The Solutions

1.

a)

i) How is the lightning surge in power network characterised? [2]

A: Lightning is characterised by very steep rise and gradual fall. Typically 1.2μsec/50 μsec. Current is of several kA.

ii) Why is the consideration of lightning surge so important in power system design and operation? [2]

A. Lightning creates large voltage spike across equipment terminals thus damages them. Lightning protection design is guided by this characteristics of lightning surge

b)

i) What is sub synchronous resonance (SSR) in the context of power system stability? [5]

- Subsynchronous resonance relates to electromechanical interaction between different section of a multistage turbine when excited by cyclic torque
- The cyclic torque is established by SSR frequency currents in the rotor body
- The rotor current originates from the network with different from power frequency
- Usually a series capacitor and line inductance gives rise to this
- It can be damaging to the shaft – in the past it has been

ii) What types of turbine in power plants exhibit SSR? [2]

Mainly multistage steam turbine in thermal or nuclear power station

They are now being observed in wind turbines as well

iii) What is the range of frequencies of SSR? [2]

It depends on the network frequency: in a typical 50/60 Hz system, the range is between 10 – 46 Hz. For wind generator they are smaller, depending on the shaft mass, gearbox ratio etc.

iv) How is the problem of SSR solved? [3]

Normally through SSR damper, controllable series compensation, power system stabiliser, additional rotor converter control in case of wind turbine

c)

i) What is the primary purpose of having a high gain fast acting excitation system? [4]

To improve the transient stability performance. Large generators have huge steam inside the turbine that will continue to spin the generator – during the fault there will be collapse of voltage – high field voltage can boost the electrical power output temporarily thus reduce the accelerating torque. The generator load angle increase but at slower pace – so the fault clearing time can be relaxed.

ii) Why is a power system stabiliser (PSS) necessary for operating large synchronous generator? [3]

High gain fast acting excitation system and its control improves transient stability but introduces negative damping at low frequency range (0.2 to 2.5 Hz) – this requires to be dampened. PSS provides that functionality

iii) What is the range of frequencies at which a PSS should be designed to provide stabilisation? [2]

Normally 0.2 to 2.5 Hz, but when it comes to stabilising the unit in question – it is the oscillatory nature of the generator with respect to the system which is between 1.2 to 2.5 Hz.

[25 marks]

2.

a)

i) The rotor of a synchronous generator is of solid construction whereas the stator is made up of laminated steel. Provide technical reason to justify such constructional practice. [4]

Rotor carries DC current – at synchronous speed no emf will be induced in rotor from stator side because of magnetic interaction between the stator and rotor. Stator carries power frequency current – with a solid stator construction there will be huge circulating currents and loss on the stator magnetic body- so they are laminated. Solid rotor also helps in offering damping torque

ii) Why is it easier to control a steam turbine than a hydro turbine? [5]

The student must establish their understanding of hydro turbine transfer function with a water starting time perspective and also water gate position increase to power production (the transiently inverse relation). They should then relate this to non-minimum phase transfer function – narrate about the reduced phase margin available – they should also suggest measure to overcome this in the form of governor transient gain reduction etc.

iii) Why is the stator windings in a synchronous generator star connected? [3]

It is important to provide solid earthing to generator. Normally power plant will have to be solidly earthed for safe and definite passage of fault current for the protection device to pick up the fault condition and operate

iii) Modern synchronous generators are designed to have large steady state synchronous reactance (between 1.0 to 2.0 pu). However, when a direct terminal short circuit occurs, the initial currents are several times the load current. Explain the reason. [5]

The students are expected to explain the flux paths for the stator current during fault – that will help them to relate the inductance with the magnetic flux path reluctance – usually it should be largely over air , so less sub transient reactance, then less transient reactance and finally steady state. 1.0 to 2.0 should be related to smaller air gap, more economic machine.

iv) Why does not a synchronous generator permit identical overload capability both in the lagging as well as leading power factor range? [4]

The flux interaction between stator and rotor during leading power factor and lagging power factor operation are different- for lagging they are demagnetising, for leading they are magnetising – the consequence is at the end of the winding, the collars are subjected to larger eddy current and hence more heating – so in leading power factor overload capability is limited.

v) Two synchronous generators of identical capacities are delivering similar amount of load to a grid network. One of them is non-salient pole (round rotor) and other one is salient pole (non-round rotor). Excitation is suddenly lost in both cases while the turbine inputs continue. Which one will go out of synchronism faster? Justify your answer with reason. [4]

The one with salient pole will produce real power because of saliency (difference between d-q axis reactance) – that will lead lesser accelerating torque for the one with salient pole machine. The non-salient pole machine on the other hand will not able to produce any power during the loss of excitation – so accelerate faster – so the non-salient pole machine is likely to go out of synchronism earlier than the salient pole one

[25 marks]

3.

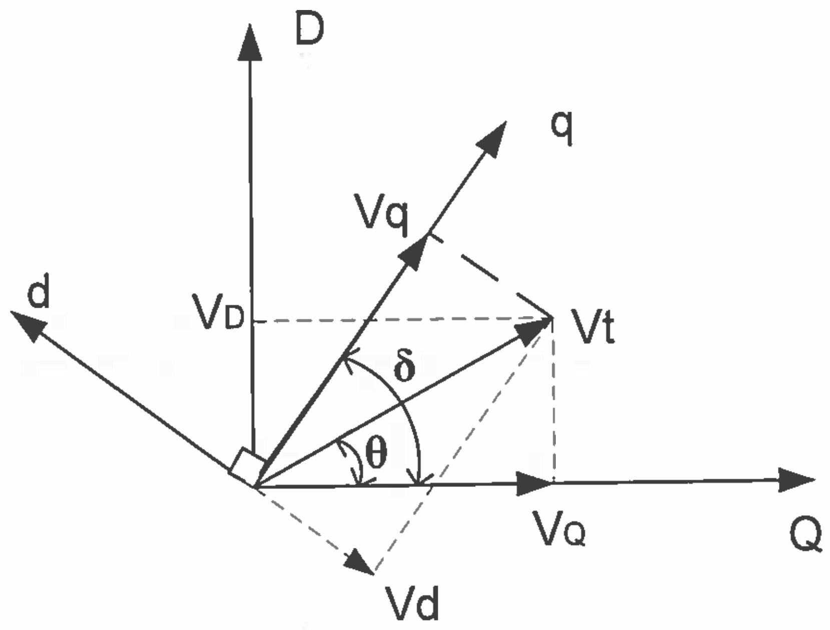
a)

i) Generally synchronous machines are analysed in d-q reference frame (Park reference frame). Why another transformation is necessary when connected to a multi-machine large power system network? [3]

In the Park frame each individual synchronous generator is represented with its terminal voltage as reference. So all the quantities are calculated in its own reference frame. In the multi-machine context – there has to be only one reference angle. Every individual machine variable in d-q co-ordinate is transformed. This is usually done by defining a network reference frame. Mathematically it is a transformation which can be constructed out of basic knowledge of trigonometry.

iii) Derive the relationship between the quantities in two reference frame when the angle difference between the two reference frames is δ-θ. [5]

Let us assume that the network reference frame is expressed as DQ and that of machine as dq. If V is a voltage of a bus with an angle θ with respect to DQ reference; its corresponding component in machine reference frame would be a rotation of (δ-θ).



$VQ + j\,VD = Vt\,e^{j\theta}$
$VQ = Vt \cos\theta$
$VD = Vt \sin\theta$
Resolving VQ and VD along machine reference d-q will produce

$$Vq = VQ\,\mathrm{Cos}\,\delta + VD \sin\delta$$
$$Vd = -VQ \sin\delta + VD \cos\delta$$
$$Vq + j\,Vd = Vt\,e^{-j(\delta-\theta)}$$

iv) A synchronous generator supports a terminal voltage of 23.5 kV line to line at the generator terminal bus. This bus is part of a large network which has a reference bus at another location. The power flow solution produces an angle (θ) of 10 degree for this bus voltage. The generator load angle (δ) is 30 degree. Compute the direct and quadrature axis components of this terminal voltage. [5]

Solutions

Vmachine = Vnetwork $e^{-j(\text{angle between two references})}$
In this case
Vmachine = $23.5\,e^{-j(30-10)}$
Vmachine = $23.5\,e^{-j20}$
$= 22.08 - j\,8.03$ kV.
Vq = 22.08 kV
Vd = -8.03 kV

b)

i) As of December 2016, roughly how much is the installed capacity of wind power worldwide? [2]

Between 475 to 500 GW

ii) List top three countries in terms of installed capacities of wind power. [2]

China, USA, Germany

iii) Why are Type 3 and Type 4 wind turbine generators preferred over Type 1 and Type 2? [2]

They have better controllability and higher operating range of wind speed. They also offer higher efficiency of energy capture.

iv) What is parking mode in the context of wind turbine operation? [3]

A wind turbine should not be let to spin at a wind speed less than cut-in speed (about 4 m/s). It should also not be rotating at a wind speed more than the cut-out speed which is about 25 m/s. The turbine is locked to avoid any damage due to unnecessary rotation.

v) In a large wind farm the wind velocity is 1m/s more than the cut in velocity. There are 10 rows of turbine. It was observed that some turbines in the subsequent rows were not producing power. Explain clearly what could be the reason(s). [3]

The student is expected to explain about wake effect and slowing down of wind speed – when reaching the next row – the speed may not be enough to roll the turbine – some may roll – some will not.

[25 marks]

4.

a)

i) What is the function of a gearbox in a wind turbine generator? [2]

Wind turbine rotate at a low speed – 10-12 rpm. This will require large number of poles to produce power at 50/60 Hz. The speed is increased with a gear box. The speed of the generator rotor is high enough (10,000 rpm)

ii) The gear box is not necessary for some types of wind turbine generators. Explain the reason behind such an option. [2]

In full converter machine (FCM – Type 4) stator voltage is rectified first to feed to an inverter that connects to the grid at power frequency (50 or 60 Hz)

iii) How does one represent the gear box in the simulation programme for stability studies? [2]

The gear box represented as unity gain in pu – and with a gear ratio in actual in simulation for steady state condition. They should be represented through differential equation for simulating mechanical transients, twist etc.

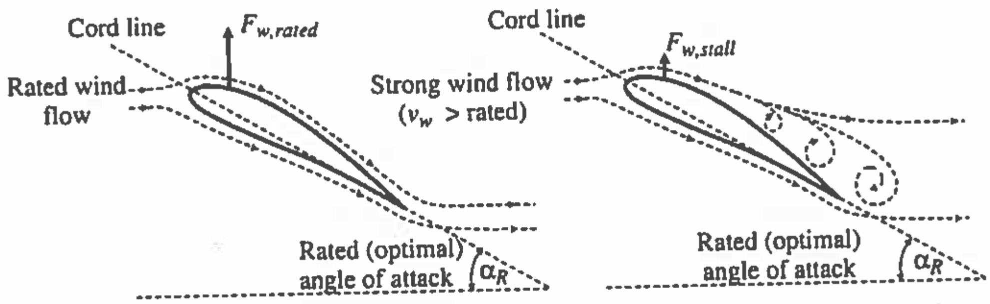
b)

i) What is meant by stall control? [4]

The stall control is the action on blade by letting it adjusts the angle of attack with the wind. The idea is to adjust the lifting force so that turbine can slow down.

ii) How is passive stall control implemented? [3]

Passive stall control is affected by blade geometry. The upper surface or leading edge of the blade is designed in such a way when wind speed increases the wind after heating the leading surface do not glide over rather became turbulent. This results in lower pressure difference between the leading and trailing edge – resulting in slowdown in wind speed.



(a) At rated wind speed (b) Above rated wind speed

iii) Why is generator torque/power control preferred over pitch control when wind blows at less than its rated speed? [3]

The wind turbine is designed to have pitch and stall control at more than rated speed (one needs to reduce power production). At subrated wind speed the generator current (so the torque) is controlled to control the speed of the turbine – the purpose is to move the turbine speed towards optimal tip speed ratio (TSR) where power production co-efficient (Cp) is largest (maximum power point tracking). The output power captured is thus optimized as the wind speed changes.

c)

i) What is the tip speed ratio (TSR)?

Tip-speed ratio (TSR) is defined as the ratio between the incoming wind speed and the blade tip speed. Mathematically, it is expressed as:

$$\lambda = \frac{\omega_m R}{v_w}$$

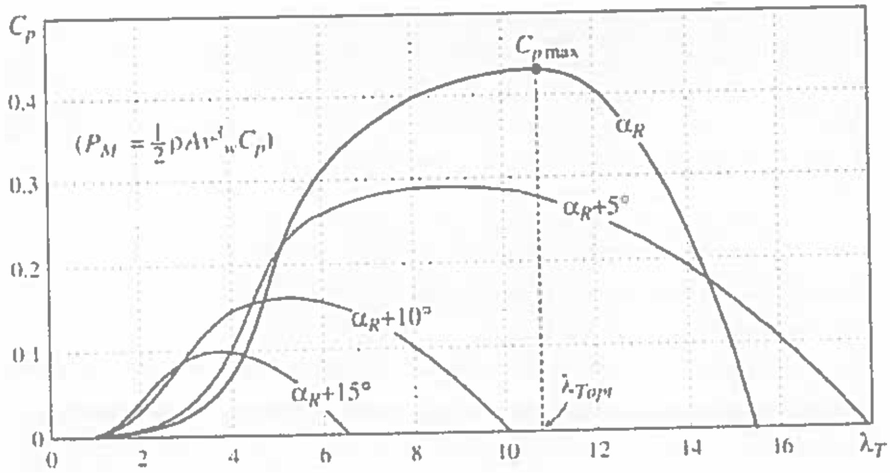
Where ω_m is the generator mechanical speed, R and v_w denote blade length and upcoming wind speed, respectively. [2]

ii) Why is it important to have an optimal TSR? [3]

TSR is very important factor as together with angle of attackα, they influence the wind turbine conversion efficiencyC_p. A turbine is usually designed with an optimal TSR point. If the upcoming wind speed changes, the generator mechanical rotation must be changed according to:

$$\omega_m = \frac{\lambda_{opt} v_w}{R}$$

A typical C_p curve versus TSR for a number of tip-speed ratios is given in the figure below. It can be clearly observed that optimal C_p is attained only at specific TSR λ_{opt} for a given pitch angle.

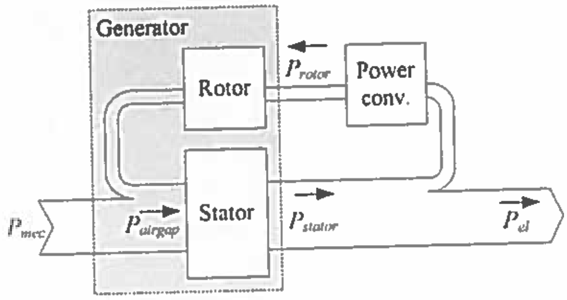


e)

How is it possible to operate a Type-3 (DFIG) machine at lower than synchronous speed (positive slip) in generator mode? [4]

The student should be able explain their understanding of power flow direction in the rotor terminal for sub synchronous and super synchronous speed.

Once that is done – they can easily demonstrate that part of the stator power produced is used to feedback the rotor circuit back to produce flux and emf in the rotor circuit. As an illustration it can be something as follows:



[25 marks]