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ACDA6004 Exam 2022

by John James

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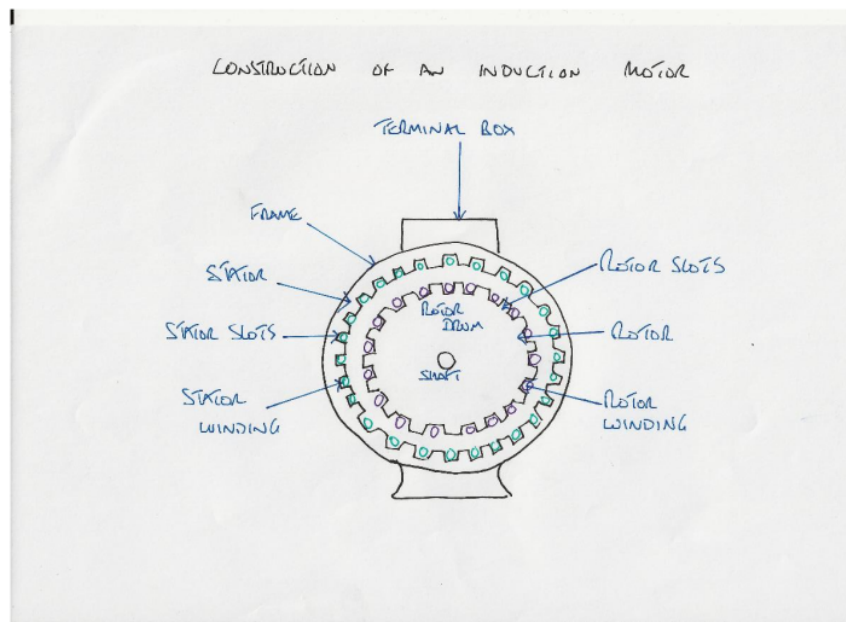
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Question 1

An Induction motor is contained in a robust frame and consists of two main parts: The stator and the rotor.

Stator – The stator is stationary and is constructed of stacks of highly permeable steel laminations inside a cast frame. The laminations are slotted and the windings are passed through these slots.

Rotor – The rotor sits inside the stator with a small air gap (0.5 to 2mm) between. It is free to rotate within the stator. The rotor is constructed in a squirrel cage shape with the bars shorted by end rings. Insulated iron core laminations are packed inside the rotor to aid electromagnetic induction..



Construction of an Induction Motor

A three phase AC current passing through three stator coils, 120 degrees apart produce a Rotating Magnetic Field (RMF). The RMF induces a current into the squirrel cage. The squirrel cage forms a closed circuit so current will flow. The current flow in the squirrel cage will create a magnetic field which opposes the RMF. These forces generated between the squirrel cage and the RMF cause the rotor to turn. (Lorenz's law). Thus, both the magnetic field and rotor are rotating. Should the rotor rotate at the same speed as the magnetic field then there would be no relative difference in speed and thus no relative magnetic field hence no EMF and no current flow. This would result in no rotating force in the bars of the squirrel cage so the rotor would slow down. As it slows down the relative speeds differ and so the cage will experience current flow due to the varying magnetic field. This increases the force and the rotor speeds up. The rotor will never match the speed of the RMF so it rotates slightly less than synchronous speed. This is known as slip and an induction motor relies on this to operate.

Question 2)

MPPT or Maximum Power Point Tracking is an algorithm used for extracting maximum available power from a PV module under certain conditions. The voltage at which a PV module can produce maximum power is called maximum power point (or peak power voltage). Maximum power varies with solar radiation, ambient temperature, and solar cell temperature. As the temperature of the cell increases then so does its resistance, resulting in a reduced current output. This in turn reduces power output ($I \times V$) causing a reduction in efficiency of the cell.

The principle of MPPT is to extract the maximum available power from PV modules. It achieves this by making them operate at the most efficient voltage (maximum power point). MPPT monitors the output of the PV module and adjusts the input resistance of the inverter in response to changes in the module output to keep the module operating at its maximum power point, thus ensuring maximum power transfer. There are various methods, or algorithms for achieving this.

The three most common are:

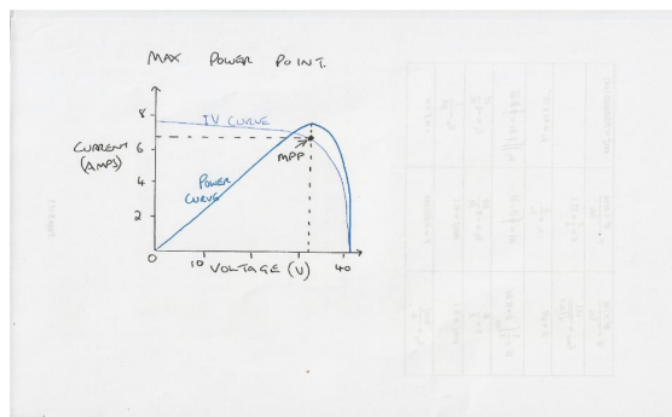
Perturb and Observe – The charge controller deviates the array voltage by a small amount and monitors any change in the power output. If the power increases then the controller carries out further adjustments in the same direction until there is no further increase in power.

- Most common due to ease of implementation
- Can result in power output oscillations
- Can result in top level efficiency

Incremental Conductance – The charge controller measures incremental changes in array current and voltage to predict the effect of a voltage change.

- Requires more computation in the charge controller (Uses the incremental conductance of the array to calculate the sign of the change in power wrt the voltage)
- Can produce power output oscillations
- Tracks changes more quickly

Current Sweep – Uses a sweep waveform for the array current which obtains the $I \times V$ characteristic of the array, which is periodically updated. The MPP voltage can then be calculated from the curve at the same periodicity.



Question 3

- 250kW twelve pole pairs three phase delta connected AC induction motor operating between 0 and 1000 rpm
- Switched at 20 pulses per cycle
- Motor rated at 6kV terminal voltage

We must consider the current, voltages and frequencies involved:

Calculate current:

$$I = \frac{P}{V} \quad I = \frac{250000W}{6000V} = 41.6A$$

Calculate frequency:

$$f = \frac{\omega p}{60} \quad (12 \text{ pole pairs})$$

$$f_{min} = 0Hz$$

$$f_{max} = \frac{1000 \times 12}{60} = 200Hz$$

Therefore, the operating parameters of the sea plane motor are:

Voltage: 6kV

Current: 41.6A

Frequency: 0Hz to 200Hz

With a PWM signal of 20 pulses per cycle, the gate switching frequency would be:
0Hz to 4kHz (200 x 20)

Characteristic	Power Bipolar	Power MOSFET	IGBT
Voltage Rating	High <1kV	High <1kV	Very High >1kV
Current Rating	High <500A	Very High >500A	Very High >500A
I/P Drive	hfe 20 – 200	Voltage V_{GS} 3 – 10V	Voltage V_{GE} 4 – 8V
I/P Z	Low	High	High
O/P Z	Low	Medium	Low
Switching Speed	Slow (μs)	Fast (ns)	Medium
Cost	Low	Medium	High

With reference to the table above, the transistor technology most suited would be Insulated Gate Bipolar Transistor (IGBT). The IGBT has very high voltage capability (>1kV) which would tolerate the 6kV supply. The resistance in the main channel (C to E) when the device is conducting is very small resulting in a high current flow, thus the very high current rating (>500A), which would tolerate the calculated 41.6A current. The calculated switching frequencies of up to 4kHz falls within the medium range switching speed. The IGBT is a voltage-controlled device that only requires a small gate voltage (4 – 8V) to maintain conduction. The low output impedance is essential as it minimises power loss through I^2R : For example, a Z_{out} of 1Ω :

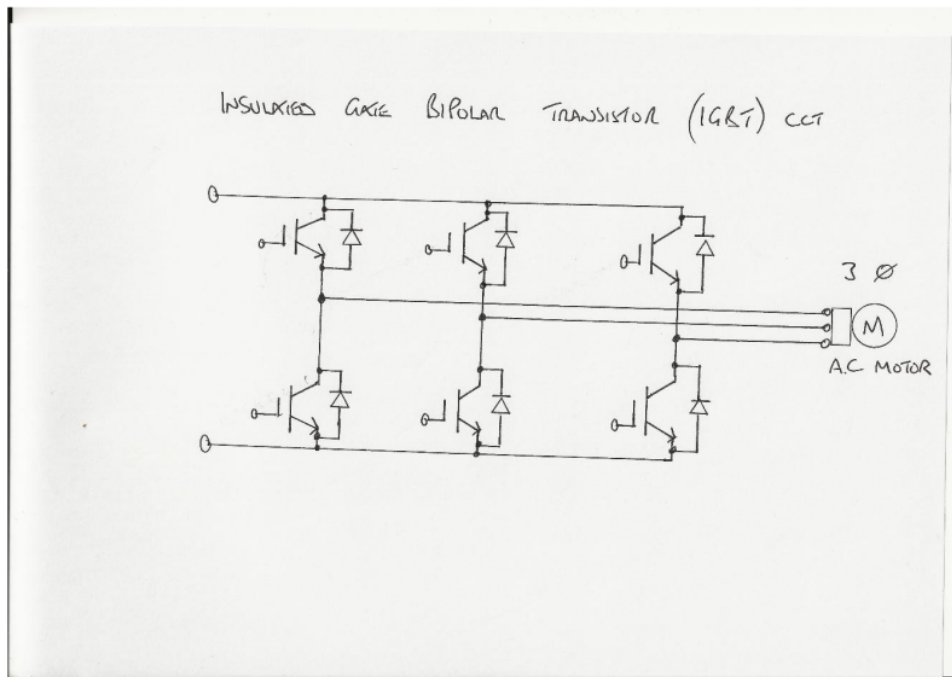
$$I^2R = (1037)^2 \times 1\Omega = 1075369W$$

This would generate high power losses so ideally a Z_{out} of $< 0.01\Omega$ would be essential to reduce these losses:

$$I^2R = (1037)^2 \times 0.01\Omega = 10753.69W$$

For this reason, the high load current would rule out the power MOSFET device as the high current would cause high power dissipation in the MOSFET transistor due to I^2R losses.

Insulated Gate Bipolar Transistor (IGBT) Circuit



With reference to the circuit diagram above:

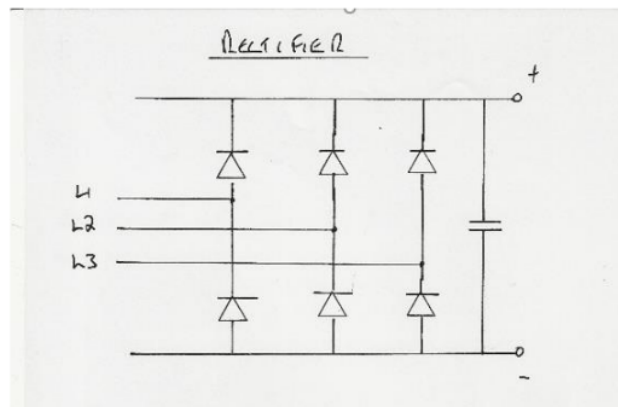
The transistors are connected in pairs (two per phase) in a push pull configuration to allow each phase to be connected to either the positive supply or ground. A freewheeling diode is connected in parallel across the IGBT to conduct any reverse current produced by the back EMF from the collapsing fields when the coils are de-energised, thus protecting the transistor.

A drive signal derived from a PWM encoded sinusoidal waveform is applied to the gate. When the drive signal is in the positive phase then the top transistor of each phase pair will be forward biased and conduct whilst the bottom pair will be reverse biased so will block current flow. Conversely when the drive signal is in the negative phase the bottom transistor of each phase pair will conduct whilst the top transistor does not. If the upper and lower transistors of the same phase are switched on at the same time then this will cause DC supply to short. To prevent the DC supply from being shorted, dead time must be given between switching off the upper transistors and switching on the lower transistors and vice versa.

Question 4

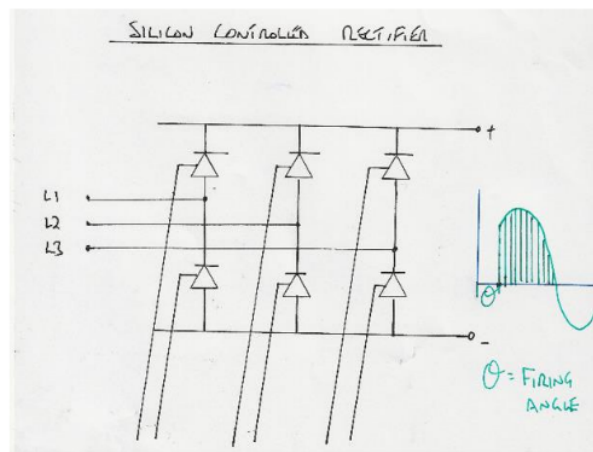
Diode Rectifier – A diode rectifier carries out rectification only and provides a DC output. Rectification of both positive and negative half cycles is carried out by the diode network pairs in each phase. Smoothing of the rectified DC is carried out by the smoothing capacitor across the output. It cannot modify the frequency or the voltage and current characteristics of the supply so as such cannot provide speed or torque control. The diode rectifier has simple circuitry so is relatively cheap.

Diode Rectifier



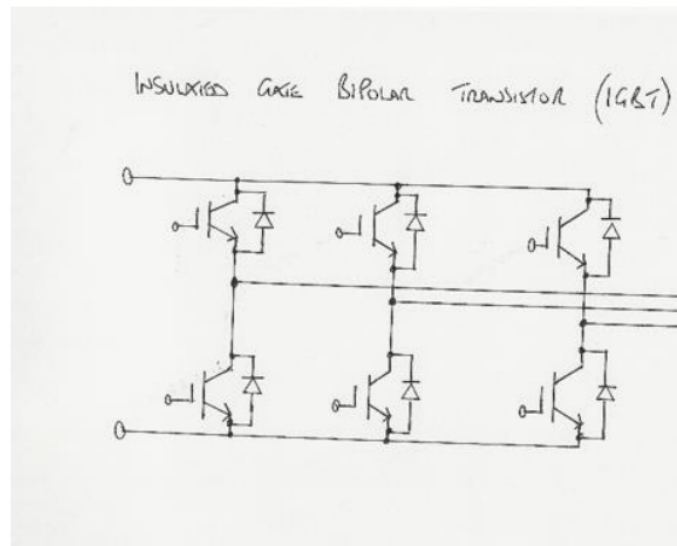
Silicon Controlled Rectifier (SCR) – Uses thyristors which are current operated devices that use a small gate current to control larger currents. The device acts like a rectifying diode once triggered. The SCR can provide torque control by varying the supply voltage. This is achieved by delaying the triggering of the thyristor until later in the cycle thus limiting the amplitude and thus average voltage. This delay is called the firing angle and thus the average voltage is proportional to the firing angle. This delay in the triggering produces a steep sharp leading edge which in turn introduces noise due to harmonics. Effective filtering is required to eliminate the noise on the mains output. An SCR has more complicated circuitry and as such is more expensive.

SCR



IGBT – Uses gate control to control three pairs of transistors connected in a push pull configuration and gate control to provide rectification. It has a very high voltage and current rating but will not tolerate high switching rates. Voltage control is achieved by controlling the gate and delaying the triggering similar to that of an SCR. The IGBT is bi-directional so can pass current from regenerative braking back to the grid. The circuitry is quite complex and hence the device is more expensive. As the gate is insulated there is a high degree of electrical isolation between the input and output buses.

IGBT Rectifier

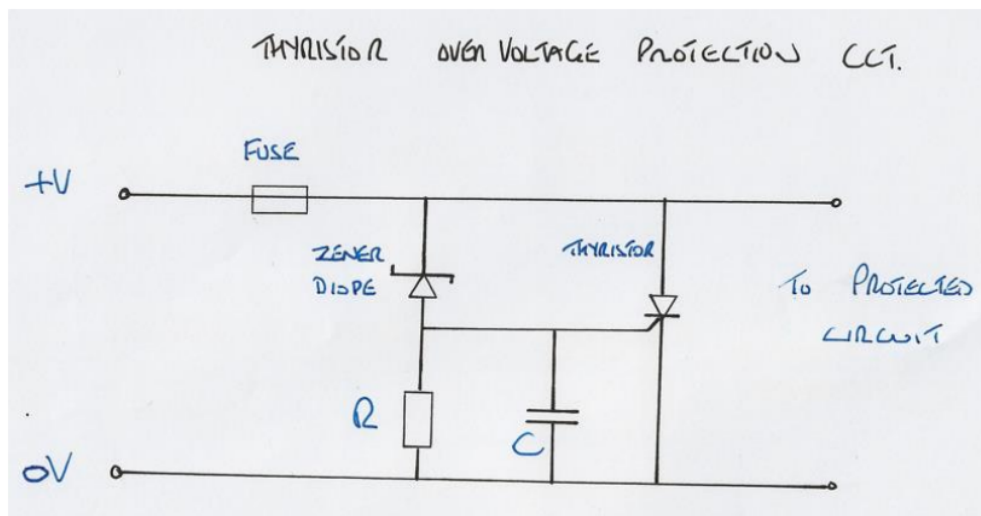


Question 5

Normal operation – The voltage of the Zener diode is rated at the normal operating voltage of the circuits to be protected. The normal operating supply voltage across the input will remain at or below this level and so the voltage across resistor R is 0V.

If the supply voltage were to increase to a level greater than the voltage rating of the Zener diode then the reverse breakdown voltage of the Zener is reached and the diode will conduct. This will allow the over voltage to drop across resistor R. A steady overvoltage will charge capacitor C, increasing the gate voltage of the Thyristor, causing it to conduct. When the Thyristor is conducting current flow will increase across fuse F causing it to blow, halting current flow thus protecting the circuit from overvoltage. Capacitor C will remove any short lived voltage spikes so the protection circuit will only respond to steady state overvoltages.

Thyristor Overvoltage Protection Circuit



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GRADEMARK REPORT

FINAL GRADE

88/100

GENERAL COMMENTS

Instructor

Q1 - 15/15

Q2 - 18/25

Q3 - 25/25

Q4 - 15/20

Q5 - 15/15

Total 88/100

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