Sample: Topics in Power Electronics and Distributed Generation – Test 3 **Points 50**

Open book exam. You can make use of three pages of formulae sheets. Make reasonable assumptions where necessary. No clarifications to questions will be provided during the test. Spend some time thinking about the questions before you start answering. ***Write the answers clearly and legibly so that they can be graded.***

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1. A feeder with a DG is modelled as a RLC load to study unintentional islanding on a $11kV$, $50Hz$ feeder as shown in the figure below. The DG is a three phase source that injects sinusoidal current at unity power factor at the PCC. The power injected by the DG is $500kW$ and the feeder equivalent circuit parameters are: $R = 233\Omega$, $L = 0.7H$, and $C = 15\mu F$.

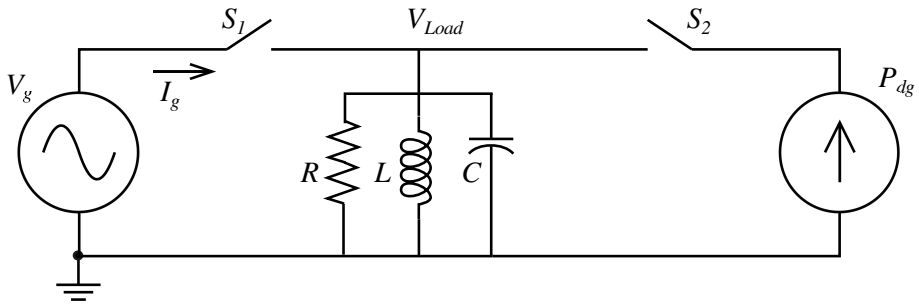

Figure 1: Feeder model for islanding analysis.

   (a) Under normal conductions, while the feeder is operating connected to the grid (S_1 and S_2 closed), calculate the current phasor, I_g, drawn from the grid? *(3 points)*

   (b) The grid gets disconnected and the feeder is islanded when S_1 is open and S_2 closed. What is the islanded steady state load voltage, V_{load}, and load frequency? *(6 points)*

2. A $6km$ overhead $11kV$ distribution feeder (ABC) has a $4km$ lateral branching at B to D. Point A is the substation end and point B is $4km$ from A. The wire resistance is $0.65\Omega/km$ and loading on the line is $30A/km$ at $0.9pf$ lag. The X/R ratio of the line is 0.8.

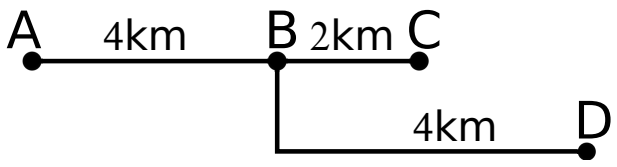

Figure 2: Distribution feeder with lateral.

(a) Plot the line current profile of the feeder ABC and ABD. *(2 point)*

(b) If the substation voltage is $11kV$, what is the line to line voltage seen at the end of the line at D? *(3 points)*

(c) At what point should the voltage be regulated to 1pu, if the line ABD should see the minimum possible deviation from the nominal all along its length? *(3 points)*

(d) What is the total power dissipation in the lines AB + BC + BD under full loading conditions? *(3 points)*

(e) A DG is used to inject $240A$ at $0.9pf$ lead into the line at point B on the feeder. What is the new voltage at the end of the line at C? *(2 point)*

(f) What is the corresponding power dissipation in the lines AB + BC + BD when the DG is operating as indicated in (e) above? *(3 point)*

3. A 5kVA 3-phase Active Front End (AFE) rectifier operates draws current at unity power factor from a distorted grid with background harmonics. The nominal grid voltage is 400V at 50Hz (The phase a voltage at the leg of the converter is given by $v_a(t) = \hat{V_{ac}} sin(\omega t + \phi)$. It is designed to be able operate at an arbitrary power factor ϕ. The phase a current is given by $i_a(t) = \hat{I_{ac}} sin(\omega t)$. Switching frequency of the converter $F_{sw} = 40kHz$, and it uses sine triangle PWM with a DC bus voltage $V_{dc} = 800V$. The modulation index, $m = \hat{V_{ac}}/(0.5V_{dc})$. The conduction drop in the IGBT is modelled as $V_{ce} = V_{T0} + i_c R_{on(T)}$, and for the diode as $V_{ak} = V_{D0} + i_d R_{on(D)}$. The switching loss for the IGBT measured under reference conditions (V_{ref}) and (I_{ref}) from the data-sheet are $E_{ON(T)}$ and $E_{OFF(T)}$ and can be scaled using exponents $K_{v(T)}$, and $K_{i(T)} = 1$. The corresponding reverse recovery loss for the diode measured under reference conditions (V_{ref}) and (I_{ref}) from the data-sheet are $E_{rr(D)}$ and can be scaled using exponents $K_{v(D)}$, and $K_{i(D)} = 0$.

   (a) Obtain a closed form expression for conduction power loss over a fundamental period in switch S_a^+ and diode D_a^-, in terms of m, ϕ, $\hat{I_{ac}}$, and relevant conduction drop parameters. *(4 points)*

   (b) Obtain a closed form expression for switching power loss over a fundamental period in switch S_a^+ and diode D_a^-, in terms of F_{sw}, $\hat{I_{ac}}$, V_{dc}, and relevant switching loss parameters. *(4 points)*

   (c) What is the modulation index m, for the AFE rectifier operating at 5kW and UPF at the grid terminals when the total filter inductance is is assumed to be 0.1pu? *(2 points)*

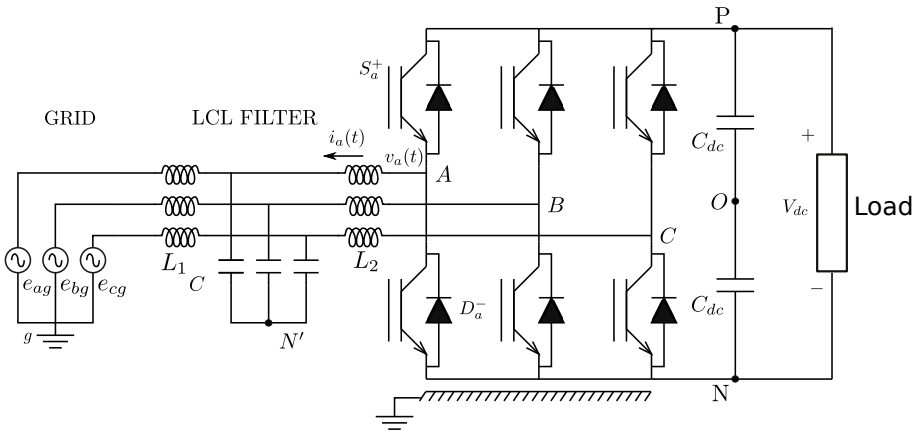

Figure 3: Three phase AFE rectifier feeding a 5kW load.

(d) Neglecting the filter capacitor current, what is the value of ϕ, for the AFE rectifier operating at 5kW and UPF at the grid terminals, when the total filter inductance is is assumed to be 0.1pu? *(2 points)*

The IGBT and diode characteristics of the converter are $V_{T)} = 0.9V$, $R_{on(T)} = 0.28\Omega$ for the IGBT and $V_{D0} = 0.95V$ $R_{on(D)} = 0.3\Omega$ for the anti-parallel diode. The data-sheet parameters evaluated at $V_{ref} = 600V$ and $i_{ref} = 40A$ are: $E_{ON(S1)} = 2mJ$, $E_{OFF(S1)} = 1.5mJ$, $E_{rr(D1)} = 1mJ$, $k_v = 0.5$, and k_i are as indicated above.

(e) Given the device parameter values, what is the total power loss in the semiconductors for the three phase inverter operating as a UPF rectifier based on the expressions obtained in (a) and (b) above? *(4 points)*

(f) Select the resonant frequency, of the LCL filter shown in Fig. 3, assuming that the converter controller needs to compensate for background harmonics upto the 13^{th}? *(2 points)*

(g) What is the minimum value of total inductance of the LCL filter if the grid current ripple is to be kept at 0.1% and the switching frequency voltage harmonics is 0.9pu? *(3 points)*

(h) What is the minimum value of total inductance if the reactive power to be drawn by the filter should be less than 5%? *(2 points)*

(i) If $L_{max} = 10\%$, what is the required LCL filter capacitance if the total filter inductance chosen is mid way between L_{min} and L_{max}? *(2 points)*