INTERUNIVERSITY PH.D. PROGRAM BETWEEN

POLITECNICO DI BARI AND UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO

IN INDUSTRY 4.0

High Frequency Power Converters: Technical Problems Analysis and Possible Hardware and Software Solutions Development

PhD candidate

Francesca Maiullari

Cycle

XXXVII

Tutors

Prof. Vito Giuseppe Monopoli

Description of the research program

Currently, high frequency (HF) DC-AC power conversion technology, with frequencies ranging from hundreds of kHz to tens of MHz, is rapidly developing. The characteristics of high efficiency, high power density and rapid response are extremely requested in many fields, from the most specialized applications both in the automotive and electric vehicle sectors, but also in the aerospace, aeronautical, medical and renewable energy sources sectors. However, switching frequency increasing lead to new challenges. Most of them are related both to power quality and variable transmission frequency. They are mostly: 1) parasitic phenomena increasing, generating temporary reflected wave overvoltage stress on motors; 2) stray emission of energy caused by voltage unbalance and harmonic distortion; 3) reflection on PWM output signal transmission; 4) high switching losses; high frequency resonance phenomena; 5) partial discharges phenomena that occur on the windings.

The need therefore arises to identify valid solutions to face these technical problems that severely limit the applications of high-frequency converters and to develop innovative methodologies for their solution in both hardware and software. The research activity will start carrying out a bibliographic study in order to identify the nature of the recurring and most debilitating phenomena for high frequency transformers and high-speed motors among the issues dealt with. Once the complete state of art has been defined, it aims to solve these problems by designing an innovative low-cost, low-volume and efficient hardware solution and a software solution that implements reliable control and improves the performance of the converter. The first part of the research project will focus on the design of an innovative hardware solution which consists in the design of a high frequency converter using both Silicon Carbide WBG (such as SiC Mosfet) or Gallium Nitride devices, and classic Si-IGBT. The SiC devices have enough capability to work in high-speed switching, at higher voltage and high temperature. However, the SiC devices can generate over-voltages and overcurrent in high frequency and high power applications, which provokes appearance of electromagnetic interference (EMI) phenomena. The generation of overshoots and oscillations problem that can cause EMI, will be avoided implementing the Active Gate Driver (AGD) technique, a control technique based on optocoupler to detect control instances and modulate the gate signal. Through a reliability study of the device downstream of the converter, the AGD technique allows to increase the winding life of a high-speed motor or transformer by reducing transient overshoot, but reduces the switching speed of the device. This approach allows preserving the functionality of the power device, but it produces more losses that consequently lead to the increasing device's temperature, the reduction of its reliability and average life. The research will be oriented towards an integrated holistic approach of the system reliability study, looking for a trade-off solution that preserves the integrity of the power converter.

The second part of the research project will focus on software analysis in order to develop a control algorithm and a modulation algorithm. With the computational power of Artificial Intelligence (IA), both the reliability of power converters could be enhanced and failures prevented by implementing predictive maintenance solutions. In the IA field, Machine Learning Approach such as Reinforcement Learning will be evaluated to optimize the selection of circuit parameter values to activate the AGD function and improve system reliability. Matlab / Simulink environment will be used for control algorithm development and implementation. Regarding modulation techniques, it is planned to implement a PWM technique, identifying among the techniques present in the literature, the most performing in relation to the HF converter. Modulation algorithm development and implementation will be performed in LabVIEW environment.

Then will be developed a test campaign to evaluate the efficiency of this converter, in terms of cost, volume, power loss and efficiency analysis by comparing the output signals with different gate resistances.

In conclusion, the combination of hardware and software solutions aims to provide valid results that will allow HF converters to be used no longer only for MV and HV applications for power transmission on lines of a few thousand km, but to make them usable also for LV applications for the solution of the voltage derivatives issue.

Schedule of the research activities

First academic year planned

	Description	Period	Activity abroad
Insert name of first research activity: High Frequency Power Converters SiC Based Analysis	Bibliographic research and state of the art of technical problems related to the development of High Frequency (HF) Converters using SiC devices. Analysis of the advantages and drawbacks of HF Converter. Creation innovative HF converter models SiC based in Matlab/Simulink environment set up a control system and simulation.	1-11-2021 31-10-2022	NO
Insert name of second research activity			

Second academic year planned

	Description	Period	Activity abroad
Insert name of first research activity: Analysis and Implementation Active Gate Driver (AGD) control algorithm	Bibliographic research and state of the art of AGD technique. Bibliographic research and state of the art of Artificial Intelligence, such as Machine Learning and Reinforcement Learning Approach. Analysis of the most performing algorithms. Identification of the physical values to control. Implementation the algorithm in Matlab / Simulink environment and testing the effectiveness, reliability and removal performance of the Active Gate Driver (AGD) control algorithm, when the most important physical values vary. Test bench set up. Control test results, by comparing the results obtained with the expected results and repeating until the test is a success.	1-11-2022 31-10-2023	NO
Insert name of second research activity			

Third academic year planned

	Description	Period	Activity abroad
Insert name of first research activity: Analysis of the PWM technique	Bibliographic research and state of the art of PWM technique and control. Analysis of the most performing technique. Using LabVIEW software, program the FPGA of the control board to implement the PWM technique and dead time. Model testing.	1-11-2023 31-10-2024	NO

Insert name of second research activity: Analysis of predictive maintenance techniques	Bibliographic research and state of the art of predictive maintenance techniques with Machine Learning and Reinforcement Learning approach to automated anomaly detection. Implementation the algorithm in Matlab / Simulink environment and testing Using software. Test bench set up. Control test results, by comparing the results obtained with the expected results and repeating until the test is a success.	1-11-2023 31-10-2024	NO

Provisional training and research activities plan

Specify with the related CFU (ECTS) the training activities that you plan to carry out or have completed in the three years (e.g., courses to attend, conferences, seminars, etc.). Please refer to the *Educational regulations of the Doctoral School of Politecnico di Bari*: http://www.poliba.it/sites/default/files/dottorati/regscudopoliba.pdf

Specify with the related CFU (ECTS) the research activities that you plan to carry out in the three years (e.g., individual research activity, supervision of students, integrative seminars to be given by the PhD student, activity of manuscript preparation for conferences or journals, activity of patents preparation, etc.).

First academic year planned

	Description	**Period**	**Duration**	**CFU**
PhD courses	Supervision and monitoring of renewable energy systems, 2 CFU, SSD: ING-IND/31. Prof. Silvano Vergura.	03/03/21-27/04/22	20h	1
	Innovative Materials for Energy Conversion Technologies, 1 CFU, SSD: CHIM/03. Prof. Andrea Listorti.	30/03/2022-21/07/2022	20h	0,5
Master's degree courses	Compatibilità elettromagnetica, ING-INF/02, Prof. Giovanna Calò	1nd Semester	60h	6
Participation to seminars and international congresses or workshops	POLIBA SOFT SKILL - TRAINING ACADEMY" I cycle A.A. 2021/2022	2nd Semester	40h	3
	European PhD Summer School: Power Electronics, Electrical, Machines, Energy control and Power System	July	4 days	4
	2022 IEEE Applied Power electronics conference and Exposition (APEC)	20-24/ 03/2022	5 days	5
	31st International Symposium on Industrial Electronics (ISIE), in Anchorage, Alaska (USA)	01-03/ 06/2022	3 days	3
Presentation of research products at international	14th IEEE Annual Energy Conversion Congress and Exposition (ECCE), Detroit, Michigan USA	09-13/ 10/2022	5 days	5
	48th Annual Conference of the IEEE Industrial Electronics Society (IECON). Brussel, Belgium	18-21/ 10/2022	4 days	4

congresses or workshops				
	TOTAL OF CFU FOR TRAINING ACTIVITIES			**31,5**
Individual research activity	Bibliographic research and state of the art of technical problems related to the development of High Frequency (HF) Converters using SiC devices, partial discharge phenomenon, harmonic distorsion and high frequency resonance phenomena, research work in the university for the research project.	01/11/2021-01/11/2022	365h	14,5
Students' supervision	Correlator and student supervisor for bachelor's and master's thesis in electrical engineering	01/11/2021-01/11/2022	125h	5
Integrative didactive activities	Integrative didactical activities for the master's degree course in Power Electronic Converter	06/10/2021-13/01/2022	50h	2
Preparation of manuscripts for conferences or journals	Drafting of a journal/conference papers on the insulation aging electrical machines in high-frequency electric drives, that is the early failure of inverter-fed AC machine insulation systems due to the very high dv/dt's of modern fast switching converters. The role of the AGD technique in the mitigation of this phenomenon.	15/12/2021-15/07/2022	175h	7
	TOTAL OF CFU FOR RESEARCH ACTIVITIES			**28,5**
	TOTAL OF CFU FOR YEAR I			**60**

Second academic year planned

	Description	**Period**	**Duration**	**CFU**
PhD courses	MATLAB Recipes For Measurements Data Processing, 2 CFU, SSD: ING-INF/07	2nd Semester	20h	1
	Smart Education for Industry 4.0, 2 CFU, SSD: INF/01 Prof. Veronica Rossano.	2nd Semester	20h	1
Master's degree courses	Digital Programmable System, ING-INF/01, Prof. De Leonardis	2nd Semester	60h	6
Participation to seminars and international congresses or workshops	Roma Tre Summer Course on Power Electronics and Applications, Roma Tre University	2 Weeks on Settember	30h	6
	2023 IEEE Applied Power electronics conference and Exposition (APEC)	19-23/ 03/2023	4 days	4
	32nd International Symposium on Industrial Electronics (ISIE), in Helsinki, Finland	19-23/ 06/2023	5 days	5
Presentation of research products at international	15th IEEE Annual Energy Conversion Congress and Exposition (ECCE), USA	29/10/2023-02/11/2023	5 days	5
	49th Annual Conference of the IEEE Industrial Electronics Society (IECON), Singapore	16-20/ 10/2023	4 days	4

congresses or workshops				
	TOTAL OF CFU FOR TRAINING ACTIVITIES			**32**
Individual research activity	Bibliographic research and state of the art of AGD technique. Bibliographic research and state of the art of Artificial Intelligence, such as Machine Learning and Reinforcement Learning Approach. Analysis of the most performing algorithms. Identification of the physical values to control. Implementation the algorithm in Matlab / Simulink environment and testing. Test bench set up. Control test results.	01/11/2022-01/11/2023	350h	14
Students' supervision	Correlator and student supervisor for bachelor's and master's thesis in electrical engineering	01/11/2022-01/11/2023	125h	5
Integrative didactive activities	Integrative didactical activities for the master's degree course in Power Electronic Converter	06/10/2022-13/01/2023	50h	2
Preparation of manuscripts for conferences or journals	Drafting of a journal/conference papers	15/12/2022-15/07/2023	175h	7
	TOTAL OF CFU FOR RESEARCH ACTIVITIES			**28**
	TOTAL OF CFU FOR YEAR II			**60**

Third academic year planned

	Description	**Period**	**Duration**	**CFU**
PhD courses	Advanced Probabilistic Methods For The Reliability (Performance-Based) Analysis In Engineering Problems, 2 CFU, SSD: ICAR/09 Prof. Sergio Ruggieri	2nd Semester	20h	1
Master's degree courses	Embedded Control, ING-INF/04, Prof. Luca De Cicco	2nd Semester	60h	6
Participation to seminars and international congresses or workshops	2024 IEEE Applied Power electronics conference and Exposition (APEC)	25-29/ 02/2024	4 days	4
	Smart Transformer Seminar – Kiel	1st Semester	60h	6
	33rd International Symposium on Industrial Electronics (ISIE).	19-23/ 06/2024	5 days	5
Presentation of research products at international congresses or workshops	16th IEEE Annual Energy Conversion Congress and Exposition (ECCE), USA	29/10/2024-02/11/2024	5 days	5
	50th Annual Conference of the IEEE Industrial Electronics Society (IECON), Chicago	13-16/ 10/2024	4 days	4

	TOTAL OF CFU FOR TRAINING ACTIVITIES			**31**
Individual research activity	Bibliographic research and state of the art of predictive maintenance techniques with Machine Learning and Reinforcement Learning approach to automated anomaly detection. Implementation the algorithm in Matlab / Simulink environment and testing. Test bench set up. Control test results.	01/11/2023-01/11/2024	375h	15
Students' supervision	Correlator and student supervisor for bachelor's and master's thesis in electrical engineering	01/11/2023-01/11/2024	125h	5
Integrative didactive activities	Integrative didactical activities for the master's degree course in Power Electronic Converter	06/10/2023-13/01/2024	50h	2
Preparation of manuscripts for conferences or journals	Drafting of a journal/conference papers	15/12/2023-15/07/2024	175h	7
	TOTAL OF CFU FOR RESEARCH ACTIVITIES			**29**
	TOTAL OF CFU FOR YEAR III			**60**
	TOTAL OF CFU FOR THE WHOLE PHD COURSE			**180**