

1809810

by David Thomas

EXCELLENT WORK THROUGHOUT WHICH DEMONSTRATED
A SOUND ALL ROUND KNOWLEDGE OF THE SUBJECT.
CRITICAL ANALYSIS WAS EVIDENT FROM THE CONCLUSION.

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TIME SUBMITTED	03-MAY-2021 07:56PM (UTC+0100)	WORD COUNT	10138
SUBMISSION ID	151465501	CHARACTER COUNT	61807

Course:	HND Electrical and Electronic Engineering
Module:	SGEE5006 Power and Machines
Assignment:	DC Motors & Drives, and AC Transmission Lines
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University number:	1809810
Date submitted:	06-05-2021
Word count:	2645

Contents

Good Structure

1. Executive Summary	7
2. Research	8
3. Simulation of a Half-Controlled Rectifier Circuit	26
4. Practical Investigation into a Single Quadrant DC drive	29
5. Simulation of a Medium Length Transmission Line	31
6. Conclusions and Recommendations	34
7. Team Working	35
8. Reference List	36
9. Appendix.....	38
9.1. Simulation of a Half-Controlled Rectifier Circuit.....	38
9.2. Practical investigation into a Single quadrant DC Drive	46
9.3. Simulation of a Medium Length Transmission Line	54

Table of Figures

Figure 1 - DC Machine Construction.....	9
Figure 2 - DC Machine Operation	9
Figure 3 - Schematic Diagram of Speed Controlled DC Motor Drive	19
Figure 4 - H Bridge.....	21
Figure 5 - H bridge regenerative drive.....	21
Figure 6 - Four quadrants of operation	22
Figure 7 - Block diagram of a controlled single quadrant drive.....	23
Figure 8 - Separately excited DC Motor fed from single phase AC Supply through half-wave convertors ..	23
Figure 9 - Separately excited DC Motor fed from single phase AC Supply through semi-convertors.....	24
Figure 10 - Simulation of a Half-Controlled Rectifier Circuit - Multisim circuit.....	26
Figure 11 - Practical investigation into a Single quadrant DC Drive – Continuous Current	30
Figure 12 - Medium Length Transmission Line - Nominal Pie Equivalent Circuit.....	31
Figure 13 - Medium Length Transmission Line - Simulated Nominal Pie Circuit	32
Figure 14 - Simulation of a Half-Controlled Rectifier Circuit - t1 at 120 degree	38
Figure 15 - Simulation of a Half-Controlled Rectifier Circuit - t2 at 120 degree	38
Figure 16 - Simulation of a Half-Controlled Rectifier Circuit - t1 at 90 degree	39
Figure 17 - Simulation of a Half-Controlled Rectifier Circuit - t2 at 90 degree	40
Figure 18 - Simulation of a Half-Controlled Rectifier Circuit - t1 at 60 degree	41
Figure 19 - Simulation of a Half-Controlled Rectifier Circuit - t2 at 60 degree	41
Figure 20 - Simulation of a Half-Controlled Rectifier Circuit - V peak Value	42
Figure 21 - Simulation of a Half-Controlled Rectifier Circuit - Back EMF Value	43
Figure 22 - Simulation of a Half-Controlled Rectifier Circuit - Half Cycle Time	43
Figure 23 - Simulation of a Half-Controlled Rectifier Circuit - 125v Back EMF	44
Figure 24 - Simulation of a Half-Controlled Rectifier Circuit - 100v Back EMF	44
Figure 25 - Simulation of a Half-Controlled Rectifier Circuit - 75v Back EMF	45
Figure 26 - Practical investigation into a Single quadrant DC Drive - Practical Setup	46
Figure 27 - Practical investigation into a Single quadrant DC Drive - Parker 512C	46
Figure 28 - Practical investigation into a Single quadrant DC Drive - V Peak Value	47
Figure 29 - Practical investigation into a Single quadrant DC Drive - t1 at 502RPM	47
Figure 30 - Practical investigation into a Single quadrant DC Drive - t2 at 502RPM	48
Figure 31 - Practical investigation into a Single quadrant DC Drive - t1 at 1003RPM.....	49
Figure 32 - Practical investigation into a Single quadrant DC Drive - t2 at 1003RPM.....	49
Figure 33 - Practical investigation into a Single quadrant DC Drive - t1 at 1500RPM.....	50
Figure 34 - Practical investigation into a Single quadrant DC Drive - t2 at 1500RPM.....	51
Figure 35 - Practical investigation into a Single quadrant DC Drive - Loading of 0.5nm.....	52
Figure 36 - Practical investigation into a Single quadrant DC Drive - Loading of 1.0nm.....	52
Figure 37 - Practical investigation into a Single quadrant DC Drive - Loading of 1.5nm.....	53

Table of Tables

Table 1 - Basic Construction of a DC.....	10
Table 2 - Summary of types of brushed DC motors.....	10
Table 3 - DC Motor type and their basic design	11
Table 4 - Advantages	11
Table 5 - DC Motor types and their applications.....	12
Table 6 - Relationships and Equations for Speed and Torque	14
Table 7 - Series Motor Control Armature Controlled Methods.....	15
Table 8 - Series Motor Control Field Control Methods.....	16
Table 9 - Shunt Motor Control Armature Controlled Methods	17
Table 10 - Field Motor Control Field Control Methods.....	17
Table 11 - Motor Control.....	18
Table 12 - DC Controller Components.....	20
Table 13 - Single Quadrant Drive Construction	24
Table 14 - Summary of single-phase, full-wave, half-controlled rectifier build	26
Table 15 - Simulation of a Half-Controlled Rectifier Circuit - Phase Angle Measured Values.....	27
Table 16 - Simulation of a Half-Controlled Rectifier Circuit - Phase Value Comparison	27
Table 17 - Simulation of a Half-Controlled Rectifier Circuit - Back EMF Measured Values.....	28
Table 18 - Simulation of a Half-Controlled Rectifier Circuit - Back EMF Value Comparison	28
Table 19 - Practical Investigation into a Single Quadrant DC drive - No Load Measured Values.....	29
Table 20 - Practical Investigation into a Single Quadrant DC drive - No Load Value Comparison	29
Table 21 - Practical Investigation into a Single Quadrant DC drive - Loading Values.....	30
Table 22 - Medium Length Transmission Line - Nominal Pie Equivalent Circuit Values	31
Table 23 - Medium Length Transmission Line - Calculated Series Impedance & shunt Admittance	31
Table 24 - Medium Length Transmission Line - Value Comparison.....	32
Table 25 - Medium Length Transmission Line - Efficiency Comparison.....	33
Table 26 - Medium Length Transmission Line - Receiving End Circuit Values	54
Table 27 - Medium Length Transmission Line - Calculated Values.....	55

Table of Equations

Equation 1 - Simulation of a Half-Controlled Rectifier Circuit - 120 Degree Half Cycle Time	39
Equation 2 - Simulation of a Half-Controlled Rectifier Circuit - 120 Degree β Value	39
Equation 3 - Simulation of a Half-Controlled Rectifier Circuit - 120 Degree α Value	39
Equation 4 - Simulation of a Half-Controlled Rectifier Circuit - 120 Degree Average Voltage	39
Equation 5 - Simulation of a Half-Controlled Rectifier Circuit - 120 Degree Phase Angle	39
Equation 6 - Simulation of a Half-Controlled Rectifier Circuit - 90 Degree Half Cycle Time	40
Equation 7 - Simulation of a Half-Controlled Rectifier Circuit - 90 Degree β Value	40
Equation 8 - Simulation of a Half-Controlled Rectifier Circuit - 90 Degree α Value	40
Equation 9 - Simulation of a Half-Controlled Rectifier Circuit - 90 Degree Average Voltage	40
Equation 10 - Simulation of a Half-Controlled Rectifier Circuit - 90 Degree Phase Angle	40
Equation 11 - Simulation of a Half-Controlled Rectifier Circuit - 60 Degree Half Cycle Time	42
Equation 12 - Simulation of a Half-Controlled Rectifier Circuit - 60 Degree β Value	42
Equation 13 - Simulation of a Half-Controlled Rectifier Circuit - 60 Degree α Value	42
Equation 14 - Simulation of a Half-Controlled Rectifier Circuit - 60 Degree Average Voltage	42
Equation 15 - Simulation of a Half-Controlled Rectifier Circuit - 60 Degree Phase Angle	42
Equation 16 - Simulation of a Half-Controlled Rectifier Circuit - Half Cycle Time	45
Equation 17 - Simulation of a Half-Controlled Rectifier Circuit - 75 Degree α Value	45
Equation 18 - Simulation of a Half-Controlled Rectifier Circuit - 60 Degree Average Voltage	45
Equation 19 - Simulation of a Half-Controlled Rectifier Circuit - 60 Degree Phase Angle	45
Equation 20 - Practical investigation into a Single quadrant DC Drive - V Peak Value	47
Equation 21 - Practical investigation into a Single quadrant DC Drive - Half Cycle Time	48
Equation 22 - Practical investigation into a Single quadrant DC Drive - 502RPM β Value	48
Equation 23 - Practical investigation into a Single quadrant DC Drive - 502RPM α Value	48
Equation 24 - Practical investigation into a Single quadrant DC Drive - 502RPM Average Armature Voltage	48
Equation 25 - Practical investigation into a Single quadrant DC Drive - Half Cycle Time	50
Equation 26 - Practical investigation into a Single quadrant DC Drive - 1003 RPM β Value	50
Equation 27 - Practical investigation into a Single quadrant DC Drive - 1003RPM α Value	50
Equation 28 - Practical investigation into a Single quadrant DC Drive - 1003RPM Average Armature Voltage	50
Equation 29 - Practical investigation into a Single quadrant DC Drive - Half Cycle Time	51
Equation 30 - Practical investigation into a Single quadrant DC Drive - 1500 RPM β Value	51
Equation 31 - Practical investigation into a Single quadrant DC Drive - 1500RPM α Value	51
Equation 32 - Practical investigation into a Single quadrant DC Drive - 1500RPM Average Armature Voltage	51
Equation 33 - Medium Length Transmission Line - Series Impedance, Cartesian	54
Equation 34 - Medium Length Transmission Line - Series Impedance, Polar	54
Equation 35 - Medium Length Transmission Line - Shunt Admittance, Cartesian	54
Equation 36 - Medium Length Transmission Line - Shunt Admittance, Polar	54
Equation 37 - Medium Length Transmission Line - Nominal Voltage	54
Equation 38 - Medium Length Transmission Line - Current at Receiving End	54
Equation 39 - Medium Length Transmission Line - I1 Calculation	54
Equation 40 - Medium Length Transmission Line - I1 Value, Cartesian	54
Equation 41 - Medium Length Transmission Line - I1 Value, Polar	54
Equation 42 - Medium Length Transmission Line - Sending End Voltage Calculation	55

Equation 43 - Medium Length Transmission Line - Sending End Voltage, Cartesian	55
Equation 44 - Medium Length Transmission Line - Sending End Voltage, Polar	55
Equation 45 - Medium Length Transmission Line - Sending End Current Calculation	55
Equation 46 - Medium Length Transmission Line - Sending End Current, Cartesian	55
Equation 47 - Medium Length Transmission Line - Sending End Current, Polar	55
Equation 48 - Medium Length Transmission Line - Sending End Angle between Voltage and Current	55
Equation 49 - Medium Length Transmission Line - Sending End Power Factor	55
Equation 50 - Medium Length Transmission Line - Sending End Power	56
Equation 51 - Medium Length Transmission Line - Receiving End Power	56

300 words should be enough

1. Executive Summary

Initial research involved DC machine types, methods of control in relation to conversion of an AC supply and use such as speed, direction and torque, and relating this information to various industrial applications. With further research undertaken into single quadrant DC drives, their construction and operation, this was then used to inform practical elements of the project. *assignment*

The practical elements were split into simulation and classroom-based exercises. The first two elements involved one, the build and simulation of a single-phase full-wave half-controlled rectifier using Multisim, and two, the use and physical connection of a DC motor to a Parker 51C single quadrant drive. The overall aims of the first two elements were to predict a number of performance factors including phase angle and armature average voltage, comparing that calculated with simulated and practical values. In the rectifier circuit, a number of measurements were taken to assess the performance at differing firing angles of 60, 90 and 120°, following which the effect of mechanical loading using back EMF values of 75, 100 and 125v was tested at the fixed angle of 75° to ascertain continuous current. Analysis of the DC drive using equipment to measure both waveforms and motor speed involved initial no-load conditions at the set points of 502, 1003 and 1500RPM, following which the performance under three mechanical loads (0.5, 1.0, 1.5nm) at the set point of 1003RPM was tested by assessing current and voltage waveforms. Both tests proved to accuracy of the calculated values, performance of the circuits being as predicted. *the*

purpose

The basis of the transmission line simulation was to assess power loss *Contain* efficiency. A simulated nominal pie equivalent circuit was constructed and predicted values for a number of performance factors compared to simulated values when connected to an AC source at a fixed load and power factor of 293.12A at 82.596KV and 0.88722 lagging respectively. All simulated results demonstrated accuracy of the calculated results, with both simulated and calculated circuits having the same percentage of efficiency. *s too much for a summary*

2. Research

Correctly cited

Almost half the world's electricity is utilised by electric motors (MaximIC, 2021). The DC motor has been in use for nearly two centuries, its operation, viability and cost-effectiveness meaning it has been incorporated into a wide range of applications (Elprocus., 2021). Significant benefits of flexibility and controllability have retained its prominence in industry, accounting for over a quarter of machines manufactured today (EEGuide, 2021).

DC machines operate on direct current supply, the essential principle being flow of an electric current through a coil sited within a magnetic field creating a magnetic force which results in generation of torque, rotation of the DC motor (Elprocus, 2021), and delivery of power to the load/application (Elprocus., 2021). DC machines are of two types: DC generator (converting mechanical to DC electrical power) and DC motor (converting DC into mechanical power) (Elprocus, 2021). However as power electric machines have evolved, DC generators use and place has decreased, incorporation of smaller, cheaper devices such as SCR rectifiers becoming significant competitors (EEGuide, 2021). They are now in the main used for supply of DC to power station DC machines (Elprocus, 2021), and in the form of separately-excited generators for speed control in the Ward-Leonard system (see later) (EEGuide, 2021).

Unnecessary paragraph, the principle of operation was not asked for.

Practical operation of DC motors involves generation a magnetic field (magnetic flux) by the conductor (armature) as it is provided with a current. Depending on the direction of field windings, this either adds or cancels the magnetic flux generated. As the magnetic flux in one direction accumulates over another, rotation of the conductor follows as a result of the force exerted. In accordance with Faraday's (electromagnetic induction) and Lenz' Laws, electromagnetic field (EMF) generated by conductors rotating will oppose supply voltage, meaning due to the back EMF, DC motors have the ability to adjust torque in response to a varied load (Elprocus., 2021).

The assignment did not ask for the construction of the DC machine, this is level 3 work and your focus should have been on the applications of DC machines.

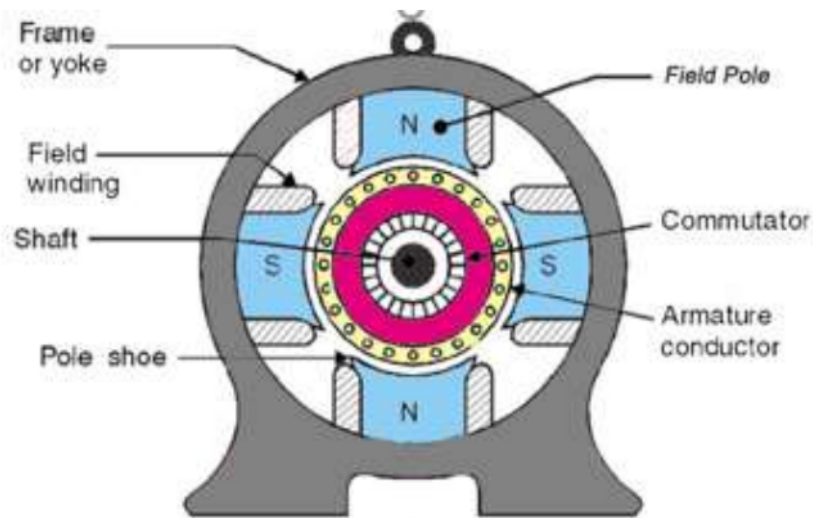


Figure 1 - DC Machine Construction

(Elprocus, 2021)

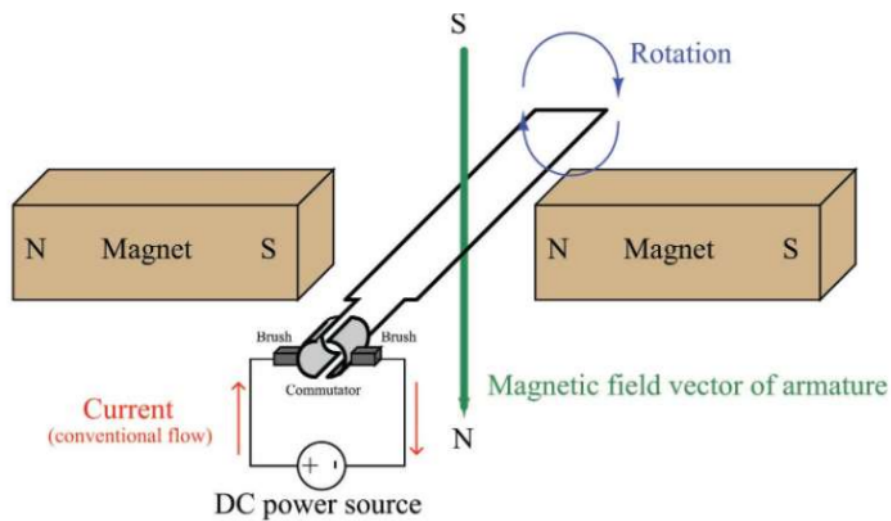


Figure 2 - DC Machine Operation

(Control_Automation, 2021)

This is too basic for level 5

Not required, read the question please

Component	Description
Rotor (Armature)	Rotating part of the machine – also referred to as the armature Armature Core includes armature conductor located within a number of slots Armature winding created from interconnection of the conductor – turning of the winding induced voltage and flux within
Stator (Field windings)	Portion of the machine that is stationary – also referred to as ‘field windings’ Supply of current → poles to be electro-magnetized → generation of flux required
Commutator	Segmented copper strips. Depending on the type of motor it may be brushed/brushless. Collects current supplied by armature conductor and provides the load with current by feeding into winding of the rotor.
Field Magnets(poles)	Required to supply the magnetic field responsible for the axle rotation that connects to the rotor

Table 1 - Basic Construction of a DC

(Elprocus, 2021) (Ikimi.O, 2020)

Although all basic construction is as above, applications within industry are varied, and as such a number of DC motors are used.

This is more like it !

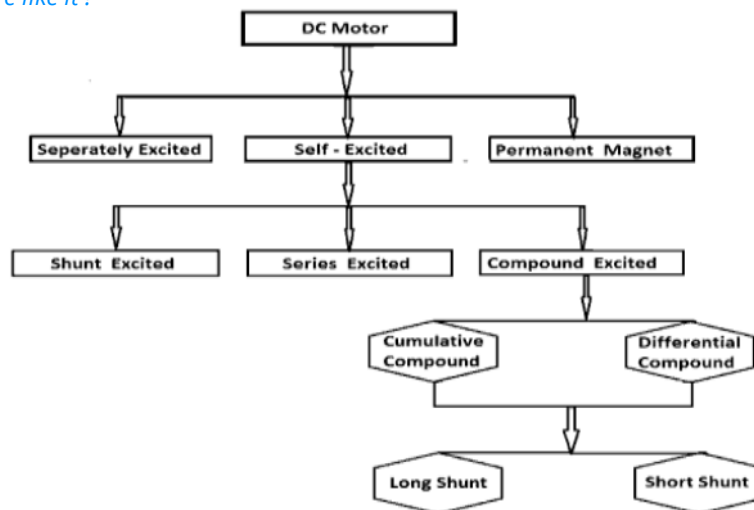


Table 2 - Summary of types of brushed DC motors

(Electrical4U, 2021)

Motor Type	Description
Self-Excited	Current flow through field windings is provided by the machine. Further subdivided depending on the connection of the field winding to the armature winding
Shunt Wound/Excited	Field coils/windings in parallel through armature – both receive the same voltage. Include a greater number of turns on windings compared to the series motor.
Series Wound/Excited	Stator field coils/windings in series through armature. Single voltage supply.
Compound Wound/Excited	Include series & shunt fields. With each machine pole there are 2 windings Depending on the connection there are 2 types of compound wound: - Short-shunt: shunt field in parallel by armature alone - Long-shunt: shunt field in parallel to armature & series field
Permanent Magnet	Has an armature winding but field windings are not always present Two permanent magnets (opposing) that are radially magnetized are mounted on the stator which generates the field flux as DC passes through → rotation of rotor (direction depends on polarity) Rotor contains standard armature (plus commutator segments/brushes)
Separately-Excited	Supply provided is separate to the field & armature windings. Separate external DC current source energizes the field winding

Table 3 - DC Motor type and their basic design

(Elprocus, 2021) (Ikimi.O, 2020)

DC machines have many advantages that are important for industry.

Summary of Advantages
- High starting & operational torque (however DC motors should be started under load as otherwise will rapidly burn out) - Can reverse, use fast start & stop and variable speeds using voltage input – faster acceleration/deceleration means faster production cycle times (useful where multiple start/stops of an application) - Simple to control - Cheaper compared to AC machines - No problems with harmonics (compared to AC motors) - Easy to install & maintain - Smaller than AC machine equivalents – due to high power density and last of stator field coil)

Table 4 - Advantages

(Elprocus, 2021) (Control, 2020)

Although varying by type, DC motors benefit from their ability to produce full torque while operating at low speeds and from zero to base speed, proving power and torque desired (Control, 2020). Below details the main DC motor types, their characteristics and common industrial applications:

*This column is
what was required*

Motor Type	Characteristics	Applications
Separately Excited	Very accurate speed from low to high	Useful for applications requiring low to high speed variation Paper machines, rolling units
Permanent Magnet	Speed is synchronous with constant frequency.	Small DC motors e.g. air conditioning units, blowers
Series Wound	Inexpensive Equal armature/field currents High starting torque (up to 500%/5x full load torque) Variable speed	High & Low power electric drive Fixed/variable speed electric drives Useful for applications involving traction due to its high starting torque Load must be positively connected • Conveyer belt drives • Electric cranes • Hoists • Cranes
Shunt Wound	Constant speed (regulation of speed approx. 5-15%) Medium starting torque (commutation limits to 200%) Using SSR it has an excellent range of variable control above/below base speed	Useful for applications with constant/fixed speed however predominantly used in low speed applications as cost and simplicity of the AC Squirrel motor is preferred in most constant speed drives • Lathes • Fans/blowers • Machine tools
Compound Excited/Wound	Degree of compounding impacts significantly on the characteristics Cumulative: High starting torque, speed regulation 25-30% Differential: ~constant torque/speed. Can suffer from speed instability	Useful for applications requiring a high starting torque with a constant speed, and pulsating loads that also need fly-wheel action • Conveyer belt drives • Rolling mills • Heavy planning machines • Hoists • Crushers

Table 5 - DC Motor types and their applications

(EEGuide, 2021) (MPLGMG, 2018) (Ikimi.O, 2020)*Always separate your sources*

As control of machine speed impacts on speed of motor rotation, therefore directly affecting load function, speed control is important for load performance and machine output (Control, 2020). This differs from speed regulation involving maintenance of speed against natural variation from shaft load changes (Electrical4u, 2020). An advantage to DC motors is both field and rotor windings are accessible and so torque and speed control is simple, curves for speed and torque being inversely linear, RPM increase leads to torque decrease (Cavallo, 2021). However, as seen above, control and characteristics vary. Comparatively to most motors, where heat generation limits maximum torque, in DC motors commutation limits this (EEGuide, 2021). Speed control can be achieved manually or more commonly using automatic controllers (Electrical4u, 2020).

The mechanical/electrical relationship for torque and speed in DC motors is described below:

- A) Torque $\propto$ strength of armature magnetic field (AMF), with AMF $\propto$ armature winding current
- B) Torque $\propto$ strength of stationary pole magnetic field (SPMF), SPMF $\propto$ field winding current

- Consideration of speed control methods begins with the basic DC motor voltage equation:

$$V = E_b + I_a R_a$$

(V = supplied voltage, E_b = back EMF, I_a = armature current, R_a = armature resistance)

- Substitution of E_b into the voltage equation (Elprocus, 2021):

$$V - I_a R_a = (P \phi N Z) / 60$$

(P = no. of poles, Z = no. of conductors, N = motor speed)

- Provides the following:

$$N = K(V - I_a R_a) / \phi$$

- From this the following can be concluded about motor speed:

- Speed $\propto$ supply voltage
- Speed $\propto \frac{1}{\text{Armature voltage drop}}$
- Speed $\propto \frac{1}{\text{Field winding flux}}$

- It therefore follows from the above that DC motor speeds can be controlled by adjusting V : supply voltage (terminal armature voltage), ϕ : flux and field winding current, or R_a : armature voltage and resistance. These can be subdivided into (Electrical4u, 2020):
 - Armature Control (terminal voltage/resistance affects armature circuit)
 - Field Control (flux affects the magnetic field)

Table 6 - Relationships and Equations for Speed and Torque

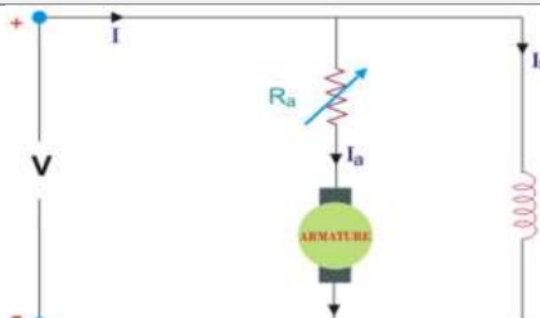
(Elprocus., 2021) (Electrical4u, 2020)

Speed control methods are further discussed with respect to DC Series & Shunt type motors.

DC Series Motor Control

Speed control methods can vary. Armature control can be achieved by adjusting/controlling one of the following: Armature Resistance, Shunted Armature control or Armature Terminal Voltage; Field control achieved by either Field Diverter or Tapped Field Control (Electrical4u, 2020).

This is not required, the question asked you to look at converting AC into DC

ARMATURE CONTROLLED METHODS	
Armature Resistance	
	
Connection of controlling resistance = directly in series with motor supply	
• Most common control method • Most cost-effective where there is constant torque • Although power loss occurs it is not significant: used for prolonged periods of time for reduction of speed under light load	

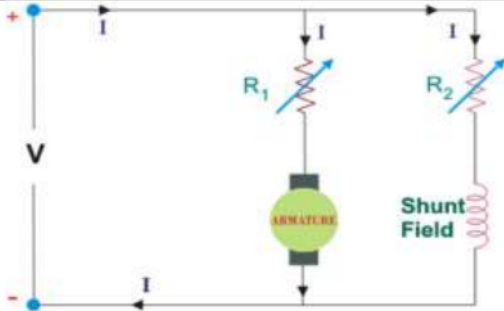
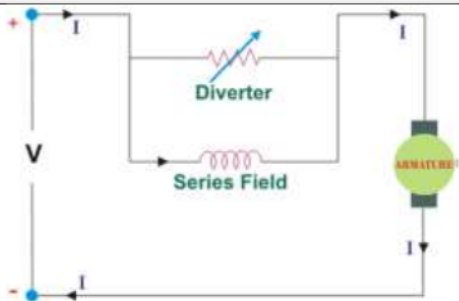
Shunted Armature Control
 Two rheostats, one shunting the armature and one in series • Changing the series rheostat (R_1) changes the voltage that is applied to the armature • Changing the armature shunting rheostat (R_2), changes the exciting current • Wide range of speed control (though all less than normal speed) • However considerable power loss therefore not economical
Terminal Voltage
• Variation in speed achieved by using a separate variable voltage supply to supply power • Rarely used due to high costs involved

Table 7 - Series Motor Control Armature Controlled Methods

(Electrical4u, 2020)

FIELD CONTROLLED METHODS
Field Diverter
 Circuit incorporates a diverter • A percentage of the motor current is shunted around the series field reducing field flux • Smaller diverter resistance = smaller field current and therefore flux which results in higher speed • Speeds above base/normal can be achieved • Commonly used in electric drives where speed increases rapidly upon reduction of the load

Not required, read the question !

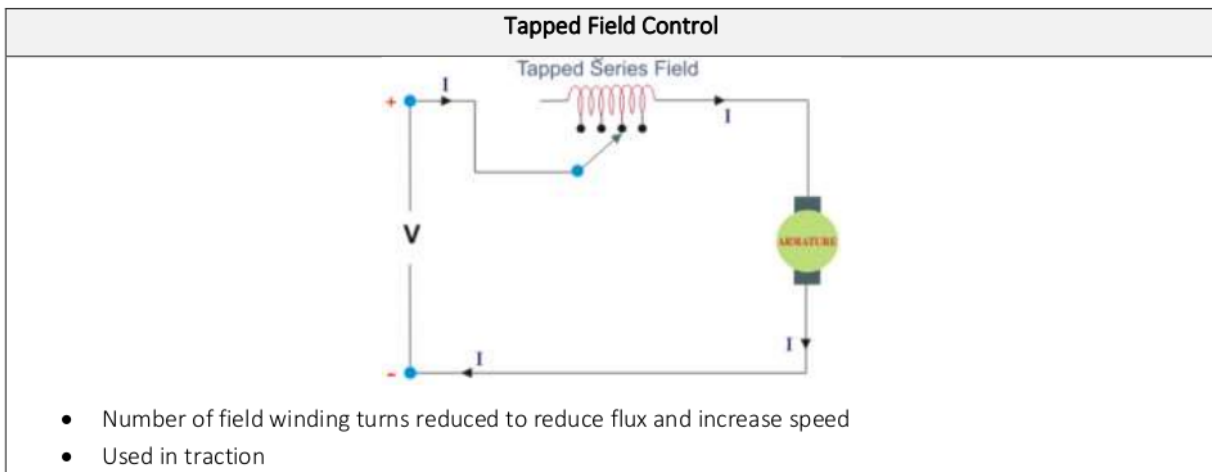


Table 8 - Series Motor Control Field Control Methods

(Elprocus., 2021) (Electrical4u, 2020)

DC Shunt Motor Control

As above, speed control can be provided by armature or field control.

ARMATURE CONTROLLED METHODS	
Armature Resistance	Armature Voltage
• Variable resistance incorporated into armature circuit • Flux remains unchanged as there is direct connection of the field across the supply • Used where periods of lower than rated speeds are short e.g. cranes/hoists	• Requires separate source of variable voltage • Used for elevators, mine hoists • Ward Leonard Method – involves an individually excited DC motor generator (M-G set). Changes to generator field current varies generator voltage. Flux kept constant with constant current. Field current delivered is different→variation of armature voltage. Increase in power→increase in speed
Advantages	Disadvantages
• Fine full range control in either direction • Acceleration is uniform • Has capacity for regenerative braking	• Requires significant space • At lighter loads it has poor efficiency • Noisy • Increased cost – Ward Leonard required a motor and generator

Table 9 - Shunt Motor Control Armature Controlled Methods

(Elprocus., 2021)

FIELD CONTROLLED METHODS	
Field Rheostat	
• Variable resistor is incorporated into the circuit in series with shunt field • As resistance increases, field current decreases, reducing flux and increasing speed	
Advantages	Disadvantages
• Control of speed in this method is independent of the motor load • Minimal power loss	• Small increases in speed not achievable • To achieve higher speeds the decrease in torque is significant

Table 10 - Field Motor Control Field Control Methods

(Elprocus., 2021)

With DC motors running on DC (non-sinusoid/unidirectional) supply (Ikimi.O, 2020), and industry supply being AC (power transmission lines), rectification is needed (Elprocus, 2021). Although DC series motors can function/operate off either AC or DC due to series connection of field and armature windings meaning resistance is low, this is not the case for most. In shunt motors AC supply causes significant slowing with heat generation, and in permanent-magnet/separately-excited

motors, there is simply vibration with no rotation (EtechnoG, 2021). Although speed and torque control can be achieved through regulation of field current, variable resistors to control total power using armature voltage and current control is inefficient, wasting a significant amount of power e.g. through heat losses (Control, 2020). Electronic DC drives consist of an AC-DC converter, or rectifier (electronic thyristor). DC motor controllers/drives, manual, semi or fully automatic, can be used to provide discrete control of a number of DC motor functions aside from simply rotation, speed and torque e.g. starting/stopping, direction (reversing) and braking, supporting use DC motors in a number of industrial applications (Motor, 2021).

Type of Motor Control	Comment
Starting	Several methods ‘Across-the-line’, where there is a connection directly to power line with manual control switch is the most straightforward however can damage some DC motors due to the inrush current being over the power supply capacity. ‘Soft-starting’ avoids this allowing for gradual acceleration by incorporating a starting resistor to reduce the line voltage in series with armature winding. Once at full speed it is removed.
Stopping/Braking	Coasting: removal of power and motor coasts to a stop. Often impractical due to time taken Braking: Mechanical/magnetic/dynamic/regenerative. In dynamic braking the mechanical energy is transferred across a braking resistor (acting as a generator while armature is rotating) to the armature. Energy is then transferred into the resistor from the armature (now a generator) dissipating energy as heat and slowing the motor Regenerative braking: Source is supplied with generated energy
Reversing	Controlled by a switch or electronic drive controller. Polarity of armature connections reversed
Plugging	Dual purpose of reversing and braking Reverse of supply voltage → reversing of armature current → Increase in back EMF and braking
Speed	Achieved by various methods e.g. armature control current via a resistor or electronic drive controller

Table 11 - Motor Control

(electrical4u, 2020) (Motor, 2021)

At last, you are following the brief again by looking at control from an AC supply

Although there are different configurations available, full-wave/6-pulse bridge configuration offers least distortion and losses (Motor, 2021), with full-wave, single-phase rectifiers most commonly seen (Kimbrell, 2016). In larger drives, to minimise effects of harmonics from AC transmission lines, a 12-pulse bridge may be chosen. Incorporation of an AC-DC converter has little effect on DC drive/motor efficiency, reducing it to around 90%, having the added benefit of maintaining control and performance even when used for high wattage applications (Motor, 2021).

DC electronic controllers provide speed control through Armature Control, varying current to supply a variable DC voltage. In the case of an AC-DC converter this can be achieved though control of the SCR bridge rectifier firing angle.

The basic DC drive (controlled rectifier circuit) consists of a closed-loop, variable speed system incorporating elements described below (Motor, 2021):

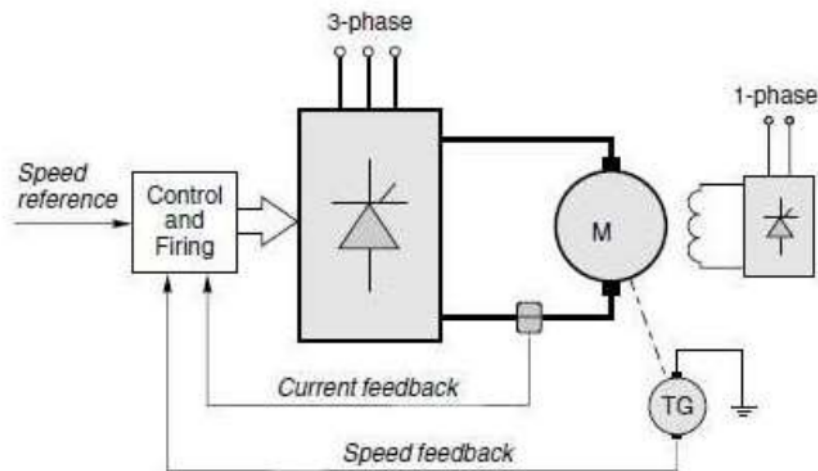


Figure 3 - Schematic Diagram of Speed Controlled DC Motor Drive

(Control, 2020)

DC Controller Drive Component	Function
Reference circuit: determines speed setpoint	Reference speed achieved by altering the differential amplifier voltage to one that is proportional to the reference speed
Differential (error) amplifier	

Firing pulse generator	Application of the error (actual - setpoint) signal to the firing pulse generator determines the SCR bridge thyristor firing angles Controller responsible for driving the circuit is often a PI(D) or Intelligent controller such as a Fuzzy Logic Controller.
SCR bridge	The variable DC voltage produced from the SCR bridge output is applied to the armature to generate a speed that is directly proportional to the above voltage.
Tachometer/encoder	Often a small DC generator connected to the motor shaft. Provides feedback on motor speed i.e. converts the detected actual speed (RPM) to a signal that is proportional to the speed of the shaft (~0-10V). Comparison with the setpoint is sent back to the differential amplifier to continue the loop and provide the desired speed. Any change requires a change in the setpoint. Disconnection will cause loss of speed control, sending full power therefore maintenance of the feedback signal is critical with regards to safety.

Table 12 - DC Controller Components

(Control, 2020) (Motor, 2021)

Although this technology of providing pulsed power to the motor is older, conversion of AC-DC is essential and therefore it is practical to achieve this during rectification. These circuits operate by essentially fluctuating times of trigger pulses comparative to pulse of the AC waveform. Early trigger of the SCR with each AC cycle results in a longer phase before current is transferred to the motor. In the DC drive, motor speed is usually adjusted by altering armature voltage i.e. altering the variable DC voltage produced from the SCR bridge drive output. Further adjustment beyond maximum output voltage can be achieved by reducing field flux ('field weakening'), however this is limited to maintain stability and commutation. Compared to armature voltage adjustment where full torque is maintained throughout the speed range, field weakening causes reduction in torque proportional to speed. Output power however is unaffected (Control, 2020).

PWM requires a rectification stage first in order

A more modern solution is ~~Pulse Width Modulation~~ *Pulse Width Modulation to control* the proportion of power delivered to the armature by rapidly switching on/off transistors using electronic power circuits, or variable speed drives. These can include remote signalling to vary motor speed in response to the electronic control signal. As with drives above, tachometer feedback signal enables precise control. To avoid radio-frequency interference from VSD electrical noise (electromagnetic waves), positioning of conductors feeding motor power or AC power should ensure remoteness from control wiring. To further reduce impact on AC power conductors, line reactors (low-pass filters) can be used to route the power (Control, 2020).

PWM is efficient, minimising power losses (Elprocus., 2021). Combining it with an H-bridge enables control of speed, as well as direction and braking (Cavallo, 2021). Correctly cited

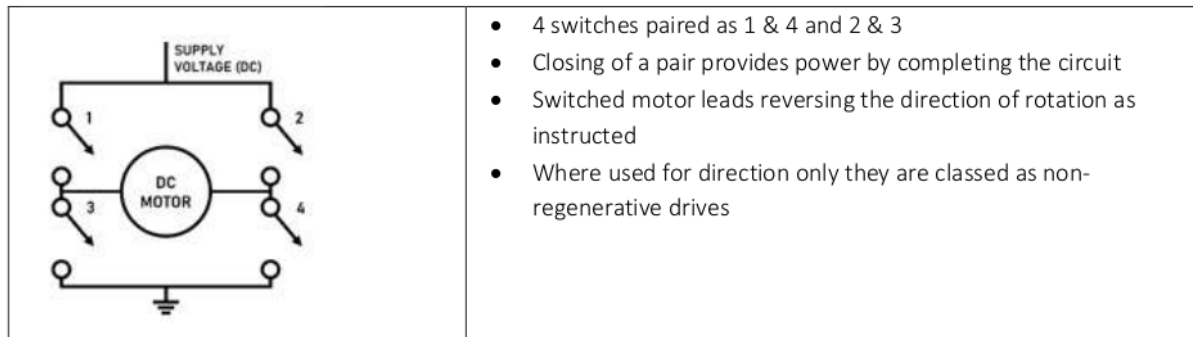


Figure 4 - H Bridge

(Cavallo, 2021)

Unlike those which cut power to reduce speed, control of speed/braking can be achieved when using the H-bridge as a regenerative drive (Cavallo, 2021).

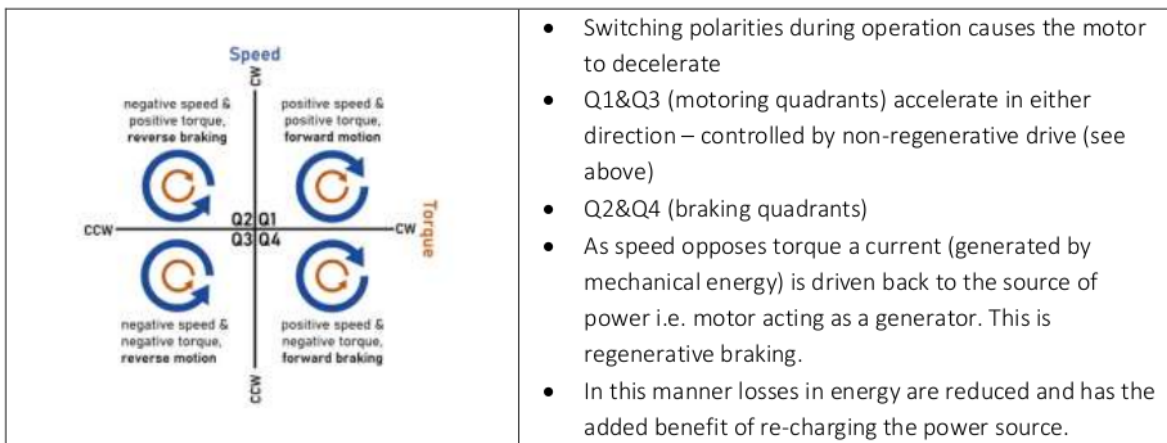


Figure 5 - H bridge regenerative drive

(Cavallo, 2021)

The relationship of torque, speed and direction control of a DC Motor controller can be viewed in quadrants.

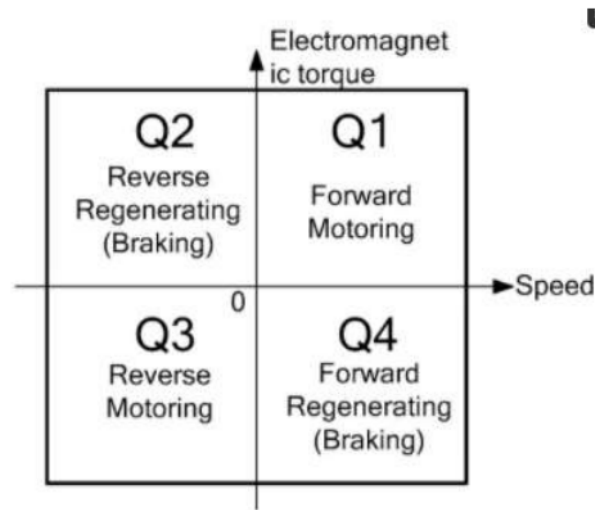


Figure 6 - Four quadrants of operation

(EtechnoG, 2021)

Depending on application and control required, DC motor controls can be single up to four-quadrant drives. Commonly seen are non-regenerative, single-quadrant drives, control of acceleration (motoring) in a single direction only as torque can only be applied in the same polarity vector as velocity i.e. Q1. The method of stopping/braking is by coasting with aid of natural friction and is therefore slow, as torque or current cannot be applied in the direction opposing rotation to actively slow the motor (Maxon, 2021). correctly stated Correctly cited

Single-quadrant drives commonly utilise a half-wave rectifier or an asymmetrical (single-phase) semi-converter, depending on voltage of the motor to be controlled, to convert incoming AC supply to DC supply to the armature. These are commonly used in fans, blowers or pumps. A block diagram of a single-quadrant drive is shown below. In addition to the power circuit, an effective closed-loop single-quadrant DC drive incorporates a controller to drive the circuit in response to feedback e.g. PI(D) controller (Electronics, 2020). The Parker 512C is an example of a single-quadrant drive utilising a closed-loop system providing feedback through a tachometer or armature voltage depending on operator selection. (Parker, 2016). Correctly cited

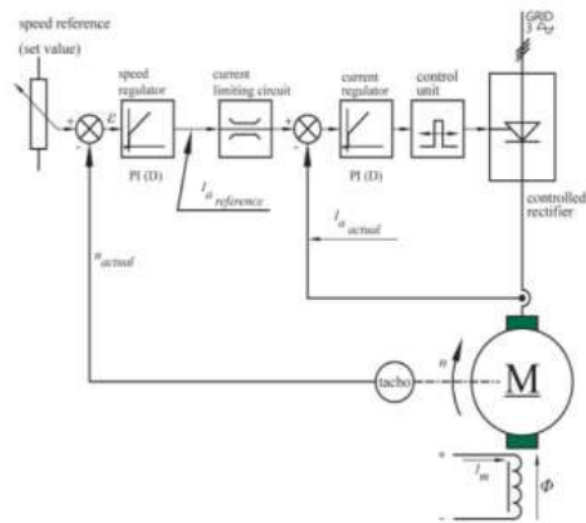


Figure 7 - Block diagram of a controlled single quadrant drive

(Sushmita, 2021)

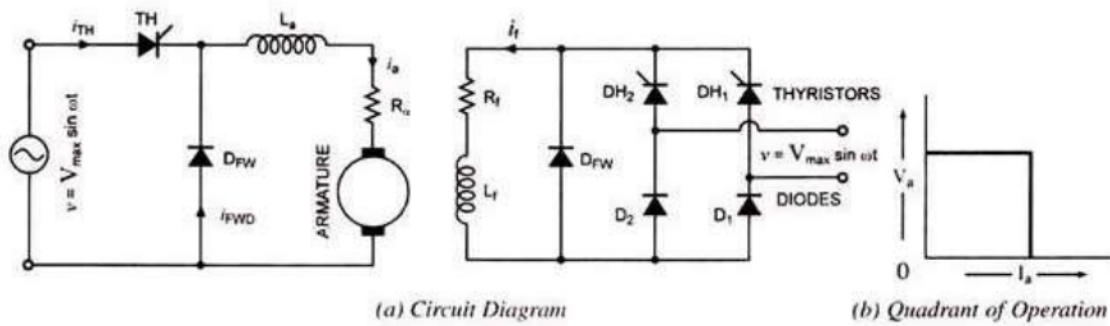


Figure 8 - Separately excited DC Motor fed from single phase AC Supply through half-wave convertors

(Sushmita, 2021)

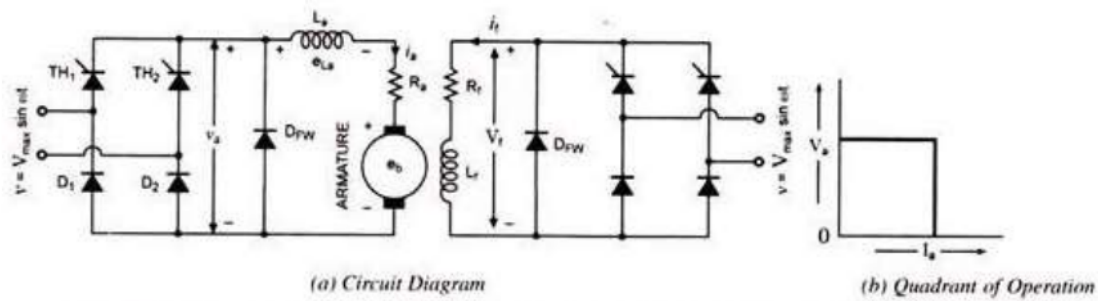


Figure 9 - Separately excited DC Motor fed from single phase AC Supply through semi-convertors

(Sushmita, 2021)

Components	Description
Power Circuit	
Thyristor Bridge	Consisting of either a half wave rectifier (control of motors up to 0.5kW) or single-phase rectifier (control of motors up to 15kW) Half-wave rectifier: single thyristor and commutating diode to provide a better load current waveform and power factor. Should the thyristors become blocked, the diode also enables dissipation of motor inductance stored energy to ensure motor current supply remains. Protection from brief over-voltages is also provided. Only passes the positive part of the sine wave therefore inefficient. Poor performance as a result of a continually discontinuous motor current limits the use to low power motors Asymmetric (single-phase) rectifier: Semi converters provide AC supply to both the armature and field circuits and circuits include commutating diodes. The firing angles of the rectifiers provide armature control to supply variable voltage
Transformer Tap Arrangement	May be included to control the output voltage to within its defined limits by altering the transformer turn ratio.
Controller e.g. P/PI/PI(D)	
Potmeter	Set required speed
Tachometer	Voltage proportional to motor speed produced
Comparator	Compare set-point and actual speeds
- Any error signal is sent back to the controller, the controller output dependant on whether a controller is P, PI or rarely PI(D) e.g. where a P amplifier is in place it is proportional to the difference (error) and control whether acceleration continues i.e. controls the armature current (input to a second controller). - Second controller output transmits a signal (pulse) to control the power circuit i.e. thyristor bridge	

Table 13 - Single Quadrant Drive Construction

(Electronics, 2020)

DC motors are found in a large number of industrial applications, often equipment requiring motion/rotary control (Ikimi.O, 2020). With a number of different types available, an understanding of operation and speed control methods is key to effective and efficient application. With industrial power being AC, DC control drives are required to enable conversion of AC to DC supply, however with many DC controllers to choose from, consideration of factors such as motor voltage range and control type is required (Cavallo, 2021). With the flexibility, versatility and controllability provided by DC machines for energy conversion, their use in industry will remain for many years(EEGuide, 2021).

3. Simulation of a Half-Controlled Rectifier Circuit

A single-phase, full-wave, half-controlled rectifier was built using Multisim as below. The circuit was constructed to represent a Parker SSD512 single-quadrant drive with two thyristors: T1/T4 and two diodes: D2/D3. Full-wave rectification is present but with only half control of the two thyristors.

Summary of single-phase, full-wave, half-controlled rectifier build

- The diodes perform as a commutative part, where no negative voltage is present due to the commutative loop, allowing the thyristors to switch off
- The resistor and inductor were used to represent a motor, with a battery added for the back EMF
- V2 battery was used to represent phase-angle controller, U1, firing angle
- The phase-angle controller produces pulses on each of its phases, T1 and T2, with α being the set point of the angle and Ph+ and Ph- the AC supply detecting the crossover
- Tx1 and Tx2 represent isolation transformers which although not required for the simulation, are needed in practice to isolate pulses produced by the phase-angle controller, which could be upwards of 300v with a phase supply of 240Vrms

Table 14 - Summary of single-phase, full-wave, half-controlled rectifier build

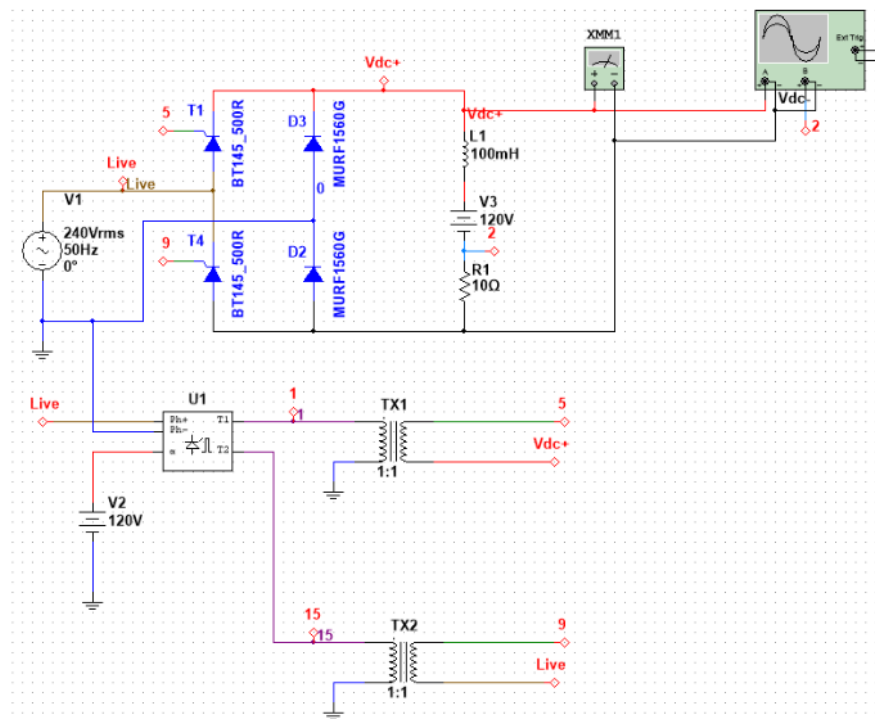


Figure 10 - Simulation of a Half-Controlled Rectifier Circuit - Multisim circuit

Using the Multisim model, V2 value, representing a set point for voltage angle, was used to alter the phase-angle for the half-controlled rectifier circuit simulation. For the three selected phase angles, shown in the table below, values of t_1 were measured by placing cursors at the cross-over point, with the value of β calculated using the time taken to cross over. For t_2 , a cursor was moved along the waveform to the firing point of the thyristor, and the time it taken recorded for calculation of α (appendix 9.1 for t_1 and t_2 simulation times).

Half-Controlled Rectifier Simulated Values		
Phase Angle	Measured t_1 Value	Measured t_2 Value
120°	0.646ms	6.634ms
90°	2.230ms	4.990ms
60°	3.278ms	3.318ms

Table 15 - Simulation of a Half-Controlled Rectifier Circuit - Phase Angle Measured Values

Utilising the three firing angle values, the back EMF value of 120v, and circuit peak voltage value of 337.247v acquired from the full-wave, half-controlled rectifier simulation using calculations demonstrated in appendix 9.1, the information in the table below was calculated allowing comparison against simulated values.

Half-Controlled Rectifier Phase Angle Comparison Values							
Phase Angle				Voltage			
Simulated	Calculated	Difference	% Difference	Simulated	Calculated	Difference	% Difference
120°	119.412°	0.588°	0.49%	124.729v	126.491v	1.762v	1.39%
90°	89.82°	0.18°	0.20%	139.525v	140.8v	1.275v	0.91%
60°	59.724°	0.276°	0.46%	160.381v	161.95v	1.569v	0.97%

Table 16 - Simulation of a Half-Controlled Rectifier Circuit - Phase Value Comparison

From the table above and calculations in appendix 9.1, only the phase-angle and average armature voltage can be compared. Although differences exist between calculated and simulated results for all phase-angle comparable data, these are minimal and can be attributed to rounding of calculated values or positioning of cursors within the simulation. The comparable data for the average armature voltage however displays greater discrepancy, with the differences be attributable to two factors: rounding of calculated values or positioning of the cursors within the simulation, and/or more significantly certain levels of expected volt drops in thyristors of simulated circuits.

To simulate mechanical loading to the half-controlled rectifier simulation, a fixed firing angle of 75° was used. Three different back EMF values were selected by altering battery voltage, V3, and voltage and current waveforms displayed below recorded for each (see appendix 9.1).

Half-Controlled Rectifier Simulated Values	
Back EMF Value	Measured t2 Value
125v	0.646ms
100v	2.230ms
75v	3.278ms

Table 17 - Simulation of a Half-Controlled Rectifier Circuit - Back EMF Measured Values

Of the three selected values (see appendix 9.1), only the 75v back EMF simulation demonstrated continuous current, where the current waveform does not reach zero. As such average armature voltage was only calculated for this simulation (appendix 9.1 for calculations).

Half-Controlled Rectifier Back EMF Comparison Values							
Phase Angle				Voltage			
Simulated	Calculated	Difference	% Difference	Simulated	Calculated	Difference	% Difference
75°	74.484°	0.516°	0.069%	136.306	136.065	0.241v	0.0177%

Table 18 - Simulation of a Half-Controlled Rectifier Circuit - Back EMF Value Comparison

Demonstrated above are calculated and simulated phase-angles and armature voltages (appendix 9.1 for calculated values). Although differences exist between the values for both phase-angle and voltage, these are minimal, and can be attributed to rounding of calculated values or positioning of cursors within the simulation.

4. Practical Investigation into a Single Quadrant DC drive

A Parker 512C DC drive was connected to a DC motor with a Prony brake and measuring equipment, shown in appendix 9.2. A Picoscope was used to measure waveforms during the tests, the Prony brake to simulate loading for the motor, and a measuring device to measure motor speed. With the required safety precautions taken, the circuit was energised, and current and voltage waveforms recorded for the required testing. Firstly, the V_{pk} value of 336.3v was recorded, as shown in appendix 9.2, following which the first set of tests were conducted. Average armature voltage and current waveforms were recorded for three speed set points with the motor under no-load conditions (Prony brake not applied). Values of t_1 and t_2 were recorded as well as average armature voltage, shown in the table below (appendix 9.2 for test images).

Single Quadrant DC Drive Simulated No Load Values		
RPM	Measured t_1 Value	Measured t_2 Value
502	1.796ms	8.218ms
1003	0.816ms	7.619ms
1500	0.757ms	6.880ms

Table 19 - Practical Investigation into a Single Quadrant DC drive - No Load Measured Values

Using the table below and calculations in appendix 9.2, practical results can be compared to calculated values for average armature voltage. Although differences exist these are minimal and can be attributed to two factors; firstly positioning of the Picoscope trend line for average armature voltage within the practical test, and secondly, expected levels of volt drops due to thyristors within the Parker 512C.

Armature Voltage - No Load				
RPM	Simulated	Calculated	Difference	% Difference
502	35.9v	39.298v	3.398v	0.91%
1003	73.2v	73.999v	0.799v	0.99%
1500	105.8v	107.36v	1.56v	0.98%

Table 20 - Practical Investigation into a Single Quadrant DC drive - No Load Value Comparison

To gather voltage and current waveforms for the motor under loading conditions, a Prony brake was used to simulate mechanical loading. A speed set point of 1003RPM was set for the motor under no-load conditions. Three mechanical loading values of 0.5nm, 1.0nm and 1.5nm were then applied, with current and voltage waveforms recorded for each (appendix 9.2 for waveform images).

Single Quadrant DC Drive Simulated Loaded Values		
Loading	Measured Peak Voltage	Measured Peak Current
0.5nm	77.32v	1.193A
1.0nm	82.46v	2.1A
1.5nm	88.8v	3.556A

Table 21 - Practical Investigation into a Single Quadrant DC drive - Loading Values

Demonstrated above are measured peak voltage and currents recorded from the practical testing of the DC Motor test images in appendix 9.2). As the Prony brake is applied, simulating the motor under load conditions, the voltage and current increase at each loading set point in order to maintain motor speed. As motor loading is increased, current also increases, until continuous current is displayed at the loading set point of 1.5nm, shown below.

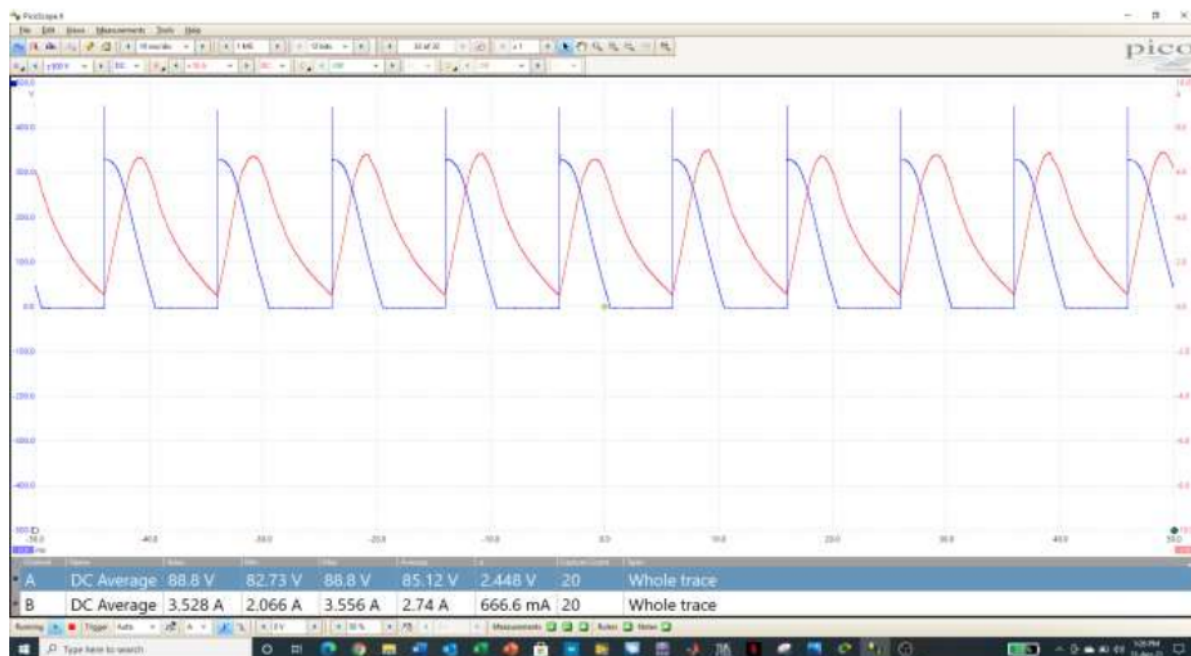


Figure 11 - Practical investigation into a Single quadrant DC Drive – Continuous Current

5. Simulation of a Medium Length Transmission Line

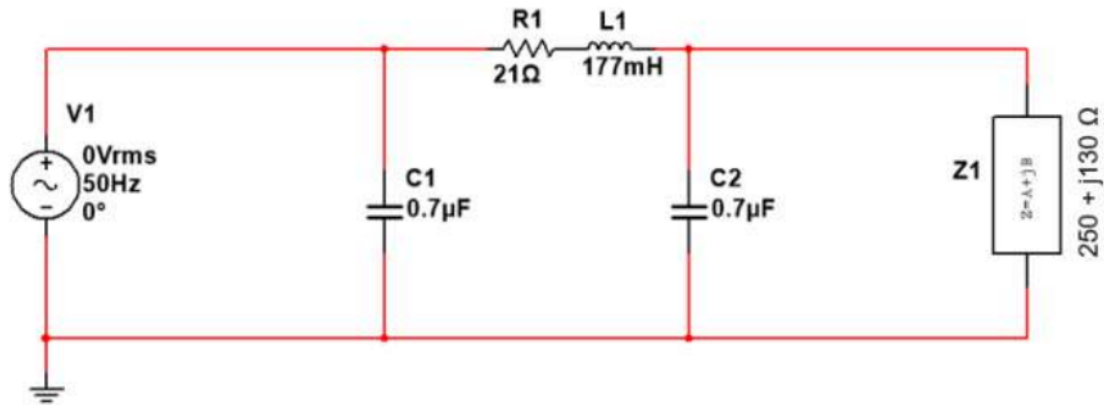


Figure 12 - Medium Length Transmission Line - Nominal Pie Equivalent Circuit

Illustrated above is the schematic of a nominal pie equivalent circuit using the given values below.

Nominal Pie Equivalent Circuit Values		
Resistance	R1	21Ω
Inductance	L1	177mH
Capacitance	C1 & C2	1.4μF
Load Impedance	Z1	250 + j 130Ω

Table 22 - Medium Length Transmission Line - Nominal Pie Equivalent Circuit Values

Using the nominal pie equivalent circuit given values, series impedance and shunt admittance were calculated and displayed below (see appendix 9.3).

Calculated Values		
	Cartesian	Polar
Series Impedance	21+j55.606Ω	59.44∠69.311°
Shunt Admittance	j439x10 ^{^-6}	439x10 ^{^-6} ∠90°

Table 23 - Medium Length Transmission Line - Calculated Series Impedance & shunt Admittance

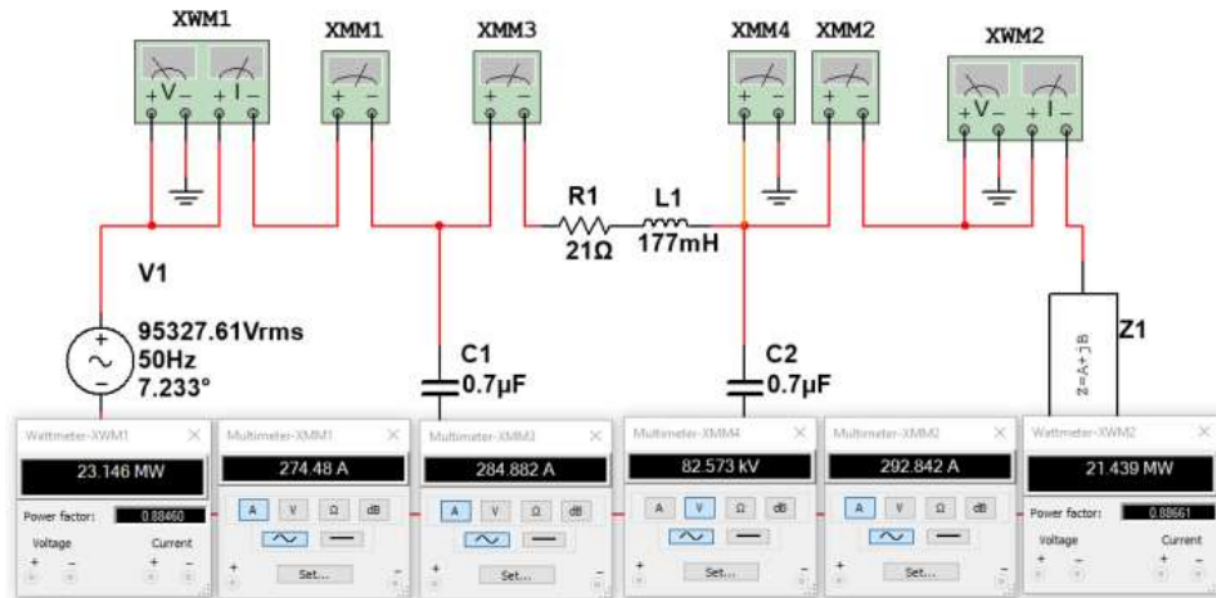


Figure 13 - Medium Length Transmission Line - Simulated Nominal Pie Circuit

Illustrated above, the simulated nominal pie circuit was constructed from the calculated sending end voltage values, (appendix 9.3). In the table below are calculated and simulated values. VSN values cannot be compared as the exact calculated value was required for the simulated value in order for the simulation to perform. Although differences exist between the results for the remaining measured data, these are negligible and can be attributed to rounding of calculated values to three and four decimal places.

Medium Length Transmission Line Value Comparison			
	Calculated	Simulated	Difference
Voltage Sending End	95327.61∠7.233° V	95327.61∠7.233° V	0
Current Sending End	274.844∠-20.502° A	274.48A	0.364A
Power factor (Sending End)	0.8851 Lagging	0.88460 Lagging	0.0005
I1	285.214∠-24.241° A	284.884A	0.67A
Voltage Receiving End	82596V	82573V	23V
Current Receiving End	293.124A	292.842A	0.282A
Power factor Receiving End	0.88722 Lagging	0.88661 Lagging	0.00061

Table 24 - Medium Length Transmission Line - Value Comparison

Medium Length Transmission Line Efficiency Comparison				
	Calculated		Simulated	Difference
Power Sending End	23.19MW		23.146MW	0.044MW
Power Receiving End	21.48MW		21.439MW	0.041MW
	Sending End	Receiving End	Difference	Percentage
Calculated Efficiency	23.19MW	21.48MW	1.71MW	92.63%
Simulated Efficiency	23.146MW	21.439MW	1.707MW	92.63%

Table 25 - Medium Length Transmission Line - Efficiency Comparison

Illustrated above are calculated and simulated transmission line efficiency values (see appendix 9.3). Although differences exist between values for power at the sending and receiving ends, both simulated and calculated circuits have the same percentage of efficiency, suggesting the minor discrepancies can be attributed to rounding of calculated values to three and four decimal places.

6. Conclusions and Recommendations

With the design, build, simulation and practical elements of the half-controlled rectifier, single-quadrant DC drive and transmission line successfully executed, the project was considered a success. In all tasks the similarity between the results predicted by calculations, and those obtained from the simulations or practical experiments proved the theory, *what theory?* demonstrating the accuracy of calculated results, and the that the response of the rectifier circuit and DC drive in response to changes in phase firing angles and motor loading, and motor speed and mechanical loading respectively, *how?* was as depicted in the literature. Similar results were seen with the investigation into transmission line efficiencies, with comparison of calculated and simulated responses proving the theory, *what did the theory say?* again demonstrating the usefulness of calculations in prediction of performance.

This was also an opportunity to explain what you have learned not just a review of how successful the assignment has been which is more of a reflection.

As with most projects involving theoretical or predicted values, small differences between results, as seen here, are expected. The discrepancies identified were however minimal, and likely to be a result of factors such as simple rounding of figures or user familiarity with software and/or equipment e.g. fine positing of cursors, and therefore do not indicate failures in the predictions made or execution.

Recommendations for further improvements would firstly relate to the practical element, whereby time spent to familiarise with the equipment and software prior to execution may have improved result accuracy especially in relation to positioning of the cursors on the Picoscope. It would also be of interest to progress the line transmission element to include practical execution, enabling comparison of simulation results. However, it is recognised that for safety and practicality reasons a significant reduction in voltage and cable lengths would be required.

7. Team Working

Due to the current pandemic team working was limited, PPE and social distancing safety measures required during the practical elements to ensure compliance with government guidelines. To optimise team working in this situation, and maintain safe but effective ways of working, each group member would undertake their task(s), and information then shared where required using a social network group.

8. Reference List

Cavallo, C., 2021. *www.thomasnet.com*. [Online]

Available at: <https://www.thomasnet.com/articles/instruments-controls/dc-motor-controllers/>

[Accessed 30 03 2021].

Control_Automation, 2021. *www.control.com*. [Online]

Available at: <https://control.com/textbook/variable-speed-motor-controls/dc-motor-speed-control/>

[Accessed 02 04 2021].

Control, 2020. *www.controlglobal.com*. [Online]

Available at: <https://www.controlglobal.com/blogs/guest-blogs/advantages-of-dc-motors-in-industrial-applications/>

[Accessed 27 03 2021].

EEGuide, 2021. *www.eeguide.com*. [Online]

Available at: <https://www.eeguide.com/dc-machine-applications/>

[Accessed 01 04 2021].

electrical4u, 2020. *www.electrical4u.com*. [Online]

Available at: <https://www.electrical4u.com/dc-motor-drives/>

[Accessed 30 03 2021].

Electrical4u, 2020. *www.electrical4u.com*. [Online]

Available at: <https://www.electrical4u.com/speed-control-of-dc-motor/>

[Accessed 01 4 2021].

Electrical4U, 2021. *www.electrical4u.com*. [Online]

Available at: <https://www.electrical4u.com/types-of-dc-motor-separately-excited-shunt-series-compound-dc-motor/>

[Accessed 02 04 2021].

Electronics, 2020. *www.mdpi.com*. [Online]

Available at: <https://www.mdpi.com/2079-9292/9/6/887/htm>

[Accessed 30 03 2021].

Elprocus., 2021. *www.elprocus.com*. [Online]

Available at: <https://www.elprocus.com/what-are-the-best-ways-to-control-the-speed-of-dc-motor>

[Accessed 27 03 2021].

Elprocus, 2021. *www.elprocus.com*. [Online]

Available at: <https://www.elprocus.com/dc-machine-types-and-their-applications/>

[Accessed 27 03 2021].

EtechnoG, 2021. *www.etechnog.com*. [Online]

Available at: <https://www.etechnog.com/2018/11/can-dc-motor-run-on-ac-supply-and-vice-versa.html>

[Accessed 02 04 2021].

Ikimi.O, 2020. *www.allaboutcircuits.com*. [Online]

Available at: <https://www.allaboutcircuits.com/news/a-basic-guide-to-dc-motors-types-of-motors-operation-modes-and-their-applications/>

[Accessed 30 03 2021].

Kimbrell, J., 2016. *www.processingmagazine.com*. [Online]

Available at: <https://www.processingmagazine.com/pumps-motors-drives/article/15586862/the-dc-motor-advantage>

[Accessed 30 03 2021].

MaximIC, 2021. *www.mouser.co.uk*. [Online]

Available at: https://www.mouser.co.uk/applications/industrial_motor_control_overview/

[Accessed 29 03 2021].

Maxon, 2021. *https://drive.tech/en*. [Online]

Available at: <https://drive.tech/en/stream-content/id-1-q-vs-4-q-controllers>

[Accessed 04 04 2021].

Motor, O. E., 2021. *www.ohioelectricmotors.com*. [Online]

Available at: <https://www.ohioelectricmotors.com/2015/07/a-guide-to-electric-drives-and-dc-motor-control/>

[Accessed 05 04 2021].

MPLGMG, 2018. *www.electricalpowerenergy.com*. [Online]

Available at: <http://www.electricalpowerenergy.com/2018/02/types-of-dc-motor/>

[Accessed 29 03 2021].

Parker, 2016. *www.parker.com*. [Online]

Available at: <https://www.parker.com/Literature/SSD%20Drives/DC%20Drives/HA389196.pdf>

[Accessed 15 04 2021].

Sushmita, 2021. *www.engineeringenotes.com*. [Online]

Available at: <https://www.engineeringenotes.com/electrical-engineering/electric-motors/single-phase-drives-for-controlling-dc-motors-electrical-engineering/37040>

[Accessed 05 02 2021].

9. Appendix

9.1. Simulation of a Half-Controlled Rectifier Circuit

120-Degree angle simulation

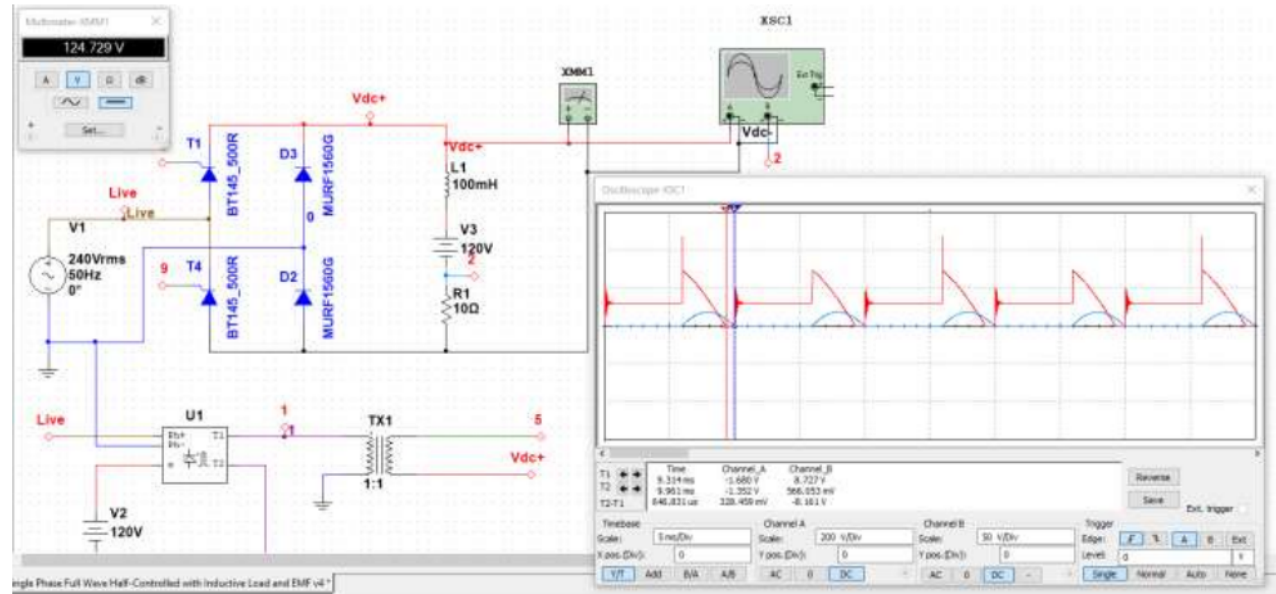


Figure 14 - Simulation of a Half-Controlled Rectifier Circuit - t1 at 120 degree

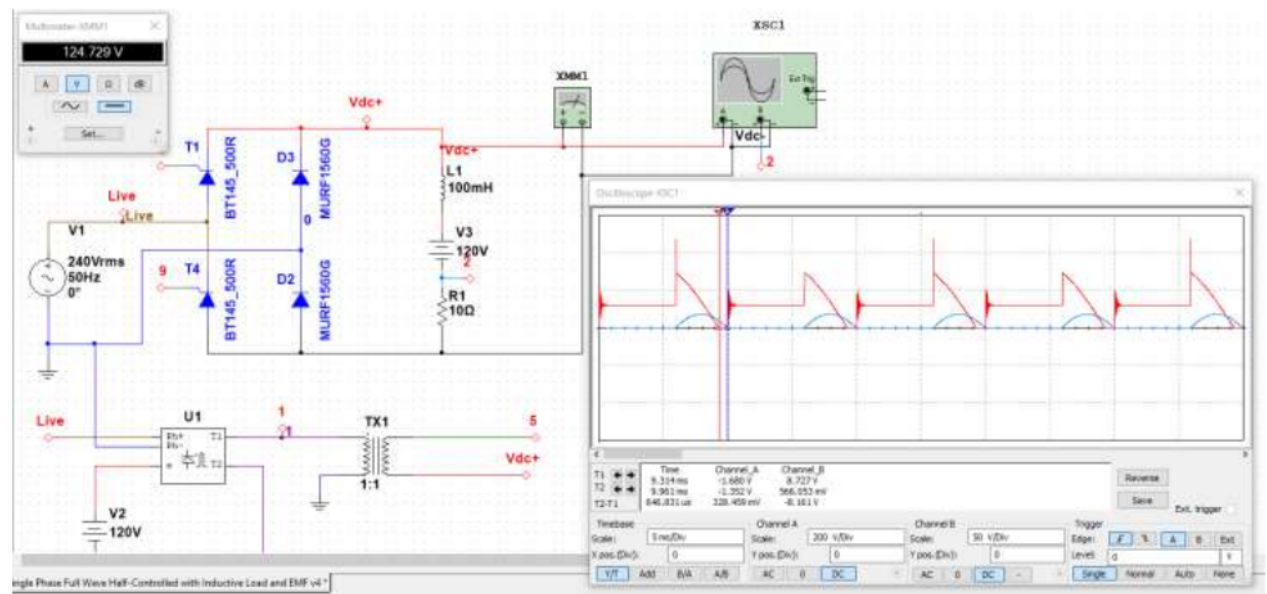


Figure 15 - Simulation of a Half-Controlled Rectifier Circuit - t2 at 120 degree

120 Degree calculations

$$\frac{1}{f} = \frac{1}{50} = 20\text{ms half cycle} = 20 \times 0.5 = 10\text{ms}$$

Equation 1 - Simulation of a Half-Controlled Rectifier Circuit - 120 Degree Half Cycle Time

$$\beta = \left(\frac{t1}{\text{Half Cycle}} \right) \times \pi = \left(\frac{0.646 \times 10^{-3}}{10} \right) \times \pi = 0.2029 \text{ rad}$$

Equation 2 - Simulation of a Half-Controlled Rectifier Circuit - 120 Degree β Value

$$\alpha = \left(\frac{t2}{\text{Half Cycle}} \right) \times \pi = \left(\frac{6.634 \times 10^{-3}}{10} \right) \times \pi = 2.0841 \text{ rad}$$

Equation 3 - Simulation of a Half-Controlled Rectifier Circuit - 120 Degree α Value

Average Voltage

$$v_{av} = \frac{1}{\pi} \left\{ E(\alpha - \beta) + \int_{\alpha}^{\pi} V_{pk} \sin \theta d\theta \right\} = \frac{E}{\pi} (\alpha - \beta) + \frac{V_{pk}}{\pi} (1 + \cos(\alpha))$$

$$= \frac{120}{\pi} (2.0841 - 0.2029) + \frac{337.247}{\pi} (1 + \cos(2.0841)) = 71.8565 + 54.6345 = 126.491 \text{ v}$$

Equation 4 - Simulation of a Half-Controlled Rectifier Circuit - 120 Degree Average Voltage

Phase Angle

$$t2 \times 180^\circ = 0.6634 \times 180 = 119.412^\circ$$

Equation 5 - Simulation of a Half-Controlled Rectifier Circuit - 120 Degree Phase Angle

90-Degree angle simulation

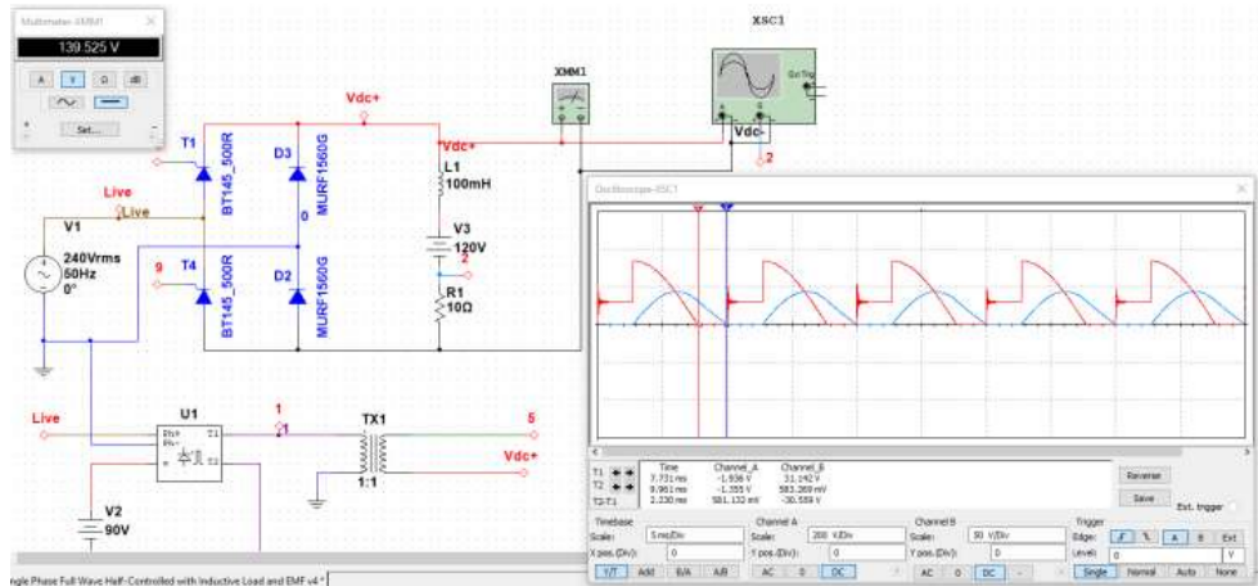


Figure 16 - Simulation of a Half-Controlled Rectifier Circuit - t1 at 90 degree

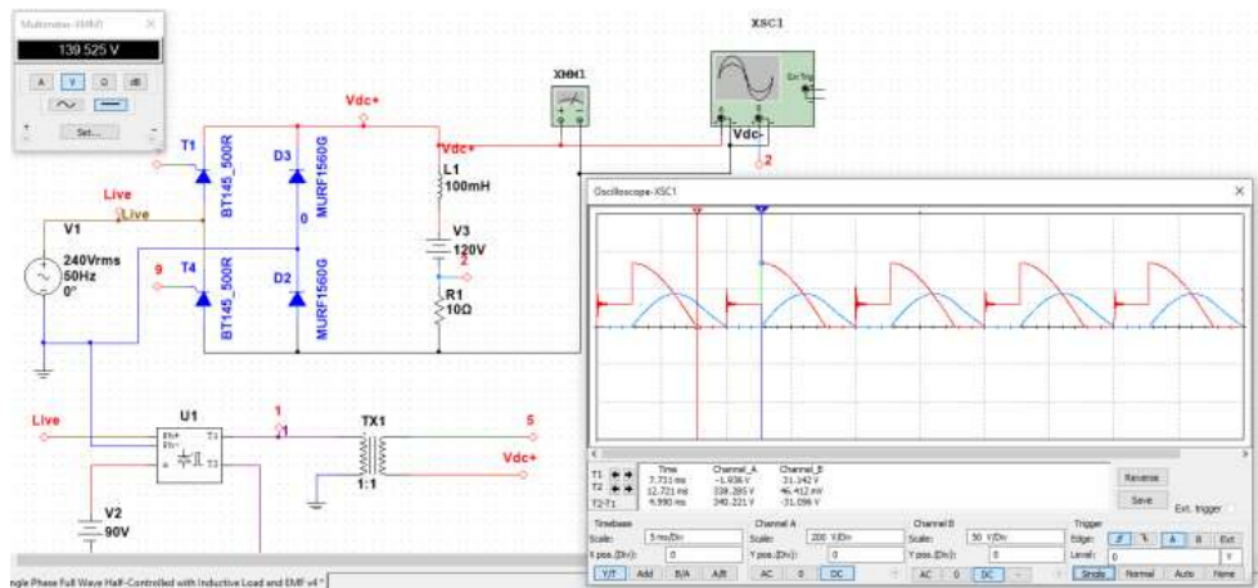


Figure 17 - Simulation of a Half-Controlled Rectifier Circuit - t_2 at 90 degree

90 Degree calculations

$$\frac{1}{f} = \frac{1}{50} = 20\text{ms half cycle} = 20 \times 0.5 = 10\text{ms}$$

Equation 6 - Simulation of a Half-Controlled Rectifier Circuit - 90 Degree Half Cycle Time

$$\beta = \left(\frac{t_1}{\text{Half Cycle}} \right) \times \pi = \left(\frac{2.23 \times 10^{-3}}{10} \right) \times \pi = 0.7006 \text{ rad}$$

Equation 7 - Simulation of a Half-Controlled Rectifier Circuit - 90 Degree β Value

$$\alpha = \left(\frac{t_2}{\text{Half Cycle}} \right) \times \pi = \left(\frac{4.99 \times 10^{-3}}{10} \right) \times \pi = 1.5677 \text{ rad}$$

Equation 8 - Simulation of a Half-Controlled Rectifier Circuit - 90 Degree α Value

Average Voltage

$$v_{av} = \frac{1}{\pi} \left\{ E(\alpha - \beta) + \int_{\alpha}^{\pi} V_{pk} \sin \theta d\theta \right\} = \frac{E}{\pi} (\alpha - \beta) + \frac{V_{pk}}{\pi} (1 + \cos(\alpha))$$

$$= \frac{120}{\pi} (1.5677 - 0.7006) + \frac{337.247}{\pi} (1 + \cos(1.5678)) = 33.1208 + 107.6814 = 140.8 \text{ v}$$

Equation 9 - Simulation of a Half-Controlled Rectifier Circuit - 90 Degree Average Voltage

Phase Angle

$$t_2 \times 180^\circ = 0.499 \times 180 = 89.82^\circ$$

Equation 10 - Simulation of a Half-Controlled Rectifier Circuit - 90 Degree Phase Angle

60-Degree angle simulation

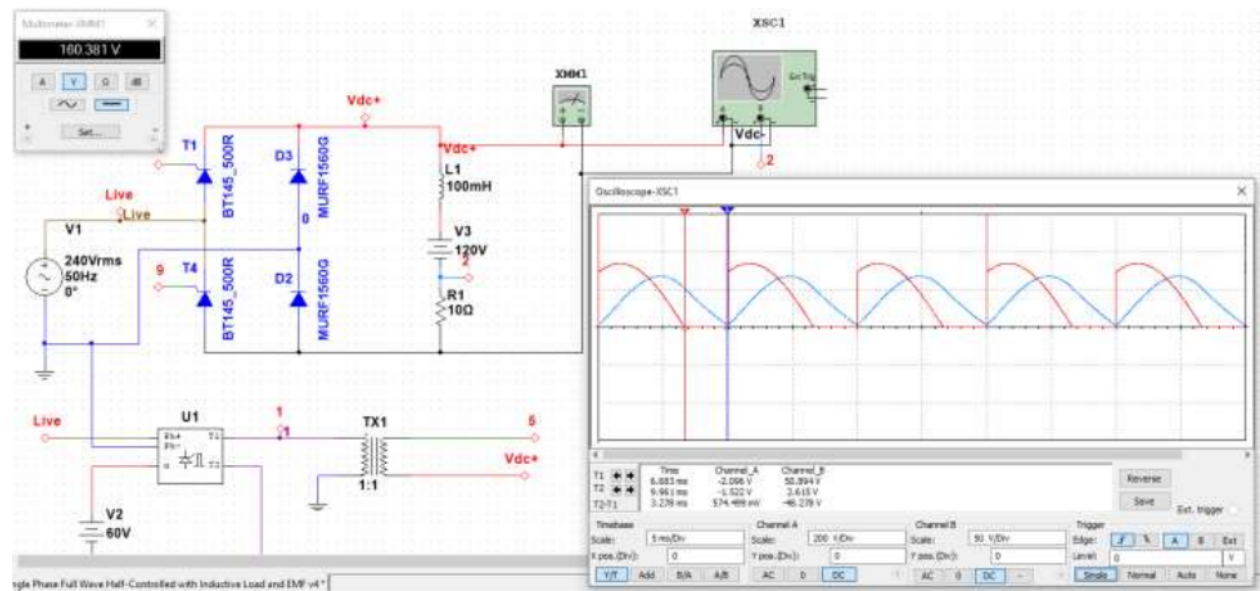


Figure 18 - Simulation of a Half-Controlled Rectifier Circuit - t1 at 60 degree

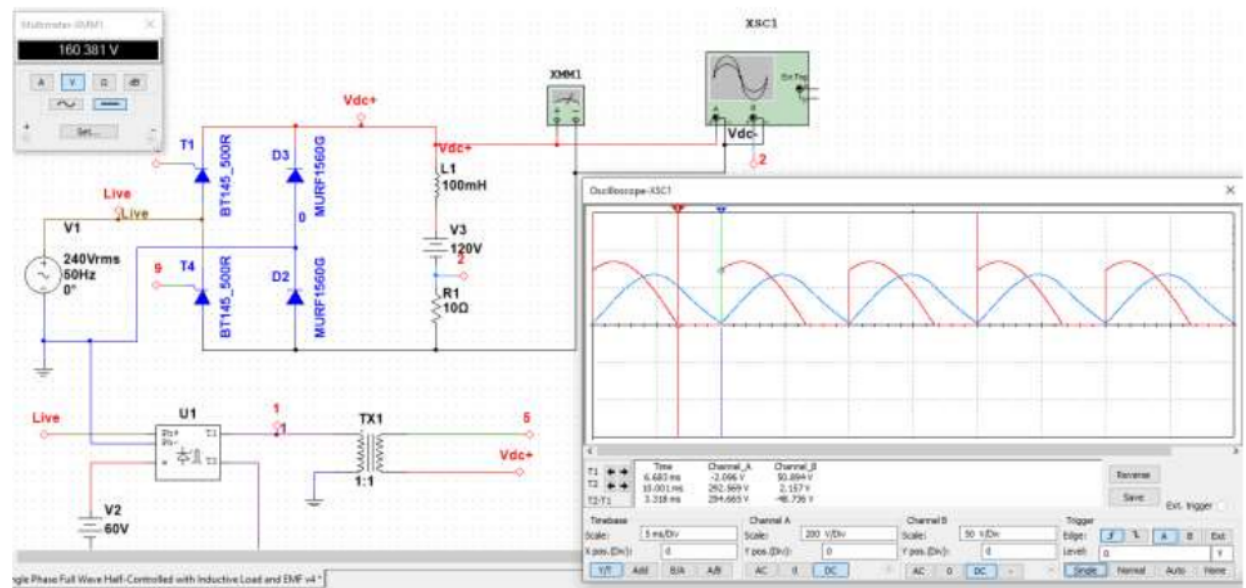


Figure 19 - Simulation of a Half-Controlled Rectifier Circuit - t2 at 60 degree

60 Degree calculations

$$\frac{1}{f} = \frac{1}{50} = 20\text{ms half cycle} = 20 \times 0.5 = 10\text{ms}$$

Equation 11 - Simulation of a Half-Controlled Rectifier Circuit - 60 Degree Half Cycle Time

$$\beta = \left(\frac{t1}{\text{Half Cycle}} \right) \times \pi = \left(\frac{3.278 \times 10^{-3}}{10} \right) \times \pi = 1.0298 \text{ rad}$$

Equation 12 - Simulation of a Half-Controlled Rectifier Circuit - 60 Degree β Value

$$\alpha = \left(\frac{t2}{\text{Half Cycle}} \right) \times \pi = \left(\frac{3.318 \times 10^{-3}}{10} \right) \times \pi = 1.0424 \text{ rad}$$

Equation 13 - Simulation of a Half-Controlled Rectifier Circuit - 60 Degree α Value

Average Voltage

$$v_{av} = \frac{1}{\pi} \left\{ E(\alpha - \beta) + \int_{\alpha}^{\pi} V_{pk} \sin \theta d\theta \right\} = \frac{E}{\pi} (\alpha - \beta) + \frac{V_{pk}}{\pi} (1 + \cos(\alpha))$$

$$= \frac{120}{\pi} (1.0424 - 1.0298) + \frac{337.247}{\pi} (1 + \cos(1.0424)) = 0.4813 + 161.4689 = 161.95 \text{ v}$$

Equation 14 - Simulation of a Half-Controlled Rectifier Circuit - 60 Degree Average Voltage

Phase Angle

$$t2 \times 180^\circ = 0.3318 \times 180 = 59.724^\circ$$

Equation 15 - Simulation of a Half-Controlled Rectifier Circuit - 60 Degree Phase Angle

Circuit voltage peak - $V_{pk} = 337.247\text{v}$

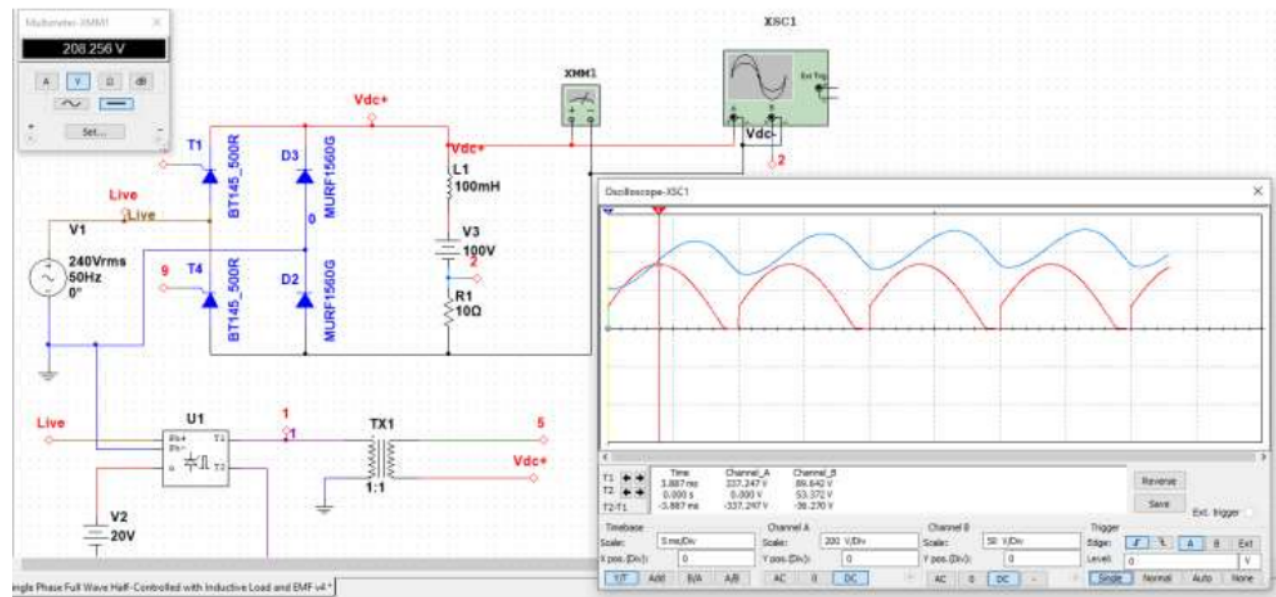


Figure 20 - Simulation of a Half-Controlled Rectifier Circuit - V peak Value

Back EMF = 120v

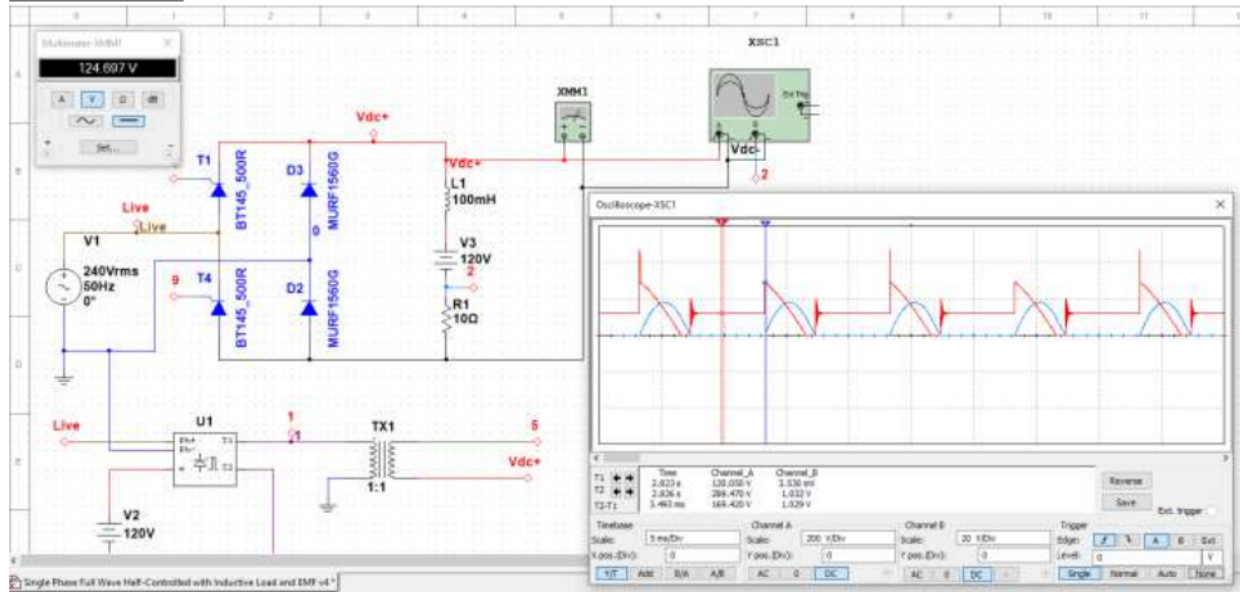


Figure 21 - Simulation of a Half-Controlled Rectifier Circuit - Back EMF Value

Half Cycle = 10ms

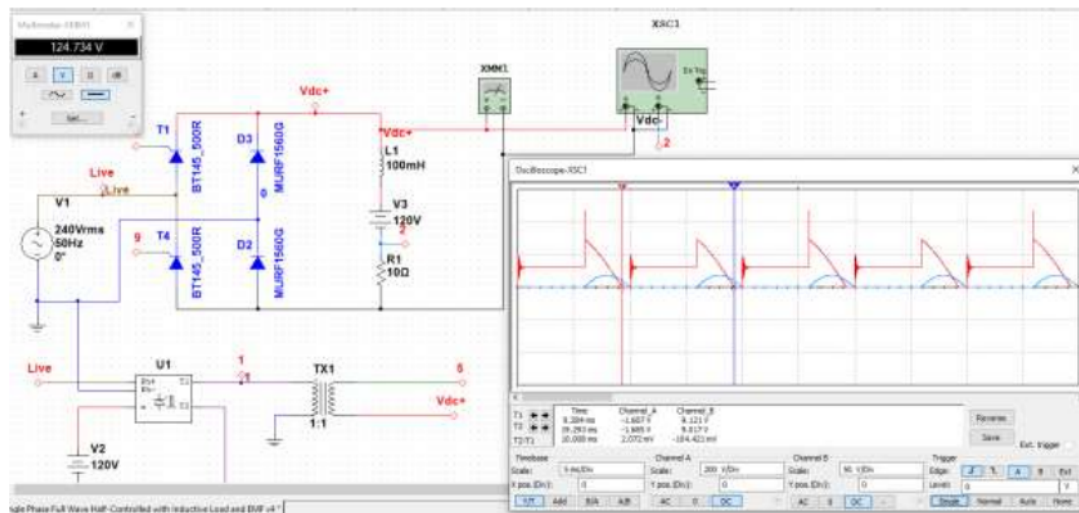


Figure 22 - Simulation of a Half-Controlled Rectifier Circuit - Half Cycle Time

125v Back EMF with firing Angle of 75 Degree

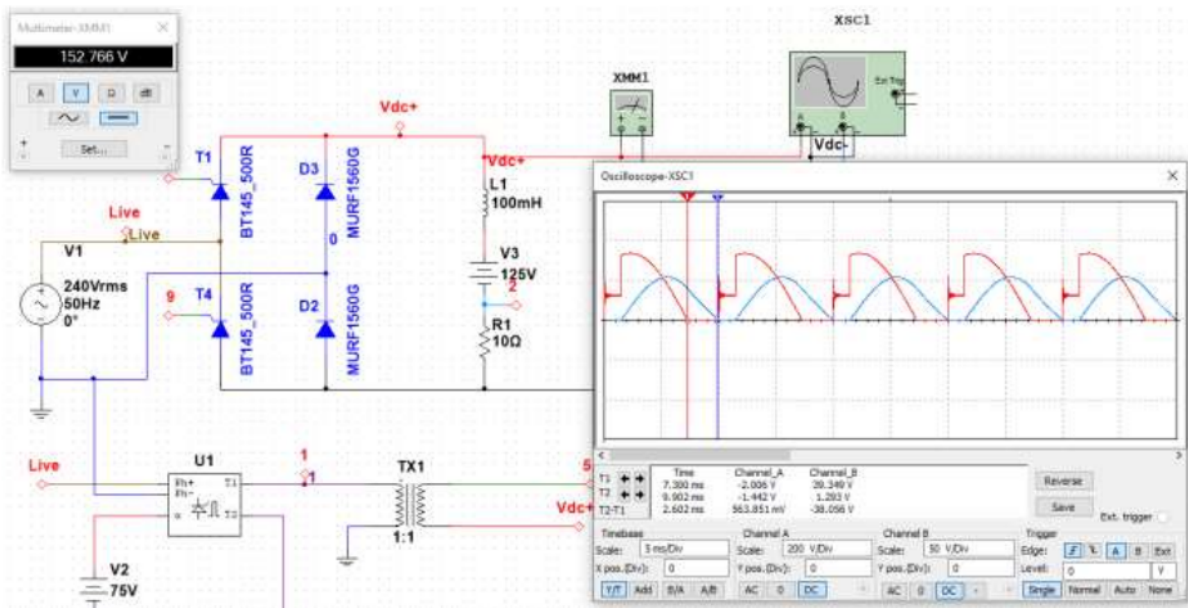


Figure 23 - Simulation of a Half-Controlled Rectifier Circuit - 125v Back EMF

100v Back EMF with firing Angle of 75 Degree

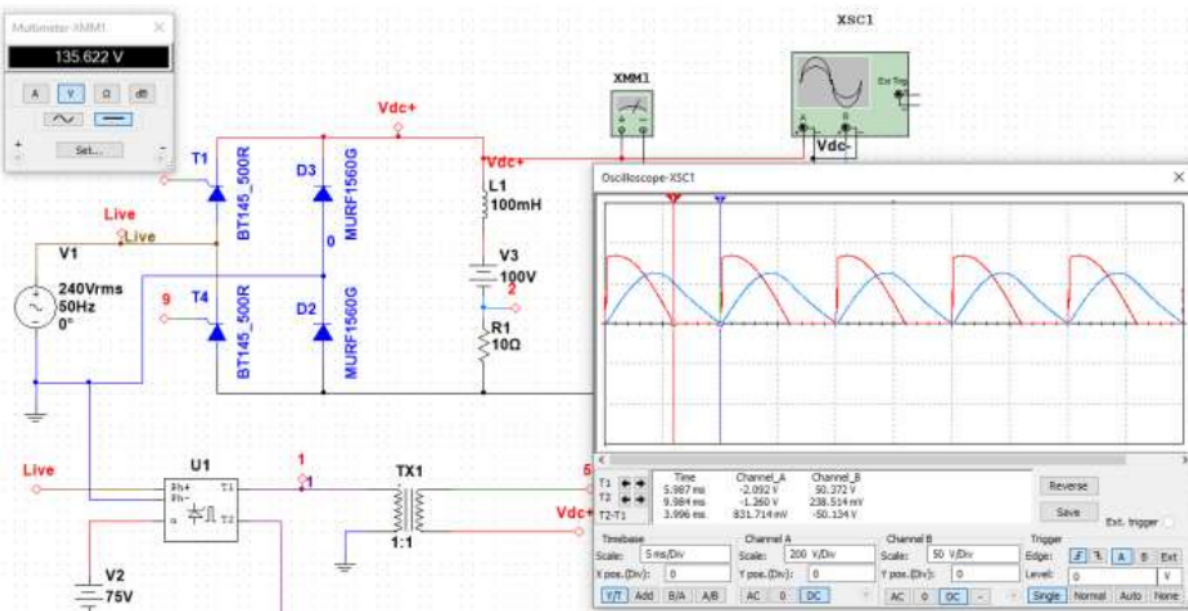


Figure 24 - Simulation of a Half-Controlled Rectifier Circuit - 100v Back EMF

75v Back EMF with firing Angle of 75 Degree

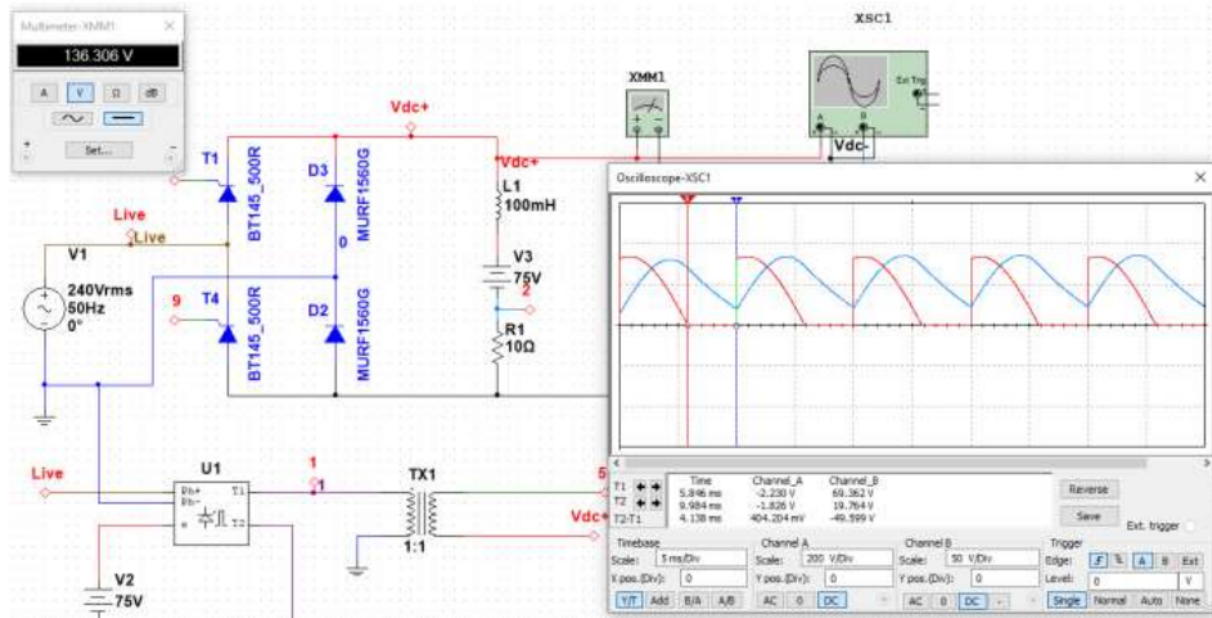


Figure 25 - Simulation of a Half-Controlled Rectifier Circuit - 75v Back EMF

75v Back EMF Calculations

$$\frac{1}{f} = \frac{1}{50} = 20\text{ms half cycle} = 20 \times 0.5 = 10\text{ms}$$

Equation 16 - Simulation of a Half-Controlled Rectifier Circuit - Half Cycle Time

$$\alpha = \left(\frac{t_2}{\text{Half Cycle}} \right) \times \pi = \left(\frac{4.138 \times 10^{-3}}{10} \right) \times \pi = 1.3 \text{ rad}$$

Equation 17 - Simulation of a Half-Controlled Rectifier Circuit - 75 Degree α Value

Average Voltage

$$\begin{aligned} v_{av} &= \frac{V_{pk}}{\pi} (1 + \cos(\alpha)) \\ &= \frac{337.247}{\pi} (1 + \cos(1.3)) = 136.065 \text{ v} \end{aligned}$$

Equation 18 - Simulation of a Half-Controlled Rectifier Circuit - 60 Degree Average Voltage

Phase Angle

$$t_2 \times 180^\circ = 0.4138 \times 180 = 74.484^\circ$$

Equation 19 - Simulation of a Half-Controlled Rectifier Circuit - 60 Degree Phase Angle

9.2. Practical investigation into a Single quadrant DC Drive



Figure 26 - Practical investigation into a Single quadrant DC Drive - Practical Setup



Figure 27 - Practical investigation into a Single quadrant DC Drive - Parker 512C

Circuit voltage peak - $V_{pk} = 336.3v$

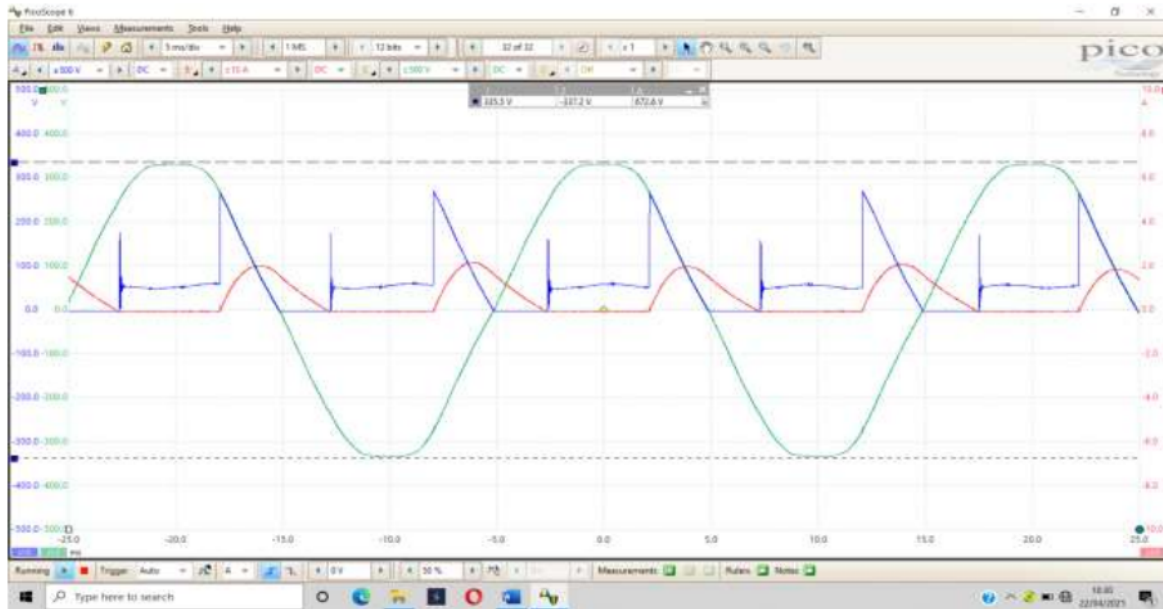


Figure 28 - Practical investigation into a Single quadrant DC Drive - V Peak Value

$$V_{pk} = \frac{672.6}{2} = 336.3 v$$

Equation 20 - Practical investigation into a Single quadrant DC Drive - V Peak Value

Average Armature Voltage 503RPM

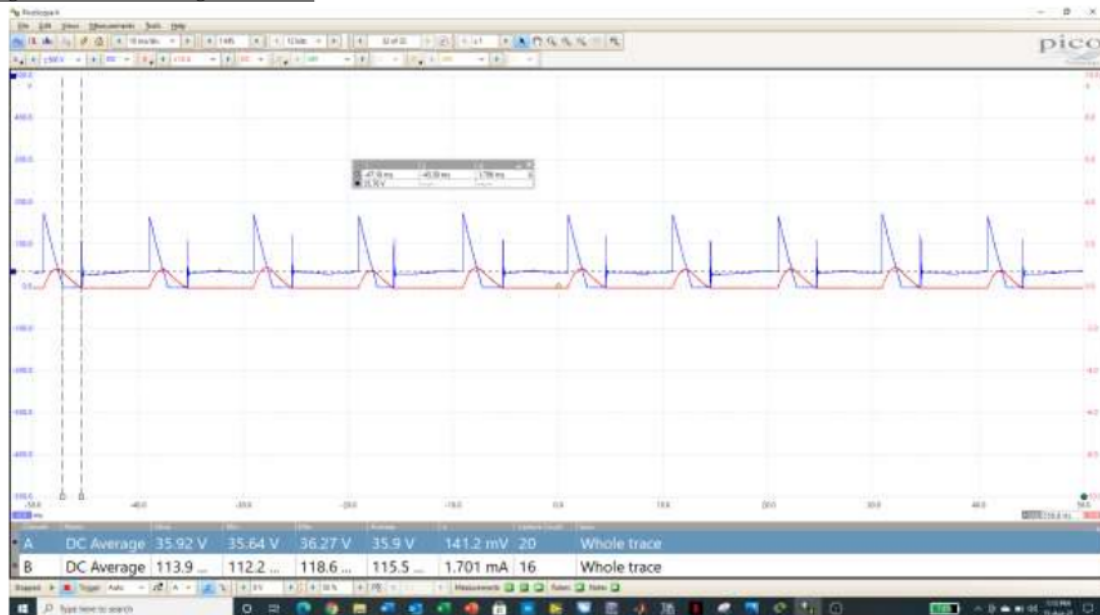


Figure 29 - Practical investigation into a Single quadrant DC Drive - t1 at 502RPM

Average Armature Voltage 1002RPM

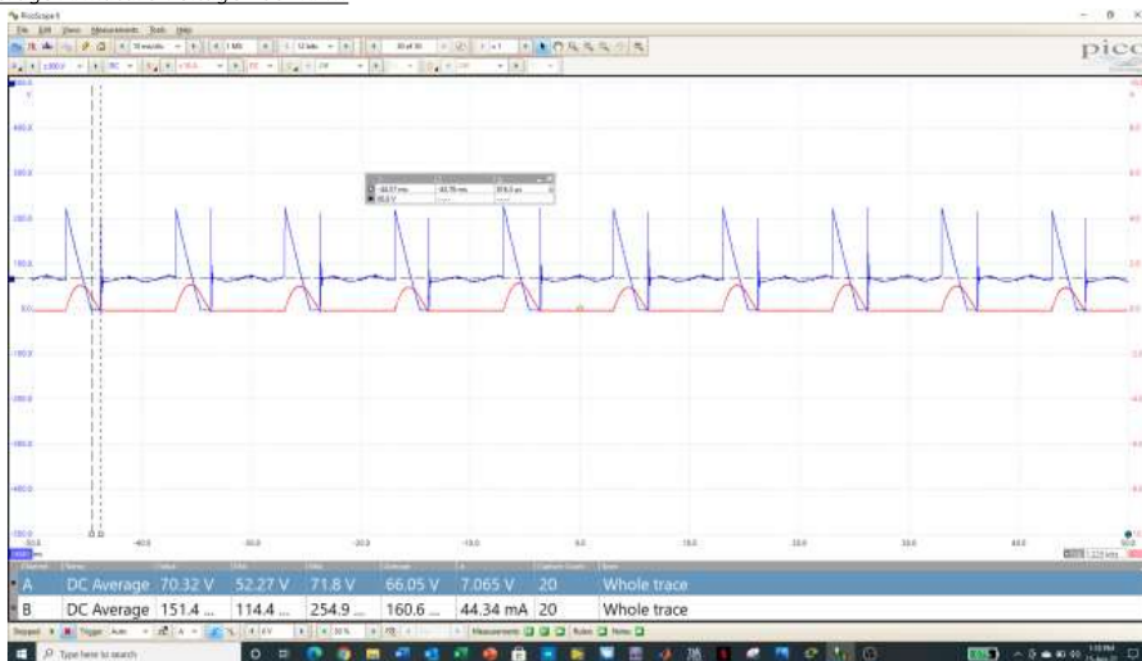


Figure 31 - Practical investigation into a Single quadrant DC Drive - t1 at 1003RPM

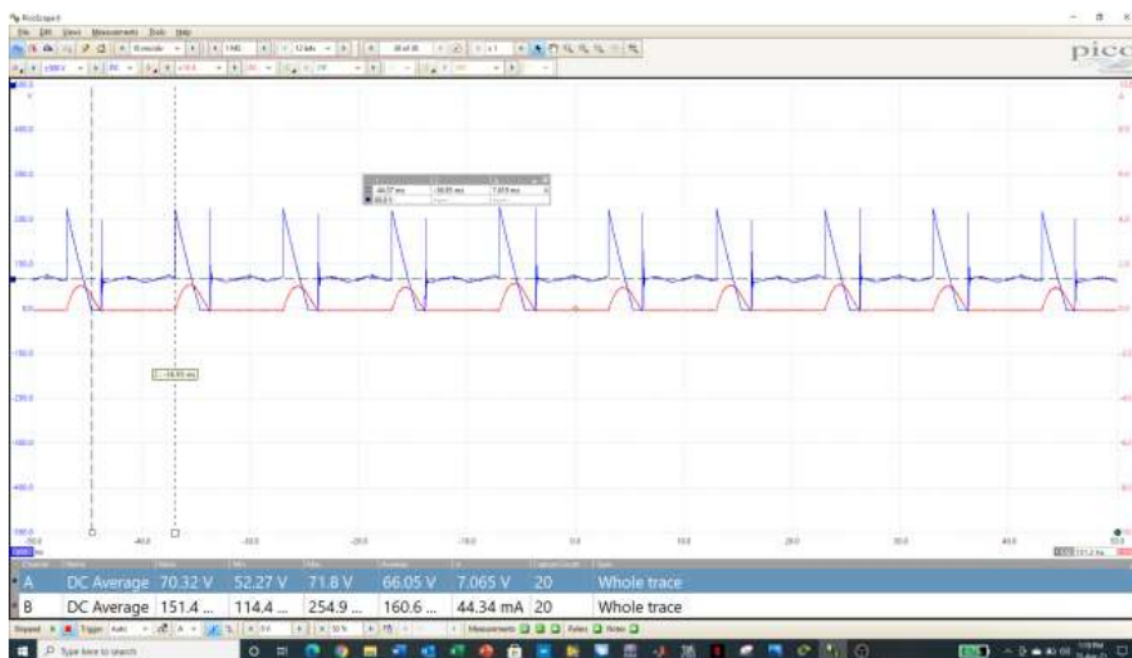


Figure 32 - Practical investigation into a Single quadrant DC Drive - t2 at 1003RPM

1003RPM Calculations

$$\frac{1}{f} = \frac{1}{50} = 20\text{ms half cycle} = 20 \times 0.5 = 10\text{ms}$$

Equation 25 - Practical investigation into a Single quadrant DC Drive - Half Cycle Time

$$\beta = \left(\frac{t1}{\text{Half Cycle}} \right) \times \pi = \left(\frac{0.816 \times 10^{-3}}{10} \right) \times \pi = 0.2564 \text{ rad}$$

Equation 26 - Practical investigation into a Single quadrant DC Drive - 1003 RPM β Value

$$\alpha = \left(\frac{t2}{\text{Half Cycle}} \right) \times \pi = \left(\frac{7.619 \times 10^{-3}}{10} \right) \times \pi = 2.394 \text{ rad}$$

Equation 27 - Practical investigation into a Single quadrant DC Drive - 1003RPM α Value

Average Voltage

$$v_{av} = \frac{1}{\pi} \left\{ E(\alpha - \beta) + \int_{\alpha}^{\pi} V_{pk} \sin \theta d\theta \right\} = \frac{E}{\pi}(\alpha - \beta) + \frac{V_{pk}}{\pi}(1 + \cos(\alpha))$$

$$= \frac{66.8}{\pi}(2.394 - 0.2564) + \frac{336.3}{\pi}(1 + \cos(2.394)) = 45.452 + 28.547 = 73.999 \text{ v}$$

Equation 28 - Practical investigation into a Single quadrant DC Drive - 1003RPM Average Armature Voltage

Average Armature Voltage 1500RPM

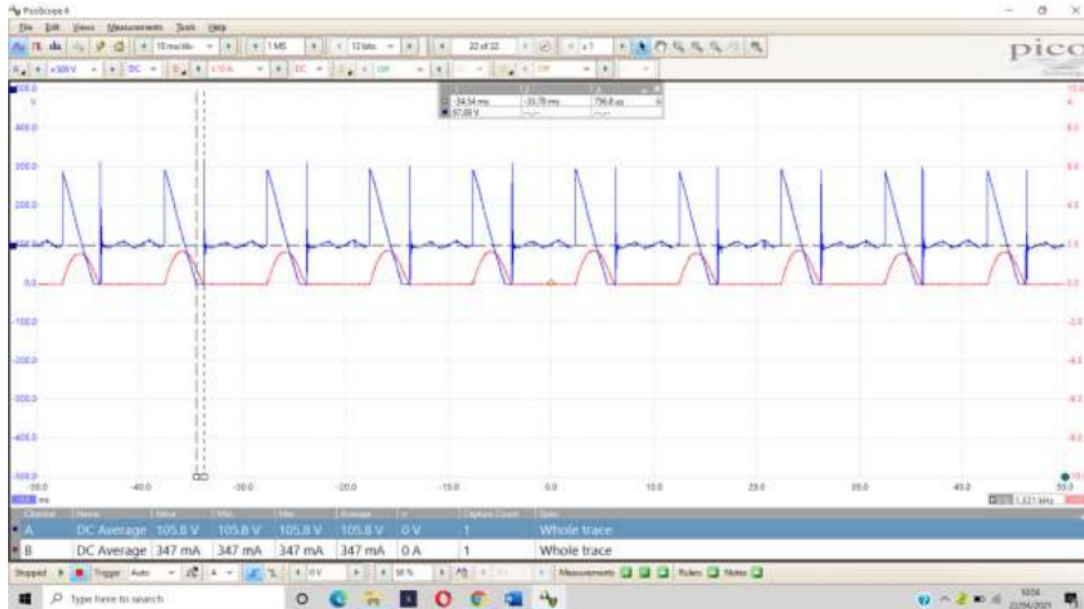


Figure 33 - Practical investigation into a Single quadrant DC Drive - t_1 at 1500RPM

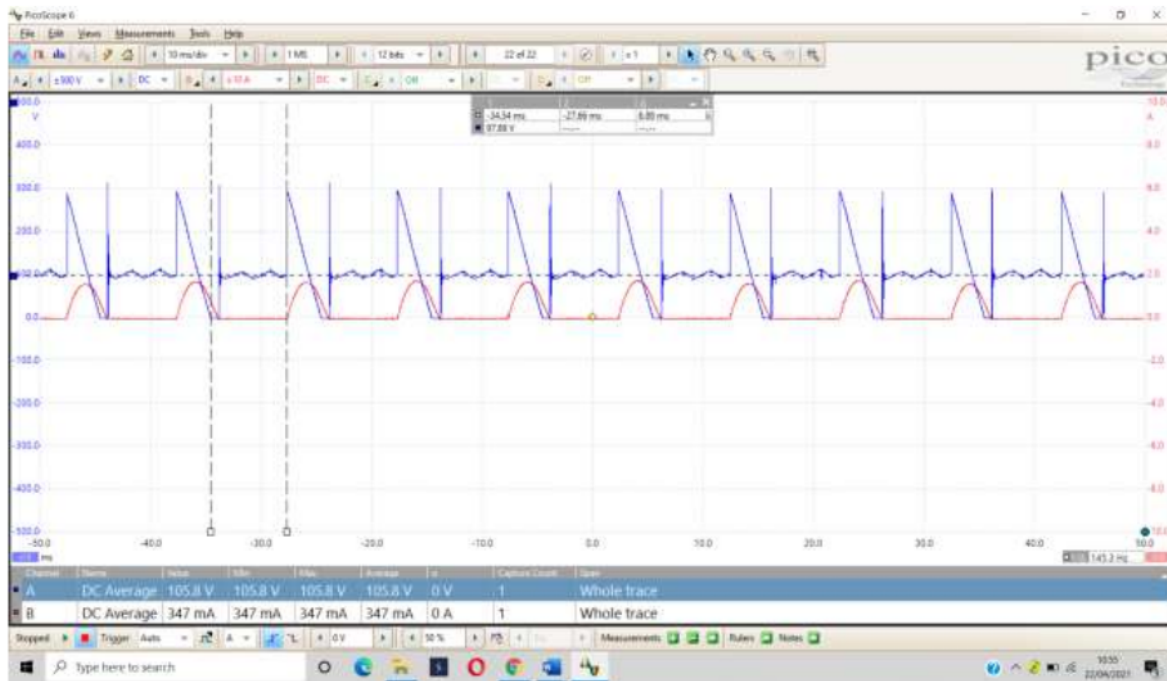


Figure 34 - Practical investigation into a Single quadrant DC Drive - t_2 at 1500RPM

1500RPM Calculations

$$\frac{1}{f} = \frac{1}{50} = 20\text{ms half cycle} = 20 \times 0.5 = 10\text{ms}$$

Equation 29 - Practical investigation into a Single quadrant DC Drive - Half Cycle Time

$$\beta = \left(\frac{t_1}{\text{Half Cycle}} \right) \times \pi = \left(\frac{0.757 \times 10^{-3}}{10} \right) \times \pi = 0.239 \text{ rad}$$

Equation 30 - Practical investigation into a Single quadrant DC Drive - 1500 RPM β Value

$$\alpha = \left(\frac{t_2}{\text{Half Cycle}} \right) \times \pi = \left(\frac{6.88 \times 10^{-3}}{10} \right) \times \pi = 2.161 \text{ rad}$$

Equation 31 - Practical investigation into a Single quadrant DC Drive - 1500RPM α Value

Average Voltage

$$\begin{aligned} v_{av} &= \frac{1}{\pi} \left\{ E(\alpha - \beta) + \int_{\alpha}^{\pi} V_{pk} \sin \theta d\theta \right\} = \frac{E}{\pi} (\alpha - \beta) + \frac{V_{pk}}{\pi} (1 + \cos(\alpha)) \\ &= \frac{105.8}{\pi} (2.161 - 0.239) + \frac{336.3}{\pi} (1 + \cos(2.394)) = 59.888 + 47.472 = 107.36 \text{ v} \end{aligned}$$

Equation 32 - Practical investigation into a Single quadrant DC Drive - 1500RPM Average Armature Voltage

Mechanical Loading 0.5nm

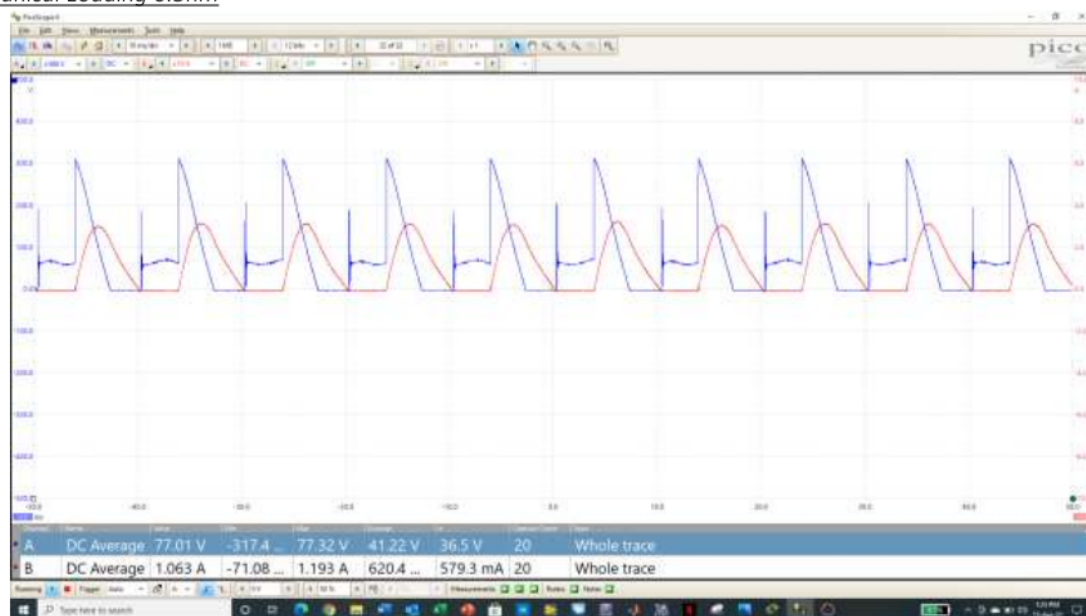


Figure 35 - Practical investigation into a Single quadrant DC Drive - Loading of 0.5nm

Mechanical Loading 1.0nm

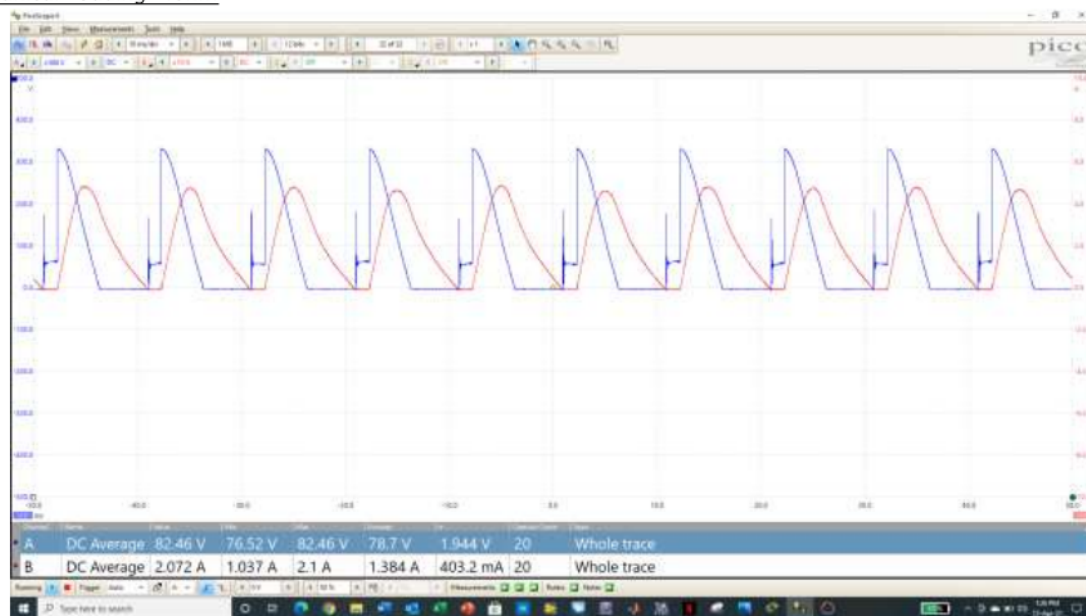


Figure 36 - Practical investigation into a Single quadrant DC Drive - Loading of 1.0nm

Mechanical Loading 1.5nm

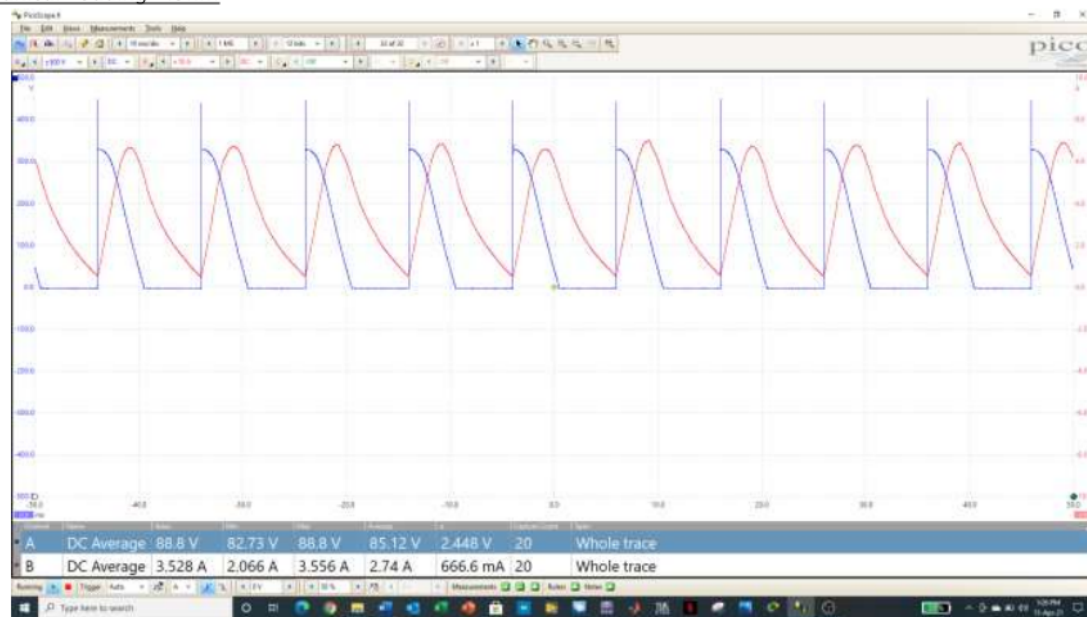


Figure 37 - Practical investigation into a Single quadrant DC Drive - Loading of 1.5nm

9.3. Simulation of a Medium Length Transmission Line

Series Impedance

$$Z_s = 21 + j\omega \times 177 \times 10^{-3} = 21 + j \times 2\pi \times 50 \times 177 \times 10^{-3} = 21 + j55.606\Omega$$

Equation 33 - Medium Length Transmission Line - Series Impedance, Cartesian

Converted from Cartesian to Polar:

$$Z_s = \sqrt{21^2 + 55.606^2} = 59.44$$

$$\tan^{-1}\left(\frac{55.606}{21}\right) = 69.311^\circ = 59.44 \angle 69.311^\circ$$

Equation 34 - Medium Length Transmission Line - Series Impedance, Polar

Shunt Admittance.

$$Y = j\omega \times C = j \times 2\pi \times 50 \times 1.4 \times 10^{-6} = j439 \times 10^{-6}$$

Equation 35 - Medium Length Transmission Line - Shunt Admittance, Cartesian

Converted from Cartesian to Polar:

$$439 \times 10^{-6} \angle 90^\circ$$

Equation 36 - Medium Length Transmission Line - Shunt Admittance, Polar

Receiving end values		
Voltage	Current	Power Factor
82.596Kv	293.124A	0.88722

Table 26 - Medium Length Transmission Line - Receiving End Circuit Values

$$VRN = 82.596Kv \text{ or } 82596v$$

Equation 37 - Medium Length Transmission Line - Nominal Voltage

$$IRN = 293.124 \angle \cos^{-1}(0.88722) = 293.124 \angle -27.474^\circ$$

Equation 38 - Medium Length Transmission Line - Current at Receiving End

From nominal π circuit,

$$I1 - IRN + VRN \times \frac{Y}{2} = 293.124 \angle -27.474^\circ + 82596 \angle 0^\circ \times \frac{439 \times 10^{-6}}{2} \angle 90^\circ$$

$$= 293.124 \angle -27.474^\circ + 18.13 \angle 90^\circ$$

Equation 39 - Medium Length Transmission Line - I1 Calculation

Converted from Polar to Cartesian:

$$293.124 \cos(27.474) = 260.066$$

$$293.124 \sin(27.474) = 135.232 = 260.066 - j135.232$$

$$260.066 - j135.232 + j18.13 = 260.066 - j117.102A$$

Equation 40 - Medium Length Transmission Line - I1 Value, Cartesian

Converted from Cartesian to Polar:

$$\sqrt{260.066^2 + 117.102^2} = 285.214$$

$$\tan^{-1}\left(\frac{117.102}{260.066}\right) = 24.241^\circ = 285.214 \angle -24.241^\circ \text{ Amps}$$

Equation 41 - Medium Length Transmission Line - I1 Value, Polar

Voltage at Sending end:

$$V_{SN} = V_{RN} + I_1 \times Z_s = 82596 \angle 0^\circ + 285.214 \angle -24.241^\circ \times 59.44 \angle 69.311^\circ = 82596 \angle 0^\circ + 16953.12 \angle 45.07^\circ$$

Equation 42 - Medium Length Transmission Line - Sending End Voltage Calculation

Converted from Polar to Cartesian:

$$16953.12 \cos(45.07) = 11973.01$$

$$16953.12 \sin(45.07) = 12002.3 = 11973.01 + j12002.3$$

$$82596 + 11973.01 + j12002.3 = 94569.01 + j12002.3$$

Equation 43 - Medium Length Transmission Line - Sending End Voltage, Cartesian

Converted from Cartesian to Polar:

$$\sqrt{94569.01^2 + 12002.3^2} = 95327.61$$

$$\tan^{-1}\left(\frac{12002.3}{94569.01}\right) = 7.233^\circ = 95327.61 \angle 7.233^\circ \text{ volts}$$

Equation 44 - Medium Length Transmission Line - Sending End Voltage, Polar

Current at Sending end:

$$\begin{aligned} I_{SN} &= I_1 + V_{SN} \times \frac{y}{2} = 260.066 - j117.02^\circ + 95327.61 \angle 7.233^\circ \times \frac{439 \times 10^{-6}}{2} \angle 90^\circ \\ &= 260.066 - j117.02^\circ + 20.924 \angle 97.223^\circ \end{aligned}$$

Equation 45 - Medium Length Transmission Line - Sending End Current Calculation

Converted from Polar to Cartesian:

$$20.924 \cos(97.223) = -2.631$$

$$20.924 \sin(97.223) = 20.758 = -2.631 + j20.758$$

$$260.066 - j117.02^\circ - 2.631 + j20.758^\circ = 257.435 - j96.262$$

Equation 46 - Medium Length Transmission Line - Sending End Current, Cartesian

Converted from Cartesian to Polar:

$$\sqrt{257.435^2 + 96.262^2} = 274.844$$

$$\tan^{-1}\left(\frac{96.262}{257.435}\right) = 20.502^\circ = 274.844 \angle -20.502^\circ \text{ Amps}$$

Equation 47 - Medium Length Transmission Line - Sending End Current, Polar

Angle between current and voltage at sending end:

$$V_{SN}\theta - I_{SN}\theta = 7.233^\circ - (-20.502^\circ) = 27.735^\circ$$

Equation 48 - Medium Length Transmission Line - Sending End Angle between Voltage and Current

Power Factor at sending end:

$$\cos(V_{SN}\theta - I_{SN}\theta) = \cos(27.735^\circ) = 0.8851 \text{ Lagging}$$

Equation 49 - Medium Length Transmission Line - Sending End Power Factor

	Voltage	Current	Power Factor
Sending end	95327.61	274.844	0.8851
Receiving end	82596	293.124	0.88722

Table 27 - Medium Length Transmission Line - Calculated Values

Efficiency of Power line.

Sending End:

$$P = I \times V \times P.F = 274.844 \times 95327.61 \times 0.8851 = 23.19MW$$

Equation 50 - Medium Length Transmission Line - Sending End Power

Receiving end:

$$P = I \times V \times P.F = 293.124 \times 82586 \times 0.88722 = 21.48MW$$

Equation 51 - Medium Length Transmission Line - Receiving End Power

FINAL GRADE

GENERAL COMMENTS

Instructor

70/100

PAGE 1

PAGE 2

QM

Good Structure

Report is structured exactly as stated in the assignment brief.

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

Text Comment. 300 words should be enough

Text Comment. assignment

Text Comment. the

Text Comment. Contains too much detail for a summary

Text Comment. purpose

Text Comment. values predicted

PAGE 8

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

Text Comment. Unnecessary paragraph, the principle of operation was not asked for.

PAGE 9

Text Comment. The assignment did not ask for the construction of the DC machine, this is level 3 work and your focus should have been on the applications of DC machines.

Text Comment. This is too basic for level 5

PAGE 10

Text Comment. Not required, read the question please

Text Comment. This is more like it !

PAGE 11

PAGE 12

Text Comment. This column is what was required

Text Comment. Always separate your sources

PAGE 13

QM

Wrong choice of word/s

You could have chosen a better word to express your thought here

PAGE 14

Text Comment. This is not required, the question asked you to look at converting AC into DC

PAGE 15

PAGE 16

Text Comment. Not required, read the question !

PAGE 17

PAGE 18

Text Comment. At last, you are following the brief again by looking at control from an AC supply

Text Comment. PWM requires a rectification stage first in order to be sourced from an AC supply



Correctly cited

Citation method conforms to Harvard standard, well done.

Text Comment. correctly stated



Correctly cited

Citation method conforms to Harvard standard, well done.



Correctly cited

Citation method conforms to Harvard standard, well done.

Text Comment. what theory?

Text Comment. how?

Text Comment. what did the theory say?

Text Comment. This was also an opportunity to explain what you have learned not just a review of how successful the assignment has been which is more of a reflection.

GRADING FORM: NEW CSG-RUBRIC

DAVID THOMAS

70

1. ENGAGEMENT WITH LITERATURE



Engagement with an extensive range of relevant and credible literature. Consistently accurate application of referencing. However, you did not read the question properly and have included information not required. (14/20)

14

2. KNOWLEDGE AND UNDERSTANDING



Excellent, detailed knowledge and highly critical understanding of the well-established concepts and principles of the subject and the main methods of enquiry. (14/20)

14

3. COGNITIVE AND INTELLECTUAL



Sound critical evaluation and analysis of concepts. Is selective in the range of evidence used and synthesizes rather than describes. Ability to devise

13

arguments that show awareness of different stances, and use evidence convincingly, to support appropriate and valid judgements. All results have been analyzed very well. However, your conclusion say little about what you have learned, it is more of a reflection on how well the assignment went. (13/20)

4. PRACTICAL APPLICATION



An advanced application of a range of established methods, materials, tools and/or techniques. The context of the application is well considered, and insightful. Consistent, accurate and logical application of theory to practice, making well-developed links between the two. Can identify problems and propose excellent, creative solutions outside the context in which they were first studied. (16/20)

16

5. TRANSFERABLE SKILLS



Can communicate well, confidently and consistently in a suitable medium for the audience. Work is coherent, fluent, well-structured and organised. Can work very well autonomously and/or as part of a team, with very good contribution to group activities. Demonstrates very good skills for employment requiring the exercise of personal responsibility and decision-making, with just occasional minor weakness. Word count has been exceeded because of the unnecessary description included which were not required by the brief. Some of the work presented is level 3

13

and not appropriate at level 5. The brief did not ask for a description of the construction of the DC machine nor speed control methods from a DC source. Your summary contains too much detail. Word count penalty applied (-5) because the Turnitin word count is 10138. (13/20)