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Feasibility Study on Thermal Energy Harvesting for Low Powered Electronics in High-Voltage Substations

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***Abstract*— Electronic devices combining sensors, wireless communications, and data processing capability allow easing predictive maintenance tasks in many applications. This paper applies this approach in power connectors for high-voltage electrical substations, which are transformed into smart connectors. Such connectors are often linked to tubular aluminum bus bars, whose temperature increases due to the Joule losses generated by the combined effect of the electrical resistance and the electric current. Since the human intervention must be minimized, an energy harvesting system is required to supply the electronics of the smart connectors. To this end, a thermoelectric module (TEM) is used to transform heat power into electrical power. Since the voltage provided by the TEM is very low, a suitable power converter is used to supply the electronics of the smart connector. This work analyzes the effect of the various parameters that affect the power generated by the TEM when placed on a substation bus bar. Experiments have been carried out by placing a TEM with different configurations on different types of bus bars for diverse operating conditions.**

Keywords—Energy harvesting, substation connectors, bus bar, thermoelectric module, high-voltage, condition monitoring.

I. INTRODUCTION

Electrical joints are possibly the weakest elements in electric systems, since their behavior tends to worsen due to ambient and operating conditions. Their temperature and power losses tend to increase due to the ageing process. This phenomenon can severely affect the reliability of the whole power system. However, the current health condition of many installed joints, including power connectors, is unknown, since many of the already installed connectors are virtually inaccessible, although these devices have more than 25 years lifetime expectancy of [1].

There is a growing demand of increased reliability and efficiency in high-voltage power systems, since it allows minimizing power system unforeseen failures and outages. Therefore, to meet the growing reliability requirements, smart power devices are appealing, since they are able to acquire data by means of suitable sensors and to analyze this data to determine their current health condition. Such smart power devices allow increasing the efficiency, reliability, availability and operating costs of power systems, while permitting to apply predictive maintenance plans. This approach allows optimizing the life cycle management by considering different aspects such as efficiency, power losses and costs points [2]. To apply predictive maintenance plans it is necessary to monitor the current health condition of the equipment involved. Predictive maintenance entails a condition-driven maintenance approach [3].

High-voltage substation connectors are simple devices, which cannot be disconnected to apply a maintenance plan. In addition, some substations are located in remote places, so they are not easily accessible. Nowadays, many maintenance plans are almost corrective, so remedial actions are applied after failure occurrence, since no updated daily data is available for these devices. In order to make a transition towards predictive maintenance plans, daily data such as temperature, contact resistance or vibrations of such devices is required. To this end, they must incorporate sensors and wireless communication systems to transmit this data to a data analysis center to facilitate the application of condition monitoring programs.

The electronics required to sense the electrical variables and to transmit the data require a suitable power supply. Due to the constraints existing in high-voltage electrical substations, human intervention must be minimized to apply customary condition monitoring programs. Since the sensors are installed on the connector or the bus bars, dedicated cables are unfeasible. In addition, some are placed in inaccessible locations where it is almost impossible the access to existing power sources, so their supply becomes very difficult. Moreover, it is required that the sensing and wireless communication systems to be non-intrusive with minimum impacts on the host equipment. Therefore, such electronic systems must be miniaturized, and must have long-live operation without the need of periodic battery replacements. Such smart devices cannot be fed by batteries since their discharge cycle is limited. Therefore, this application must be powered autonomously, and thus, an ambient energy harvesting system is an appealing solution [4]. This approach allows maximizing the time interval between consecutive maintenance operations of the electronics. To this end, diverse strategies have been analyzed such as harvesters based on the electric field, magnetic field, vibrations, solar radiation or thermal energy [4], [5]. However, when dealing with HVDC (high-voltage direct current) power systems, electric and magnetic field based harvesting systems are unfeasible, whereas in indoor substations solar or vibrations based energy harvesting systems present inherent difficulties. Therefore, this work is focused on thermal energy harvesting, taking advantage of the temperature gradient between the ambient temperature and that of reference bus bar of the substation connector. This approach is also valid for HVAC and HVDC systems

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and for indoor and outdoor applications, thus being feasible in a wide range of applications.

Previous energy harvesting research for high-voltage and high-current applications is reported in [4]–[7]. In [4] a hybrid solution is proposed, which increases the cost and size of the energy harvesting system along with the complexity, [5] does not provide a universal solution for AC and DC systems, [6] proposes the use of solar energy harvesting which requires periodic maintenance, whereas [7] implements a heat dissipater in a rectangular bus bar, which requires liquid refrigeration and a big corona protection, thus making it difficult its application.

Electrical bus bars are very common in electrical substations, and their temperature increase due to Joule losses. This paper presents an efficient way to capture a small percentage of the total losses of current carrying electrical bus bars, which are converted into electrical energy by taking advantage of the thermoelectric effect, by using a TEM (thermoelectric module), as shown in Fig. 1.

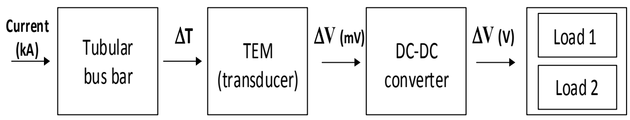


Fig. 1. Energy flow of the proposed energy harvesting system.

The electrical power generated by the TEM can be used to supply the electronics to acquire the data by means of the sensors, and transmit this data by using a wireless communication system. This approach allows the electronic system to have a long-life operation free of maintenance, reliable and without battery replacement requirements.

This paper presents an experimental study of the minimum temperature gradient between the ambient and the bus bar and between the ambient and the heat sink to generate electrical power to supply the electronics. It has been tested in high-current tubular aluminum bus bars commonly used in high-voltage substations. The TEM is tested with and without heat sink, and the behavior of different types of heat sinks are analyzed.

II. Energy Harvesting Technology

This section presents a comparison of different energy harvesting techniques, which are well suited to be applied in high-voltage electrical substations.

These technologies can be broadly classified as solar photovoltaic, thermal, magnetic/electric field, vibrations and radio-frequency (from ambient or specially radiated from an external antenna for the application) energy harvesting, whose main features are summarized in Table I.

From the comparison shown in Table I, the only technologies compatible simultaneously with alternating current (AC) and direct current (DC) are solar photovoltaics, thermal, vibrations and radio frequency energy harvesting.

Although sun is the main source of energy that exists, some substations are indoors, and thus, their effectiveness is limited. In outdoor substations, it is not possible to harvest during the night, and in some countries, there is almost no light during the whole day. Another problem of the solar photovoltaic energy harvesting is soiling, the accumulation of dust, dirt, and pollen , which reduces the amount of sunlight on the surface of the solar cells, thus requiring periodic cleaning. Vibrations from the wind or another origin can also be used for energy harvesting. However, in indoor substations the potential of this technology is very limited and also in outdoor substations, since in some calm days the energy generated by this technology is very reduced, since the power generated is usually below 1 mW [8]. Another possibility is harvesting energy from the nearby radio waves using an antenna. But near to substation, it is not always feasible to find a continuous supply of radio waves, the antenna required to capture the radio waves is sometimes incompatible with corona requirements, and the power harvested is often in the range of the µW [9].

Owing to the abovementioned reasons, it seems that the most universal energy harvesting solution compatible with AC and DC systems is the thermal energy harvesting. This technology will always be able to generate electrical power as long as there is a sufficient current flowing through the bus bars.

TABLE Ia. Comparison of Different Energy Harvesting Techniques for Electrical Substations

Harvesting techniques	Devices used	Source	AC & DC compatibility	Cost
Solar	Solar PV cells	Radiation from sun or indoor light	Yes	Low
Thermal	Peltier	Heat from bus bar	Yes	Moderate
Electric field	Capacitor	Electric field from power system	No	High
Magnetic field	Inductor	Magnetic field from power system	No	High
Vibration	Piezo crystals	Wind or mechanically generated	Yes	Low
Radio frequency	Antenna	Radio signals from environment/dedicated external antenna	Yes	Low

TABLE Ib. Comparison of Different Energy Harvesting Techniques for Electrical Substations

Harvesting techniques	Installation	Maintenance	Continuous energy
Solar	Moderate	Very high	No
Thermal	Moderate	Low	Yes
Electric field	Difficult	Low	Yes
Magnetic field	Difficult	Low	Yes
Vibration	Difficult	High	No
Radio frequency	Low	Low	No

III. Thermoelectric Modules (TEM) and Associated Heat Sinks

A thermoelectric module (TEM) is a reversible solid-state device that transforms heat into electricity or vice versa. There are two types, TECs (thermoelectric coolers) and TEGs (thermoelectric generators). TECs are used for heat pump applications or cooling uses, although they can act as an electrical generator transforming a temperature gradient into electrical power. TEGs transform thermal power due to a temperature gradient into electrical power [10]. The main differences between TEC and TEG is the welding temperature, under very low temperature gradients TEC often performs slightly better than TEGs [10], and TECs are usually more economical than TEGs. A TEM is a static element with no moving parts, it is quiet and compact, highly reliable and environment-friendly [11]. There are different processes governing the physics of a TEM, that is, power conversion due to the Seebeck, Peltier and Thomson heating/cooling effects, Fourier heat transfer due to a temperature gradient and Joule heating generated by resistive components [12].

As long as current flows through the bus bar, the heat generated due to the Joule effect will be continuous, thus generating a temperature gradient between the bus bar and the ambient, which is exploited by the TEM to generate electrical power. In order to maximize the generated electrical power, a suitable heat sink is required, especially in low temperature gradient applications [12]. There exist many works focusing on this application for harvesting energy [13]–[16]. However, there is a lack of works implementing TEM applications on high power conductors or bus bars in substations except [2], which analyzes a rectangular bus bar for currents up to 2 kA. In this paper, the behavior of a commercial TEM is analyzed in a high-current tubular bus bar of up to 8 kA. To this end, a high temperature environment of up to 80°C, and different heat sinks configurations are analyzed. The output electrical power of a TEM can be described by the following law [7],

$$P_{generated} = \frac{\alpha^2 \cdot (T_{Bus\ bar} - T_{Heat\ sink}) \cdot R_L}{(R_L + r)^2} \tag{1}$$

where α (W·Ω/ºC)$^{1/2}$ is the Seebeck coefficient of the semiconductor, r (Ω) is the internal resistance of the TEM, R_L (Ω) is the load resistance (input resistance of the DC-DC converter), $T_{Bus\ bar}$ (ºC) is the average temperature of the bus bar and $T_{Heat\ sink}$ (ºC) is the temperature of the heat sink. It is noted that both α and r depends on the material properties of the TEM. According to (1), the output electrical power of the TEM depends mainly on the temperature difference between the bus bar and the heat sink, so this temperature gradient is a key point in designing energy harvesters based on TEM.

It is noted that in the case of having very low temperature gradients, which do not generate sufficient voltage to feed the DC-DC converter that supplies the electronics, it is possible to connect several modules in series to increase the voltage output between the terminals of the different TEMs. Depending on the input requirement of the DC-DC converter, a suitable configuration of TEMs should be selected. However, when possible, it is better to use a single module because of size, cost and probability of failure concerns.

As explained before, the temperature gradient across the cold and hot terminals of the TEM ($T_{Bus\ bar}$ - $T_{Heat\ sink}$) plays a key role to determine its behavior and the output power capability. Therefore, a suitable heat sink is required to this end. In this work three different heat sink types are analyzed, i.e., squared compact crosscut, rectangular angled fins and omnidirectional.

Fig. 2 summarizes the TEM dealt with in this work, as well as the associated heat sinks analyzed, whose details are found in Table II.

TABLE II. ANALYZED HEAT SINKS

Type	Fin Style	Color	Dimensions	Thermal resistance*
Type 1	Squared compact crosscut	Black	Length = 40 mm Breadth = 40 mm Height = 5 mm	5.14
Type 2	Rectangular angled fins	Gold	Length = 58 mm Breadth = 37 mm Height = 23 mm	1.60
Type 3	Circular omnidirectional	Silver	Diameter = 90 mm Height = 40 mm	0.54

*(sink to ambient) °C/W at 1.0 m/s

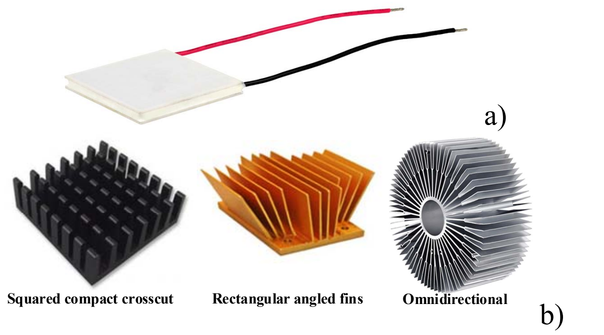


Fig. 2. a) CP85338 TEM from CUI Inc. analyzed in this work (30 mm x 30 mm). b) Types of heat sinks studied.

A. Specific DC-DC converters for TEG systems

In this application, due to the low voltage provided by the TEM, a suitable DC-DC boost converter with very low startup voltage is required to amplify the output voltage generated by the TEM into few volts required by the electronics. Table III compares the characteristics of different DC-DC converters along with their startup voltages.

TABLE III. COMPARISON OF DIFFERENT LOW STARTUP DC-DC CONVERTERS

Component	Brand	Startup voltage	Energy storage	Voltage regulation	MPPT
LTC3108	Analog Devices	20 mV	Super capacitor	2.2 to 5 V	No
LTC3109	Analog Devices	30 mV	Super capacitor	2.2 to 5 V	No
BQ25570	Texas Instruments	330 mV	Super capacitor/ Battery	No regulation	Yes
MAX17710	Maxim Integrated	750 mV	Battery	Programma ble	No
SPV1050	ST Microelec.	180 mV	Super capacitor/Battery	Programma ble	Yes
MB39C831	Cypress	300 mV	Rechargeable battery ≥ 2.6 V	3 to 5 V	Yes
ADP5091	Analog Devices	380 mV	Super capacitor/ Battery	1.5 to 5 V	Yes

From the technical literature [17]–[20] it is concluded that the LTC3108 and LTC3109 are suitable and commercially available DC-DC converters for this purpose.

IV. TEMPERATURE CALCULATION OF THE BUS BAR AND THE HEAT SINK

A. Temperature of the tubular bus bar

As already stated, the temperature gradient between the hot and cold sides of the TEM, and for instance, between the bus bar and the ambient, is a key point to determine the performance of the TEM and its suitability for the application analyzed. Therefore, to analyze the applicability and suitability of a TEM solution for a specific bus bar configuration, it is necessary to determine the expected temperature gradient between the bus bar and the ambient. In this section this is done by applying the method in the IEEE std. [21] at steady state operation, which performs an energy balance as,

$$I^2 \cdot R_{AC} = q_c + q_r - q_s \tag{2}$$

where I (A_{RMS}) is the current through the bus bar, q_c (W/m) is the convective heat loss, q_r (W/m) is the radiative heat loss, q_s (W/m) is the solar heat gain, and R (Ω/m) is the AC resistance of the bus bar at the operating temperature. The expressions of q_c, q_r and q_s can be found in [21].

Fig. 3 shows the steady state temperature difference between the bus bar and ambient of 40 commonly applied hollow tubular bus bar configurations with outer diameters ranging from 80 to 300 mm calculated according to (2), supposing natural convection when $T_{ambient} = 30$ ºC and $q_s = 0$ W/m.

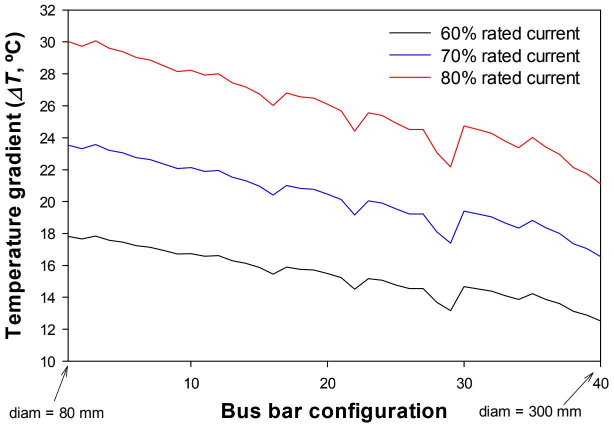


Fig. 3. Temperature gradient ($T_{Bus\ bar} – T_{ambient}$) of 40 commonly applied hollow tubular bus bar configurations for natural convection when $T_{ambient}$ = 30 ºC and q_s = 0 W/m.

From Fig. 3 it is deduced that in order to have a temperature gradient $T_{Bus\ bar} – T_{ambient}$ around 15 ºC the current in the bus bar should be at least 60% of the rated current, depending on the specific configuration.

The TEM can be placed inside or outside of the cylindrical bus bar. However, when placed inside it is difficult to produce a significant temperature difference between both sides of the TEM, so it requires to be installed outside. A good choice is to place the TEM on the top of the horizontal tubular bus bar.

B. Temperature of the heat sink

The hot side of the TEM is mounted on the outer surface of the bus bar, whereas the cold side is under the influence of atmospheric air. To optimize the performance of the TEM, an important temperature gradient between the two sides is required. It is recommended to use thermal grease in both sides of the TEM to increase thermal conductivity. When using a heat sink on the cold side of the TEM, the thermal resistance between the cold side of TEM and the ambient can be calculated as [22], [23],

$$R_{tca} = R_{TIMc} + R_{spc} + R_{hs} \tag{3}$$

R_{tca} being total thermal resistance between the cold side of TEM and the ambient, R_{TIMc} the thermal resistance of the thermal interface material on the cold side, R_{spc} the spreading or contact resistance between the cold side of the TEM and the heat sink, and R_{hs} the thermal resistance of the heat sink.

Usually, the resistance of the TEM is high compared to the resistance of the heat sink, due to the larger surface of the heat sink to provide an improved heat dissipation. Hence, from (3) it is concluded that when adding a heat sink, the total thermal resistance R_{tca} between the cold side of the TEM and the ambient is lower than without a heat sink, thus increasing the temperature gradient.

There exist different types of heat sinks in the market as shown in Fig. 2 and Table II. The selection of the appropriate heat sink is a challenge, because the bus bar itself is a heat sink, dissipating heat in all directions.

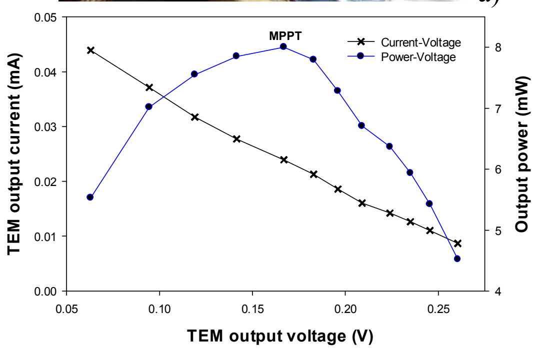
V. EXPERIMENTAL

This section performs experimental tests to choose the most appropriate heat sink and DC-DC converter, as well as to characterize the thermoelectric module in order to design a suitable energy harvesting system for a wide range of operating conditions. For acquiring data during the experiments, a NI USB-6000 (USB Multifunction DAQ) from National Instruments was used jointly with an Omega TC-08 thermocouple data logger to acquire the temperature of the bus bar, heat sink, and ambient, using T-type thermocouples.

A. TEM characterization

This section characterizes the output power and the MPPT (maximum power point transfer) of the TEM in order to select a suitable DC-DC converter based on the minimum start-up input voltage and the rated power. The I_{out}-V_{out} and P_{out}-V_{out} curves of the TEM are shown in Fig. 4.


a)



b)

Fig. 4: a) Experimental setup to determine the characteristic curves of the TEM when mounted on a 50 mm diameter bus bar. b) Characteristic I_{out}-V_{out} and P_{out}-V_{out} curves of the CP85338 TEM from CUI Inc. when installed on an aluminum tubular bus bar of 50 mm diameter including a heat sink (rectangular angled fins), when circulating 1500 A_{RMS} with $T_{ambient}$= 15ºC, $T_{Bus\ bar}$ = 80ºC and $T_{Heat\ sink}$ = 71ºC.

Fig. 4 shows that the MPPT is around 8 mW for the specific conditions of the test, which are very favorable for power generation, since the current in the bus bar is above the rated one. Therefore, when the current in the bus bar is close to the rated current, a DC-DC converter with MPPT tracker allows maximizing the output power. However, when the current in the bus bar is well below the rated one (its temperature is low), the output TEM voltage reduces, so the input voltage of the DC-DC converter is not enough to apply a MPPT strategy, since it needs at least 380 mV, as shown in Table III (ADP5091 converter). Therefore, when the current in the bus bar is low, the DC-DC converter cannot follow a MPPT strategy.

To cover a wide range of operating conditions, a power converter with very low startup voltage without MPPT capability is chosen, since the MPPT capability is not useful for applications where the TEM output voltage is too low. Therefore, a choice has to be made between LTC3108 and LTC3109, but from the results of [14] LTC3109 performs better than LTC3108. Hence, the LTC3109 DC-DC converter is selected in this paper since it provides an optimal solution for all the above mentioned requirements.

B. Heat sink selection

To select the most suitable heat sink configuration, initial tests were carried out on a 300 mm diameter tubular aluminum bus bar, as shown in Fig. 5.


a)

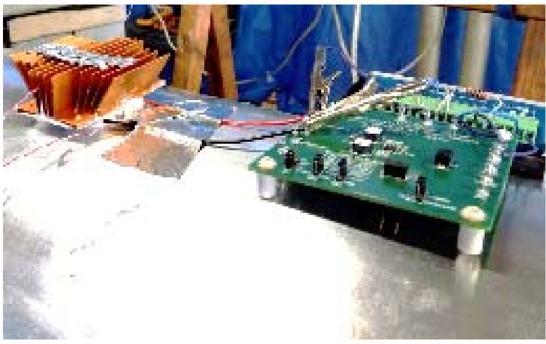

b)

Fig. 5: a) Tubular bus bar of 300 mm diameter under test. b) TEM and heat sink mounted on the 300 mm diameter tubular bus bar.

Table IV summarizes the results obtained when dealing with the three types of heat sinks mounted on the 300 mm bus bar and using the CP85338 TEM.

Results from Table IV show that only heat sinks type 2 and 3 can activate the LTC3109 step-up DC-DC converter. These results also show that the type of heat sink plays an important role in the temperature difference between the bus bar and heat sink, whereas the temperature difference between bus bar and ambient mainly depends on the bus bar current.

Results from Table IV show that heat sinks Type 2 (rectangular angled fins) and Type 3 (circular omnidirectional) are more suitable than Type 1 (squared compact crosscut). Therefore, Type 2 is selected because it is lighter and easy to install due to the reduced dimensions, which simplify the requirements of corona protections.

TABLE IV. RESULTS OF THE ENERGY HARVESTING SYSTEM (TEM +DC-DC CONVERTER) WITH DIFFERENT CONFIGURATIONS AND HEAT SINKS ON THE 300 MM DIAMETER BUS BAR OF 12 MM WALL THICKNESS

Bus bar current (kA)	**Heat sink type from Table II**	**Minimum $T_{Bus\ bar} - T_{Heat\ sink}$ to activate the DC-DC converter**	**Minimum $T_{Bus\ bar} - T_{Ambient}$ to activate the DC-DC converter**
8-9 kA	Without heat sink 1 TEG 2 TEG in series 2 TEG in parallel	Not applicable*	Not applicable*
	Type 1 with 1 TEG	Not applicable*	Not applicable*
	Type 2 with 1 TEG	3.2 ºC	16.0 ºC
	Type 3 with 1 TEG	6.0 ºC	13.0 ºC

* Not applicable: it is not possible to generate electrical power because of the large thermal resistance of the cold side of the TEM.

C. Bus bar minimum current rating

To further support the results obtained with the 300 mm diameter bus bar, Table V shows experimental results obtained with a 50 mm diameter tubular bus bar.

TABLE V. RESULTS OF THE ENERGY HARVESTING SYSTEM (TEM +DC-DC CONVERTER) ON THE 50 MM DIAMETER BUS BAR OF 0.5 MM WALL THICKNESS USING THE HEAT SINK TYPE 2 (RECTANGULAR ANGLED FINS)

Bus bar current (A)	**% of maximum rated current**	**Minimum $T_{Bus\ bar} - T_{Heat\ sink}$ to activate the DC-DC converter**	**Minimum $T_{Bus\ bar} - T_{Ambient}$ to activate the DC-DC converter**
690 A	56.5 %	2.5 ºC	13.7 ºC
515 A	44.8 %	2.3 ºC	14.6 ºC
370 A	32.2 %	2.2 ºC	16.5 ºC
260 A	22.6 %	Not applicable**	Not applicable**

** Not applicable: it is not possible to generate electrical power because of not enough current in the bus bar or too low temperature in the bus bar.

Results in Table V show that in order to generate electrical power, it is required a minimum temperature gradient between the bus bar and ambient of around 15 ºC, which corresponds to a temperature gradient close to 2.5 ºC between the bus bar and heat sink. These results are similar to those displayed in Table IV.

Next, the possibility and performance of connecting different TEMs in series (sandwich mode) was explored. The results attained are summarized in Table VI.

Results in Table VI show that even when connecting two TEMs in series instead of only one, the minimum temperature difference required between the bus bar and ambient is approximately the same. Hence, it can be concluded that it is not necessary to use two TEMs for energy harvesting, because ultimately the energy harvested depends on the bus bar and the ambient temperatures. Two or more TEMs can be used if the power required by the electronics is higher than the power that can be provided by only one TEM, when there is enough temperature difference between the bus bar and ambient.

Finally, results from Tables IV, V and VI show that a minimum temperature difference of around 15 ºC between the bus bar and ambient is needed for energy harvesting. This temperature gradient can be obtained only if there is sufficient current in the bus bar. When comparing this result with the simulation results shown in Fig. 3, it is deduced that for the most used bus bars this temperature gradient of 15 ºC corresponds to around 60% of the rated current in the bus bar. It is noted that the electronic device must be able to accumulate energy, for example using a super capacitor, to supply the electronics during the hours in which the current in the bus bar is below 60% of the rated current.

TABLE VI. RESULTS OF THE ENERGY HARVESTING SYSTEM (DIFFERENT CONFIGURATION OF TEM +DC-DC CONVERTER) ON THE 50 MM DIAMETER BUS BAR OF 0.5 MM WALL THICKNESS USING THE HEAT SINK TYPE 2 (RECTANGULAR ANGLED FINS)

Bus bar current (A)	% of maximum rated current	Number of TEMs in series	Minimum $T_{Bus\ bar} - T_{Heat\ sink}$ to activate the DC-DC converter	Minimum $T_{Bus\ bar} - T_{Ambient}$ to activate the DC-DC converter
690 A	60.0 %	1	2.5	13.7
		2	0.7	13.9
515 A	44.8 %	1	2.3	14.6
		2	1.1	14.4

VI. CONCLUSIONS

Predictive maintenance tasks require on-line data monitoring and post processing. Electronic devices combining sensors, wireless communications, and data processing capability are required to this end. This is a challenging problem in high-voltage applications, where human intervention must be minimized, so an energy harvesting system to supply the electronics is a must.

This paper has analyzed the suitability to generate electrical power using a thermoelectric module in a high-voltage electrical substation environment. Due to the low voltage amplitude generated by the TEM, a suitable DC-DC power converter was applied to supply the electronics of the smart connector. Different experiments were carried out to characterize the behavior of the TEM, to select the most suitable heat sink to improve the performance of the whole system, and to select the most suitable DC-DC step up converter to cover a wide range of operating conditions. By analyzing the most used tubular bus bar geometries, it has been found that a temperature gradient of around 15 ºC, that corresponds to nearby 60% of the rated current in the bus bar, is required to produce electrical power. If this condition is not fulfilled during the whole day, the system must be able to accumulate energy to supply the electronic system during the hours in which the current in the bus bar is below 60%.

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