Assessment cover

OXFORD BROOKES UNIVERSITY

Module No:	ENGR7025	Module title:	Electric Vehicles

Assessment title:	Assignment 1 Mini Project: DC-AC inverter and Regenerative Breaking

Due date and time:	10/03/23

Estimated total time to be spent on assignment:	30 hours per student

LEARNING OUTCOMES

On successful completion of this module, students will be able to achieve the module following learning outcomes (LOs): *LO numbers and text copied and pasted from the module descriptor*
1) Appraise different electric vehicles architectures, evaluate and compare their performance.
2) Evaluate different types of electric machines for vehicle propulsion to recommend choices and assess associated energy recovery systems.
3) Analyse and assess performance of a range of energy storage systems, including associated safety and battery management systems.
4) Consider different controller and inverter types and evaluate their operation and suitability for automotive applications.
5) Assess different electronic sub-systems such as on-board communication and shutdown system required for safe operation of an electric vehicle.
6) Assess electrical energy provision, energy sources and electrical grid mix composition. Quantify different options using whole lifecycle assessment.

Engineering Council AHEP4 LOs assessed (from S1 2022-23) *LOs copied and pasted from the AHEP4 matrix*	
M1	Apply a comprehensive knowledge of mathematics, statistics, natural science and engineering principles to the solution of complex problems. Much of the knowledge will be at the forefront of the particular subject of study and informed by a critical awareness of new developments and the wider context of engineering
M2	Formulate and analyse complex problems to reach substantiated conclusions. This will involve evaluating available data using first principles of mathematics, statistics, natural science and engineering principles, and using engineering judgment to work with information that may be uncertain or incomplete, discussing the limitations of the techniques employed
M3	Select and apply appropriate computational and analytical techniques to model complex problems, discussing the limitations of the techniques employed
M4	Select and critically evaluate technical literature and other sources of information to solve complex problems
M5	Design solutions for complex problems that evidence some originality and meet a combination of societal, user, business and customer needs as appropriate. This will involve consideration of applicable health & safety, diversity, inclusion, cultural, societal, environmental and commercial matters, codes of practice and industry standards
M7	Evaluate the environmental and societal impact of solutions to complex problems (to include the entire life-cycle of a product or process) and minimise adverse impacts

Statement of Compliance ***(please tick to sign)***

[x] I declare that the work submitted is my own and that the work I submit is fully in accordance with the University regulations regarding assessments (*www.brookes.ac.uk/uniregulations/current*)

1. INTRODUCTION

Electric vehicles are the future of the automotive industry. The European Parliament approved a new legislation that will ban combustion engines by 2035, making the subject of electric vehicle technologies a critical factor to develop. (Riegert, 2023)

The first DC electric motor was developed in 1832, it converts electrical energy into mechanical energy. In this work, the principal concept of electric motors is studied, firstly as an engine; and secondly, as a generator, introducing the concept of regenerative braking. This technology was developed in 1967 by AMC, and was firstly commercialised by Toyota (Clark *et al.,* 2011); and consists, as the name suggests, in using a motor to transform breaking energy (normally dissipated in heat and friction) into electric energy and recharge the battery of the car while the vehicle is slowing down.

A regenerative braking system schematic is proposed and analysed in performance and improvements.

2. PART A

The circuit shown in figure 1 represents a Voltage Source DC-AC Inverter, which aims to transform DC into 3 phase AC current, in order to run a motor. The function of components is shown in table 1.

Component	**Function**
DC source	Produce DC voltage of 200V
Capacitor	Smoothen the back EMF produced by the switches
Transistor Diodes	Switch the current on and off to produce AC
Pulse Width Modulator	Control the transistor switching pattern to ensure 3-phase AC
Resistors	Loads modelling an AC machine

Table 1. Component functions for circuit in figure 1

The Pulse Width Modulator splits the current into 3 phases, which are 120 degrees apart. The trigger pattern of each of the can be seen in figure 1.

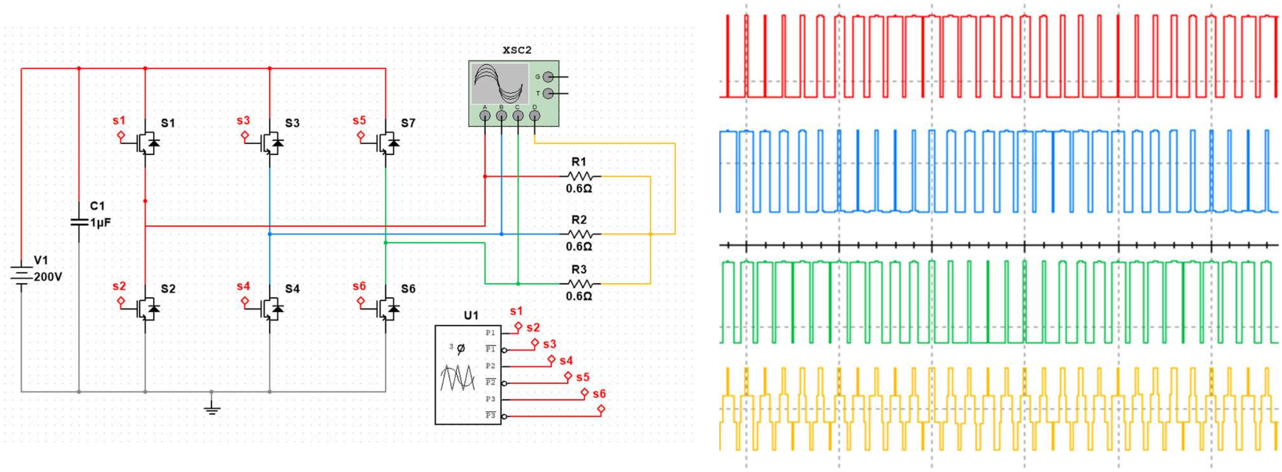

Figure 1. Circuit schematic part A and measured voltages for each load line

Appendix A shows readings of input Power and output voltage and current. Using equation 1, the values for the output power at each of the stator coils were calculated.

$$Power = \sqrt{3} \times V_L I_L \qquad \textit{eq. 1}$$

The efficiency of such system is calculated by equation 2.

$$Efficiency\,(\%) = \frac{\mathrm{P_{out}}}{\mathrm{P_{in}}} * 100 \qquad \textit{eq.2}$$

Figure 2 shows the output power of each line with respect to the input power administered by the voltage source. There is a loss of 14% average throughout the voltage range, on all of the load lines.

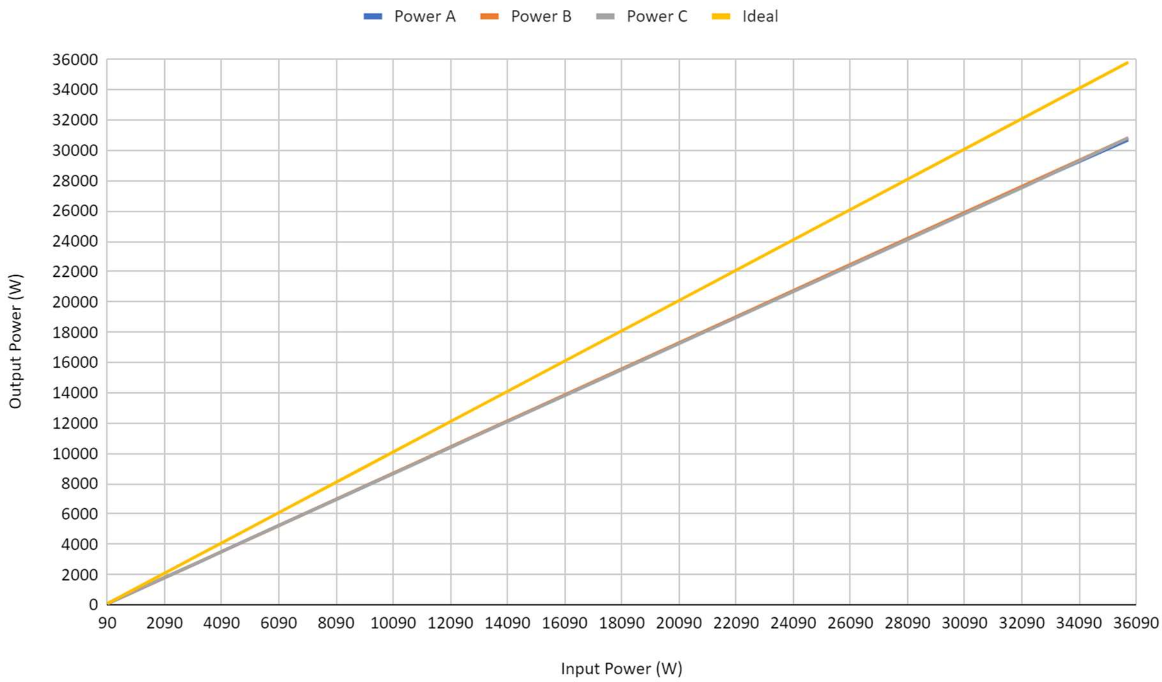

Figure 2. Power output with respect to the input power for each line and the ideal case

From Ohm's Law, voltage in parallel lines is equal but current is drawn from the main line to satisfy the load requirements. This means that:

$$I_{total} = I_1 + I_2 + I_3$$

Furthermore, as explained before, the PWM turns on and off the current, which certainly generates an average AC current, but this average is less than the input voltage due to the continuous switching and the back EMF generated from the transistor diodes. This back EMF is reduced by the use of a capacitor; however, is not completely eliminated, being the main source of power losses.

3. PART B

The circuit shows a load producing a constant RPM, which inputs into the permanent magnet synchronous machine. This machine represents a brushless DC machine with sinusoidal back EMF, which produces 3 outputs. Each output has two transistor diodes attached in parallel, which trigger the current managed by a 3-phase Pulse Width Modulated Controller, acting as a rectifier. The DC current is then transmitted to the capacitor bank modelled as 2 pairs of transistor-diodes in parallel, controlled by a switch which activates upon braking.

The modified schematic for the regenerative system is proposed in figure 3. The main idea is proposed based on the 2010 Toyota Prius (Hayes *et al.,* 2018). The power from the driven wheels is taken by a synchronous machine, rectified using diodes. This produces a stable DC current by the use of filtering capacitors and a resistor.

This current is fed into the Bi-directional DC-DC half-bridge converter, which reduces the 300V current into 48V, a standard industry voltage for this kind of system, manageable for the ultracapacitor bank and the battery (Ford.co.uk, 2023). The battery acts as an auxiliary device in case the capacitors fail.

For driving mode, the current flows from the ultracapacitor bank into the boost (in this case) DC-DC converter and a switch is activated, allowing current to flow into the driving motor. The driving machine is based on the same principle explained in question 1. However, a capacitor is added for filtering, and an inductor is also introduced to reduce the back EMF produced upon switching. A simulation of the work of such system is shown in Figures 4 and 5.

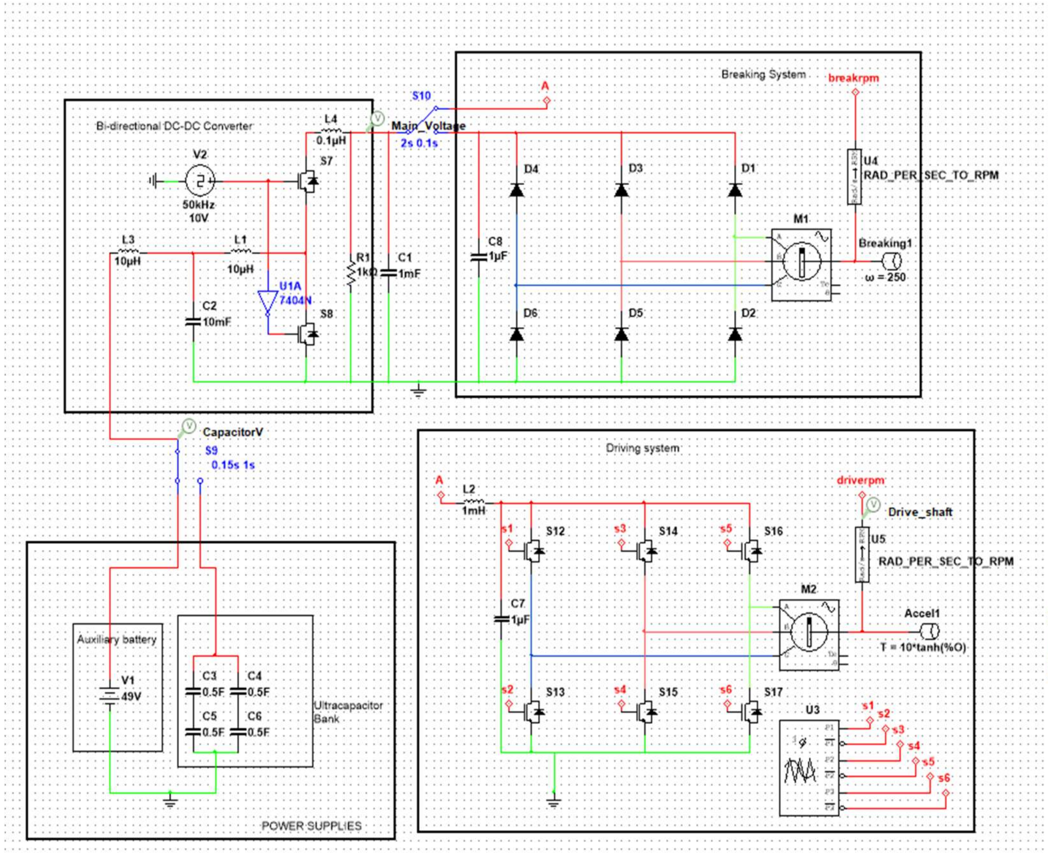

Figure 3. Circuit schematic for part B

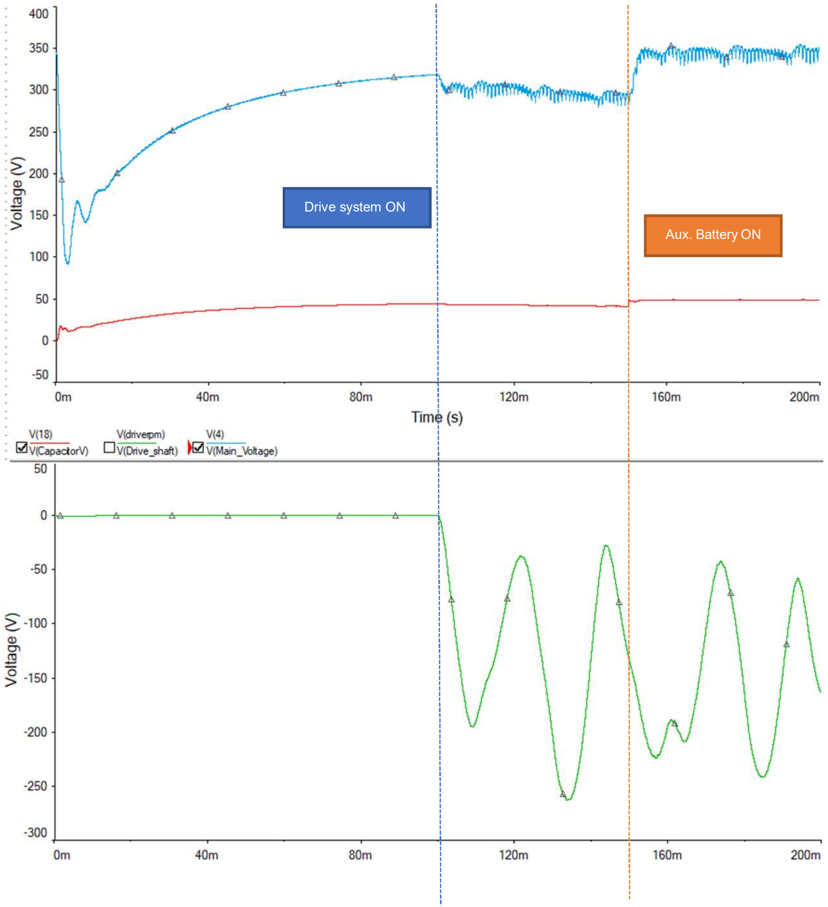

Figure 4. Simulation Voltages for the capacitor, main boosted line and wheel speed.

4. PART C

The design proposed in part 1 lacks a DC-DC converter, which means that the high voltage produced by the rotation of the machine, which can peak 600V at 4000RPM has to be dealt by the capacitor bank, reducing the possibility of using a battery as an auxiliary device.

The circuit proposed in part 2 solves the issues described above; however, it still has room for lots of improvement. Firstly, the use of the DC-DC converter might lead to heat caused by the inductor in the converter, and cooling might be necessary. Furthermore, a 3-way switch can be introduced where S10 is placed, instead of the 2 switches system, and can be electronically controlled to manage the drive and braking actions, e.g. when the accelerator is pressed highly, turn on the drive system; when the brake is pressed, turn on the braking system; for cruising, turn everything off.

Furthermore, this system does not introduce a voltage regulator: the voltage supplied by the braking shaft is purely dependent on its speed. Therefore, the ultracapacitor will charge differently every time, risking the integrity of the transistor diode switches, which can cause issues if their critical voltage is overcome. This problem would be solved by regulating such braking motor voltage output to be fixed. While the half bridge has less magnetic field, has less components, which reduces the cost, they also have a 99% efficiency compared to a full bridge 95%. These last are also used for high voltage applications, and are noisy. In this case, the values of the ultracapacitor allow for a charging and discharge time of around 0.1. Therefore, this circuit needs upscaling for its use in a realistic system.

5. CONCLUSION

In this work, the electric motor is analysed for both transforming and generating mechanical energy. A schematic of a regenerative braking system is presented and analysed. It is clear that such a system is the future of the automotive industry and can lead to fully independent electric cars that might not even require a charging point. However, the time spent in breaking and the energy generated are much less than in driving the shaft. Therefore, it is a long way until such progress can be achieved.

6. REFERENCES

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1. APPENDIX A. SIMULATION VALUES OF RMS VOLTAGES, CURRENTS AND POWER FOR THE CIRCUIT IN PART A.

Source Voltage	**Voltage A**	**Voltage B**	**Voltage C**	**Current 1**	**Current 2**	**Current 3**	**Rms (Power source)**	**Power A**	**Power B**	**Power C**	**Loss A**	**Loss B**	**Loss C**
(V)	(V)	(V)	(V)	(mAmp)	(mAmp)	(mAmp)	(W)	(W)	(W)	(W)	%	%	%
10	7	7	7	6	6	6	90	77	77	77	14.00	14.00	14.00
20	14	14	14	13	13	13	358	306	308	310	14.53	13.97	13.41
30	21	21	21	19	19	19	805	689	692	697	14.41	14.04	13.42
40	28	28	28	25	25	25	1432	1225	1230	1240	14.46	14.11	13.41
50	35	35	35	31	32	32	2238	1924	1922	1937	14.03	14.12	13.45
60	42	42	42	38	38	38	3220	2756	2767	2759	14.41	14.07	14.32
70	49	49	49	44	44	44	4387	3781	3763	3768	13.81	14.22	14.11
80	57	56	56	50	51	51	5729	4937	4915	4922	13.82	14.21	14.09
90	64	63	63	57	57	57	7251	6234	6245	6222	14.03	13.87	14.19
100	71	70	70	63	64	63	8953	7696	7711	7682	14.04	13.87	14.20
110	78	77	77	69	70	70	10834	9313	9330	9295	14.04	13.88	14.21
120	85	83	85	76	77	75	12882	11083	11103	11061	13.97	13.81	14.14
130	91	91	92	82	83	82	15131	13007	13031	12982	14.04	13.88	14.20
140	98	98	99	88	89	89	17548	15085	15113	15056	14.04	13.88	14.20
150	105	105	106	94	95	95	20145	17317	17349	17283	14.04	13.88	14.21
160	113	112	113	101	102	101	22920	19703	19740	19665	14.04	13.87	14.20
170	120	119	120	107	108	108	25875	22243	22284	22200	14.04	13.88	14.20
180	127	126	127	113	114	114	29009	24937	24983	24888	14.04	13.88	14.21
190	134	133	134	20	121	121	32332	27785	27836	27730	14.06	13.91	14.23
200	141	140	141	126	127	127	35814	30688	30824	30823	14.31	13.93	13.94
Average											14.11	13.96	14.02