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Power cable modelling for WIPS electromechanical chain

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1 Problem statement

Several promising technologies are being explored and developed by Clean Sky, one of which is the optimization of electrical Wing Ice Protection System (**WIPS**), which provides electro-thermal protection protects against the build-up of ice on structures of the aircraft.

The electro thermal WIPS protection system embeds electro-thermal heater mats into the surface to be protected, for instance, the inner surface of a designated area of the aircraft wing.

For this purpose, the heater element is powered by a power electronic switching supply through the power cable as shown in Fig. 1.1, which due to the natural switched operation of the solid state technology introduces new challenges related to switching frequencies, switched voltage and (sometimes) switched current on the electric and electronic circuits of the aircraft. They include the wiring for the Electrical Wiring Interconnection System (**EWIS**) of the aircraft and specifically for the WIPS.

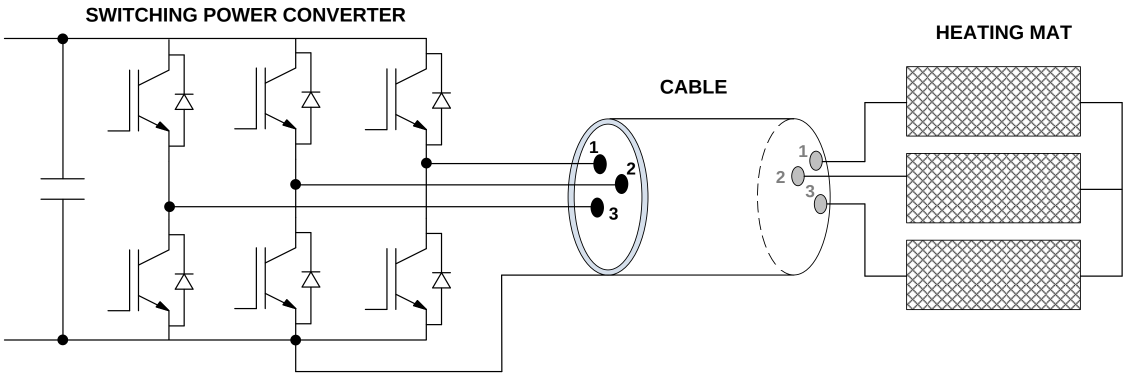

Fig. 1.1. Power electronic converter, power cable and heating mat.

The power cables analyzed in this project connect the loads with power supplies or electrical high voltage buses mainly through electronic power converters. Since the power converters operate in switching mode, that is in ON-OFF operation which can include unipolar or bipolar PWM, switched AC or DC voltage source or others, new electromagnetic effects arise. They comprise switching and commutation harmonics, high dv/dt, skin effects or EMIs among others. Therefore, basic cable models are not appropriate for this type of simulations.

These effects have to be included in an accurate model of the cable that feeds the heater system from the output of the power converter. This advanced cable model has to be able in facilitating the analysis of the complete EWIS system by means of accurate simulations, which will be helpful in the optimization of improved future WIPSs.

To include these effects in the cable model, a Multi Layer Cable Model (**MultyCaB**) must be developed, which must be able to predict by means of simulations based on real data phenomena such as transient and steady state voltages, dv/dt and skin effects. To this end, the model will include the harmonic behavior of the cable and thermal effects.

Modern IGBT-based converters have modulation frequencies in the range of 2 to 20 kHz with typical switching times of 50 ns or about 13 V/ns for a 460 V system. These operating conditions induce high voltage variations (dv/dt) which in turn excite the parasitic elements of the cables and mats, so to simulate the system behavior, a high frequency model is required.

2 The cable model based on experimental data

As explained, different effects such as skin and proximity effects, capacitive and inductive couplings among nearby conductors or standing waves occurrence will be included in the cable models.

Due to the wide range of frequencies analyzed (40 Hz - 40 MHz range) a model based on distributed parameters must be considered instead of a concentrated parameters model. The complexity of such model must be selected as a tradeoff between the desired accuracy and the required computational burden, since the computational requirements greatly increases with the model complexity.

The cable model to be simulated in this project consists in several cells connected in series each other. The number of cells to be considered depends on the cable length to be simulated. An indicative initial number is about 10 cells/meter.

Since at high frequency, eddy and proximity effects arise, thus they must be included in the model. Similarly, capacitive interactions between different cables and between cables and screen also happen.

To include these effects in the cable model, both the longitudinal impedance and transversal impedance are included in the cable model, as shown in Fig. 2.1. These impedances must include different branches to reproduce the wide-frequency cable model.

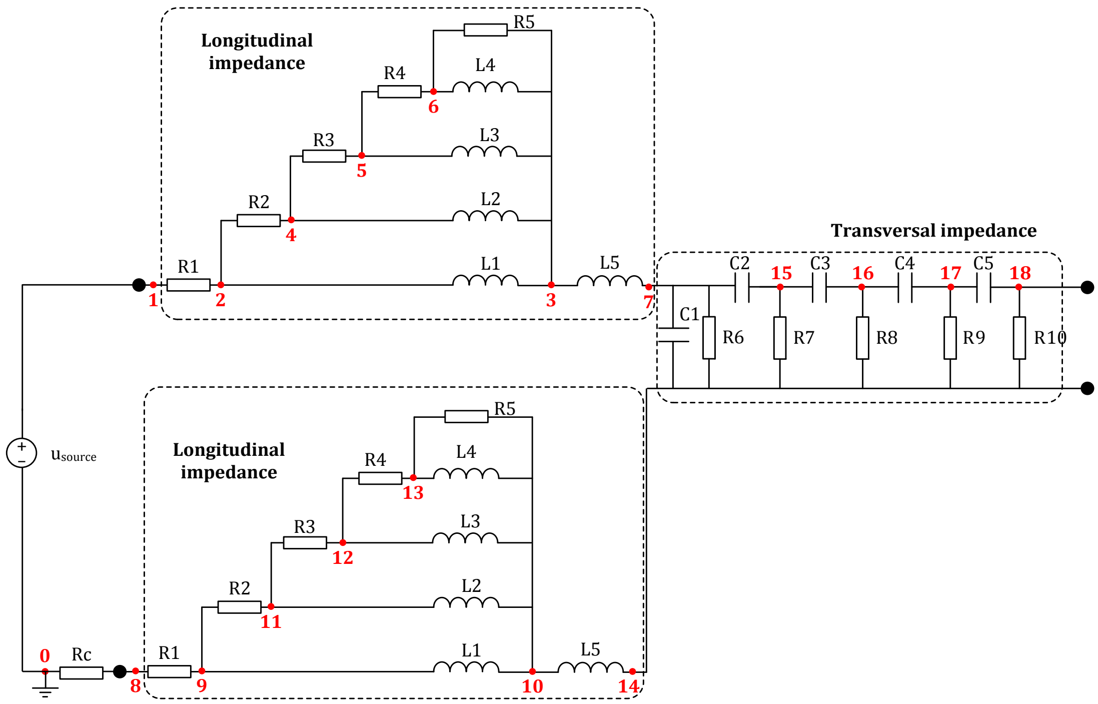

Fig. 2.1. Single cell equivalent circuit considering the longitudinal and transversal impedances.

The parameters of these impedances must be measured experimentally by using a precision high-frequency impedance analyzer in the range 40 Hz – 40 MHz.

To this end, two test types must be carried out, that is, short circuit and open circuit tests to a short sample of the cable to be characterized in order to ensure that the model is able to reproduce the real cable response for the wide range of frequencies analyzed.

The cable must be fed by the output voltage of the power converter, which will be obtained through simulations or experimental measurements.

3 Specifications agreed

This task is devoted to set the specifications related to constructive and operational parameters on electric operation and thermal behavior of the power cable for WIPSs .

After a two-days meeting among the Topic Manager and MCIA-UPC representatives, held on 18th of September 2014 in Topic Manager facilities, the following specifications were settled,

- Power supply for thermoelectric WISP system is AC, which will be provided by a **power inverter**
- DC bus of power inverter is **540 VDC**
- Cable length between power supply and mats is in the range **20 - 30 m.**
- Effects to be taken into account for cable model are **high-frequency and thermal**.
- Cable model will cover effects up to **40 MHz.** Effects agreed to be modelled and considered in the cable model:
    - Fundamental and harmonic losses
    - Skin and proximity effects analysis
    - Dielectric losses
    - Critical cable length, over-voltages (cables of less than 10 m do not present problems, but they appear for cable length larger than 20 m)
- Cable model will be developed by UPC in **temporal domain**, in order to use it as a part of global model including loads, connectors, etc., to simulate the whole application.
- Cables to be modeled (although the case study could be extended) are the following:
    - **Two – wires unshielded cable**
    - **Three – wires shielded cable**

Other agreed statements:

- Topic Manager will provide information about the configuration of the cable harnesses (number of cables, single or three phase, sections, ..).
- Total model will require power inverter characteristics, cable and connectors parameters and load mats characteristics.
- Topic Manager will provide cable specifications for developing the first models. Topic Manager will provide power supply and mats characteristics for constructing the global model.
- Two solutions are considered to supply the cable model with the output of the power converter. **Solution 1.** From a text file (txt, csv,..) containing the synthetized power converter output wave which will be obtained from previous simulations or from an analytical way. **Solution 2.** To model the power inverter in the temporal domain; this model should be able to produce a continuous switched output wave description (rise/fall times, amplitude, T_{ON}, T_{OFF}, etc.).

- It is possible to characterize the power inverter at open circuit conditions, that is, considering it as an ideal one and assuming its operation independent on the load. The power converter will be available soon in Topic Manager facilities.
- It has been agreed a short stay (one/two days) of MCIA technicians to Topic Manager facilities to measure and characterize the power system. These measures will be used to fill de parameters of the developed cable model, especially those related to power converter. The power cable could be characterized during this visit, although it is also possible to do it in MCIA facilities, by using a cable sample provided by the companies.
- Topic Manager will provide cable specifications for developing the first models. Topic Manager will provide also power supply and mats characteristics for constructing the global model.
- To concentrate the research/development in full temporal model of the cable, to study directly the high frequency effects of interest. It is agreed to go step by step, starting with 10-meters cable model (full or reduced operational frequency), and then enlarging cable length and frequency up to meet project specifications.
- Integration of cable models and power converter as well as load connectors models will be performed at the second stage of the project (Task 3.2).
- Topic Manager will decide if we need a special web page and/or direct access to some companies' servers with very confidential information to use only in the framework of the project.
- Final validation of the project, i.e., experimental test on a real WIPS system (at laboratory scale) and comparison with model results, will be performed in Topic Manager facilities, by the end of the project.