconnectors these are cable terminals and the sliding contact zone.

In the discussed approach the thermal ratios are used as factors invariant to load and ambient variations. In the first step a pre-set number of regions is defined. These regions should cover the most critical areas for the given object type. In the case of HV/MV disconnectors it makes 3 characteristic regions: two heads and the arms sliding contact zone (A, B, C – see figure 2.). The figure 2 illustrates the principle.

Next a characteristic temperature value is computed for all defined regions. In the proposed approach it is taken as median temperature within each selected area for its suitability to skip possible outliers (e.g. erroneous temperature peaks due to pointwise reflections). Other methods of computing the characteristic temperatures (e.g. division into subregions and weighted average computation) are also possible and may depend on the actual application. Thereby one obtains 3 characteristic values *a, b, c*. Then a set of thermal invariant factors tif_i is defined as ratios:

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$$tif_1=a/b;\ \ tif_2=c/b;\ \ tif_3=a/c \tag{1}$$

The above procedure is repeated for all thermograms in the sequence thus producing a train of 3-element vectors. In the normal condition the tif_3 value should be close or equal to one (identical thermal properties), whereas the remaining two ratios need to be normalised with respect to the first thermogram in the sequence.

The diagnostic reasoning is based on the defined characteristic ratios tif_i. Having set arbitrary warning and alarm thresholds that impose a limit on the tif_i variations, we may define a set of *if-then* rules. These rules describe all plausible combinations of *tif* with respect to the thresholds. For example:

$$\text{IF } tif_1 > alarm \text{ AND } tif_3 > alarm \text{ THEN } \{\textit{region A is in alarm state}\} \tag{2}$$

The resulting conclusions provide one of three possible condition states {*OK, warning, alarm*} for each defined region. This way not only we get a general state assessment but also information about the defect localisation.

As we record the findings over time it is possible to extrapolate the tif_i trend lines and assess not only the actual state but also the severity of the possible defect development in future.

5. Case study

As an example consider a sequence of 11 thermographic measurements taken on a common 110 kV / 1250 A disconnector operating at a wide range of load and ambient conditions (table 1).

Following the procedure described above a train of the thermal factors tif_i was computed and plotted (figure 3). The rule-based reasoning led to the conclusion that clearly there is a problem developing at the cable terminal A and judging from the slope of the increase it will soon shift from *warning* to *alarm* state. Thus an immediate action is required.

6. Conclusion

The proposed solution allows for thermal trend analysis without direct temperature comparisons. A definition of thermal invariant factors makes the state assessment robust to changes in the operating and ambient conditions. A set of rules provides a reasoning engine so as to assess the condition, localise the defect and predict future development.

Further research is devoted to investigation of the level of the severity criteria thresholds and how they are related to the actual object type.

REFERENCES

[1] HURLEY (T. L.) – *Infrared qualitative inspections for electric utilities* – in Proc. SPIE Vol. 1313 Thrmosense XII, 1990

[2] NIELSEN (T.), SORENSEN (J.) – *Guidelines to thermographic inspection of electrical installations* – in Proc. SPIE Vol. 2245 Thrmosense XVI, 1994

[3] GROVER (P.) – Applying temperature standards to IR inspections of electrical systems - Maintenance Technology, October 1993, pp. 31-36

[4] KAPLAN (H.) – Practical applications of infrared thermal sensing and imaging equipment – SPIE Optical Engineering Press, 1992

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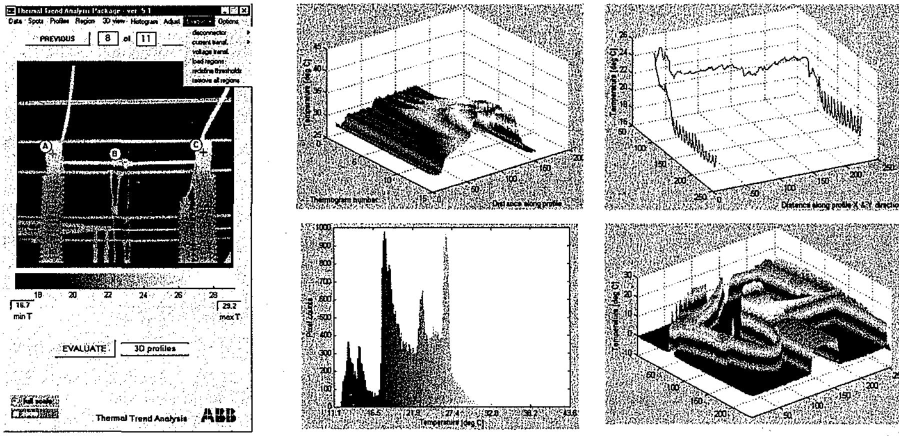

Figure 1. Thermal Trend Analysis Package screenshots.

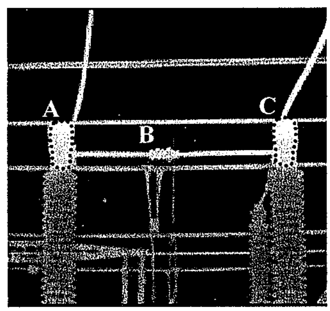

Figure 2. Characteristic regions definition.

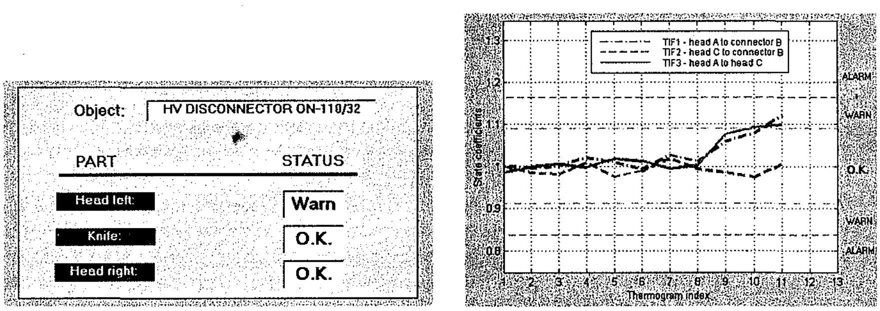

Figure 3. A plot of the *tif$_i$* values computed for the sequence of 11 thermographic inspections and the assessment provided by the rule-based system (right)

Table 1. Load and ambpient temperature values at corresponding measurements

Thermogram #	1	2	3	4	5	6	7	8	9	10	11
Load [A]	390	415	455	370	500	440	385	365	470	390	430
Ambient T [°C]	16	23	16	18	12	15	20	25	19	23	20