MECHANICAL ENGINEERING | PHYSICS | PRESERVATION OF THE ARCHITECTURAL HERITAGE | SPATIAL PLANNING AND URBAN DEVELOPMENT | STRUCTURAL, SEISMIC AND GEOTECHNICAL ENGINEERING | URBAN PLANNING, DESIGN AND POLICY | AEROSPACE ENGINEERING | ARCHITECTURAL COMPOSITION | ARCHITECTURE, BUILT ENVIRONMENT AND CONSTRUCTION ENGINEERING | ARCHITECTURE, URBAN DESIGN, CONSERVATION OF HOUSING AND LANDSCAPE | ARCHITECTURAL, URBAN AND INTERIOR DESIGN | BIOENGINEERING | DESIGN | **ELECTRICAL ENGINEERING** | ENERGY AND NUCLEAR SCIENCE AND TECHNOLOGY | ENVIRONMENTAL AND INFRASTRUCTURE ENGINEERING | INDUSTRIAL CHEMISTRY AND CHEMICAL ENGINEERING | INFORMATION TECHNOLOGY | INTERIOR ARCHITECTURE AND EXHIBITION DESIGN | MANAGEMENT ENGINEERING | MATERIALS ENGINEERING | MATHEMATICAL MODELS AND METHODS IN ENGINEERING

PhD Yearbook | 2018

DOCTORAL PROGRAM IN ELECTRICAL ENGINEERING

Chair:
Prof. Gabriele D'Antona

The main objective of the PhD Program is to allow a direct, prompt and efficient involvement of PhD graduates in academic and non-academic research and development bodies. A PhD in Electrical Engineering has a solid basic knowledge of applied mathematics and physics. This is essential, particularly for handling and understanding advanced tools and methods as well as for proper modelling, analysis and design of electrical engineering applications, with particular regard to power applications. A PhD in Electrical Engineering well knows methods and applications in the main disciplines of Basic Electric Circuits and Fields, Power Systems, Electrical and Electronic Measurements, Converters, Machines and Electrical Drives.
The most important part of the PhD program is the development of the research that will be the core of the PhD dissertation.
The main research areas are:
A) **Electric Circuits and Fields**: This area is intended to provide the basic knowledge of methods in electrical engineering for power applications. PhD students are specifically trained to develop critical ability and innovative approaches. The training method encourages the development of discussion and debate skills in a team environment.
The main research and training subjects are: Nonlinear networks and periodic time-variant networks; Analysis of three-phase and multiphase systems; Switching circuits; Electromagnetic field equations; Electromagnetic field numerical analysis; Electromagnetic compatibility; Design techniques devoted to electromagnetic compatibility
B) **Power Systems**: A PhD in the field of Power Systems deals with the following subjects: electrical energy production (e.g., frequency and voltage control, protections, renewable energy sources, Dispersed Generation, Microgrids); electrical energy transmission (e.g., power system analysis, real and reactive power optimization, security and stability, integration of renewables); electricity markets (e.g., models, ancillary services, regulations); power quality and Smart Grids (e.g., harmonic distortion, active filters, UPS, interruptions and voltage dips, DC distribution).
C) **Electric machines and drives**: This research field is strictly related to the rising demand for improved machine and converter performance, in terms of low price, efficiency, robustness, dynamic response and drive control. This need leads to device optimization and better design and testing criteria. Moreover, a system approach is required for accurate integration of technical and economic aspects for final application. The main subjects in this field are: Use of new materials; Novel magnetic structures; Methodologies of model development for design and operating analysis; Optimization procedures; Use of finite elements code, simulation programs and environments for device study; Control system definition both on the device and system side.
D) **Measurements**: This research field concentrates on the fundamentals of metrology, particularly with respect to characterization of modern measurement systems based on complex digital signal processing structures. Some of the main subjects of study are: measurement methodology as it relates to power systems, including medium and high voltage systems and components, as well as both digital and analog signal processing. Methodologies and measurement systems associated with industrial automation and, in particular, microelectronic sensor applications, distributed structures and advanced methods and algorithms for maintenance-oriented diagnosis of complex systems are investigated in detail.

After graduation, PhD are typically employed at:
- Major research centres;
- R&D departments;
- Power generation, transmission and distribution firms;
- Engineering consultant offices;
- Metrology reference institutes and certification laboratories;
- Process and transport automation areas.

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- Fondazione Ing. Paolo Foresio
- MCM Energy Lab
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INJECTION OF CONDUCTED COMMON-MODE DISTURBANCES AS AN ALTERNATIVE APPROACH TO RADIATED-SUSCEPTIBILITY VERIFICATIONS: STATISTICAL CHARACTERIZATION IN TERMS OF OVERTESTING MARGIN

Ludovico Badini - Supervisor: Giordano Spadacini

Electromagnetic Compatibility (EMC), in essence, deals with interference phenomena in electrical and electronic systems, how to asses them by testing, and how to prevent them by correcting design patterns. As a matter of fact, since high-speed digital communications have started to be widely used in every kind of applications (together with high frequency switching converters), the problem of dealing with electromagnetic (EM) interference has grown exponentially. In the last years, since time-to-market of industrial products has been dramatically reduced, the identification of the dominant phenomena that generate EM interference in the early-design stage is more important than ever. Even though the standardization of device compliance is usually devoted to specific applications, many common points among the causes of noncompliance can be identified. These unifying elements require in-depth analysis. Above all, a particular attention has to be devoted to the so called “common mode” (CM), since it plays a dominant role in the generation of EM emissions and the designers are deeply involved in the suppression of these interference effects. It is not a coincidence that the vast majority, if not all, of the international standards, in all application fields, foresee testing schemes that involve, as the dominant effect, the CM susceptibility.

It is the case of the Radiated Susceptibility (RS) test and the Conducted Susceptibility (CS) test foreseen in many standards at unit level verifications. Both RS and CS test procedures are foreseen for assessing the immunity of the equipments to radio-frequency (RF) interference in specific frequency ranges.

Even though RS and CS testing are aimed at assessing different phenomena and their co-existence maybe consistently foreseen, the presence of overlapping frequency ranges (in which both tests are executed) poses an interesting problem related to the possible correlation of test outcomes.

Solid reasons make the substitution of RS with CS testing very appealing to EMC engineers. Namely, RS testing is more time-consuming than CS testing, and requires expensive instrumentation like an anechoic chamber (AC) and the related control system. Large amplifiers are needed to feed antennas with enough RF forward power for the generation of low-frequency electric fields. Moreover, test repeatability in AC is strongly dependent on the configuration of the equipment under test (EUT) and the test setup. In particular, the experience shows large sensitivity to setup arrangements at low frequencies when far-field conditions are barely verified, as well as difficulties in ensuring reproducibility in ACs having different size. Conversely, CS testing based on the use of bulk current injection (BCI) probes clamped on cables, is characterized by energetic efficiency, repeatability, simplicity and economics of time.

Hence the substitution of time-consuming radiated susceptibility (RS) verifications with faster conducted-susceptibility (CS) techniques is a research issue of great relevance in the aerospace and automotive industry.

At low frequencies (typically, well below 1 GHz), the direct coupling of external fields to electrical/electronic equipment (e.g., through weak shielding and/or apertures) is not very effective, indeed the coupling path for radiated disturbances has a main conductive nature, since the involved phenomenon is field coupling to external cables. The induced currents show a dominant CM component, propagate along

the wiring harness, and enter in the equipment’s circuitry through terminal connectors. It seems therefore possible to directly reproduce similar currents by using CS injection techniques. Unfortunately, such a task is not trivial since coupling devices for CS like Bulk Current Injection (BCI) probes are not inherently able to reproduce the frequency response of RS currents. Despite several past works were presented in the literature on this subject, no solution can be found which is able to retain the appealing simplicity of the conventional BCI test procedures (i.e., the so-called “substitution method” in two steps: probe pre-calibration and subsequent testing) and, concurrently, to enforce correlation with the outcome of RS verifications. The search for an innovative approach to this problem is the objective of this work.

Since both RS and BCI are based on the control of CM interference, whereas other propagation modes are generated by the system response (due to imbalance effects), an in-depth study of the problem of modal conversion has been initially carried out. Well known factors of modal conversions include imbalance of terminal loads and geometrical imbalance of interconnects. Here, an contribution is developed concerning the proximity of balanced differential lines and the resulting complex phenomena of mutual conversion between differential mode (DM) and CM. In the end, the acquired confidence on modal-circuit representations is the basis for the development of CM circuit models of the RS and BCI test setups, oriented to the study of equivalence conditions. Namely, piecewise-linear reference test levels (RTLs) for BCI-probe calibration are developed and associated with the novel concept of over-testing (OT), intended as a quantification of the excess of radio-frequency disturbances injected by BCI with respect to those due to RS. Owing to the lack of knowledge about parameters of the test setup (e.g., CM impedance of equipment, position of the BCI probe), which is common in practical testing conditions, OT turns out to be a random variable. However, the proposed analysis shows that the cumulative distribution function (cdf) of OT can be predicted and univocally associated with the proposed RTLs. Moreover, the proposed RTLs are flexible and can be easily tailored to the main geometrical parameters of the test setup (e.g., harness length, height above ground), and to the RS test conditions to be reproduced (e.g., field strength, elevation angles, antenna polarization, etc.), by means of closed-form rescaling expressions. Finally, the quantiles of the cdf can be purposely used to modify the RTLs and relax the test severity, while retaining a controlled OT margin in probabilistic terms, which may even imply a non-null probability of undertesting ($OT \leq 0$).

The theoretical derivation is corroborated by experimental measurements. In conclusion, the proposed BCI test procedure establishes a clear correlation in statistical terms between CS and RS testing and represents a powerful tool for engineers in charge for setting electromagnetic-compatibility requirements.

DESIGN AND DEVELOPMENT OF TECHNOLOGIES FOR THE MEASUREMENT OF BIOMECHANICAL PERFORMANCE IN ATHLETES PRACTINCING JUDO

Stefano Frassinelli - Supervisor: Prof. Riccardo Zich

The training methodology is proposed as a science to manage, organise and plan the evolution of the athletes performance.
Like other sciences, training methodology needs objective data to formulate his theories and laws. The sportsman study on the field, of sports training and of sport competition, is the best way to acquire the parameters characterizing the athletes performance. In this direction, the design and tools development that are able to investigate and measure the exercise biomechanic phenomena during real workouts and competitions, far from the reality of aseptic laboratory research, are the future sports analysis. Future whit great grow prospects.
Judo is a fighting sport where the contact between the athletes, the friction and impact derived therefrom and the moisture linked to sweating, produce a lot of problems to wearing the measuring devices. Inertial Sensors designed and developed specifically, would allow reducing drastically the criticality of usage into unconventional experimental environment as the "tatami" (mat which hosts judo workouts). In addition right fit would allow athlete who wear it, to move without constraints or special care to preserve the equipment integrity.
The goal of the study is create a useful tool to collect specific data to measure athletic performance during workout and simulation of judo competitions.
The issue has been analyzed and developed along three different path:

a) an approach through the theory of movement
b) a biomechanical approach
c) an engineering approach

a) About specific examination of the factors that contribute to athletic performance in Judo, we considered only the movement aspect. All movement performance start from its technique. The movement technique and even more sport technique, are the ultimate means that the sporty performance uses to express itselves. Analyze and measure sport technique means to collect useful data to improve the performance that it produces.
The sport technique is strongly influenced by the athlete *motor abilities* and *capabilities*. The various *motor abilities* aren't precisely identifiable because they contribute in building up the movement itself and, with it, they make an only thing. During the development of the sports activities on the field, the *motor abilities* can be *observed* but *not measured*. Consequently the taking charge and examination of *observable* parameters together with those *not measurable* involves a specific mathematical analysis.
We propose two different but complementary mathematical matrices to quantify the *motor abilities* that are involved in sporting gestures: a Boolean matrix (A(i,j) = 0;1) and a Fuzzy matrix ($\mu_F(x) = \mu\ ;\ 0 \leq \mu \leq 1$). The first one allows us to discriminate motor abilities according to a global criterion, while the second one follows an analytical criterion. This allows a unitary quantification of the motor abilities. At the same time, it enables to quantify the weight and importance of capabilities (conditional and coordinative) that contribute to its formation and expression on the field.

b) The judo technique is analyzed according to biomechanical criteria and finds its basis in the Optimization principle and in the Minimum Action (MA) principle.
The classification of throwing techniques, which are the fundamental technical movements of judo, is reduced to only two classes: techniques where Tori uses of a couple of forces for throwing Uke and techniques where Tori uses of physical lever for throwing Uke. Consequently, it also simplifies the classification of all the movements that are performed in preparation for the execution of the technique. These movements are called the General Action Invariants (GAI) and Specific Action Invariants (SAI).
We have identified for each analyzed movement:
Strength (= Mass x Acceleration) - [x 1kg 1 m / s2 = 1N]
Work (= Force x Displacement) - [1N x 1m = 1J]
Power (= Work x Time) - [1J x 1s = 1W]

c) By commom inertial sensors currently on the market, it has been designed and developed a specific tool that was able to overcome the problems of an "unfriendly" experimental environment.
The pair of athletes who struggle and throw themselves at each other on the mat, certainly presents an unconventional experimental reality. Most wireless inertial sensors are assembled with an accelerometer, a gyroscope, and a magnetometer. In our sensor there is only the accelerometer. This choice has been done with the aim to make the most compact instrument and improve its wearability. Two configurations in the dressing phase with the tools of the tested athletes have been choosen: the first one with seven devices, the second one with five devices. The acquisitions carried out involved lower limbs.
The sensors were compared with a magnetic and inertial sensors system (TSDN121, ATR Promotions) and a gold standard, a markerless stereo-photogrammetric acquisition system based on synchronized digital cameras with a frame rate of 90 fps.

Traces analysis and their processing through the subsequent construction of the stick diagram, showed that:

- there are important differences between the throw techniques performed by low qualification athletes and high qualification athletes. The latter showing a much better performance.
- the athletes sizes have effects on the technical execution: the light weights express greater acceleration in relation to the mass comparated to medium weights and heavy.
- the genre, jointly to body weight, has influences on the technical execution.
- the techniques of the couple of forces are faster than those that use a physical lever for throwing the opponent. That is in accordance with the biomechanics principles.
- the acceleration and the angular velocities detected during the preparatory movements to the tecnical execution (GAI and SAI) don't present significant differences compared to those recorded in the execution of the true and proper throwing. The difference is given by the direction changes, which serve to break the opponent's symmetry and to put the same opponent in a situation of instability, thus facilitating the subsequent throwing.
- the principle of Minimum Action (MA) is not always respected in a more dynamic combat phases.

During the analysis of dinamical situation to put as objective the function of the MA is a necessary condition but not sufficient. Actually it's appropriate to integrate the principle of MA with the concept of Maximum Effectiveness (ME). The athletes, searching ME, are often forced to choose (instinctively) solutions which require a greater physical work (W). To enter the defense of an experienced opponent (putting him in a situation of instability, breaking its symmetry) means to make actions that are not biomechanically advantageous. This increased energy output is repaid by the ME of the final gesture. So, ME means not only MA as minimization of energy expenditure, but also the greater possible result in relation to the energy used.

At the end the wireless inertial sensors have showed to be an effective tool, useful to the purpose for which they were designed. The equipment with its good wearability allowed the athletes to express themselves freely, concentrating totally on their exercises, without any constraint and distraction. This research shows good flexibility of the evaluation system and opens an important window into the world of sporting evaluations carried out directly on the training field. There are many sports that already benefit from the scientific investigations that concern them, but many other are still waiting. They are those sports that take place in environments difficult to equip as laboratory or whose technical and sporting dynamics presenting a problem to be standardized. The instruments, object of this study, could certainly cover some of these gaps.

INNOVATIVE METHODS FOR THE CHARACTERIZATION OF VOLTAGE TRANSDUCERS UNDER DISTORTED CONDITIONS

Christian Laurano - Supervisor: Prof. Sergio Toscani

Voltage instrument transformers are typically tested at the rated frequency. In order to assess their accuracy in measuring harmonic components, usually their frequency response is evaluated. This approach does not take into account nonlinear phenomena that may have a non-negligible impact on the accuracy, especially when the transducer under test is represented by an inductive voltage transformer. Such nonlinearities are actually rather small, but their impact is magnified because the typical spectral content of the voltage waveforms in ac power system, which consist in a prevalent fundamental harmonic component and harmonics that differs by more than an order of magnitude .
IEC and IEEE Standards do not provide a systematic procedure to test instrument transformers under real-world conditions that is able to consider and quantify nonlinear effects that can jeopardize measurement accuracy. Moreover, the scientific community is investing huge efforts in the development of new test methods that allow a reliable estimation of the accuracy of instrument transformers when they are employed for harmonic measurements. Such assessment should take into account linear as well as nonlinear phenomena. For this reason, this work is focused on proposing innovative methods that allow an accurate characterization of voltage instrument transformers in presence of distorted voltage waveforms.
Firstly, it has been proposed to apply the concept of *Best Linear Approximation* (BLA) to the metrological characterization of voltage instrument transformers. For a given class of input signals, the BLA represents the frequency response function that allows the optimal reconstruction of the input voltage starting from the transducer output, thus guaranteeing the most accurate measurement with a simple linear model. In order to achieve the best results, such class of excitation signals should resemble the voltage waveforms typically found in ac power networks.
Other than estimating the BLA, the noise and the total standard deviations can be easily computed. The first measures the overall impact of noise on the BLA. The total standard deviation represent a synthetic index of the achieved accuracy: when it is much higher than the noise standard deviation, it means that the definitional uncertainty due to the (linear) measurement model is prevalent. In this case, accuracy can be improved only by considering a nonlinear model of the instrument transformer.
Several nonlinear modeling techniques have been proposed in literature; above them, the frequency-domain *Volterra-Wiener* representation of nonlinear systems appears to be particularly suitable for modeling measurement devices subject to periodic signals. This approach arises from a generalization of the input-output representation of linear time invariant systems.
In literature, frequency-domain Volterra models are generally employed up to the 3rd degree (or nonlinearity order), since the number of coefficients required to represent its behavior grows rapidly with the number of injected harmonics and the nonlinearity order. However, the impressive growth of the computational power makes now possible to manage Volterra models characterized by higher degrees. For this reason, a general method to define the structure of frequency domain Volterra models with arbitrary degree and number of input harmonics has been developed and validated.
The number of coefficients defining a Volterra-Wiener model is extremely high. Even if it could be managed thanks to the availability of low-cost computational power, its identification inherently requires a complex and time-consuming identification process. For this reason, several techniques allowing to "prune" the number of coefficients have been proposed in the literature. When focusing on the modeling of power systems devices (such as voltage instrument transformer) a consistent simplification of their Volterra models can be performed, by exploiting the typical spectral content of voltage waveforms. In fact, such waveforms consists of a largely prevalent fundamental component, and harmonics that are characterized by much lower amplitudes: starting from this assumption, *Quasi-Sinusoidal Volterra Models* have been defined, developed and implemented. The expression that allows computing the number of independent coefficients for an arbitrary nonlinear degree and number of input harmonics has been obtained, and a method for the implementation and identification of such models has been proposed. The proposed modeling approach has been firstly employed in numerical simulations to predict the harmonic currents drawn by a strongly nonlinear device (a nonlinear inductor) and a portion of grid consisting in linear and nonlinear loads subject to distorted voltages. Simulation results highlight the effectiveness of the quasi-sinusoidal simplification, since it dramatically reduce the computational cost with a negligible loss of accuracy for a given order of nonlinearity.
The different approaches have been applied to the characterization of voltage instrument transformers with realistic, distorted primary waveforms. The methods have been firstly tested by means of numerical simulations and then, thanks to proper experimental setups, it has been employed to assess the metrological performance of low voltage and medium voltage instrument transformer.
The BLA allows the best linear reconstruction of the primary voltage spectrum starting from the output; together with the standard deviations it is a useful tool for quantifying the impact of the nonlinearities on the harmonic measurements. On the one hand, the BLA allows to compensate only systematic nonlinear effects associated with a peculiar class of excitation signals, that cannot be taken into account by performing a conventional frequency response measurement with single-tone excitations. On the other hand, this technique return information about the influence of unmodeled (stochastic) nonlinearities, but it is not able to qualify them. To overcome this problem, a nonlinear measurement model should be employed.
Experimental results highlighted that nonlinearities significantly affect the measurement accuracy of low-order harmonics, while a frequency response compensation is effective only when higher frequencies are considered. The main nonlinear phenomena in voltage transformer are represented by the harmonic distortion caused by the fundamental component, and its intermodulation with the other harmonics. Hence, an *ad-hoc* simplification of the Volterra-Wiener frequency domain model (that is able to represent these phenomena) have been developed and implemented. Experimental results clearly show the effectiveness of the approach, since the obtained models are able to accurately represent the nonlinear phenomena that limits the accuracy of voltage instrument transformers devoted to harmonic measurements.

PREDICTIVE ALGORITHMS FOR PROGNOSTICS AND HEALTH MANAGEMENT OF COMPLEX SYSTEMS

Giacomo Leone - Supervisor: Prof. Loredana Cristaldi

In the last years, the rapid technological development has led to the definition of new industrial paradigms such as Industry 4.0, which goal is to make modern factories smart by applying intelligent information processing approaches, communication systems and future-oriented techniques based on new technological concepts like the Internet of Things and Cyber-Physical Systems.
If on one hand this technological revolution has opened new scenarios and perspectives, on the other hand the high complexity, automation, and flexibility required by such intelligent factories has brought new challenges in terms of reliability and safety. In this regard, the area of intelligent maintenance and diagnostics and prognostics of machinery has been lately looked at with increasing interest. In particular, the concept of Prognostics and Health Management (PHM) has experienced a remarkable diffusion, becoming object of study and attention of many industrial organizations.
PHM represents one of the most cutting-edge engineering approaches in the field of the health assessment and maintenance of industrial systems. It consists in the application of suitable techniques that assist in the early prediction of the failure time of the systems of interest and the consequent application of a Condition-Based Maintenance (CBM) strategy, a management philosophy for which the decision of repairing or replacing is based on the current or future condition of assets.
Despite the growing interest on PHM methods and the considerable amount of literature on specific techniques, it is a fact that their massive industrial application is still far away. Several key issues, in fact, remain to be addressed in order to make PHM more influential in industrial realities. In particular, it can be stated that currently most of the proposed PHM approaches are application or equipment specific and a clear systematic way to design and implement PHM does not exist. It follows that the development of PHM solutions towards the modern engineered systems, characterized by increasing complexity of the employed technologies and of the interactions among several subsystems, is an issue as it may be highly time- consuming and resources demanding, without the certainty of achieving meaningful results.
The goal of this research activity is to propose technical solutions to eliminate the previously mentioned weaknesses in the current scenario which characterizes PHM methods. The first step in doing so is the development of an innovative systematic approach that aims to go beyond a structured and coherent application of PHM and to offer a methodological framework for a correct CBM-oriented product management along the entire life-cycle, from design to disposal. The proposed process starts with the identification of the most critical failure modes and associated mechanisms, which are preparatory to the application of sensors selection and optimization schemes. Finally, the measured signals obtained from the Condition Monitoring systems, defined accordingly to the indications of the previous steps, can be given in input to suitable PHM tools for diagnostic and prognostic scopes. Also for this last step, the choice of the proper algorithms has to be carried out taking into account different factors, such as number and type of monitored signals, computational sources and so on.
Different predictive algorithms have been presented as innovative PHM solutions for complex systems. In particular, various Data-Driven (DD) approaches in the class of Machine Learning techniques, such as Artificial Neural Networks, Principal Component Analysis, Auto Associative Kernel Regression, and hybrid approaches based on a mixture of physics-based and statistical models have been explored. The proposed algorithms have been applied to two different case studies, namely Power Circuit Breakers and Photovoltaic (PV) plants, exhibiting very successful diagnostic and prognostic performances.
Nevertheless, the employed DD models, relying only on the analysis of collected sensor data and/or statistical data, can be easily adapted to different application cases, making the set of algorithms presented in this work a valuable library of predictive algorithms, in principle applicable for PHM of a large set of heterogenous and complex systems.
One of the constitutive pillars of PHM is represented by the prognostic process, whose most valuable output is the estimate of the Remaining Useful Life (RUL), that is how long the system of interest will take until a failure occurs. For this reason. one of the objectives of the research activity is the presentation of two different approaches for the representation and propagation of the uncertainty sources in prognostics. Both methods can be grouped in the class of similarity-based algorithms. Such algorithms are based on the hypothesis that a set of run-to-failure degradation patterns are collected in a reference library. An evaluation of similarity between the test degradation pattern (associated to the test item whose RUL has to be predicted) and the reference trajectory patterns in the database is then performed in order to estimate the RUL of the test item. This approach is particularly promising and suitable in the growing scenario inspired by the Industry 4.0 paradigm, where different machines and devices interact, communicate, learn from each other and share information (enabling modern concepts such as Big Data Analytics, Cloud Computing and Machine-To-Machine).
The first proposed prognostic algorithm is a statistical algorithm which relies on the application of Monte Carlo simulations for the propagation over time of the uncertainty about the future degradation profile of the target product. The second prognostic approach, instead, estimates the test product RUL as weighted sum of the RULs of the reference products. The weight assigned to each reference product depends on the distance between their degradation curve and the one of the test item, and in this regard an element of novelty is introduced by handling the measurement uncertainty in a possibilistic framework, namely through a Random-Fuzzy Variable (RFV) approach, which allows to take into account, within the same mathematical framework, both the random and systematic contributions to measurement uncertainty. Another advantage derived from the application of the RFV approach is the possibility to include in the prognostic model also experts' opinion and the associated epistemic uncertainty in a unique framework.
A further innovation element of the proposed research is the development of a methodology for the reliability assessment of PV modules. The proposed scheme can be defined as a hybrid approach since it incorporates a statistical model and a physical model. The statistical technique relies on Monte Carlo simulations for the propagation of the stochasticity about failure modes occurrence time and their effects on the PV module performances; the physical model, instead, allows to take into account constructive and physical parameters of the module, such as the number of cells and the number of bypass diodes, but also to simulate more complex phenomena. From the literature analysis, it seems that this proposal is the first attempt in developing a model capable to include in the reliability analysis of PV modules both the effects of the environmental conditions (which directly affect the occurrence frequency and the effects of failure modes) on their performances and the physics behind their functioning.

NEW CURRENT SENSOR FOR HIGH CURRENT MEASUREMENT

Sathish Kumar Packiam- Supervisor: Roberto Ottoboni

Current measurement is inevitable in a wide range of electrical and electronics application with different requirements in performance of the measurement devices with respect to its cost, isolation, accuracy, bandwidth, measurement range and size. Magnetics sensors were effectively utilized in numerous fields of applications when there is the availability of magnetic field that can be sensed. This research project details the study, the characterization and the development of a pre-industrial product, the "Sensor Array for High current Measurement (SAHM)" with the scope of being utilized in the fast growing electrical field for the measurement of high DC current. This Thesis work has been carried out with the aid of the research project commenced in need of the ABB R&D center, Ladenburg, Germany for measuring high currents in one type of ABB's three-phase DC circuit breaker (CB) and the product is developed in collaboration with ABB SACE Spa, Bergamo and Politecnico di Milano, Italy.

This research project details about ideas, techniques and technologies in current measurement using magnetic sensors from various literatures published over the years that we have adopted in our research. It details about the analysis and the evaluation performed in selecting the devices that are suitable for this product development based on the study and market survey performed from various magnetic sensors regarding its merits, demerits and their technological limitations. The SAHM has considered integrating the current measurement of both monitoring and the protection scope in a single product. Two different sensor arrays having sensors with different technology in measuring the nominal current for the monitoring purpose and the fault current for the protection purpose. Finally, the design of the complete circuit model has been discussed for the magnetic sensor array with the electronic circuit that performs the analog signal processing.

Finalizing the initial design for the prototype PCB fabrication, from the broad range of available magnetic sensors, it is narrowed down to Integrated Hall Effect sensor ICs with inbuilt amplification and thermal compensation from three different manufactures for inner array (measurement of nominal current) and simple Hall effect elements for outer array (measurement of fault current).

The complete scenario of the sensors performance characteristics related to its linearity and thermal drift over the operating temperature, experimental activities have been carried out for prototypes with different commercially available Hall Effect sensors for high current measurement in a three phase circuit breaker.

In addition, the developed prototypes are evaluated for verifying the influence of the external magnetic field to the actual quantity to be measured. Further investigation have been carried out by modifying the Hall sensor interfacing electronics like voltage source for the sensor array, reference signal source and the thermal compensation components in order to fine-tune the complete design of the prototype. A new enhanced power supply section for the developed SAHM device has been developed and tested for the performance improvement of sensor array. The evaluation results of the enhanced prototypes is described and also as a case study, the prototypes are tested by placing in a three-phase circuit breaker for which the SAHM is developed.

The results from the case study, especially the crosstalk error results provided a way for a deeper investigation to perform analysis of the magnetic model inside the three-phase circuit breaker by finite element method simulation as initially the crosstalk influence is considered only from a nearby long circular bus bar. The theoretical crosstalk value has been estimated for the circular array of sensors by also considering completed circuit breaker model and it shows that the crosstalk value measured is not the same for all the poles and the circuit breaker exhibits an asymmetric behavior. The problem related to the experimental value of crosstalk measurement of the sensor array in any pole is always two to three times higher than the value estimated from finite element method simulations.

The reasons for such behavior are listed and different solutions regarding this problem have been proposed in terms of calibrating the developed SAHM device for its effective utilization in a 3-phase circuit breaker for the measurement of high currents.

DIAGNOSTIC METHODS FOR ELECTRIC ARC PLASMA IN LOW VOLTAGE CIRCUIT BREAKERS: MODELING AND COMPUTATIONAL ASPECTS.

Francesco Rigamonti - Supervisor: Prof. Gabriele D'Antona

Low voltage circuit breakers are protection devices in use in order to prevent faulty and dangerous conditions in civil and industrial electric networks. A key aspect in circuit breaker engineering is the capability to timely switch the electric arc plasma occurring when the electric current flow is interrupted by breaking the circuit. The modeling and simulation of electric arc plasma, under the conditions which are met in low voltage circuit breakers, is a complex and not completely dominated issue. The aim of this research project is to develop an effective diagnostic method and the underlying know-how to monitor the complex and fast behavior of the electric arc plasma during the transient opening phase of a low voltage circuit breaker. The final deliverable is a signal processing algorithm returning a space-time map of a characteristic physical quantity associated to the arc plasma, in this case, its current density distribution. The processed quantities are the external magnetic flux densities measured by the Hall effect sensor array specifically designed for this project, placed along breaker sidewall. Such technique would be a significant improvement over and supplement to state of the art diagnostics, currently limited to electric measures of purely macroscopic electric quantities or optical methods affected by problems of practical nature. The establishment of the correlation between plasma location and macroscopic measurement will help the modeling of partially understood arc plasma physics, as well as designers and engineers working in the R&D of protection devices. Nowadays the design for those devices is based on a phenomenological and semi-empirical approach, or the analysis of multi-physical simulation and lab measurements. The developed approach is based on lumped parameter model of the arc, where the ferromagnetic nonlinearities are also evaluated and modeled. The solution is reached by minimizing a nonlinear goal function. An ad hoc, novel regularization technique was developed to improve the resolution without impacting the robustness of the regularization scheme. Numerical simulation methods are nowadays possible, based on computational magnetohydrodynamics and rich of fine modeling. Thanks to these tools, realistic synthetic data are generated, and the developed identification procedure was tested and validated, by comparison with a reference solution. The main goal of this work was accomplished with an experimental arc identification in a real breaker, during standard short circuit tests. Inversion results are in agreement with present interpretation and knowledge of arc behavior, and add useful information regarding arc evolution in low voltage circuit breaker.

DIAGNOSTIC METHODS FOR ELECTRIC ARC PLASMA IN LOW VOLTAGE CIRCUIT BREAKERS: MEASURING AND APPARATUS DESIGN

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The aim of this research project is to develop an effective diagnostic method and underlying know-how to monitor the complex and fast behavior of the electric arc plasma during the transient opening phase of a low voltage circuit breaker.

Our idea relies on adopting inverse methods based on magnetic measurements to be recorded by an apparatus which, owing to the many demanding requirements, would inevitably has to be fast, accurate, compact and located in a hostile environment.

The final deliverable is an experimental setup returning a space-time map of the magnetic flux density close to the circuit breaker side wall associated to the unknown arc plasma current density distribution.

Such technique would be a significant improvement over and supplement to state of the art diagnostics, currently limited to electric measures of purely macroscopic electric quantities or optical methods (e.g. IR and high speed cameras, optical fibres) affected by problems of practical nature.

The complexity and time behavior of the phenomena under study requires sampling the magnetic flux density at a large number of locations at high sampling rate. This work has lead to the design of a magnetic sensor array, based on Hall effect sensors, and a data acquisition system meeting the following requirements:

- Dynamic range: ±100 mT
- Accuracy: 1 mT
- Bandwidth (3 dB): 20 kHz
- Size: 35x35 mm
- Number of sensors: 8x8

The diagnostic methods to develop strongly rely on high quality and massive magnetic and electric measures. Particularly, owing to the strong sensitivity of inverse methods to signal noise, accurate sensor signal conditioning and calibration is required. This is a difficult challenge due to the reduced space available to locate sensors and the rapid dynamics and high intensities of the spurious electric and magnetic fields around the current breaker during the short circuit event.

Laboratory tests have proven the ability of the developed system to reconstruct the arc current density distribution under real experimental conditions.