

I. IDENTIFICATION DATA

Thesis name:	Multi-agent MPC protocols for micro-grid energy management and optimization
Author's name:	Pavel Elis
Type of thesis :	master
Faculty/Institute:	Faculty of Electrical Engineering (FEE)
Department:	Department of Control Engineering
Thesis supervisor:	Kristian Hengster Movric, PhD
Supervisor's department:	Department of Control Engineering

II. EVALUATION OF INDIVIDUAL CRITERIA

Assignment	challenging
<i>Evaluation of thesis difficulty of assignment.</i>	
<p>This Master thesis assignment is challenging as it required the student to survey a wide body of current literature in diverse fields of MPC, distributed cooperative control and micro-grid control and to independently develop distributed algorithms guaranteeing cooperative stability, <i>i.e.</i> consensus, to solve the economic dispatch problem in micro-grids.</p>	

Satisfaction of assignment	fulfilled
<i>Assess that handed thesis meets assignment. Present points of assignment that fell short or were extended. Try to assess importance, impact or cause of each shortcoming.</i>	
<p>The submitted thesis fulfills all assigned tasks and even goes further beyond the original assignment. In particular, it offers a crucial modification of the distributed protocol proposed in the current literature so that the modified version guarantees cooperative stability for arbitrary initial conditions. The existing comparable protocol, in contrast, is found to suffer from instability on general interconnection graph topologies. Moreover, a rigorous proof of this property is given for the proposed modified algorithm. Work on such level of sophistication is usually not assigned in Master theses but is rather more appropriate to PhD level research.</p>	

Activity and independence when creating final thesis	A - excellent.
<i>Assess that student had positive approach, time limits were met, conception was regularly consulted and was well prepared for consultations. Assess student's ability to work independently.</i>	
<p>The student was very inquisitive, interested in his graduate work and indeed worked hard to keep a tight schedule, eventually meeting a rather short deadline. Namely, this thesis was defended in more-or-less its present form at RWTH Aachen in October 2019. Throughout development of the thesis results the student was always adequately prepared for our regular meetings. The student worked independently on this topic, and with great effort he succeeded in bringing together diverse areas of MPC and cooperative control to accomplish the assigned tasks.</p>	

Technical level	A - excellent.
<i>Assess level of thesis specialty, use of knowledge gained by study and by expert literature, use of sources and data gained by experience.</i>	
<p>The assigned tasks required a high level of competence in designing MPC and distributed cooperative protocols. The student made expert use of the existing methods and algorithms obtained from the literature; he combined the MPC and cooperative control protocols in a novel way to provide micro-grid control for economic dispatch. Designed control was implemented on a numerical model of the actual micro-grid providing results from which the student reached valid conclusions justifying the proposed control approach.</p>	

Formal and language level, scope of thesis	A - excellent.
<i>Assess correctness of usage of formal notation. Assess typographical and language arrangement of thesis.</i>	

Formal notation is correctly used. The thesis is well-ordered and the exposition is clear. The level of language is more than satisfactory. Although the previous version of the thesis, defended at the RWTH Aachen, contained some minor typos, all those have been corrected in this revised version.

Selection of sources, citation correctness

A - excellent.

Present your opinion to student's activity when obtaining and using study materials for thesis creation. Characterize selection of sources. Assess that student used all relevant sources. Verify that all used elements are correctly distinguished from own results and thoughts. Assess that citation ethics has not been breached and that all bibliographic citations are complete and in accordance with citation convention and standards.

Ample relevant sources of high quality were used: peer reviewed journal papers and international conference proceedings. Furthermore, a number of them were found by the student himself, independent from the advisers' suggestions. All elements from existing literature are properly referenced and cited. The student's own original results and contributions are clearly distinguished and distinct from those appearing in the existing literature.

Additional commentary and evaluation

Present your opinion to achieved primary goals of thesis, e.g. level of theoretical results, level and functionality of technical or software conception, publication performance, experimental dexterity etc.

The student worked admirably, on a tight time-schedule, to develop the results theoretically and deftly implement the designed protocols on the MatLab model of the Simris micro-grid. The proposed control method is applicable to general micro-grids and fairly promising in achieving significant savings (e.g. up to 6% over a three-week period).

III. OVERALL EVALUATION, QUESTIONS FOR DEFENSE, CLASSIFICATION SUGGESTION

Summarize thesis aspects that swayed your final evaluation.

This work required substantial theoretical understanding of MPC methods as well as distributed cooperative control approaches, together with practical/numerical modelling and real-time control implementation. The student worked at the RWTH Aachen, having regular consultations with me *via* video conferences. In his work the student was fairly independent and readily took initiative in pursuing promising lines of inquiry. He managed to bring together, in a novel way, theoretical results in cooperative control and MPC so that the control design proposed in this thesis avoids potential instability issues found in existing approaches, resulting in a flexible, versatile and robust control architecture for a nascent field of micro-grids. These results are expected to attain an ever increasing importance in the future as current trends in power engineering and management aim for transitioning to renewables in Europe and across the developed world, in part facilitating the reduction of carbon emissions required to combat global climate change. Hence, the results of this thesis are current and compelling. The work this student has undertaken therefore, in my opinion, merits the excellent grade.

I evaluate handed thesis with classification grade **A - excellent**.

Date: **24.1.2020**

Signature:



Prague January 20th, 2020

Master thesis opponent's review

Master thesis: Multi-agent MPC protocols for micro-grid energy management and optimization

Author: Bc. Pavel Elis

Thesis supervisor: Kristian Hengser-Movric, Ph.D.

Thesis opponent: Doc. Ing. Zdeněk Müller, Ph.D.

Rating (1 – 5)
(1 = best; 5 = worst):

1. Fulfillment of assignment requirements:	<input type="text" value="1-"/>
2. Systematic solutions of individual tasks:	<input type="text" value="1"/>
3. Ability to apply knowledge and to use literature:	<input type="text" value="1"/>
4. Thesis formal and language level:	<input type="text" value="1-"/>
5. Thesis readability and structuring:	<input type="text" value="1"/>
6. Thesis professional level:	<input type="text" value="1-"/>
7. Conclusions and their formulation:	<input type="text" value="1-"/>
8. Final mark evaluation (A, B, C, D, E, F):	<input type="text" value="B"/>

very good

Brief summary evaluation of the thesis (compulsory):

The thesis could be divided into 4 parts:

- In the first one the author describes microgrids (scattered RES resources, BESS energy storage, Consumers, Users), available control methods managing dispersed ESS (central energy storage management, decentralized management, multi-agent approach). This introductory part also include description of 3 different multi-agent communication models.
- The second part of thesis is in fact description of the SIMRIS test network located in Sweden (E.ON).
- The third part is detailed specification of the control structure and control parameters of the SIMRIS test network.
- The fourth part consist of analysis of the results obtained by various controller settings and their impact on the energy balance (kWh) and the price balance (EUR).

The thesis is highly topical. Authors own contribution is energy optimization of the operation of individual sub-elements based on use of predictive controller (MPC) and combination with multi-agent approach applied to measured data of real SIMRIS network. The list of references is appropriate. The thesis meet high graphic standards with minor notes only.

Notes:

Page 13, Fig. 2.3. –no description of axes (quantities or units)

Page 21, Fig 2.6 c) - why there is no "connection" of all agents, compare with text in last paragraph Page 21)

Page 22 - misprint in equation numbering (2.2 vs. 2.3)

Page 27- missing description – parameters $\Phi, \Psi, Q, R, \Theta, S_Q, S_R$

Page 30 - description of all the signals in figure is missing.

Page 39 - what is "a" and "b" in the matrix?

Page 50 - why there is no higher number of prediction horizons?

Questions:



Strana 3/4

- 1. Is it possible to minimize the overall network losses through multi-agent control?**
- 2. Please create formulae F and G (page 26).**

Date: 20.1.2020

Signature:

Notes:

- 1) The total thesis evaluation needn't be determined by the partial evaluations average.
- 2) The total evaluation (item 8) should be from the following scale:

excellent	very good	good	satisfactory	sufficient	insufficient
A	B	C	D	E	F