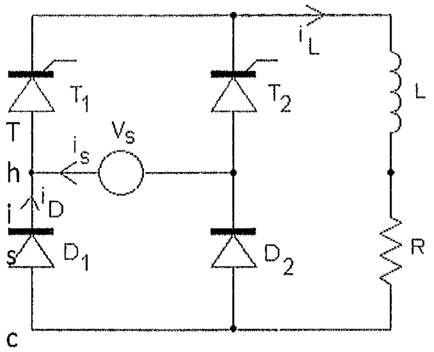
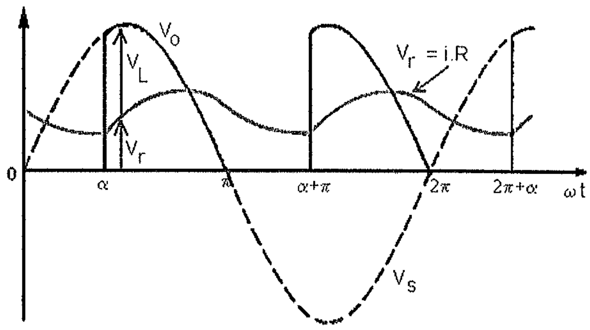
Answers EEE307 / EEE6023 - 2013 / 2014

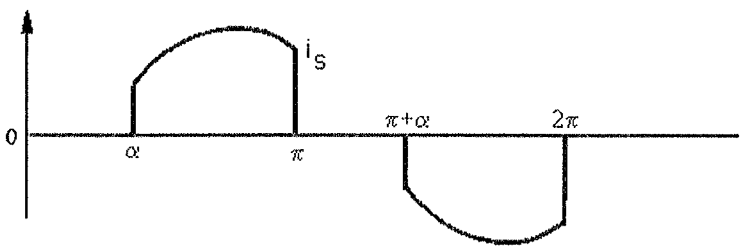
Question 1

a.Single phase semiconverter (Half controlled rectifier)





This circuit has simple drive requirements, as both thyristor cathodes are commoned to the same potential, therefore the drive circuit may have a common signal return. However, the load current freewheels through a thyristor during part of the operating cycle, and this may cause problems with excessively long circuit shutdown times. The current drawn from the supply is shown below. The current circulates via a freewheel path for the rest of the cycle. This implies power is not drawn from the supply continuously.



The circuit always operates in continuous current mode (continuous output inductor current), as diodes provide a freewheel path for the output current. The average output voltage may be found by integrating the output voltage waveform between the point where the thyristors are fired (firing angle), and the end of the appropriate half cycle i.e.

$$V_o = \int_{\alpha}^{\pi} \sqrt{2}\, V_s \sin(\omega t)\, d(\omega t)$$

This gives

$$V_o = \frac{\sqrt{2}\, V_s}{\pi} (1 + \cos\alpha)$$

$$for \quad 0 \le \alpha \le \pi$$

This expression implies that the output voltage is always +ve and independent on the load. This independence on the load is useful as it simplifies the control of the output voltage.

b. 8V across the load at 400A, gives a load resistance of 0.02Ω.

For 8V output with $12V_{rms}$ input, the firing angle is **α = 61.25° or 1.07 rad**

c. If the diodes were replaced by thyristors the circuit would become a full converter, and for continuous load current,

$$V_o = \frac{2\sqrt{2}V_s}{\pi}\cos(\alpha)$$

Therefore the firing angle becomes, **α = 42.2° or 0.74 rad**

d. The minimum value of load inductance to ensure continuous current would be given from:

$$\phi = \tan^{-1}\left(\frac{\omega L}{R}\right)$$

From this, **L > 5.6mH** for continuous load current.

Question 2

a) When switch T is on, current in the inductor increases at a rate: $\frac{di_L}{dt} = \frac{E}{L}$

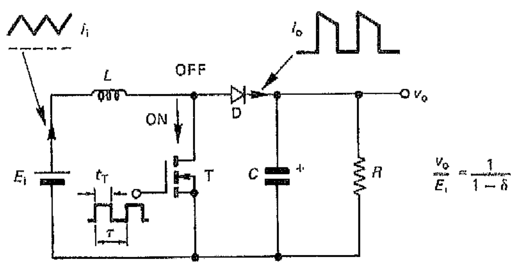
When switch T is off the current in the inductor decreases at a rate: $\frac{di_L}{dt} = \frac{V_o - E}{L}$

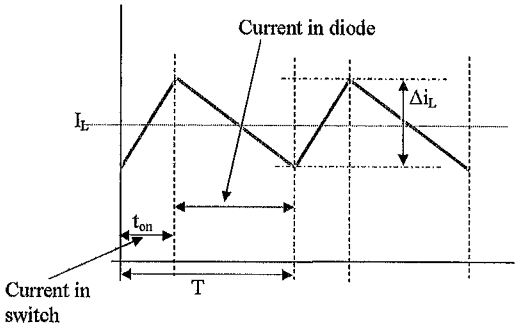
With continuous Inductor (Choke) current we have for time switch is on, the current increase is:

$$\Delta i_L = \frac{E}{L}.t_{on}$$

For the time the switch is off, the current decrease is: $\Delta i_L = \frac{(V_o - E)}{L}.(T - t_{on})$

In steady state, the current increase equals the current decrease, there fore by equating the two equations for the ripple we get: $\frac{V_o}{E} = \frac{1}{(1-\delta)}$ where $\delta = t_{on}/T$, and δ can take values between 0 and 1 inclusive.





a) $V_o = 5 \times 1/(1-0.6667) = 15V$

c) To keep the current in inductor continuous at lowest current (50mA), the inductor is given by: $L \geq \frac{E}{2I_o}.T.\delta.(1-\delta)$

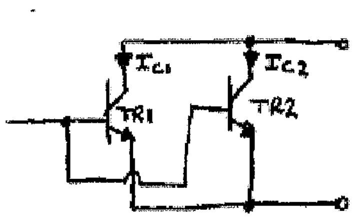
Therefore $L > 278\mu H$

d) The value of C can be found from $C = \frac{I_o \delta T}{\Delta V_o}$ with maximum output current, therefore $C > 35.5\mu F$, say $47\mu F$.

e) An appropriate switching device would be a MOSFET as it would be capable of operating at this frequency being a majority carrier device. The ratings should be $V_{ds}>15V$, $I_d>0.2A$. This should be easy to achieve, with a small MOSFET rated at $V_{ds} = 40V$, $I_d = 1A$ for example.

f) The diode will need to have a breakdown voltage in excess of 15V + possible voltage spikes around the circuit, usually choose rating at around 30V or above, and be a fast recovery, (high frequency) diode. It may be useful to ensure the device is a schottkey device to ensure no reverse recovery stored charge.

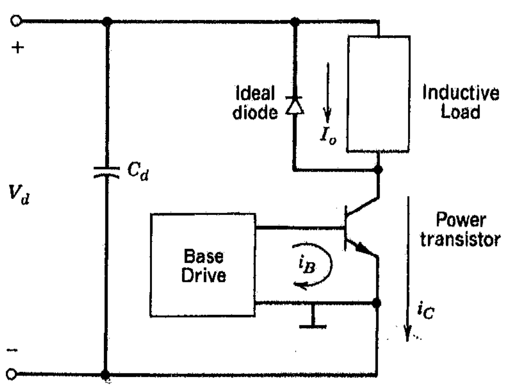
Question 4



The parallel operation of BJT's should be approached with caution. The high standards of today's construction leads to the possibility of being able to parallel BJT devices by direct connection of their terminals. Unfortunately, in most cases, this may lead to thermal runaway in one or more of the paralleled devices if further components aren't used to ensure static and dynamic current sharing between the devices.

If I_{C1} is greater than I_{C2}, TR1 gets hotter than TR2. as the conductivity of BJT's increase with temperature, I_{C1} increases giving a positive feedback mechanism, and the device overheats. This is termed thermal runaway. Therefore we need to closely couple the devices on the same heatsink, and externally share the current using emitter resistors (or coupled inductors) as with respect to diodes.

b) Here, the inductive load keeps the current flowing, via the ideal freewheel diode. The diode cannot start conducting when the BJT switches off until the voltage across the BJT has risen above V_d and forward biased the diode. Until the diode conducts, it cannot provide an alternate path for the load current, so the BJT must carry the full load current whilst the voltage across the BJT rises to forward bias the diode at switch off of the BJT. Similarly, at turn-on of the BJT, the diode cannot switch off until the current flowing through it falls to zero, therefore the voltage across the BJT is clamped at the power supply rail until the current through the BJT rises to the load current level.



Here then, the energy per turn on switching event can be calculated from the following, assuming a linear characteristic:

$$E_{on} = V_{CE} \cdot \int_0^{t_1} \frac{I_C . t}{t_1} dt + I_C \cdot \int_0^{t_{21}} \left(V_{CE} - \frac{V_{CE} . t}{t_1} \right) dt$$

$$E_{on} = \frac{V_{CE} . I_C}{2} . (t_1 + t_2)$$

$$E_{on} = \frac{V_{CE}.I_C}{2}.t_{on}$$

Now when operating at switching frequency f:-

$$P_{AVE(on)} = \frac{V_{CE}.I_C.t_{on}.f}{2}$$

similarly,

$$P_{AVE(off)} = \frac{V_{CE}.I_C.t_{off}.f}{2}$$

Average switching loss becomes

$$P_{AVE(switching)} = \frac{V_{CE}.I_C.(t_{on} + t_{off}).f}{2}$$

c) Consider a bridge leg drive application.

Here, there is a need to switch the BJT's alternately in order to produce an alternating voltage at the output of the leg. In this application, the base drive for the bottom device is referenced to it's emitter and hence to 0V. The base drive for the top device, is also referenced to it's emitter, however, the emitter of the top device is referenced to the output. As the output potential varies between 0V and V_{cc}, an isolated base drive circuit is required for the top switches in a bridge leg. If a non-isolated drive was used for the top device, when the top device was switched on, a short circuit would be placed on the link due to the emitter being connected to 0V by the base drive circuit. This would lead to the destruction of both the device, and the base drive circuit. A typical method of generating an isolated base drive is to use a transformer isolated supply, and an opto-isolator to transfer the control signal to the device. A more complicated system, employing a pulse transformer is also possible. A further problem may occur if both devices are turned on at the same time leading to a short across the dc link and a 'shoot-through' condition. This can be avoided by having an interlock to ensure both devices cannot be turned on at the same time, and a dead-time generator to ensure that one device is fully turned off before the other is turned on at a switching edge.