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 – Second Year

Tutor: Mario di Bernardo

1. Information

   I have 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 scholarship reserved to foreign students 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. External courses
      Control and Optimization of Autonomous Power Systems (3 CFU)
      Lecturer: Prof. Florian Dörfler and Prof. Saverio Bolognani
   b. Internal courses
      Nonlinear systems (from L.M. in Mathematical Engineering)(6 CFU)
      Lecturer: Mario di Bernardo

3. Research activity
   a. Title: Electrical Power Network: A systems and control approach
   b. Study:
      Electricity distribution has an important role in the correct development and appropriate operation of what are called the Critical infrastructures (ICs), a set of interconnected systems comprising goods supply chains, aqueducts, oil and gas pipelines, communication systems, financial markets, and of course electrical networks. The power network, principal mean for the generation and distribution of the electrical power, is composed of three main elements, generators, transmission lines and loads. The generators are in charge of producing the electrical power required by the loads, the latter being power consumers. The electrical power is transferred from generators to loads through the transmission lines. These three elements have been studied for many years through the use of different modelling approaches and control strategies. All these approaches are interconnected through the physics used and assumptions made, but there are just a few literature reviews that connect them using a modelling and control perspective. With the purpose to introduce some clarity on this topic, the scope of my thesis is twofold, i.e.,
         i. perform a comprehensive literature review of the literature on power network from a modelling and control perspective, highlighting the control layers, the models used and the links between them.
         ii. Use a complex networks approach to study the power network and solve planning and control problems.

      To fulfill (i), we have reviewed and defined all control and modelling approaches as follows:

         1. **Primary Control Layer**: This control layer is in charge of the control of the power generation devices, that must follow setpoints for active and reactive power (p_k^*, q_k^*), voltage magnitude $(\|v_k^*\|)$ and frequency (ω_{ref}). Here, generators, loads and transmission lines are modelled based on the physics of their elements and most of the dynamics are compressed in a timescale between 0 and 30 seconds [1].

2. **Secondary Control Layer**: Frequency set-point following is not precise because of its sensibility to small imbalances between generated and consumed power coming from unmodelled dynamics and perturbations [2,3]. The secondary control layer is then in charge of ensuring precise frequency set-point following through the use of integral control, having as control input the reserve power generation. Here, the most relevant are the frequency dynamics. For this reason, most of the secondary control strategies are designed using coupled oscillators models like the Kuramoto model and the swing equations [4]. Most of the models used in the primary control layers can be simplified to this frequency dynamics if the other variables are considered to be close to their steady state value, so that timescale separation can be used. The dynamics in this case are encompassed in the timescale between 30 seconds and 10 minutes.

3. **Tertiary Control Layer:** set-points for generated power (p_k^*, q_k^*) and voltage magnitude ($\|v_k^*\|$) must be managed in case the power imbalances become too large to be handled by secondary control, or in the case that a reconfiguration of the network is needed due to malfunctioning, change of power buy-sell contracts, etc. This set-point computation is done through the tertiary control layer. In this layer, no dynamics of generation or loads are considered, and network physics are modelled through the power flow algebraic equations [5]. The tertiary control problem can then be seen as a constrained optimization problem that minimizes the power generation cost. The decision variables are the desired setpoints, while the constraints are the made by the power flow equations together with physically related bounds on the values of the decision variables. Encompassed in the timescale greater than 10 minutes.

As part of goal (ii), we focused our attention to a new paradigm for the planning and control of the power network, which is the Microgrid. This paradigm has the purpose to decrease centralization of the power generation and, as a consequence, avoid the transmission infrastructure reaching maximal power transmission limits that can lead to device damage and cascading failures [6]. In doing so, the microgrid uses two additional elements, electrical power storage devices (batteries) and switches that allow its disconnection from the main network (islanded Mode).

The main question that arises is how to allocate switches and storage devices in the power network to obtain microgrids able to share power or island when needed (See Figure 1). Assuming that storage devices have been previously allocated, switch positioning can be formulated as a network partitioning problem [7]. We are currently exploring the use of algorithms from network science to solve these problems (See Figure 1)

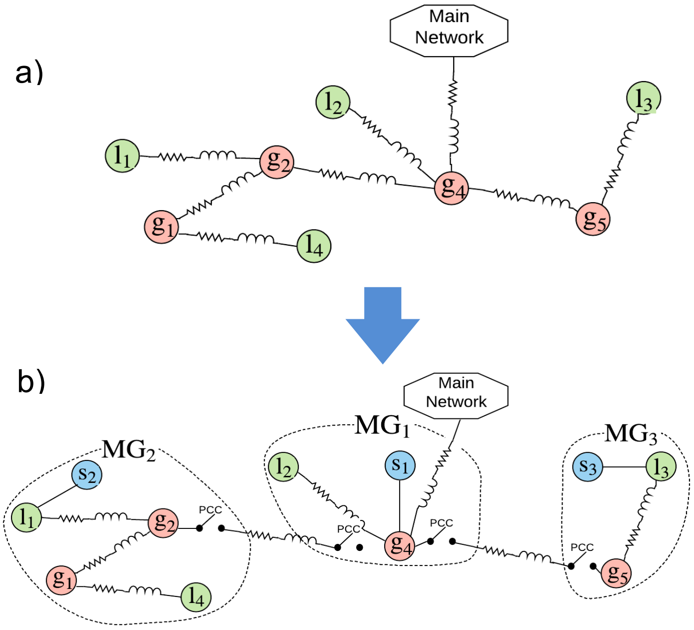


Figure 1. From Power network to network of Microgrids a) Power network composed of generators (Red Nodes), Loads (Green Nodes), Transmission Lines and a possible link to an Upstream Power Network (Main network) b) Network after the introduction of switches and storage devices (Blue Nodes), which lead to a network partitioning in Microgrids. This interconnection of microgrids is then called Network of Microgrids

Next Steps:

1. Complete the review article on power network modelling and control with a estimated publishing date on the first semester of next year
2. Study methods reported in literature to obtain power network partitioning in microgrids
3. Define and improve our method with the optimization objectives reported in literature

Main Bibliography

[1]. Milano, F., Dörfler, F., Hug, G., Hill, D. J., & Verbič, G. (2018, June). Foundations and challenges of low-inertia systems. In *2018 Power Systems Computation Conference (PSCC)* (pp. 1-25). IEEE.

[2]. Khayat, Y., Shafiee, Q., Heydari, R., Naderi, M., Dragičević, T., Simpson-Porco, J. W., ... & Bevrani, H. (2019). On the secondary control

architectures of AC microgrids: An overview. *IEEE Transactions on Power Electronics*, *35*(6), 6482-6500.

[3]. Kundur, P., Balu, N. J., & Lauby, M. G. (1994). *Power system stability and control* (Vol. 7). New York: McGraw-hill.

[4]. Dörfler, F., Chertkov, M., & Bullo, F. (2013). Synchronization in complex oscillator networks and smart grids. *Proceedings of the National Academy of Sciences*, *110*(6), 2005-2010.

[5]. Dommel, H. W., & Tinney, W. F. (1968). Optimal power flow solutions. *IEEE Transactions on power apparatus and systems*, (10), 1866-1876.

[6]. Zia, M. F., Elbouchikhi, E., & Benbouzid, M. (2018). Microgrids energy management systems: A critical review on methods, solutions, and prospects. *Applied energy*, *222*, 1033-1055.

[7]. Bichot, C. E., & Siarry, P. (Eds.). (2011). *Graph partitioning*. ISTE.

[8]. Haddadian, H., & Noroozian, R. (2017). Multi-microgrids approach for design and operation of future distribution networks based on novel technical indices. *Applied energy*, *185*, 650-663.

[9]. Che, L., Zhang, X., Shahidehpour, M., Alabdulwahab, A., & Al-Turki, Y. (2016). Optimal planning of loop-based microgrid topology. *IEEE Transactions on Smart Grid*, *8*(4), 1771-1781.

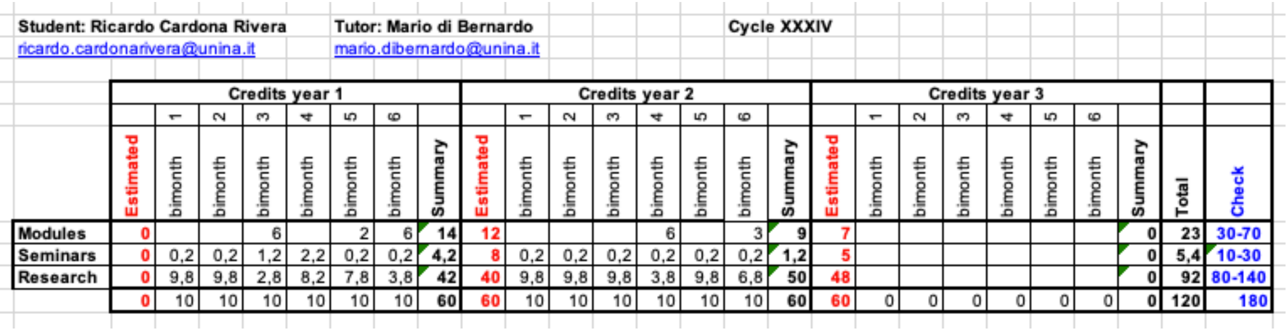
[10]. Arenas, A., Diaz-Guilera, A., & Pérez-Vicente, C. J. (2006). Synchronization reveals topological scales in complex networks. Physical review letters, 96(11), 114102.

4. Products
   a. Publications
      i. R. Cardona-Rivera, F. Lo Iudice, M. di Bernardo *A systems and control approach to study the power network* (in Progress)

      ii. Della Rossa, F., Salzano, D., Di Meglio, A., De Lellis, F., Coraggio, M., Calabrese, C., Guarino A., Cardona-Rivera R., De Lellis P., Liuzza D.,Iudice, F. L. (2020). *A network model of Italy shows that intermittent regional strategies can alleviate the COVID-19 epidemic. Nature communications*, *11*(1), 1-9.

5. Conferences and Seminars:
   a. Weekly participation in internal lab meetings (48 hours) of SINCRO group research.

6. Tutorship:
   a. Assistance and coo-direction of M. Sc. Laureate Antonio Grotta with his thesis “Complex Networks Approach to Modeling and Controlling Networks of Microgrids”



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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		2	6	**14**	**12**				6		3	**9**	**7**							**0**	**23**	**30-70**
Seminars	**0**	0,2	0,2	1,2	2,2	0,2	0,2	**4,2**	**8**	0,2	0,2	0,2	0,2	0,2	0,2	**1,2**	**5**							**0**	**5,4**	**10-30**
Research	**0**	9,8	9,8	2,8	8,2	7,8	3,8	**42**	**40**	9,8	9,8	9,8	3,8	9,8	6,8	**50**	**48**							**0**	**92**	**80-140**
	0	10	10	10	10	10	10	**60**	**60**	10	10	10	10	10	10	**60**	**60**	0	0	0	0	0	0	**0**	**120**	**180**