PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Ricardo Cardona Rivera

XXXIV Cycle

Training and Research Activities Report – First Year

Tutor: Mario di Bernardo

1. Information

I got a M. Sc. Degree in Automation Engineering the 25th September 2017 at Universidad Nacional de Colombia. During my master thesis, I worked a period of two months (03/05/17 - 13/07/17) at the University of Naples – Federico II under the direction of Mario di Bernardo as tutor and Pietro De Lellis as co-tutor and my research topic was focused on local stability conditions for the synchronization and pinning control of networks of coupled maps.

In December 2018 I won a PhD ordinary foreigners fellowship at the ITEE-University of Naples – Federico II (XXXIV cycle) under the direction from Mario di Bernardo as tutor.

2. Study and Training activities
    a. Courses
        i. Analisi e Controllo di Reti Complesse (6 CFU)
        Lecturer: Professor P. De Lellis.

        ii. Piece-wise smooth dynamical systems (2 CFU)
        Lecturer: Professor J. Hogan

        iii. Dinamica e Controllo Non Lineare (6 CFU)
        Lecturer: Professor M. di Bernardo

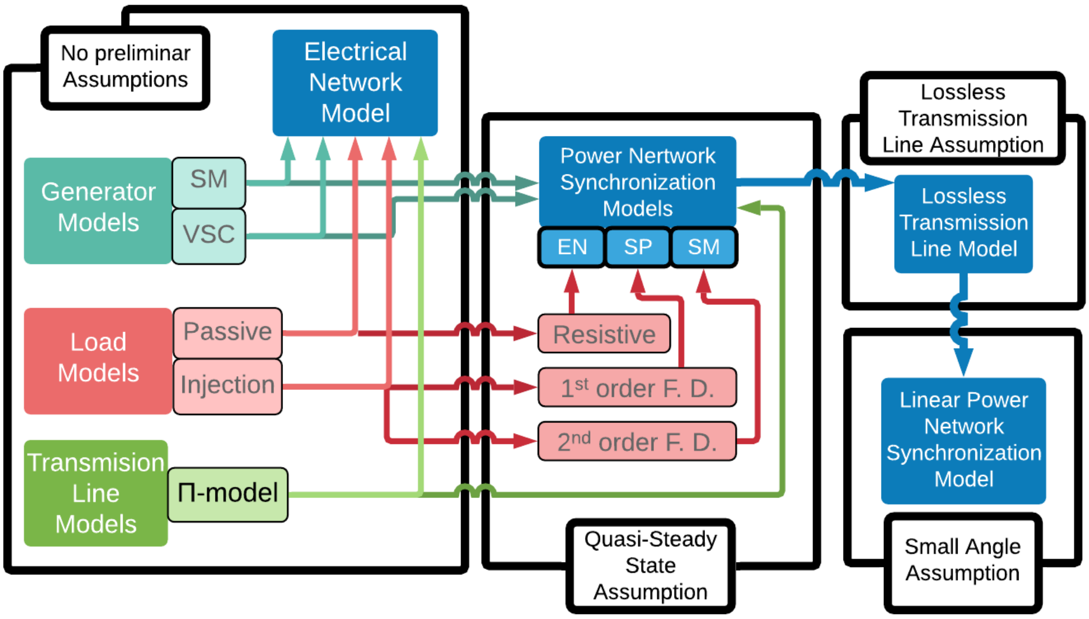
    b. Seminars
        i. Robotics in medical applications: An overview of the current medical robotics market from the industry's point of view (0.6 CFU)
        Lecturer: Ing. Vincenzo Schettino
        ii. Delay differential equations (DDEs) and their application (1.2 CFU)
        Lecturer: Professor J. Hogan
        iii. Research work in active perception and robot interactive learning lab in IIT (0.4 CFU)
        Lecturer: Dr. Fei Chen
        iv. Presentazione ADI- Vittorie, Sfide, Obiettivi (CFU 0.2)
        Lecturer: Mirella Paolillo
        v. Artificial Intelligence for Energy and Environmental Systems (0.4 CFU)
        Lecturer: Professor Peter P. GroumposResearch activity
3. Research Activity
    a. Title: Modelling and Control of Electrical Power Networks
    b. Research description:

Electricity distribution has an important role in the correct development and appropriate operation of what is called the Critical infrastructures (ICs), which are a set of interconnected systems comprising: goods distribution chains, Aqueducts, Oil and gas pipelines, communication systems, financial markets, and electrical networks themselves. In order to provide a constant supply of these services, the stability of these coupled networks must be ensured [8]. As a consequence of these stability requirements, there is a current need of modelling and control strategies that ensure that the electrical power network keeps a steady supply and remains robust against external perturbations. An electrical power system is composed of five main elements, (i) power sources, (ii) generators, (iii) transmission lines, (iv) loads and (v) Points of Common Coupling (PCC). Nowadays, there are many electrical energy generation devices, depending on different energy sources like, fossil fuels, sun, wind, geothermal resources, etc. These devices are in charge of converting the produced energy from the energy sources into electrical energy compatible with the three phase AC power network. After this conversion process, the electrical energy is transported through transmission lines, that are conductors carrying three-phase AC currents. The electrical energy transported by these lines ends in what we previously called loads, that are elements that use this electrical energy to carry out certain task. Depending on the power that has to be transmitted, voltages have to be increased or decreased forming networks with different voltages. To couple these networks PCC's are used, whose most representative members are the electric transformer and the substation. The presence of the previously mentioned voltage differences let us classify the power networks in two categories, being:

1. Distribution network with mainly radial (three) topology, compressing voltage levels:
    a. Low voltage network (LV): ranging from 100-127 V to 220-240V.
    b. Medium voltage network (MV): ragging from 5kV to 35kV.
2. Transmission network with voltages higher than 110kV.

These components have been the standalone elements of the network and have been working properly until some new technologies have been introduced. The increasing presence of new energy sources like solar, wind generation or fuel cell technologies technologies, which are distributed generation technologies that highly sensitive to weather conditions and network perturbations, increases the need of a control paradigm change that can ensure. These distributed generation technologies have are commonly attached to the distribution network, creating an entity commonly named as microgrid. The microgrid is then a subset of the power network, commonly also a subset of the distribution network, that is connected to the remaining network through a PCC and that is composed of power generating units, storage elements and loads. All these elements can be independent of the remaining network for a period of time, because is normally equipped with enough power capacity to cover the power demand inside itself. [4, 22]. As stated in [17], distributed generation technologies suffer from what is called low inertia which means the time constants in the generators are comparable to the time constants of the transmission network and the power demand dynamics. This low inertia phenomenon means that the time scale separation assumption, used in actual power systems for power flow optimization and network control, cannot be considered anymore for the design and control of power systems. As also exposed in [12, 9]. most of the control strategies for these kinds of networks have been deployed in a centralized fashion [16]. This control paradigm is prone to get obsolete soon due to the presence of multiple distributed energy sources, located in possibly far places from the central control unit and with perturbations of different nature. This leads to the need of proposing new control methods based on distributed and decentralized paradigms, that use the power network topology and properties. As stated previously, renewable energy use and installation increase is one of the main issues that the power network has to face. This kind of power generation has a common issue between strategies (solar, wind, etc) and is that most of the interfacing between them and the grid is done by means of electronic power converters. These power converters have the drawback that are low inertia systems and are poorly resilient to perturbations that are common in power networks [17]. The current increase of renewable power generation and the closure of fuel and atomic energy generators leads the current power networks to a inertia decrease. The consequences of the low inertia can be seen in countries like Australia, where the amount of power produced by renewables is comparable with the one coming from conventional sources [9]. Another additional problem is that almost all control strategies and hardware developments implemented in renewable energy generation are under the assumption that it will be attached to a resilient and robust power network (Stiff Network) through the microgrid, which is not feasible anymore. The presence of low inertia systems increases also the need of new control strategies related with the power scheduling and resource allocation, like the new developments in what is called feedback optimization exposed in [3, 20, 7]. As a first approach to the problem, a bibliography review related with the power network modelling was made, with the purpose to generate a unifying framework. As a result, a Model taxonomy is proposed. This taxonomy differentiates diverse power network models based on three main assumptions over network dynamics and parameters. These assumptions are [19, 14, 5, 11]:

1. Quasi-steady state assumption: this assumption considers that all voltages in the network can be expressed in phasor representation with constant amplitude and time varying phase deviation. It implicitly assumes that all voltages can also be expressed as three-phase AC signals and that generators can be expressed as ideal AC voltage sources. It is also assumed that there are only power injecting sources, whose expression depend on the generators and loads present on the network.
2. Lossless transmission line assumption: here, the resistive (dissipative) component of the transmission lines is neglected, leading to purely inductive transmission lines
3. Small angle assumption: in order to linearize the network, the small angle assumption of the sine function sin(x)≈x <<1 is used.



In Figure 1 a representative flowchart of the models is presented. All these models are used in different stages of the control syntheses. As stated in different studies [4, 6, 13] the control strategies for complex networks can be grouped in three main categories, being (i) Primary Control, (ii) Secondary Control and (iii) Tertiary control. Primary control is in charge of ensuring stability on the generators level. This control also ensures setpoint following. Control strategies here are mainly decentralized, which makes the system prone to have steady state error [24]. To overcome this, integral control must be applied which has been historically applied in a second control layer, called secondary control [1, 2, 10, 15, 23] . Secondary control reaches to fulfil the control objective of eliminating steady state error in the voltage and frequency quantities and reduce the energy generation cost. This has been done through the use of different models, all of them using the Quasi-steady state assumption, that is, analysing the dynamics close to the desired three-phase AC signal. In order to determine set-point values of the network, that must be later fed on the primary control, are computed through a tertiary layer, called the tertiary control. This tertiary control is also in charge of determining the feasibility of power transmission and production, due to the fact that these tasks must agree with Kirchhoff Laws and power market price biding. This task is proposed as an optimal control problem [18].

The main purpose of this project is to generate a comprehensive summary of modelling and control strategies for power networks, and the define new control strategies exploiting the network nature if the power networks and some results in pinning controllability and PI-multiplex control of complex network [15, 21]. These control strategies are going to be designed with the aim of overcoming the previous challenges related with low inertia issues, generation uncertainty.

Bibliography

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4. Products
    a. We are currently writing a review paper on modelling and control of the power grid.

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Cycle XXXIV

	Credits year 1								Credits year 2								Credits year 3									
		1	2	3	4	5	6			1	2	3	4	5	6			1	2	3	4	5	6			
	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	**Summary**	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	**Summary**	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	**Summary**	**Total**	**Check**
Modules	**0**			6			6	**12**	**9**							**0**								**0**	**12**	**30-70**
Seminars	**0**			1	1,8	2		**4,8**	**16**	0	0		0		0	**0**								**0**	**4,8**	**10-30**
Research	**0**	10	10	3	8,2	8	4	**43,2**	**40**	0	0	0	0	0	0	**0**								**0**	**43,2**	**80-140**
	0	10	10	10	10	10	10	**60**	**65**	0	0	0	0	0	0	**0**	**0**	0	0	0	0	0	0	**0**	**60**	**180**