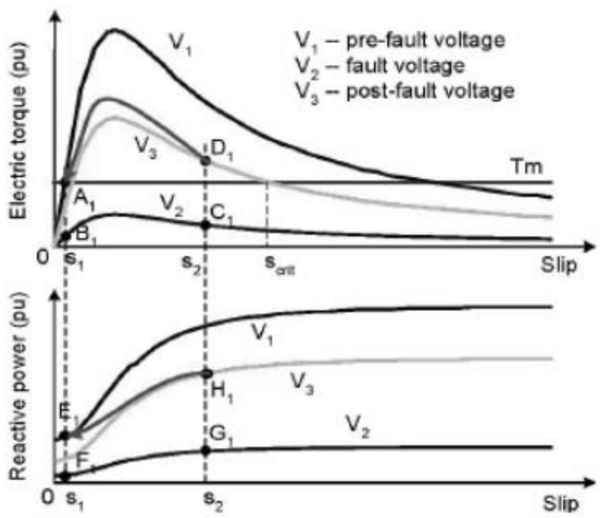
Solutions of Tutorial 9

Q1

a)

Under grid fault, the collapse of voltage reduces electric torque (and electric power). The operating point moves from A1 to B1. The WT accelerates as $T_m > T_e$. Operating point moves from B1 to C1. At C1 the fault has cleared and voltage recovers but remains less than nominal voltage. As the voltage recovers, the operating point moves from C1 to D1. Now $T_e > T_m$ and the turbine decelerates back to stable region towards A1.

SCIG reactive power consumption is high when operating point moves from points C1 to D1 then to A1 (high slip operation). When the turbine returns to A1, it is said the WT has ridden through the fault.

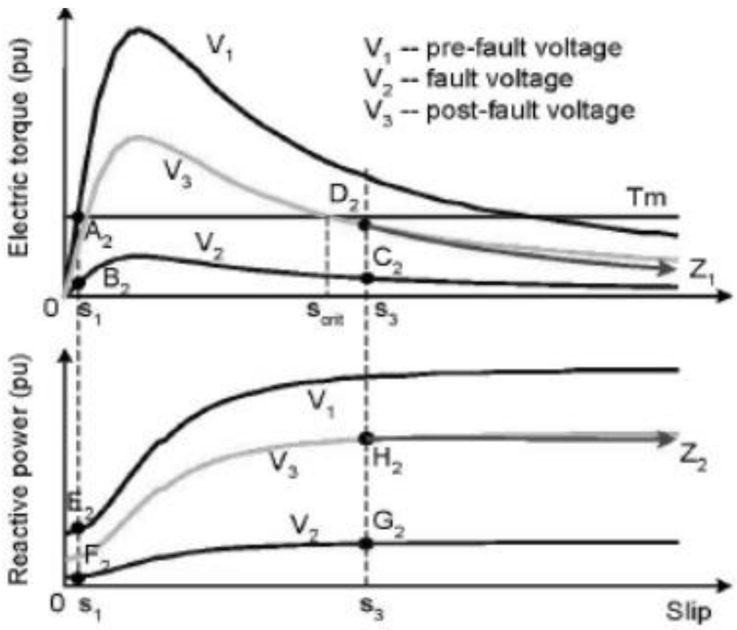


Fault ride-through was possible since highest slip (s_2) was less than critical slip (S_{crit}) which is the slip at which $T_e = T_m$ at voltage recovery b)

At fault clearance, the voltage may not recover high enough due to lengthy fault or weak grid.

In this case, slip at recovery $S_3 > S_{crit}$ and the WT will undergo uncontrolled acceleration as $T_e < T_m$ post fault.

Fault ride-through was not possible since highest slip (s_2) was higher than critical slip (S_{crit}). The WT disconnects from grid as reactive power consumption becomes too high. Mechanical and aerodynamic brakes activated.



Q2

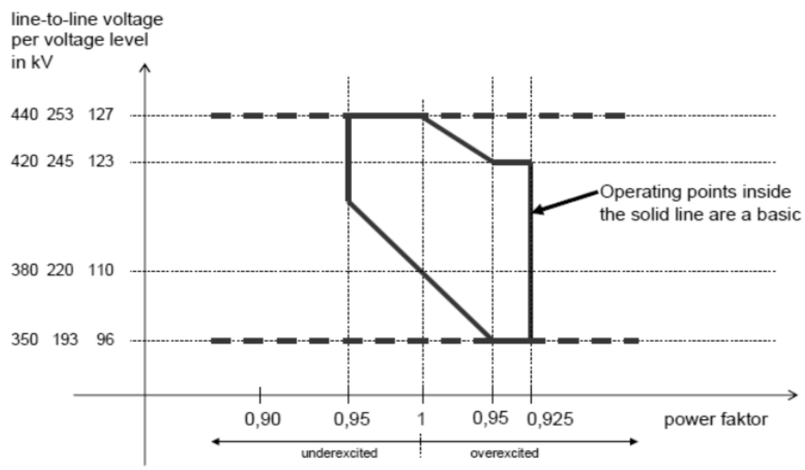


Figure Q2

a)

Nominal voltage at high side = 220kV ➔ operating voltage at high side= 0.9*220 = 198kV

Operating voltage at low side= 0.9*160 = 144kV

From graph: operating power factor range: 0.925 to 0.96 lag (overexcited)

The higher power factor corresponds to lower power angle, thus lower reactive power

<u>@0.96 power factor:</u>

P = S*pf = 250*0.96 = 240MW

Q = S*sin($\cos^{-1}$(pf)) = 70MVar

Minimum rms current = Q/ √3/ V/ sin($\cos^{-1}$(pf)) = $70*10^6$/1.732/144000/0.28 = 1002.3 A

b)

for three phase 2 level SPWM

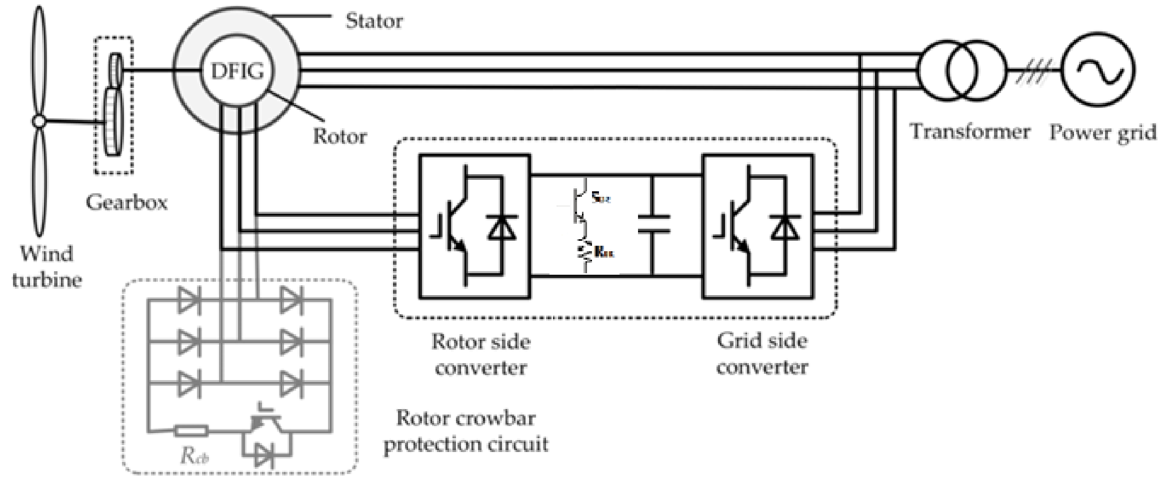
$V_{l\text{-}l(rms)} = \frac{1}{2}\sqrt{3/2}\, mV_{dc}$ ➔ $m = 2\sqrt{2/3}\, V_{l\text{-}l(rms)}/V_{dc} = 2\sqrt{2/3}*144/300 = 0.784$

c)

Leading pf means underexcited operation

Range of voltage from 235kV to 253kV at the high voltage side which is 107% to 115% of nominal voltage

Q3



A 3-phase bolted fault at the terminals of a DFIG-WT results in high rotor and stator currents, torque transients, DC-link voltage surge, and slight acceleration of WT.

High rotor currents and DC-link voltage transients may damage the RSC and GSC.

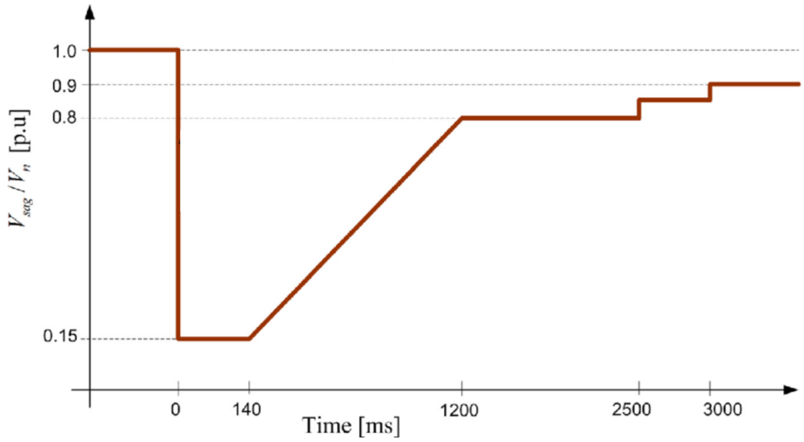
The WT may have to trip to protect the converters.

One of the FRT solutions for a crowbar circuit can be connected across rotor terminals to act as a chopper circuit and dissipate rotor energy and limit high currents. However, it may not entirely protect the RSC and controller action along with crowbar is normally needed.

As the crowbar dissipates rotor energy, a reduced DC-link voltage surge results.

A dc chopper circuit may be required to dissipate excess DC-link energy and limit voltage rise.

Q4



a)

Transformer impedance = $0.1*V^2/S_b = 0.1*220^2/200 = 24.2$ ohm

Voltage at the PCC (high voltage side) = voltage at fault point + voltage drop in 30km line

= 2*(4500+1000) + 1000*(1*30) = 41kV

Voltage at PCC = 41/220*100% = 18.64%

The station does not trip since voltage is above 15% during fault.

Voltage at the PV inverter terminal = 41kV + (24.2*1000) = 65.2kV

b)

Time from fault inception = 140+200=340ms

Using graph, minimum voltage for the PV station to remain connected:

(x-0.15)/ (0.8-0.15) = (340-140)/(1200-140) ➔ x = 27.3% of nominal voltage

Q5

a)

Inertia constant of a power plant is defined as the time elapsing until the rotating mass discharges its kinetic energy down to standstill when delivering rated power output.

$H = E_r/S_r = ½\, J\omega_r^2/S_r$ whrer subscript r denotes rated value.

b)

H = 15s means the plant can produce 30MW for 15s.

$E_r = H*S_r /\eta = 15*30/0.93/0.95 = 509.35$ MJ

$½\, NJ\omega_r^2 = 509.35*10^6$ ➔ N = no of flywheel units

$N = 1018.7*10^6/3.46/(2*3.14*15000/60)^2 = 119.43$ ➔ round up to 120 sets

Time elapsing for 20MW primary frequency power = $0.9*E_r*\eta/S = 0.9*509.35*0.93*.95/20 = 20.25$s

Q6

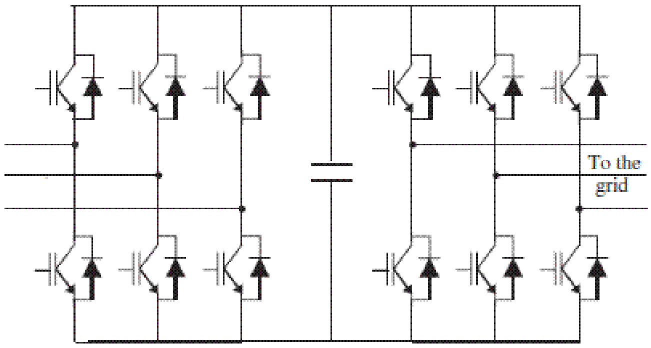
Each unit is 250kW

GSC is normally controlled to operate at unity power factor

$S_{unit} = P_{unit} = 250$kVA ➔ $\sqrt{3} V_{l\text{-}l} I_r = 250$kVA

$I_r = 250000/\sqrt{3} / 480 = 300.7$A

$V_{l\text{-}l(rms)} = ½ \sqrt{(3/2)}\, m V_{dc}$ ➔ $V_{dc} = 2V_{l\text{-}l(rms)} *\sqrt{(2/3)} /m = 2*480*\sqrt{(2/3)}/0.85 = 922.16$V



Each IGBT must be rated to DC-link voltage at least as it is required to block (withstand) the whole DC voltage when the other IGBT of the same phase leg is switched on. DC voltage can increase over rating during grid fault. Also, current can increase in case of fault; hence, the safety margin.

With safety margin, minimum voltage rating = 1383.24V

Minimum current rating = 451.05 A

Referring to standard ratings: IGBTs should be rated at 1.5kV and 800A.