# Tutorial 9

1- Aided with neat sketches, explain briefly the operation of a fixed speed wind turbine under AC grid fault (large voltage dip) when:

a) The fault is cleared before the FSWT reaches the critical slip $S_{crit}$
b) The fault is cleared after the FSWT reaches the critical slip $S_{crit}$

2- A 300kV sub-sea HVDC line transmits the power generated by an offshore windfarm to the onshore grid. The 250MVA onshore DC/AC converter station (Grid-side converter) is connected to the AC transmission system through a 160kV/220kV step-up substation. The TSO stipulates that renewable power plants or DC/AC converter stations connected to the transmission system should strictly operate within the steady-state power factor ranges indicated in Figure Q2. Find:

a) The minimum current supplied by the converter station to the AC grid if the converter transmits to the AC grid at voltage 10% below nominal value.
b) Find the modulation index in the operating conditions of (a) if the grid-side converter station is built as a 2-level three-phase voltage source converter with sinusoidal pulse width modulation.
c) The range of grid voltage variation (in percent of nominal voltage) for which the converter station is allowed to operate at a 0.95 leading power factor.

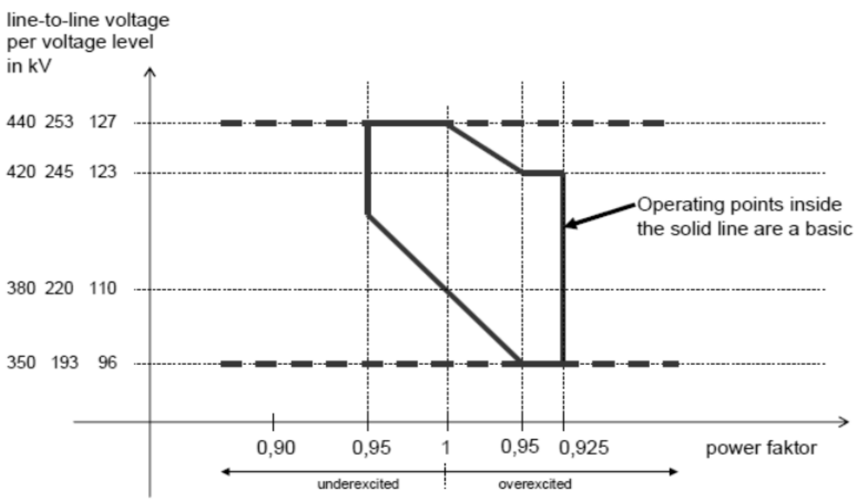


Figure Q2

3- Plot a schematic of a DFIG-WT and explain briefly how the WT components are exposed to danger under low-grid voltage. Show what extra circuits need to be connected to protect the WT.

4- A 200MW Solar PV power station is connected to the ac transmission grid. The TSO grid code imposes low-voltage ride-through capability on connected power plants as in Figure Q4. The PV station is connected to the grid at the point of common coupling through a step-up substation whose series reactance is 0.1pu and high side voltage is 220kV. A 3-phase fault occurs 30km away from the PCC. The line series impedance is 1ohm/km. Fault impedance is 2ohms. The fault drew 4.5kA from the other end of the transmission line. The PV inverter was able to limit the fault current contribution from the PV station to 1000A.

(a) Find the voltage at the PCC during fault and whether or not the PV station protection is allowed to trip. What is the voltage at the PV inverter terminal?
(b) What is the minimum value of the post-fault recovery voltage 200ms after fault clearance such that the protection does not trip?

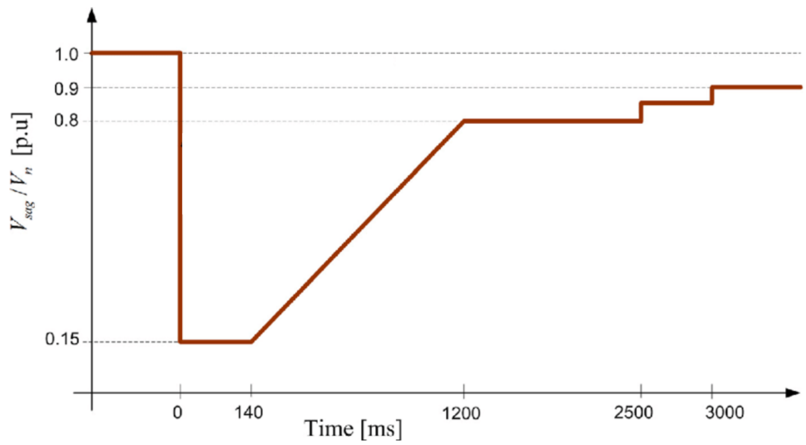


Figure Q4

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a) Define inertia constant (H) using a simple formula.
b) A 30MW utility scale flywheel energy storage plant is connected to grid to balance supply-demand mismatches by providing primary frequency control power for grid frequency regulation. The plant is composed of many flywheel units each comprising a high speed electric machine driving a rotating mass and connected to the plant internal network via a full-rated back-to-back converter. Each back-to-back converter is rated for 250kW, and each flywheel is rotating at 15000rpm. Flywheel inertia J = 3.46 kg.m$^2$. If the inertia constant of the plant H = 15s, how many units are in the plant? For how long can the plant provide 20MW primary frequency power to support the grid frequency if 10% of stored energy has to remain unused? Consider the efficiency of the converters and the motor/generator is 93%, the efficiency of the flywheel unit is 95%.

6- For the same energy storage plant in question Q5, if the voltage of the internal network in the plant is 480V, find the rated current of the grid-side converter and the DC-link voltage in each flywheel unit if the steady-state modulation index is 0.85 and the converters are 3-phase two-level VSCs driven by sinusoidal pulse width modulation. Sketch the circuit of the three phase back-to-back voltage source converter (IGBT-based) and indicate the voltage and current ratings you would select for the used IGBTs.

Note that:

- At least 50% margin of safety is normally accounted for in IGBT ratings selection.
- Standard IGBT voltage ratings: 600V, 1.2kV, 1.7kV, 3.3kV, 4.5kV.
- Standard IGBT current ratings: 400A, 800A, 1000A, 1200A, 1500A