PhD in Information Technology and Electrical Engineering
Università degli Studi di Napoli Federico II

PhD Student:

Cycle: XXXVI

Training and Research Activities Report

Academic year: 2021-2022 - PhD Year: Second

Tutor: Prof. Mario Pagano

Date: October 30, 2022

1. Information:

- **PhD student:** Antonio Di Pasquale
- **PhD Cycle:** XXXVI
- **DR number:** DR995136
- **Date of birth:** 13.06.1995
- **Master Science degree:** Electrical Engineering
- **University:** University of Cassino and Southern Lazio
- **Scholarship type:** UNINA
- **Tutor:** Prof. Mario Pagano

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
All roads lead to WebRTC: an introduction to Janus	Seminar	2	0.4	16.12.22	Dr. Lorenzo Miniero	N
Ph.D. School F. Gasparini	PhD School	-	4	24.02.22-28.02.22	Prof. Fabio Villone	Y
The Spatial structure of Bi-photon States	Seminar	1	0.2	12.01.22	Dr. Alessandro D'errico	
La CATENARIA RIGIDA: Applicazione sulle linee RFI	Seminar	2	0.4	21.01.22	Collegio Ingegneri Ferroviari Italiani (CIFI)	Y
Exam PhD school "Ferdinando Gasparini"	PhD School	-	2	-	Prof. Fabio Villone	Y
Potential and challenges of next generation railway signaling systems: Moving Block and Virtual Coupling	Seminar	1	0.2	06.04.22	Joelle Aoun	N
History of Fusion	Seminar	3	0.6	01.07.22	Prof. Piero Martin	N
La Sostenibilità del Trasporto Pubblico Locale su Ferro: Elementi di Efficientamento	Seminar	3.5	0.7	12.07.22	Prof. Mario Pagano	Y
Inkjet printing	Seminar	1	0.2	14.10.22	Prof. Detlef Lohse	N

MATLAB Campus-Wide License per la formazione nelle discipline STEM	Seminar	1	0.2	26.10.22	MathWorks	N

1) Courses, Seminar, Doctoral School, Research, Tutorship
2) Choose: Y or N

2.1. Study and training activities - credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	0	0.4	7	0	7.4
Bimonth 2	4	0.6	5	0	9.6
Bimonth 3	2	0.2	7	0	9.2
Bimonth 4	0	0	10	0	10
Bimonth 5	0	1.3	9.5	0	10.8
Bimonth 6	0	0.4	12.6	0	13
Total	6	2.9	51.1	0	60
Expected	30 - 70	10 - 30	80 - 140	0 – 4.8	

3. Research activity:

During the second year of the PhD my research activity focused on the following topics:

i. optimal management strategies for metro railway systems;
ii. harmonic power-flow study of polyphase grids with converter-interfaced distributed energy resources;
iii. scheduling algorithms for Ultra-Fast Charging Stations for plug-in electric vehicles.

3.1. Optimal Management Strategies for Metro Railway Systems

The growing concerns about environmental issues draw attention to the need to improve the efficiency of railway systems. The expression ‘optimal management strategies for metro railway systems’ refers to a wide range of solutions aimed at improving the efficiency of these systems.
This goal can be pursued through several approaches. The technical literature proposes many models and algorithms, involving mechanical (i.e., train speed and acceleration) and electrical variables (i.e., train power absorption, power supplied by substations, etc.).
In particular, I focused my attention on solutions for the optimal motion of a rolling stock fleet and control strategies for the optimal management of the power flow of both the AC supplying grid and the DC traction grid.

3.1.1 Optimal Motion of a Rolling Stock Fleet

To reduce the energy consumption of electric rail transit systems, the optimal management of train driving modes plays a key role [1]. Indeed, most of the energy consumption in the railway system is associated with the train propulsion system. Therefore, coordinating the motion of the rolling stocks fleet, and optimizing trains' speed profiles and timetable design can provide significant benefits in terms of energy-saving [2].

To address these issues, I developed some optimization models, based on mechanical (i.e., train acceleration and speed, resistance forces, etc.) and electrical (i.e., electric power and energy consumption, voltage drops, etc.) variables. The aim is to correlate the mechanical aspects with electric power and energy consumption. Thus, the problem is formulated as a constrained optimization problem, in which the mechanical constraints are related to the kinematics equation of each train, its maximum acceleration and speed values, and dwell time. The electrical constraints refer to the rated power of substations, and the voltage drop along the traction grid and, eventually, along the AC supply grid. Thus, a suitable model for the train motion and the power flow study of the traction system was developed and embedded into the optimization problem.

Finally, several objective functions were considered, such as energy consumption minimization or travelling time minimization, or multi-objective functions which aim to combine both aspects.

3.1.2 Optimal Control Strategies

The reduction in the energy consumption of DC metro railway systems also passes through proper management of regenerative energy. Indeed, the urban rail transportation service is characterized by repetitive starts and stops, therefore regenerative braking is an attractive measure for reducing energy consumption.

Hence, suitable control strategies for substations and wayside storage devices are indispensable for providing energy savings and voltage stabilization [3].

However, DC metro railway systems are usually equipped with not-reversible Traction Power Substations (TPS), whereas Energy Storage Systems (ESSs) are rarely installed along the track. This significantly compromises the opportunity of recovering energy from regenerative braking.

In this context, I worked on a centralized control strategy to manage not-reversible TPSs and trains to exploit regenerative braking by enhancing the power flow exchanges among trains while simultaneously regulating the voltage supply along the entire track.

In the cases outlined above, train braking energy cannot be stored or sent back to the AC grid. It can only be used to feed other trains travelling on the track in respect of operative constraints. Indeed, the amount of power injected by braking trains on the grid must be limited to contain the overvoltage. Also, the host capability of the network limits the amount of power that each train can inject into the grid. The proposed control strategy uses a Central Controller that exchanges information with the TPSs and trains according to its information rate. According to the trains' position and power requirements, the controller determines the optimal value of output voltage for each TPS and the optimal amount of power coming from the regenerative braking that each train can inject into the grid. The strategy is formulated as an optimization problem, whose objective function is to minimize is represented by the fluctuation of train voltage around the nominal value. Constraints refer to the power requirement of trains for their motion, power supplied by the TPSs and voltages.

3.2. Harmonic Power-Flow Study of Polyphase Grids With Converter-Interfaced Distributed Energy Resources

Power distribution systems are experiencing a large-scale integration of distributed energy resources, such as renewable generators, energy storage systems, and modern loads, which are, typically, interfaced with the grid via power electronic converters. The presence of a large number of *Converter-Interfaced Distributed Energy Resources* (CIDERs) may compromise the stability of the system, in particular, the interaction of the latter with the grid can lead to unstable oscillations at harmonic frequencies [4].
Therefore, in order to assess the steady-state behaviour of such grids and design controllers which are robust w.r.t. harmonic instability, the creation and propagation of harmonics must be studied in detail.
In [5], authors developed a *Harmonic Power-Flow* (HPF) method for three-phase power grids with CIDERs, which is based on polyphase circuit theory and *Linear Time-Periodic* LTP systems theory.
With reference to this model, my efforts focus on the assessment of the mathematical properties of the HPF model, in order to define, if possible, explicit conditions for the existence and uniqueness of the solution. Indeed, due to the non-linearity of the equations, the existence and uniqueness of the solution to the load-flow problem is not guaranteed in general.

3.3. Scheduling Algorithms for Ultra-Fast Charging Stations for Plug-in Electric Vehicles

The growing development of the electric vehicle (EV) market emphasizes the need for charging infrastructures technologically efficient and widespread throughout the territory. In this context, Ultra-Fast Charging Stations (UFCSs) represent one of the most interesting technological solutions thanks to their capability to charge EVs in less than ten minutes [6].
They are, typically, equipped with energy storage systems and are partially supplied by renewable energy resources in order to reduce the burden on the power supply grid. This gives rise to several issues concerning the charging power profiles of each EV and, particularly, how to share the available energy among more EVs. Indeed, the recent years, the EV charging scheduling problem has received a great deal of attention and several algorithms have been proposed. According to their features, they can be classified as either offline or online using both not-preemptive and preemptive scheduler policies. The offline algorithm requires a huge amount of available data, such as future time arrival, energy demands and time departure of EVs. The main drawback of such algorithms is that information may be not available or too expensive to obtain. To overcome these limitations, online algorithms were introduced since they do not require any future information but only rely on the current and past EV profiles, including the arrival and departure times, and the charging demand of EVs [7].
In this framework, I worked on an online EV charging scheduling strategy based on the power loss modelling of the UFCS. Indeed, the efficiency dependence on operating conditions during the scheduling decision is not well addressed in the literature, however, it may significantly affect the scheduling decisions. The decision algorithm is formulated as a constrained optimization problem, which aims to reduce charging times, taking into account several constraints, such as maximum EV charging rate, available energy and priority among vehicles.

References

[1] Tian, Z., Zhao, N., Hillmansen, S., Roberts, C., Dowens, T., & Kerr, C. (2019). SmartDrive: Traction energy optimization and applications in rail systems. *IEEE Transactions on Intelligent Transportation Systems*, 20(7), 2764-2773.
[2] Hasanzadeh, S., Zarei, S. F., & Najafi, E. (2022). A Train Scheduling for Energy Optimization: Tehran Metro System as a Case Study. *IEEE Transactions on Intelligent Transportation Systems*.
[3] Kleftakis, V. A., & Hatziargyriou, N. D. (2019). Optimal control of reversible substations and wayside storage devices for voltage stabilization and energy savings in metro railway networks. *IEEE Transactions on Transportation Electrification*, 5(2), 515-523.
[4] Enslin, J. H. R., & P. J. M. Heskes, "Harmonic interaction between a large number of distributed power inverters and the distribution network". *IEEE Trans. Power Electron.*, vol. 19, no. 6, pp. 1586–1593, Nov. 2004.
[5] Kettner, A. M., Reyes-Chamorro, L., Becker, J. K. M., Zou, Z., Liserre, M., & Paolone, M. (2021). Harmonic Power-Flow Study of Polyphase Grids With Converter-Interfaced Distributed Energy Resources—Part I: Modeling Framework and Algorithm. *IEEE Transactions on Smart Grid*, 13(1), 458-469.
[6] H. H˜oimoja, M. Vasiladiotis, S. Grioni, M. Capezzali, A. Rufer, H. B. Puttgen, Toward ultrafast charging of electric vehicles, Tech. rep. (2012).
[7] Cao, Y., Wang, H., Li, D., & Zhang, G. (2021). Smart online charging algorithm for electric vehicles via customized actor–critic learning. *IEEE Internet of Things Journal*, 9(1), 684-694.

4. Research products:

[R1] Di Pasquale, A., Fedele, E., Iannuzzi, D., & Pagano, M. (2022, May). Contribution of Wayside Energy Storage Systems to Short Circuit Currents in DC Railway Traction Power Systems. In *2022 International Power Electronics Conference (IPEC-Himeji 2022-ECCE Asia) (pp. 1101-1106). IEEE.* (**Published**).

[R2] Fedele, E., Di Pasquale, A., Iannuzzi, D., & Pagano, M. (2022, May). Integration of Onboard Batteries and Supercapacitors Based on the Multi-Source Inverter for Light Rail Vehicles. *In 2022 International Power Electronics Conference (IPEC-Himeji 2022-ECCE Asia) (pp. 698-704). IEEE.* (**Published**).

[R3] Andreotti, A., Di Pasquale, A., Mottola, F., Pagano, M., & Proto, D. (2022, May). Voltage Quality of an AC Grid Supplying a Railway Power System with Energy Saving Strategy. *In 2022 20th International Conference on Harmonics & Quality of Power (ICHQP) (pp. 1-6). IEEE.* (**Published**).

[R4] Andreotti, A., Di Pasquale, A., Pagano, M., Ravichandran, N., & Volpe, F. (2022, June). An Optimal Centralized Control Strategy for Regenerative Braking Energy Flow Exchanges in DC Railway Traction Systems. *In 2022 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM) (pp. 436-441). IEEE.* (**Published**).

[R5] Andreotti, A., Di Pasquale, A., Pagano, M., Ravichandran, N., & Volpe, F. (2022, October). *Analysis of Lightning Transients in 2×25 kV 50 Hz Railway Traction System using EMTP. AEIT 2022 International Annual Conference.* (**Accepted**).

[R6] Di Pasquale, A., Pagano, M., Petrarca, F., & Volpe, F. (2022, October). *Assessing a Health Index Algorithm for High Voltage Overhead Power Lines. AEIT 2022 International Annual Conference.* (**Accepted**).

[R7] Attaianese, C., Di Pasquale, A., Fedele, E., Iannuzzi, D., Pagano, M., & Ribera, M. (2022, November). *Energy Efficiency Assessment for an Ultra-Fast Charging Station. 2021 IEEE Vehicle Power and Propulsion Conference (VPPC). IEEE, 2022.* (**Accepted**).

[R8] Botte, M., D'Acierno, L., Di Pasquale, A., Mottola, F., & Pagano, M. (2022). Optimal Motion of a Rolling Stock Fleet under Traction Power System Constraints. *IEEE Transactions on Transportation Electrification.* (**Published**).

5. Conferences and seminars attended

2022 20th International Conference on Harmonics & Quality of Power (ICHQP). IEEE, 2022.

- **Member of the Local Organizing Committee** of the 20th International Conference on Harmonics & Quality of Power (ICHQP).
- **Presenting author** of the paper "Voltage Quality of an AC Grid Supplying a Railway Power System with Energy Saving Strategy". (See [R3]).

6. Periods abroad and/or in international research institutions

I started my period abroad on September 12th, 2022, therefore the effective period spent abroad during the second year was 48 days.
The hosting institution is the Distributed Electrical Systems Laboratory (DESL) at École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland, where I am carrying on my research activity under the supervision of Prof. Mario Paolone, IEEE Fellow.
As an expert in power systems with reference to real-time monitoring and operational aspects, Prof. Mario Paolone leads me to study the Harmonic Power-Flow (HPF) for polyphase grids with converter-interfaced distributed energy resources.
The HPF method is based on the resolution of nonlinear equations, typically solved through Newton's method. Thus, the focus of my research activity at EPFL is to assess the mathematical properties of HPF to provide conditions for the existence and uniqueness of the solution to this problem.

7. Tutorship

8. Plan for year three

For the third year, I planned

1. completing the research period at École Polytechnique Fédérale de Lausanne (until December 12th) under the supervision of Prof. Mario Paolone. The main goal of this activity is to assess the mathematical properties of the HPF problem for distribution grids with converter-interfaced distributed energy resources, to define explicit conditions for the existence and uniqueness of the solution;
2. deepening the study of HPF, paying particular attention to electrical networks supplying railway systems to assess all the aspects concerning the power quality;
3. studying and implementing optimal control strategies for railway systems to reduce the energy consumption of the entire electrical system (i.e., AC supplying grid and railway traction system)
4. PhD Thesis Writing.

My PhD thesis will focus on optimal control strategies for railway systems to improve the efficiency of the railway system and, thus, reduce energy consumption. In particular, after a comprehensive state-of-the-art review, the work will propose several solutions to achieve this goal by coordinating the motion of rolling stock, controlling both their power absorption and the power supplied by substations and energy storage systems. It has to be highlighted that, at the same time, several operational constraints, i.e., limitation of voltage drop for the supply voltage, maximum rated power for substations, number of charging/discharging cycles for energy storage systems, etc., must be met. Thus, the strategies will be formulated as a constrained optimization problem, where constraints refer to the technical limitation of the systems, whereas the decision variables and the objective function depend on the specific strategy.