OLLSCOIL NA hÉIREANN, CORCAIGH
THE NATIONAL UNIVERSITY OF IRELAND, CORK

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

SUMMER EXAMINATIONS, 2008

B.E. DEGREE (ELECTRICAL)

ELECTRICAL AND ELECTRONIC POWER SUPPLY SYSTEMS
EE4010

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Time allowed: *3 hours*

Answer *five* questions.

All questions carry equal marks.
The use of a Casio *fx570w* or *fx570ms* calculator is permitted.

$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{H\,m^{-1}}$ $\varepsilon_0 = 8.854 \times 10^{-12}\ \mathrm{F\,m^{-1}}$

1. (a) A small alternator in an electrical power station is driven by a steam turbine system which may be approximated as an ideal Carnot heat engine. This system absorbs 1 MW of heat from a source at 600°C and rejects heat to a condenser at 20°C. Estimate the ideal Carnot efficiency of the engine, the power delivered to the alternator and the power requirements of the condenser. Give a typical practical efficiency figure for such a steam turbine system.

[5]

(b) Derive an expression for the electrical output power P available from a hydroelectric power station in terms of the flow rate of water Q $\mathrm{m^3\,s^{-1}}$, the head of water H m and the overall efficiency η. A river-based hydroelectric power station has a mean head of 28.5 m. The minimum average flow rate of water in summer is 180 $\mathrm{m^3 s^{-1}}$ and this increases to a maximum of 400 $\mathrm{m^3 s^{-1}}$ in winter. Calculate the summer and winter generating capacities of the station assuming an overall efficiency of 87%. [Density of water = 1000 $\mathrm{kgm^{-3}}$]

[5]

(c) Draw a schematic diagram of a Pressurised-Water nuclear fission Reactor, (PWR) and hence describe the process by which the nuclear fuel in this reactor generates thermal energy for steam production via a controlled nuclear reaction. Compare the annual fuel requirements of a typical 1 GW PWR nuclear power station with that of a comparable coal-fired electrical power station and list two advantages and disadvantages of these technologies for electrical power generation in future decades.

[5]

[Q.1 continued overleaf]

(d) Describe, using appropriate diagrams, the use of solar energy for (i) direct generation of electricity, (ii) indirect generation of electricity and (iii) as a source of domestic heating. Summarise the advantages and disadvantages of solar energy in comparison with wind energy as a potential source of alternative energy for the future.

[5]

2. (a) Derive from first principles an expression for the theoretical maximum power available from a wind turbine in terms of the swept area of the blades, A m^2, the velocity of the wind, u ms^{-1} and the density of air at standard temperature and pressure (STP), ρ kgm^{-3}.

List one advantage and one disadvantage of a Doubly-Fed Induction Generator (DFIG) in comparison to a squirrel cage machine for wind power generation.

[8]

(b) A small wind generator has a diameter of 2 m. The wind turbine itself operates at an efficiency of 45% of the theoretical maximum and it is connected to a gear box/three-phase induction generator which have a combined efficiency of 75%.

Calculate the electrical output power of the generator at a wind velocities of (i) 4.5 ms^{-1}, (ii) 9.0 ms^{-1} and (iii) 18.0 ms^{-1}.

What is the value in € of the energy generated over a 100 hour period at a constant wind velocity of 9.0 ms^{-1}?

What is the value in € of the energy generated over a 100 hour period if the wind velocity for one third of this time is 18.0 ms^{-1} and the wind velocity is 4.5 ms^{-1} for the remainder of the time? Comment briefly on the significance of this last result compared to the calculation based on a constant wind speed of 9.0 ms^{-1} over the 100 hour period?

[Density of air at STP = 1.29 kgm^{-3}]
[Cost per kWh= 10 c/kWh]

[12]

3. (a) Define the terms (i) *sequence voltage vector* (ii) *sequence current vector* and (iii) *sequence impedance matrix* for a three-phase electrical load.

A three-phase, balanced star-connected load consists of a resistance R_Y in each phase and the load star-point n is isolated relative to ground g. This load is fed from a set of unbalanced three-phase voltages $\overline{V}_{ag}$, $\overline{V}_{bg}$ and $\overline{V}_{cg}$. Derive the sequence impedance matrix and the associated sequence networks for this load and hence deduce an expression for the current flowing in the resistance in Phase a.

[10]

(b) An unbalanced three-phase sinusoidal voltage source, of phase sequence abc, has phase-to-ground voltages given by $\overline{V}_{ag} = 100\angle 0°$ V, $\overline{V}_{bg} = 200\angle 270°$ V and $\overline{V}_{cg} = 100\angle 120°$ V. Three identical voltmeters, each of resistance 10 kΩ, are connected in star to this unbalanced supply via a three-wire connection in which the star point n is isolated relative to ground g. Calculate the voltage reading of the voltmeter connected to Phase b.

[10]

4. (a) Prove that the use of the per-unit method of analysis can eliminate the ideal transformer element from the single-phase transformer equivalent circuit model and define the conditions on the selection of base parameters under which this simplification can be achieved.

[8]

(b) Three single-phase, two-winding transformers, each rated at 25 MVA, 34.5 kV/13.8 kV, are connected to form a three-phase delta-delta bank. Balanced, positive sequence voltages are applied to the high voltage terminals and a balanced three-phase resistive load which is connected to the low voltage terminals absorbs 75 MW at 13.8 kV. Calculate the currents in the transformer windings. If one of the transformers is now removed and the load is reduced to 43.3 MW, calculate the MVA supplied by the two remaining transformers and determine if these devices are overloaded?

[12]

5. (a) Draw the exact per-phase equivalent circuit of a three-phase, round-rotor, synchronous generator when connected to an infinite system, noting the significance of each component of the model.

Neglecting resistive losses, derive expressions for the real power P and the reactive power Q delivered by the machine to the system in terms of the terminal voltage V_t, the generated back-emf, E_f, the synchronous reactance X_s and the load angle δ.

Show that the locus of the complex power transfer derived above is a circle in the complex P/Q plane. Deduce the radius and the centre of this circle in terms of the specified parameters.

[10]

(b) A 10 MVA, 11 kV, 50 Hz, three-phase, star-connected, round-rotor, synchronous generator has a synchronous reactance of $j10.0\,\Omega$/ phase and negligible armature resistance. It is delivering a per-phase current of 220 A at unity power factor to a set of 11 kV, constant voltage, constant frequency busbars.

If the prime mover power remains unchanged while the excitation is increased by 25%, calculate the new armature current and the reactive power supplied by the machine for this operating condition.

If the excitation is now maintained constant at this new value, what is the theoretical maximum power which the machine could supply before losing synchronism with the busbars and evaluate the armature current supplied for this limit condition.

[10]

6. (a) Prove that the per-unit fault volt-amperes for a symmetrical fault in a three-phase system is given approximately by

$$VA_{f\,pu} = \frac{1}{X_{T\,pu}}$$

where $X_{T\,pu}$ is the total per-unit phase reactance up to the fault point.

[Q.6 continued overleaf]

Explain the use of current limiting reactors in electrical power systems and describe, in particular, the tie-bar method of connecting such reactors in a large multi-generator power station.

[8]

(b) A small electrical power generating station has a 5 MVA generator with 8% reactance and a 4 MVA generator with 6% reactance connected in parallel to 11 kV, 50 Hz busbars. These busbars feed an industrial load via switchgear with a rated short circuit breaking capacity of 180 MVA.

It is desired to extend the station by connecting a new grid supply to the station busbars via a 10 MVA transformer having a leakage reactance of 10%. A current limiting reactor is to be used in series with this transformer in order to safeguard the existing switchgear. Calculate the value, in ohms, required for this reactor and also determine the per-unit current which it carries under three-phase symmetrical short circuit conditions on the station busbars.

[12]

7. (a) Derive an expression for the fault current when a single-phase-to-ground fault occurs at the terminals of a three-phase, round-rotor, star-connected synchronous generator with a solidly grounded star point. It may be assumed that the generator is initially operating at rated voltage and frequency and that it is unloaded prior to the fault.

[8]

(b) A power station houses two identical round-rotor, star-connected synchronous generators, A and B, each rated at 37.5 MVA, 11 kV, 50 Hz. The alternators are connected by an inter-busbar current-limiting reactor rated at 25 MVA (3-phase) with a per-unit reactance of 5% per phase.

Machine A is earthed via a resistance of 90% based on the alternator rating. The neutral of Machine B is isolated. The positive, negative and zero sequence reactances of the two machines are $j0.21$ pu, $j0.17$ pu and $j0.06$ pu respectively.

On Section A, a three-phase, 50 Hz, 20 MVA, 11 kV(delta)/ 66 kV(star) transformer bank with a per-unit reactance of 10%, is used to connect the power station to a 66 kV transmission line. The star point of the transformer high-voltage winding is solidly earthed.

A bolted single-phase-to-ground fault occurs on Phase a of the 66 kV transformer winding. Draw the sequence network corresponding to this fault and calculate the per-unit fault current in Phase a using a base of 20 MVA. It may be assumed that the machines are initially operating on no-load at rated voltage and frequency.

[12]