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RESEARCH ARTICLE

Assessing the service condition of an electrical panel board

W.M.N. Surawimala[1,*] and J.B. Ekanayake[2]

[1]*KIK Lanka (pvt) Ltd, Export Processing Zone – Katunayake, Sri Lanka*
[2]*Department of Electrical and Electronic Engineering, Faculty of Engineering, University of Peradeniya, Peradeniya, Sri Lanka*

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Abstract: Electrical panel boards are used to locate controlling, measuring and metering devices which are used in electrical power distribution. It is a customised product which is used for a specific purpose. The proper functioning of an electrical panel board can be ensured by properly maintaining it. Normally, it will be routine maintenance which will be performed once a year or half a year. But it is essential to know the service condition of an electrical panel board to avoid failures and perform the maintenance activity where it is necessary. This research presents a method to assess the service condition of an electrical panel board. Initially, the importance of the temperature, humidity and number of operations of a circuit breaker is highlighted by referring to the international standards such as IEC 61439-1 and IEC TR 60890. Field measurements of a selected sample space were used to evaluate the condition of panel boards against the above standards by considering the age of the electrical panel board and its maintenance status. These measurements were statistically analysed, and a device called **Service Condition Analyser (SCA)** was fabricated and tested under laboratory conditions. It was observed that under the stressed conditions, an upward trend of the service status was shown by the SCA.

Keywords: Predictive Maintenance, Electrical Panel Board, Service Condition Analyser, Predicted Temperature and Humidity Profiles.

INTRODUCTION

Low Voltage Switchgear and Controlgear Assemblies

In the context of electrical distribution systems, the low voltage (LV) electrical panel boards such as switchgear and controlgear are a critical asset that acts as the brain in the electrical installation system. The electrical panelboard is a customised device that ensures reliability and safety in the usage of electrical energy so that electrical installations function smoothly while protecting invaluable human lives and property by eliminating possible electrical hazards. The IEC 61439 series is the recommended standard which applies to LV switchgear assemblies. It explains technical requirements for the following typical LV switchgear and controlgear assemblies.

- Assemblies for which the rated voltage does not exceed 1000 V in the case of ac or 1500 V in case of dc.
- Stationary or movable assemblies with or without an enclosure.
- Assemblies designed for use under special service conditions (Ex – Ships, Rail vehicles etc.) provided that the other relevant specific requirements are complied with.
- Assemblies designed for electrical equipment of machines provided that the other relevant specific requirements are complied with.

As technology improves, the electrical power requirement becomes more sophisticated which eventually increases the complexity of an electrical panel board. Also, the necessity of providing protection, measuring and metering aspects while minimising unscheduled breakdowns was a crucial factor in the operation of an electrical panel board.

Maintenance of LV Switchgear and Controlgear Assemblies

Maintenance is essential for any electrical appliance or devices to harness its intended lifetime. Maintenance could be reactive, preventive, predictive and proactive. According to the statistics, preventive maintenance is the cost-effective method which will increase the return on investment ten times, reduce the maintenance cost by 25% to 30%, and reduce downtime by 35% to 45%. Also, the condition based maintenance allows establishing the real limits of the monitored equipment which will serve as the missing link between the product designers and end users with the real applications (Livshitz, *et al*., 2004).

According to the statistics, mechanical, insulation, and temperature conditions are the most important factors that need to be monitored in the predictive maintenance activities (Shi *et al*., 2002). Even though the statistics say so, the integration of monitoring of the above three factors has not been implemented due to the following reasons (Shi *et al*., 2002).

**Corresponding Author's Email:* nilupuls@kik.lk
http://orcid.org/0000-0001-5404-2335

- Because of the compact and various structures of electrical panel boards, it is difficult to install sensors and transmitters inside the panel board.
- Cost impact of existing sensors and transmitters will be significant compared to the cost of the panel board.
- Introduction of sensors and transmitters will affect the original function of the panel board.

Most of the existing predictive maintenance activities are carried out using complex technologies such as thermography, vibration analysis, ultrasonic analysis etc. Since these measurements should be analysed using different software, the necessity of a device which indicates the condition of an electrical panel board was risen (Lazarescu & Andea, 2017). Some of the characteristics of this device include,

- Operating as an independent service,
- Working as a flexible and versatile device,
- No interaction with the service capacity of the electrical panel board or any aspect of its reliability, and
- Compatible to be integrated into a control automation system

By considering the factors mentioned above, in this research project, the design and fabrication of a cost-effective device called **Service Condition Analyser (SCA)**, which gives the operator a performance indicator of electrical panel board, is presented.

THEORETICAL ANALYSIS

Predicted Temperature Profile

According to the IEC 61439-1 standard for low voltage switchgear and controlgear assemblies, the proper operating conditions can be summarised as follows.

- The normal operating conditions are implied as the designed conditions that ensure the proper operation. If these conditions are not met, appropriate steps should be taken to ensure proper operation.
- The ambient air temperature for indoor installations shall not exceed +40 °C and its average shall not exceed +35 °C over a period of 24 h. The lower limit of the ambient air temperature shall be –5 °C. Similarly, ambient air temperature for outdoor installations shall not exceed +40 °C and its average shall not exceed +35 °C over a period of 24 h. The lower limit of the ambient air temperature shall be –25 °C.

During the operation of panel boards, it is important to consider the temperature rise in the air inside them due to the power losses of the various components in the panel board which is described in IEC TR 60890. Figure 1 shows the calculation process used to evaluate the temperature rise of air inside the panel board.

Firstly, enclosure constant (k), temperature rise factor (d), temperature distribution factor (c) and exponent for the effective power loss (x) were found by referring to IEC TR 60890. As per IEC TR 60890, effective power loss was calculated by using equation 01 with the aid of actual current (I), rated current (I_{rated}), current independent power loss (P_1) and current dependent power loss (P_2) which are mentioned in manufacturer's catalogues.

$$P_{total\ loss} = P_1 + \left(\frac{I}{I_{rated}}\right)^2 * P_2 \quad \text{..................(01)}$$

By using these values and equations 02 and 03, the temperature rises at the mid-point ($\Delta t_{0.5}$), and the temperature rise at the top (Δt_1) were calculated respectively. Temperature rise at the bottom was assumed to be zero as per IEC TR 60890.

Temperature rise at mid-height of enclosure

$$(\Delta t_{0.5}) = k.d.P^{x}_{total\ loss} \quad \text{........... ....(02)}$$

Temperature rise at the top of the enclosure

$$(\Delta t_1) \quad = c.\Delta t_{0.5} \quad \text{..............................(03)}$$

According to $\Delta t_{0.5}$ and Δt_1 values, predicted temperature profile was obtained as shown in Figure 2.

Predicted Humidity Profile

As per IEC 61439-1, Humidity in the air inside the electrical panel board should be as follows.

"The air must be clean, and its relative humidity will not exceed 50% at a maximum temperature of +40 °C. But higher relative humidity may be permitted at lower temperatures, for example, 90% at +20 °C."

Even though the temperature is the prime factor that determines the humidity inside an electrical panel board, in this study for completeness with the conditions stipulated in IEC 61439-1, the humidity was also included as an indicating parameter.

FIELD DATA ANALYSIS

Initially, a proper sample space was defined by considering the age and the maintenance status of a particular panel board. Normally, the organizations which have routine maintenance plan are categorized as "Well maintained (WM)" whereas the organizations which do not have a proper maintenance plan are categorized as "Less maintained (LM)". Then, by using temperature and humidity measuring devices, field data were obtained and compared with predicted profiles.

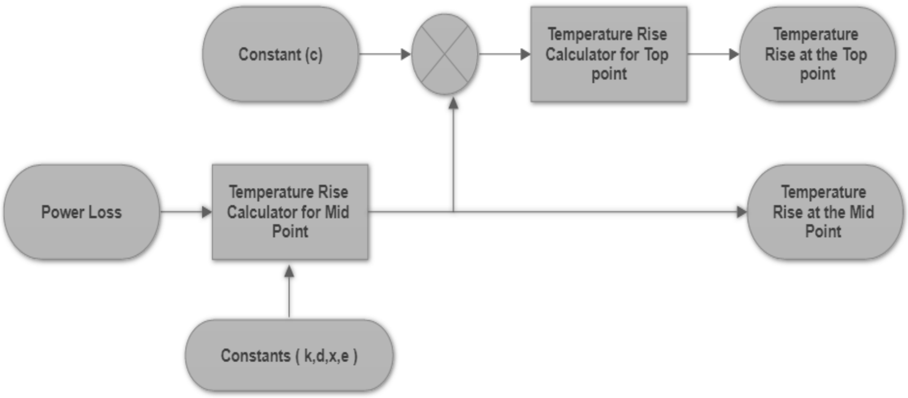

Figure 1: Temperature rise calculation as per IEC TR 60890. Power Loss value and respective enclosure constants should be provided as inputs.

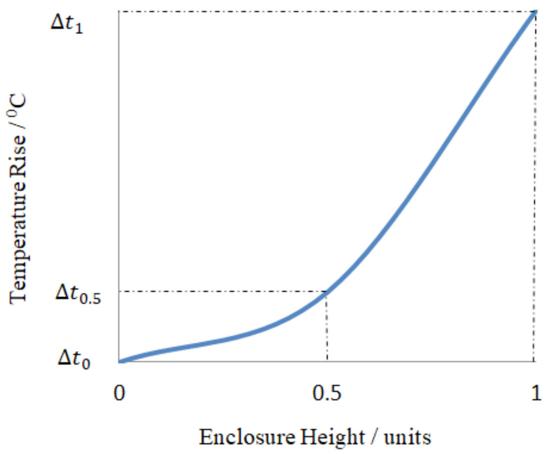

Figure 2: Predicted temperature profile with enclosure height of the Panel Board as per IEC TR 60890. Enclosure height is considered as a unit measurement.

Selection of Sample Space

Table 1 shows the selected sample space.

Table 1: Sample space for the field data collection

Age of the panel board	Maintenance status	Organisation	Name of the panel board	Current Rating (A)	Size (WxHxD) (mm)
Below 05 years	WM	DCSL	ATS panel	3200	600 x 2125 x 1250
	LM	Ocean Lanka (OL – 2)	The main incoming panel	2500	800 x 1925 x 1250
			Distribution panel	3200	800 x 1925 x 1250
			MSB	800	400 x 1925 x 650
Between 05 to 10 years	WM	KIK - 01	Bus-bar panel	400	200 x 2125 x 650
			Capacitor Bank	250	400 x 2125 x 650
	LM	Ocean Lanka (OL – 01)	1000A Sub Panel 01	1000	400 x 1925 x 850
			1000A Sub Panel 02	1000	600 x 1925 x 850
More than 10 years	WM	YKK - 01	ATS panel	1250	800 x 2125 x 1050
	LM	Packages Lanka Ltd - PLL	630 A change over panel	630	600 x 1925 x 850

Temperature Variation

By using three different temperature measurement devices, average temperature (in five minutes period) of the air inside the panel at the bottom, the middle and the top were observed and recorded. The characteristics of the temperature measurement devices are given in Table 2.

Then, predicted temperature profile and actual temperature profile were compared, and observations were made as given in Table 3 for the selected sample space.

By considering the results, a normalised temperature variation with respect to predicted temperature variation was obtained as per equation 04.

$$Normalized\ Temperature\ Value = \frac{Actual\ Temperature\ Value}{Predicted\ Temperature\ Value} \quad \ldots\ldots(04)$$

Normalised temperature profiles with respect to the enclosure height are depicted in Figure 03 for the sample space. Regardless of the actual height of the panel board, it is considered that the height of the panel is equal to 1 (Top point = 1, Mid-point = 0.5 and Bottom point = 0).

According to Figure 3, the following observations have been made and an appropriate colour code was used to depict the condition of the electrical panel board.

- Starting point of various graphs deviated from 1. Even though, the temperature rise of the bottom is assumed to be zero as per IEC TR 60890, there can be a small rise due to factors such as ground temperature, the temperature in the metallic plinth etc.
- If the condition of the electrical panel board is poor, the temperature variation deviates upwards with respect to the unit step function (highlighted in **RED** colour).
- If the condition of the electrical panel board is better, the temperature variation deviates downwards with respect to the unit step function (highlighted in **GREEN** colour).
- If the condition of the electrical panel board is good, the temperature variation deviates around the unit step function (highlighted in **YELLOW** colour).

Humidity Variation

For the sample space, humidity value at the mid-point of the enclosure was taken and recorded. Then it was compared with the predicted humidity value with respect to the temperature at the mid-point. The difference between the actual and predicted humidity values was calculated as shown in Table 4.

By considering Table 4, the following observations have been made.

- When the service condition is poor, the difference between the actual and predicted humidity values is more than 5%.
- When the service condition is good, the difference between the actual and predicted humidity values is less than 5%.

Table 2: Characteristics of temperature measurement devices.

Characteristic	Device with Probes / ^{0}C	Device with IR sensors / ^{0}C	Thermal image camera / ^{0}C
Accuracy	(±) 1	(±) 2	(±) 2
Range	-10 to 50	-35 to 500	-20 to 250
Resolution	0.1	0.1	0.1

Table 3: Observations of temperature data analysis.

Observation	Name of the Installation
Theoretical values and field data coincide each other	KIK – 01, YKK – 01
Theoretical values are below the field data	OL – 01, OL – 02, PLL
Theoretical values are above the field data	DCSL

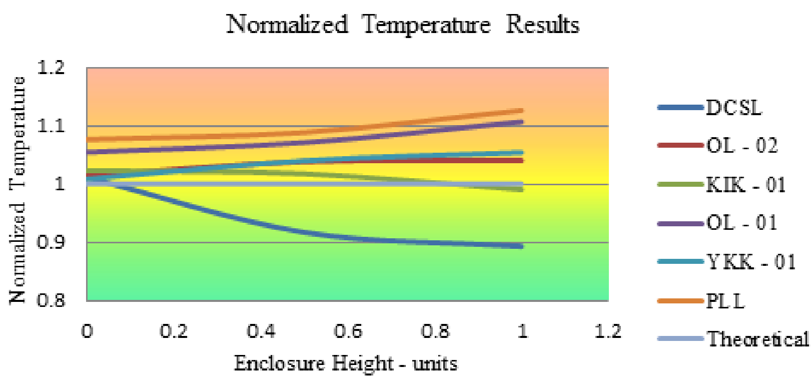

Figure 3: Normalized temperature results.

IMPLEMENTATION OF SERVICE CONDITION ANALYSER

By considering the theoretical and practical results, Service Condition Analyser (SCA) was designed and fabricated. The temperature and humidity inside the panel board and operation of the switchgear and controlgears were considered as the parameters which reflect the condition of the panel board. A programmable logic controller (PLC), temperature sensors with 4-20 mA converters and humidity sensors were used to arrange the complete setup for analysing the service condition. Service status on temperature, humidity and wear & tear condition were given as the output of SCA.

Service Status on Temperature

To compare the deviation between normalised temperature variations with unit function, D_{rms} value was calculated by using equation 05.

$$D_{rms} = \sqrt{\frac{(T_{0n}-1)^2 + (T_{0.5n}-1)^2 + (T_{1n}-1)^2}{3}} \quad ..(05)$$

where T_{0n}, $T_{0.5n}$ and T_{1n} are normalized temperature values at the bottom, the mid-point and the top respectively. By considering the observation from the field data collection, the following method stipulated in Table 5 was used as the decision making logic.

Service Status on Humidity

By considering the humidity difference percentage with respect to the predicted humidity value, the condition of the electrical panel board was estimated with the aid of the conditions stipulated in Table 6.

Wear and Tear Status

As per the manufacturer's specification, there is a rated number of operations for switchgear or controlgear. By using the auxiliary contact of the switchgear or control-gear, the number of operations was counted and compared with the rated number of operation as a percentage. This implies the lifetime of the switchgear or controlgear. According to the number of operations, the condition of the switchgear or controlgear was estimated by using equation 06.

$$\text{Tear Wear Condition} = \frac{\text{Number of Operations of the Circuit Breaker}}{\text{Electrical Life of the Circuit Breaker}} * 100\,\% \quad ....(06)$$

Table 4: Observations of humidity data analysis.

No	Name of the installation	Actual Humidity %	Temperature	Predicted Humidity %	Difference
1	DCSL	77	27.4	75.2	1.8
2	OL - 02	66	38.6	52.8	13.2
3	KIK - 01	60	34.1	61.8	-1.8
4	OL - 01	65	38.1	53.8	11.2
5	YKK - 01	53	37.3	55.4	-2.4
6	PLL	74	31.6	66.8	7.2

Table 5: PLC Logic for service condition on temperature.

Logic in PLC	The condition of the Panel Board	Service Percentage on Temperature %
If $(T_{1n}-1) > 0$ & $D_{rms} > 0.5$	WORST	100
If $(T_{1n}-1) > 0$ & $0.5 > D_{rms} > 0.25$	POOR	$75 + ((D_{rms} - 0.25) * 100)$
If $(T_{1n}-1) > 0$ & $0 < D_{rms} < 0.25$	GOOD	$50 + D_{rms} * 100$
If $(T_{1n}-1) < 0$ & $0 < D_{rms} < 0.25$	GOOD	$25 + ((0.25 - D_{rms}) * 100)$
If $(T_{1n}-1) < 0$ & $0.5 > D_{rms} > 0.25$	BETTER	$(0.5 - D_{rms}) * 100$
If $(T_{1n}-1) < 0$ & $D_{rms} > 0.5$	BEST	0

Table 6: PLC Logic for service condition on humidity.

Logic in PLC	The condition of the Panel Board	Service Percentage on Humidity %
If the | difference | < 5 %	GOOD	$\frac{\text{(The Humidity Difference)}}{5} \times 50$
If the 5 < | difference | < 10 %	POOR	$50 + \frac{\text{(The Humidity Difference) - 5}}{5} \times 50$
If the | difference | > 10 %	WORST	100

Also, monitoring of a number of tripping activities is an important aspect to understand the nuisance tripping of the system. The frequency of the tripping activity is calculated inside the PLC to give an indication to the operator to mitigate unwanted tripping. If the frequency of tripping increases, that gives an indication that there could be other issues like loose connections in the panel boards.

Status of the Surge Protective Device (SPD)

Surge Protective Device (SPD) is one of the important devices in an Electrical Panel Board which is there to provide a grounding path to the surges that are entering the distribution system. By using the auxiliary output of a SPD, the condition of the SPD is merged with the SCA to provide information about the availability of the SPD.

VERIFICATION

To validate the proposed Service Condition Analyser (SCA), a test setup was established and the results were obtained. A sample test panel, a control panel with SCA, a current injector and a test bench were the main parts of the test setup and shown in Figure 4.

For the testing purpose, a sample panel board was developed with a single feeder along with a Moulded Case Circuit Breaker (MCCB) which has a thermal rating of 250A as depicted in Figure 5.

The above mentioned distribution system was designed as a wall mounting electrical panel board as shown in Figure 6.

Test Procedure

In order to test the developed SCA, such analysers should be installed in a number of panel boards which are having different operational and ageing profiles and leave there for a longer period of time. As this is not practical, the panel board was stressed by sending a current greater than its rated value. This is to simulate the stressed condition which occurs due to poor maintenance of the panel board. In this condition, the SCA should give a service status in POOR region which is corresponding to RED colour area of the service status plot. The following procedure was followed to obtain the test results.

- **Step 01**: Initially the test set-up was established and the test bench and the current injector were powered up.
- **Step 02**: Current injector output was gradually increased with an interval value of 25A from 0 to 300A. For a particular current value, the test was performed for 15 minutes.
- **Step 03**: Then the service status on temperature, service status on humidity and wear & tear status were recorded.
- **Step 04**: Finally the observations were plotted and analysed.

Results

Initially, service status on temperature was recorded and plotted with respect to the applied current value as depicted in Figure 7.

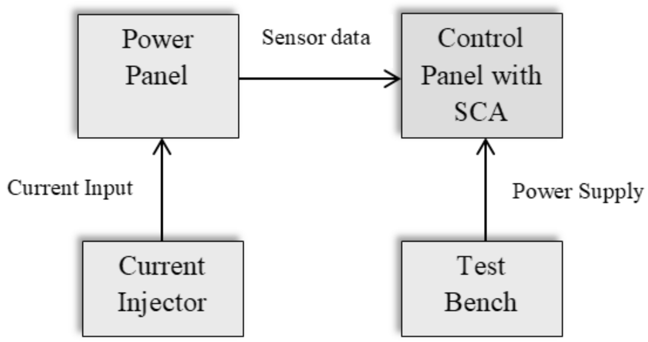

Figure 4: Test setup. It consists of four main parts namely power panel, current injector, control panel with SCA and test bench.

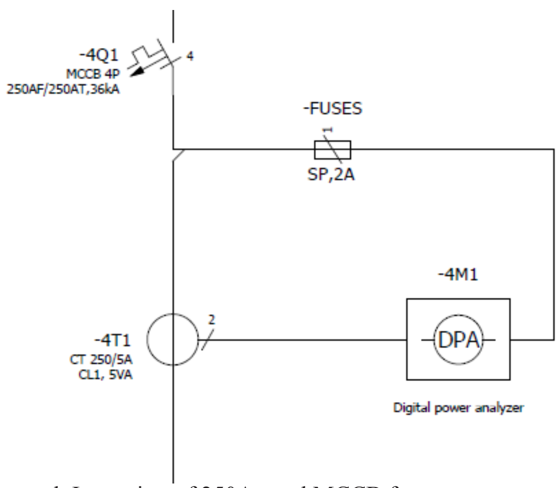

Figure 5: Distribution system for test panel. It consists of 250A rated MCCB for test purpose.

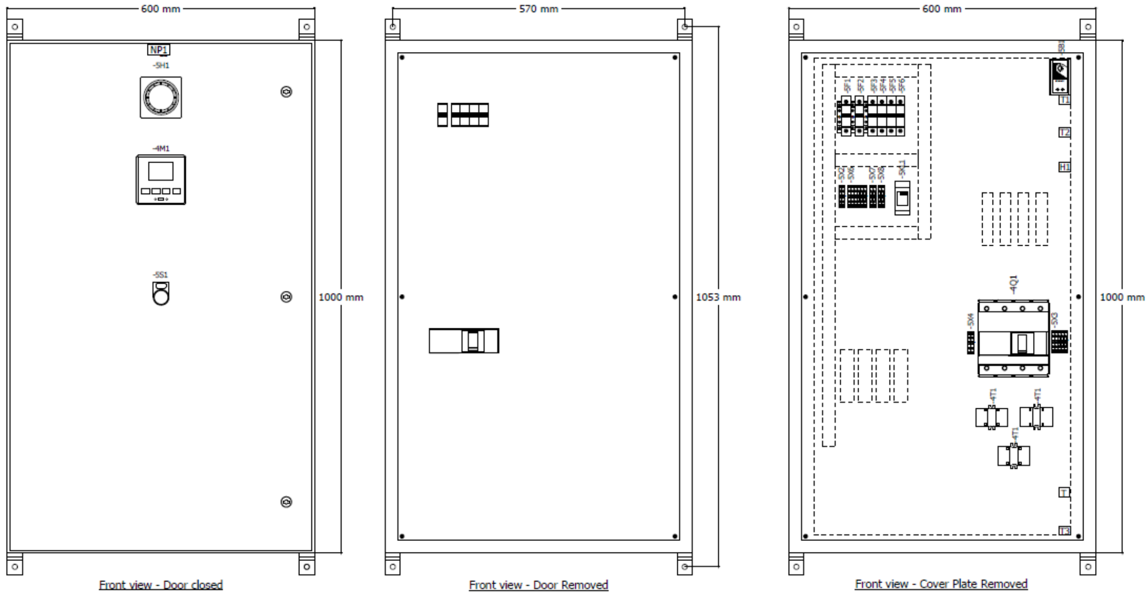

Figure 6: Layout diagram of the test panel board.

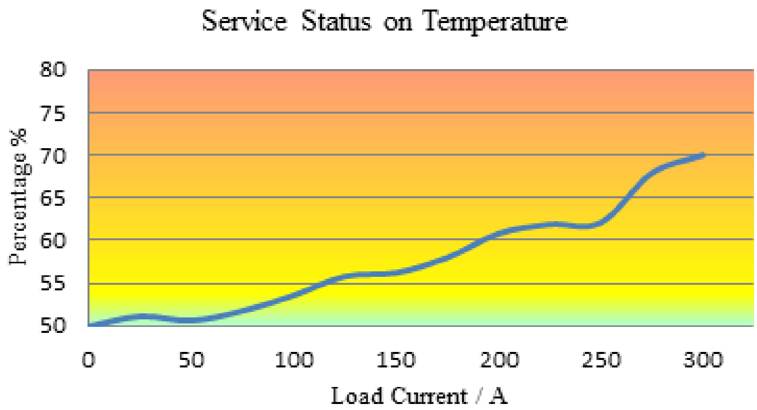

Figure 7: Service status on temperature with respect to the current applied as per Table 4.

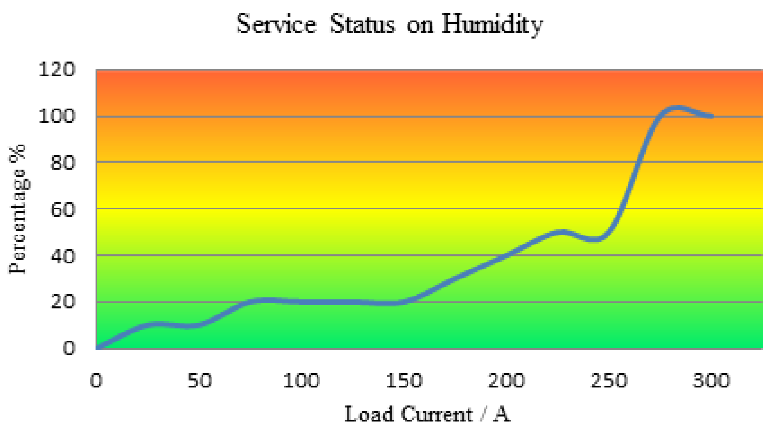

Figure 8: Service status on humidity with respect to the current applied as per Table 5.

According to the graph, it shows if the electrical panel board is operated in a stressed condition, the service percentage will increase. This shows the correct trend and indicates to the operator to check the operational condition of the panel board. So by considering the factors mentioned above, it shows that the SCA is showing the correct trend for over temperature conditions.

Then service percentage on humidity were recorded and plotted with respect to the load current as depicted in Figure 8.

According to the graph, it shows if the electrical panel board is operated in a stressed condition the service percentage will increase and shows the correct trend. This indicates to the operator to check the operational condition of the panel board. So by considering the factors mentioned above, it shows that the SCA is showing the correct trend for improper humidity conditions.

CONCLUSIONS

A device called SCA that can successfully provide the information of service of an electrical panel board was developed and validated. It can be used to indicate the service level of an electrical panel board and to analyse the condition of Main Distribution Boards (MDB). When compared against the cost of an MDB, the additional cost needed for the SCA is very small, and it enhances the lifetime of the MDB. Also, it can be used to prevent hazardous situations in an electrical panel board. In addition to that, SCA can be used to arrange maintenance activities where it's necessary to prevent unscheduled breakdowns.

The following future studies are proposed to improve the functionalities of SCA:

1. The proposed study can be further improved by analysing the quality of the air inside the electrical panel board. This allows the recognition of the pollution degree as explained in section 7.1.3 of IEC 61439-1. Also, a dust detector can be introduced to detect the dust content of the air inside the panel board to analyse the service level of the panel board.

2. A flash sensor to detect arcing conditions inside the panel board can be considered, and it can be used to interrupt the power supply through the SCA. Further to that, a common service level indication can be calculated by assigning weights to the service percentages on temperature, humidity and wear & tear.

3. Service condition indications provided can be merged into the Building Management System (BMS). This enables further analyses required to initiate the decisions of maintenance policy for an effective power distribution system. Also, these indications can be uploaded to the internet so that the operator can check the condition remotely to the powerhouse which leads to the smart panel concepts.

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