SEN720 Engineering Project Initiation

Pass Task 12.1 (Team task): Project Closure Template

Please use the template recommended below to organise information that explains your project implementation and evaluation activities and to bring your project to a closure.

Project implementation and evaluation report

Project name			
Project due date			
Project Sponsor (Supervisor)			
Project Stakeholders (if any)			
Project Team members	**Name**	**Role**	**Responsibilities**
Project executive summary (250 words maximum)	Include information about the following: What was the need for your project? What key results did you achieve? Provide high-level evidence What worked, what did not work, and why? What are your key recommendations? What lessons did you learn through planning and implementing your project?		

Introduction (500 words max)

Problem statement

Describe the problem / need you attempted to solve / fulfil through your project

Impact of this problem

Explain why you believe it is important to address this problem.

Strategic project rationale

Succinctly describe what your project is, why was your project needed, what did your project address / achieve in the end.

Project overview (750 words max)

Project goals

Explain your project goals in quantitative and/or qualitative terms.

List / describe the original goals of your project

List the original outcomes that you expect to achieve

Possible solutions

List and describe briefly all the possible solutions that were explored to address this problem

List the criteria that you used for evaluating the success of your project (100 words)

Solution strategy

What solution strategy did you choose for implementation and why?

Validation

Tell us about what data or insights do you have to support these claims. This is where you weave in your background research to justify your understanding of the problem.

Project scope

Explain what is in scope and what is not in scope and why. Include a detailed description of the project deliverables and the work needed to accomplish them.

Project design

State the overall approach utilised in the design of your project activities and engineering methodology.

As it has been already established that the goal of the project can be broadly categorized into the design and development of two methodologies i.e., FOC and DTC for control of PMSM. Further to study, research, design and implement these strategies successfully our team has not only efficiently coordinated and effectively managed the project activities but also demonstrated professional and problem-solving skills at individual and collective level. We used the following approach for defining and fulfilling project activities:

- Division of technical workload among team members based on past experience and interest of the field
- Converting the divided responsibilities into time targeted deliverables
- Constructive discussions regarding problems faced and any improvements required
- Integration of individual targets into a complete solution by sharing the ideas and knowledge
- Upholding the ethical values by being honest, original and professional
- Documentation of the journey to the project completion and its professional representation

Based on these principles we applied following engineering techniques for successful completion of the project:

- Research and reflection studies to develop the tangible goals and criteria
- Mathematical modelling and analysis
- Simulation and case studies
- Feedback controller design and tunning
- Engineering system management to define system interfaces
- Troubleshooting using bottom-up approach

Validation

Tell us about what data or insights do you have to support your decisions. Use your background research to justify your project design.

During the background studies, we were able to clearly identify the advantages and disadvantages of various control techniques used for PMSM. Based on these studies via different research papers we identified the two most used techniques. Both techniques offer different advantages and also suffer from some drawbacks. Now that we have completed our project and have thoroughly analysed and compared the results, we can confidently support our decision with the simulation results. FOC controlled is clearly more efficient technique based on high torque, low current, low ripple and harmonic content. In contrast to the conventional DTC technique, SVPWM based DTC system also does not use any external sensor for speed but produce comparable to FOC speed and torque response with relatively high current component. But at lower speed, DTC response show high stator current distortion due to inaccurate estimation resulting from flux dynamics at lower speed. Similarly, throughout different stages in projects, we made different informed decisions whose evidence have been provided in iteration reports and well as in simulation results. Some of them are:

- Manual PID tunning using knowledge of intermediate signals and system dynamics to have desirable output response
- Use of ANN based control technique for improvement in FOC based system
- Use of bi-polar two stage convertor which provided lower DC component in the system
- Use of rate limiter for signals to have them in desired operating ranges of torque, current and flux

Project highlights (750 words max)

Major accomplishments

List and briefly describe the outputs achieved by the team and each team member

The project from its initiation till its completion have been a journey full of learning, developing, problem-solving, coordination and enlightenment. We as a team and as well as individually not only contributed towards successfully delivery of project but also groomed as a professional engineer.

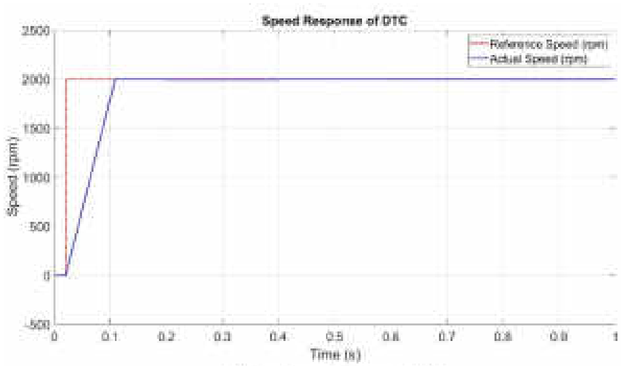
Model Parameters of the PMSM:

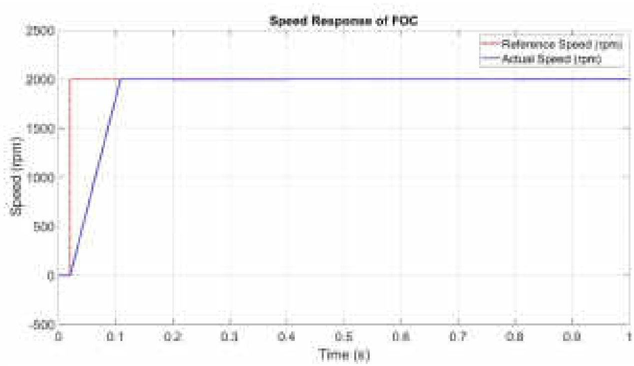
Following parameters have been used for PMSM to simulate the responses for closed loop FOC and DTC.

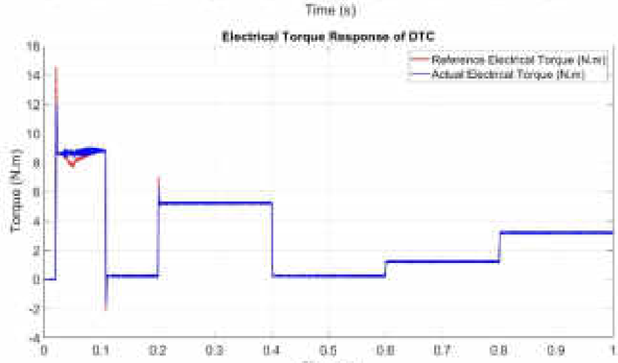
$L_d = L_q$	$53.24\ mH$
Φ_f	$0.249\ Wb$
K_t	$0.9149\ \frac{Nm}{A}$
R_s	$2\ \Omega$
J	$0.0036\ Kg.m^2$
B	$0.0011\ Nm.s.rad^{-1}$
N	3
V_{DC}	$300\ V$

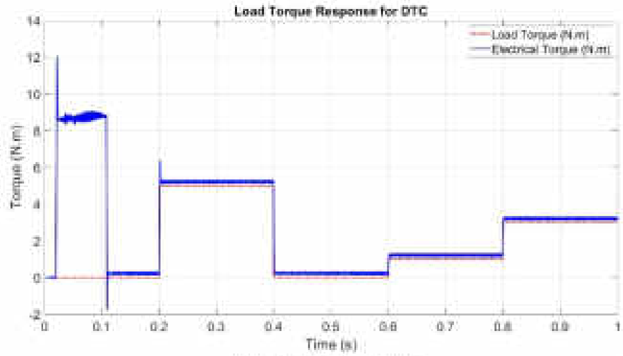
High Speed Characteristics of FOC and DTC:

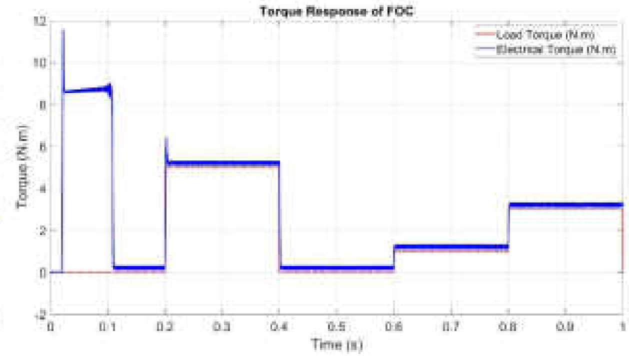
Output responses for both FOC and DTC based systems have been shown below. For DTC, the flux setpoint is kept constant at 0.2 Wb for all simulations and similarly setpoint for direct current component in case of FOC is kept at 0 A. At time 0.02s a reference speed step of 2000 rpm is applied and the variation of parameters like torque and currents have been plotted to evaluate the system performances. It can be clearly seen that both DTC and FOC follow the speed completely with zero steady state error in almost 0.1s. During the motor startup,

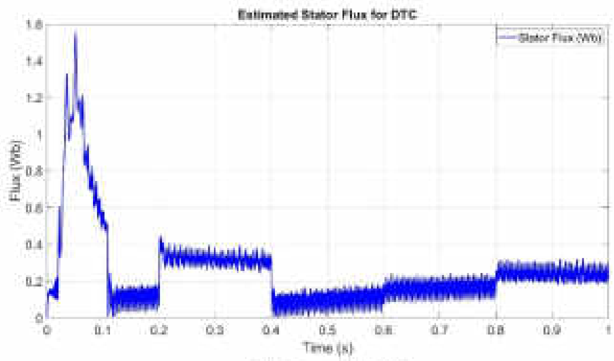


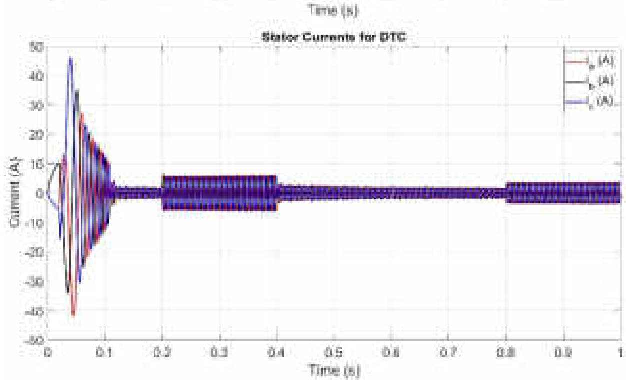


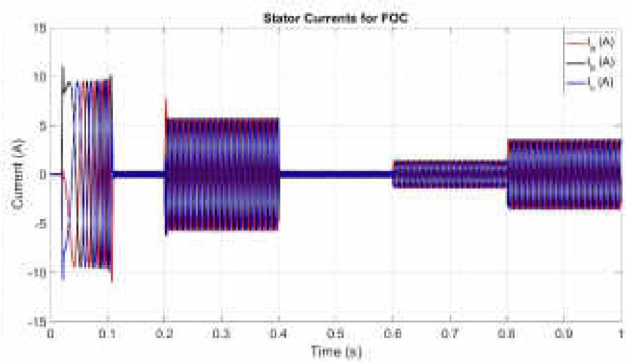


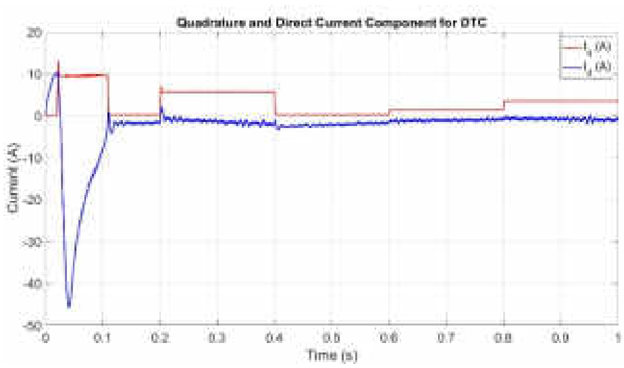

Load Torque Response for DTC
Load Torque (N.m)
Electrical Torque (N.m)
Torque (N.m)
Time (s)

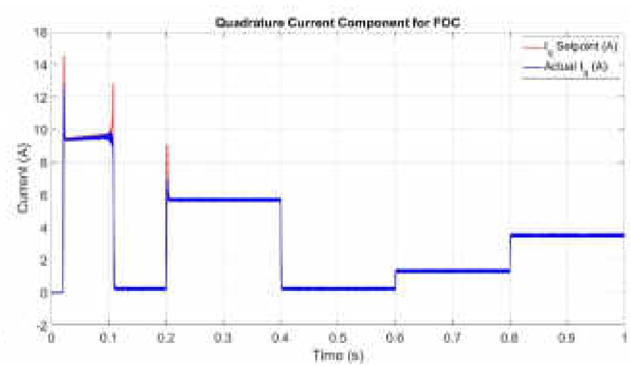

Torque Response of FOC
Load Torque (N.m)
Electrical Torque (N.m)
Torque (N.m)
Time (s)

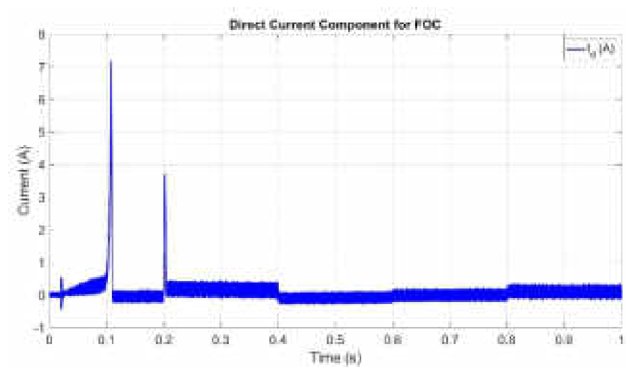

Estimated Stator Flux for DTC
Stator Flux (Wb)
Flux (Wb)
Time (s)


Stator Currents for DTC
I_a (A)
I_b (A)
I_c (A)
Current (A)
Time (s)


Stator Currents for FOC
I_a (A)
I_b (A)
I_c (A)
Current (A)
Time (s)


Quadrature and Direct Current Component for DTC
I_q (A)
I_d (A)
Current (A)
Time (s)


Quadrature Current Component for FOC
I_q Setpoint (A)
Actual I_q (A)
Current (A)
Time (s)


Direct Current Component for FOC
I_d (A)
Current (A)
Time (s)

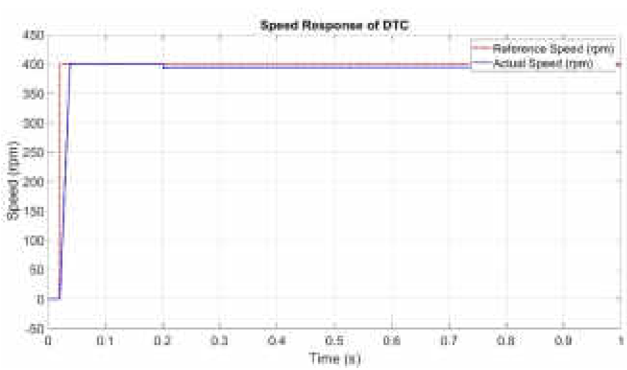
- DTC generates a setpoint for electrical torque, it can be seen that PMSM follows the setpoint. The only exception is observed while the motor speeds up where there is a dip in reference torque. The observed flux in this case rises upto 1.8 Wb but it settles down as soon as speed reaches its steady state value. FOC in comparison to DTC produces slightly little amount of torque than 12 N.m.
- DTC draws a high starting current upto 45 A which settles to 10 A as the speed settles where as FOC draws almost constant 10 A during the startup.
- FOC generates a setpoint for direct and quadrature current component. The motor follows these setpoints with the exception of transients. Max values for I_q and I_d is around 12 A and 7 A which settles to 10 A and 0A. In case of DTC, I_q current follows same trend and values but I_d touches values as high as -40 A during the startup.
- The ripple content in DTC flux, torque and currents are considerably small and comprarble to FOC. It is due to use of the SVPWM technique which produces lower hamonic distortion as well low ripple content.
- It can be concluded that FOC technique produces high torque with lower current and hence is more efficient. DTC technique on the other hands draws higher current but uses estimation methods and does not require speed sensors.

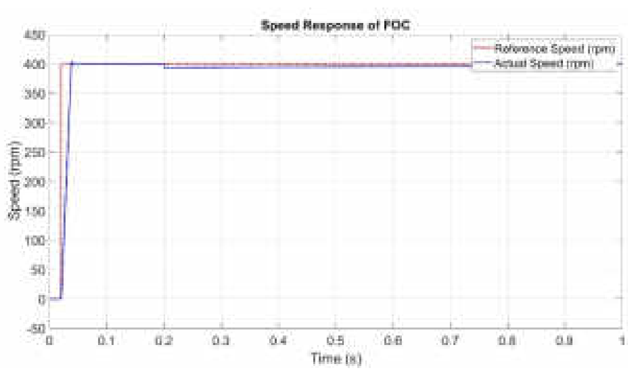
After the startup, the motor is subject to variations of load torque upto max 5 N.m which is applied at 0.2s. Following observations are made:

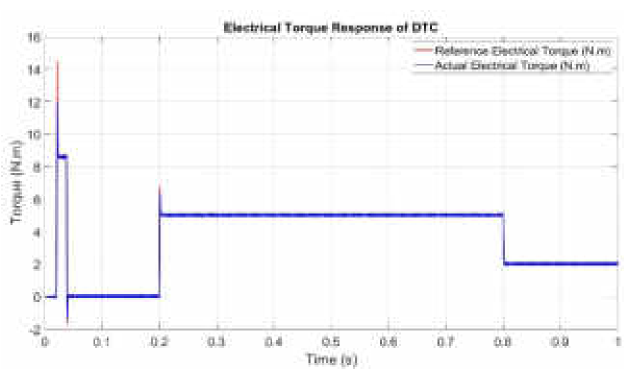
- The steady state value of speed does not change considerably for both FOC and DTC under load
- Electrical torque follows the load torque with low ripple content and steady state error for both the techniques
- Flux for DTC varies with load torque proportionally and reaches slowly to its steady state value. It goes as high as 0.4 Wb when toqrue is 5 N.m.
- As the load torque is applied, the stator current increases for both the techniques, but DTC draws more current (7-8 A) as compared to FOC which draws 5 A for the torque of 5 N.m. The currents I_d and I_q follow the similar trends as stator currents for both DTC and FOC.

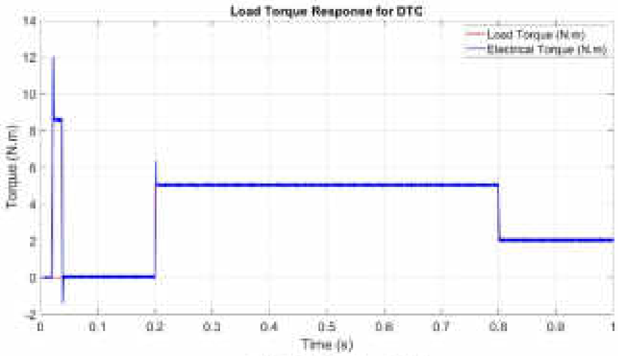
Low Speed Characterisics of FOC and DTC:

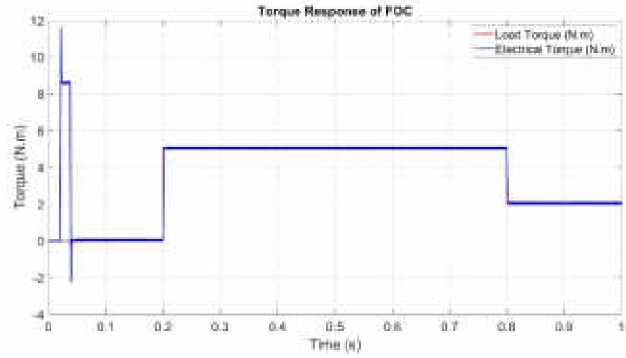
When the PMSM is operated at a speed of 400 rpm, the application of load torque causes a noticeable speed drop for DTC and FOC as can be seen below which takes a lot of time to reach the speed setpoint. The torque responses of both the techniques are like high-speed responses. The stator current for DTC on the other hand shows high harmonic content as compared to FOC which produces smooth sinusoidal currents. Also the flux for DTC technique demonstrates higher distortion than the high-speed characteristics. Finally, the direct current component shows higher ripple than before for FOC but for DTC it not only shows more distortion but also a high peak to peak value of 12 A for a load of 5 N.m. These degradation of DTC response is attributed to the inaccurate flux estimation at low motor speeds and hence more challenging control of PMSM.

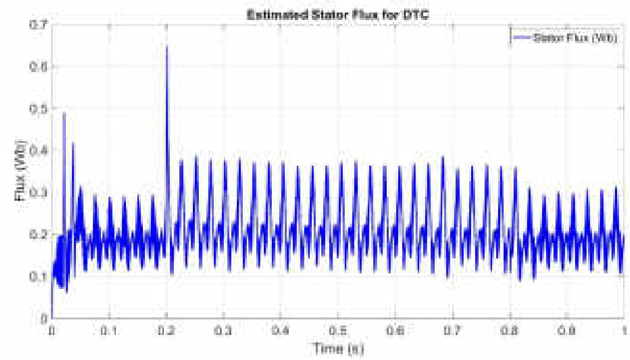


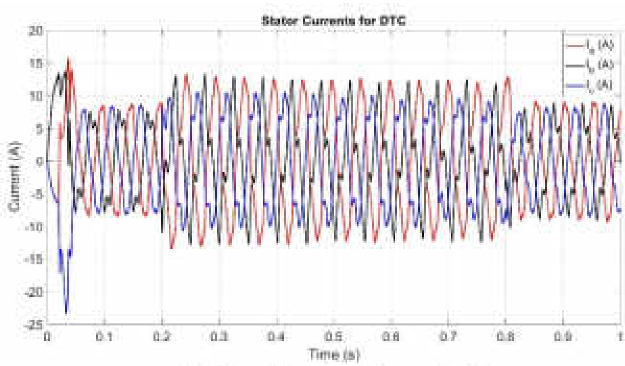


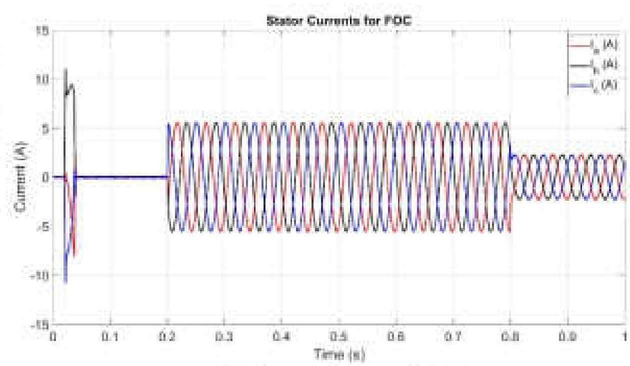


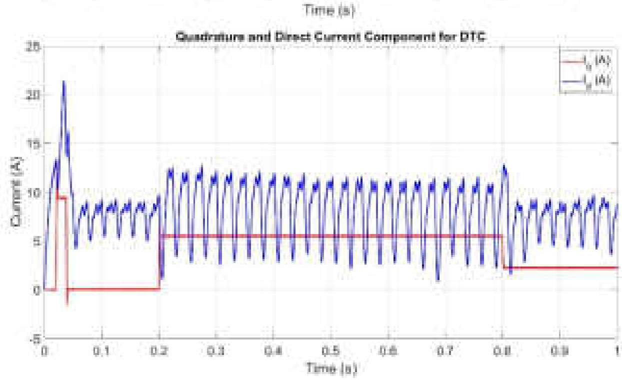

Load Torque Response for DTC
Load Torque (N.m)
Electrical Torque (N.m)
Torque (N.m)
Time (s)

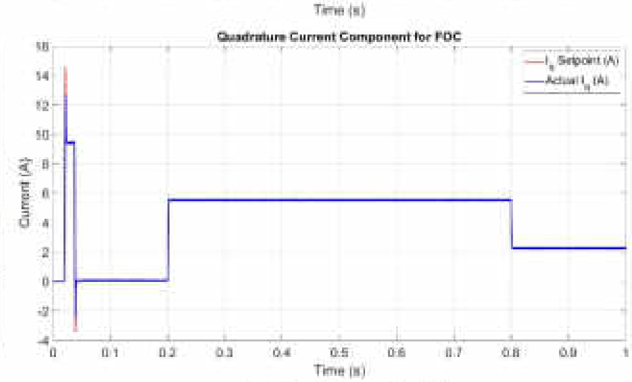

Torque Response of FOC
Load Torque (N.m)
Electrical Torque (N.m)
Torque (N.m)
Time (s)

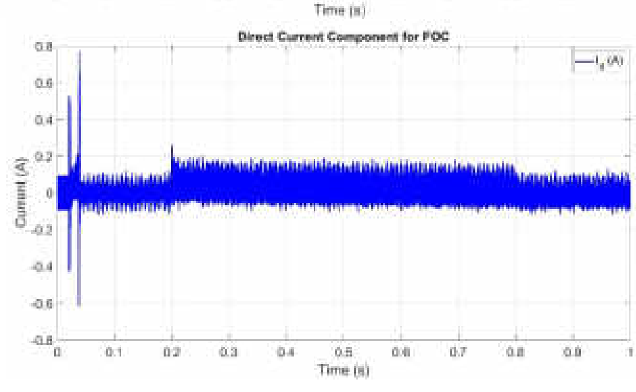

Estimated Stator Flux for DTC
Stator Flux (Wb)
Flux (Wb)
Time (s)


Stator Currents for DTC
I_a (A)
I_b (A)
I_c (A)
Current (A)
Time (s)


Stator Currents for FOC
I_a (A)
I_b (A)
I_c (A)
Current (A)
Time (s)


Quadrature and Direct Current Component for DTC
I_q (A)
I_d (A)
Current (A)
Time (s)


Quadrature Current Component for FOC
I_q Setpoint (A)
Actual I_q (A)
Current (A)
Time (s)


Direct Current Component for FOC
I_d (A)
Current (A)
Time (s)

Significance of individual contribution

Demonstrate how each team member's individual output(s) contributed to the overall goals and outcomes of your project.

Post implementation review (500 words min – 750 max)

Evaluation criteria

What criteria did you use to evaluate the quality of project outcomes?

Critical review

What worked well in the project? Why?

What did not work? Why?

What processes / aspects of work needs improvement? Why?

Lessons learned

What lessons did you learn through planning and implementing your project?

If you were to do your project again, what will you recommend to yourself?

Project closure acceptance

Confidence rating

Based on your assessment of the student's capstone project work, please provide a rating for each of the following EA competencies

1. Knowledge and skill base

On a scale of 1 – 10 (10 being high confidence), how confident are you that the student demonstrates a comprehensive conceptual knowledge of natural and physical sciences and in-depth knowledge of their specialism area of study.

2. Engineering Application ability

On a scale of 1 – 10 (10 being high confidence), how confident are you that the student demonstrates application of established engineering design and synthesis methods, techniques to the conduct and management of engineering projects

3. Professional and personal attributes

On a scale of 1 – 10 (10 being high confidence), how confident are you that the student demonstrates ethical conduct, professional responsibility and accountability as an engineer.

Project Sponsor (Supervisor) rating – use the rating scale above		**Knowledge and skill base**	**Engineering application ability**	**Professional and personal attributes**
Name	**Student Signature**			
Project team member 1				
Project team member 2				
Project team member 3				
Project team member 4				
Project Sponsor (Supervisor) Name	Signature: Date:			