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Master degree in Industrial Engineering

Master final thesis

Study of the PMSM modelisation for Hardware-in-the-Loop simulation applications

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1 Project time management

This chapter is dedicated to the planning of the whole project that has been developed before the start of it. Consequently, some dates might not exactly fit the real ones since there have been many obstacles during the project due to the uncertainty that research projects usually bear. However, all milestones have been accomplished in time.

1.1 Work Breakdown Structure (WBS)

This section includes all the short-term objectives that have been thought to be needed for achieving the main aim of the project which is the development of the model for HiL applications. The following table includes a brief description of each goal.

Table 1.1 Table of WBS activities with descriptions.

ID	Code	Name	Description
0	-	PMSM for HiL	Development of a PMSM model for HiL applications.
1	1	Project management	Tasks required for the right development of the project.
2	1.1	Stakeholder contacts	Starting meetings with laboratory and department managers.
3	1.2	Meetings	Continuous meetings with the tutor and advisor for providing feedback about the progress of the project.
4	2	Deliverables	Deliverables development and other tasks required to make the thesis valid.
5	2.1	Documents	Execution of report, appendices, project management, and other documents.
6	2.2	Thesis defence preparation	Preparation for the presentation of the thesis.
7	3	Research	Group of previous tasks required for the right modelling of the PMSM system.
8	3.1	MicroLabBox features	Research of MicroLabBox available features and usable possibilities that this type of board provides.
9	3.2	RTI implementation	Research of available libraries for MicroLabBox that can be useful for the project.
10	3.3	ControlDesk	Research of how ControlDesk works and how it must be utilised for simulating in real-time.
11	3.4	MATLAB and Simulink	Research on how to create models with Simulink, to programme using MATLAB code and the best utilities available for an optimised working methodology.
12	3.5	PMSM models	Research about the equations that define the behaviour of the PMSM, drive, PWM generator, resolver, RDC, and a PMSM control system.
13	4	PMSM Simulink modelling	Development of the whole model with Simulink.
14	4.1	Basic model	Creation of the model for Simulink simulations.
15	4.2	Adapted model for real-time implementation	Adaptation of the model for real-time behaviour. This is the model utilised before real-time testing.

16	4.3	Real-time models	The required modifications on the previous model utilising the RTI libraries that can make use of MicroLabBox features. It also includes the customisation of ControlDesk.
17	5	PMSM implementation	Hardware and software setting up required for the real-time simulation tests.
18	5.1	MicroLabBox configuration	Basic configuration and installation fo MicroLabBox and all the required software installation and configuration.
19	5.2	Wiring and setup assembly	Schematic designing of connections, soldering and connection testing.
20	5.3	Methodology and code development	Development of a methodology for quick tests with real-time simulations including the code designed for it.
21	6	Testing and commissioning	Group of tests performed for a good validation of the model.
22	6.1	Synamics Surface Mounted PMSM	Tests for basic features validation of the model.
23	6.2	Marathon Interior PMSM	Tests for validating the functioning with both IPMSM and SMPMSM.
24	6.3	ABB Surface Mounted PMSM	Tests for validating the simulation results with the ones measured of the real ABB motor.
25	7	Project Closure	Milestones that determine the end of the project.
26	7.1	Document delivery	The delivery date of the report, appendices, project management, and other documents.
27	7.2	Thesis defence	The date of the thesis defence for a formal evaluation.

1.2 Project schedule

For the schedule of this project, it has been performed a Gantt Chart utilising the software application MS Project. The resulting schedule is displayed in the following figure.

ID	Priority	Task Name	Work	Duration	Finish
0	**500**	**PMSM for HIL**	**560 h**	**112 d**	**04/02/2021**
1	**500**	**1 Project management**	**37.64 h**	**101.25 d**	**20/01/2021**
2	540	1.1 Stakeholder contacts	8.24 h	1 d	02/09/2020
3	540	1.2 Meetings	29.56 h	90 d	20/01/2021
4	**500**	**2 Deliverables**	**81.98 h**	**105.38 d**	**27/01/2021**
5	520	2.1 Documents	51.18 h	80 d	04/01/2021
6	480	2.2 Thesis defence preparation	30.8 h	15 d	27/01/2021
7	**500**	**3 Research**	**122.89 h**	**30.38 d**	**14/10/2020**
8	500	3.1 MicroLabBox features	10.27 h	3.13 d	07/09/2020
9	500	3.2 RTI implementation	30.8 h	15 d	14/10/2020
10	500	3.3 ControlDesk	20.53 h	10 d	08/10/2020
11	500	3.4 MATLAB and Simulink	20.53 h	10 d	22/09/2020
12	500	3.5 PMSM models	40.91 h	12.5 d	21/09/2020
13	**500**	**4 PMSM Simulink modelling**	**184.33 h**	**52.5 d**	**28/12/2020**
14	500	4.1 Basic model	30.8 h	4.41 d	21/10/2020
15	500	4.2 Adapted model for real-time implementation	102.36 h	14.71 d	13/11/2020
16	500	4.3 Real-time models	51.18 h	7.35 d	28/12/2020
17	**500**	**5 PMSM implementation**	**53.2 h**	**8.13 d**	**25/11/2020**
18	500	5.1 MicroLabBox configuration	8.24 h	1.18 d	16/11/2020
19	500	5.2 Wiring and setup assembly	20.53 h	2.94 d	19/11/2020
20	500	5.3 Mehtodology and code development	24.58 h	3.53 d	25/11/2020
21	**500**	**6 Testing and commissioning**	**79.96 h**	**15.11 d**	**16/12/2020**
22	500	6.1 Synamics Surface Mounted PMSM	51.18 h	7.35 d	07/12/2020
23	500	6.2 Marathon Interior PMSM	8.24 h	1.82 d	09/12/2020
24	500	6.3 ABB Surface Mounted PMSM	20.53 h	4.55 d	16/12/2020
25	**500**	**7 Project Closure**	**0 h**	**16 d**	**04/02/2021**
26	500	7.1 Document delivery	0 h	0 d	13/01/2021
27	500	7.2 Thesis defence	0 h	0 d	04/02/2021

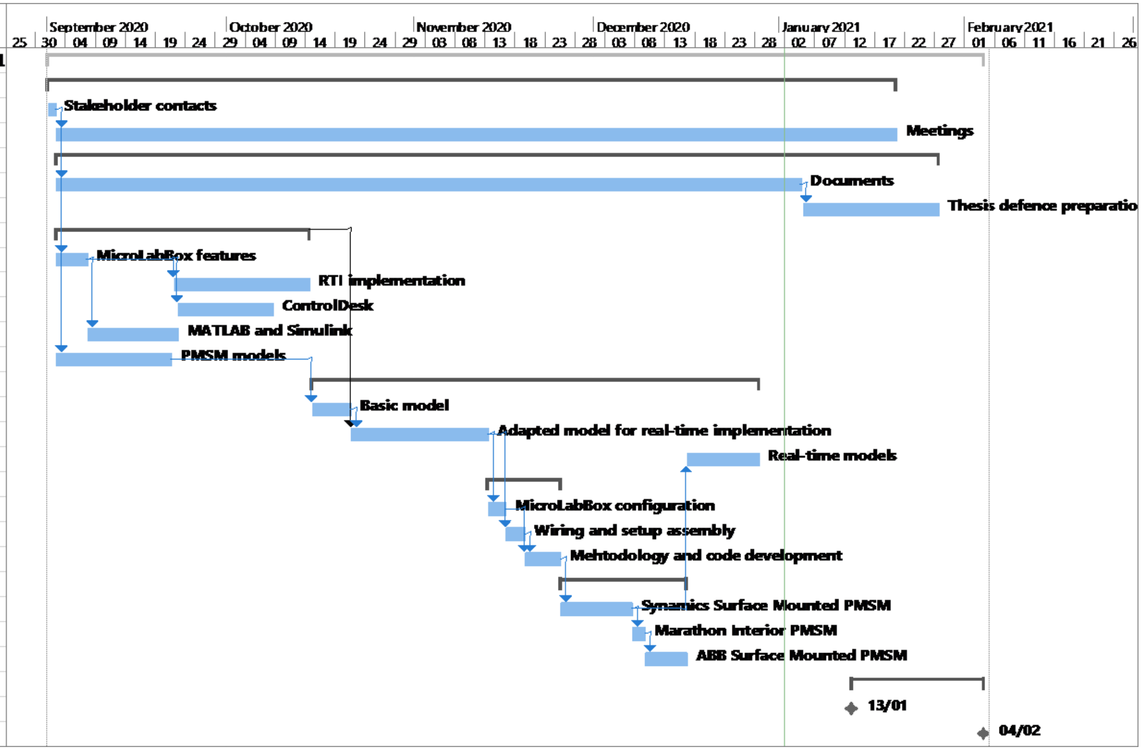

Figure 1.1 Schedule of the project represented with a Gantt Chart.

2 Project cost management

In this chapter, there are listed all the costs regarding the project and thesis development. Since every part price is detailed, it can be a useful tool for those who need to replicate the setup utilised for this real-time model.

Table 2.1 Required budget for the project.

	Item	Unitary cost (€/u)	Quantity	Total cost (€)
Main devices				
	MicroLabBox board	10,000.00	2	20,000.00 €
	Ethernet cable for host connection	-	1	-
	Power supply cable	-	1	-
	Sub-D plugs	-	4	-
	Case for storage and transportation	-	1	-
	Data retrieval utility for flight recorder	-	1	-
	Comprehensive C libraries	-	1	-
	Real-Time Interface (RTI) for Simulink	-	1	-
	Host PC	750.00	1	750.00 €
	Network switch	18.00	1	18.00 €
				20,768.00 €
Tools and other				
	Soldering station	50.00	1	50.00 €
	Tin wire coil	-	1	-
	High-temperature resistant sponge	-	1	-
	Side-cutting plier	10.00	1	10.00 €
	Potentiometer 2k Ohm	0.35	2	0.70 €
	Resistance 1.5k Ohm	0.15	2	0.28 €
	Heat-shrink tubing	1.45	3	4.35 €
				65.33 €
Cables				
	BNC Male Plug to Dual Hook Clip Test Probe Cable Leads	6.00	7	42.00 €
	Ethernet for switch	5.00	1	5.00 €
	Red cable by the metre	0.29	5 m	1.45 €
	Grey cable by the metre	0.29	5 m	1.45 €
				49.90 €
Software				
	MATLAB (student version)	0.00	1	0.00 €
	Simulink (student version)	0.00	1	0.00 €
	ControlDesk (included with MicroLabBox)	0.00	1	0.00 €
				0.00 €
Time				
	Student time of dedication	15.00	560 h	8,400 €
	Tutor time of dedication	20.00	25 h	500 €
				8,900 €
				29,783.23 €

This budget shows all the required equipment, software and time cost that has been required for the project. For replication of the project, some items might be already available or not required. Nevertheless, the listed costs including workforce must be taken into account when starting the project from scratch.

3 Project environmental assessment

As it has been explained in the journal article [1] the electric motors play a critical role in the environmental impact of the electric vehicle market. It also states that although the environmental concerns related to the rare-earth permanent magnets that are commonly utilised in PMSM, they do not represent a significant share of the total impact. Nevertheless, energy consumption has shown to be the main responsible for the environmental impact in the assessment of the article.

The MicroLabBox power consumption is 125 W as it is specified in the official website. It is also possible to find an approximate consumption of the computer by the following online tool:

https://outervision.com/power-supply-calculator

It has provided an approximated 200 W consumption of the computer utilised. Note that this might vary depending on the utilisation of the device and other factors. The total consumption has been estimated at around 325 W. Since this project is not meant for a specific motor, the consumption varies depending on the desired motor for testing. For this project, the rated power consumption of all the motors utilised is at least 4 times this value and most of the motors utilised in the industry also have higher values.

Additionally, the impact caused by the rest of the materials of the motor is more significant than the magnets and it is something that must be taken into account. Since the nature of this project prevents the damage of the motor while making tests it is a great advantage real motors does not take. Actually, the coil insulation destruction caused by a short-circuit might oblige to replace the coils or even the whole motor in some cases.

On the other hand, the model provided in this project can be applied to many different motors without the need for building a new one. Besides, many transportations that are usually required for testing a motor with certain load conditions (as it can happen with high power motors). When working with high-power motors the consumption reduction will become more important and therefore, the impact of this model for these applications will be really low compared to the current one.

Stating that it is possible to state that, for a wide number of HiL applications, the real-time model developed in the project will cause a great contribution to the energy consumption reduction constituting a small but excellent decrease on the environmental impact of motor testing.

4 Project safety management

One of the main advantages that Hardware-in-the-Loop simulations provide is the safe environment that a test of a real PMSM cannot assure. In fact, this is one of the main reasons why developing a real-time model of this kind of motor is one of the best options for a control designer company.

Nowadays, the vast majority of accidental injuries is caused by electrical motors danger underestimating. Working with an electrical motor that is powered by a small battery might not be a problem. However, when working with industry motors with high-power machines the most imperceptible oversight might cause several damages.

Starting by the high speeds that these kind of motors are capable of reaching. If by any chance, there is an error on the control design that makes it to lose control over the motor, it can reach such high speeds that it becomes a dangerous machine. This might cause flying debris that requires protective gears especially safety goggles for eye protection. Such high speeds tend to make a noise that can be hazardous for long exposures to it. With rotating machines also exists the possibility of getting caught by the operator clothes and accessories that can be snatched by the motor.

Another associated risk is the high voltage and currents that they utilise. They can cause electric shocks and short-circuits if some limits are overpassed. The high currents itself increase the temperature of the motor so bad convection refrigeration may cause short-circuits. These problems are a destructive risk for the motor but also a hazardous characteristic of high-power machines that can cause fires and electrocutions with an insecure environment.

Utilising a real-time simulation for performing these type of tests is the definitive solution for preventing all of these risks. The only damage that can be taken when simulating in real-time is only caused to the hardware by making a short-circuit. Nevertheless, MicroLabBox is properly designed for avoiding such negligences.

For all these reasons, the project developed has proved to provide a fully safe environment that cannot be assured when performing real tests with PMSM.

5 References

[1] M. Hernandez, M. Messagie, O. Hegazy, L. Marengo, O. Winter and J. Van Mierlo, "Environmental impact of traction electric motors for electric vehicles applications," *The International Journal of Life Cycle Assessment,* vol. 22, no. 1, pp. 54-65, 2017.