Benha University
Faculty of Engineering (Shoubra)
Electrical Engineering Department
Postgraduate (master)

Final Term Exam (Model Answer)
Date: 21/1/2017
Generation of Electrical Power from Renewable Resources
Duration: 3 Hours

- Answer all the following questions.
- Illustrate your answers with sketches when necessary.
- Total mark: 60 marks
- Number of questions: 4
- The exam consists of three pages.

Q.1 *Complete the following sentences with correct answers* ***[20 marks]***

1- What are the procedures have been suggested as an approach to sequestering carbon technological sequestration, ocean direct injection, and geological storage.

2- The different hybrid electrical generation systems are wind generator with acid batteries, ………………….

3- Optimum tilt of solar panels for each geographic region can be estimated by latitude.

4- The output of a wind turbine system in the Northen Hemisphere is typically highest in which season Winter.

5- The collection efficiency is maximum in paraboloid dish collector.

6- The efficiency of various types of solar collectors decreases with increasing temperature.

7- Solar radiation flux is usually measured with the help of a Pyranometer.

8- The global radiation reaching a horizontal surface on the earth is given by hourly beam radiation + diffuse radiation.

9- Direct solar energy is used for water heating, distillation and Drying.

10- The forms of renewable energy that draw their energy from solar radiation are wind, Biomass, Wave energies.

11- Absorption of solar radiations at earth's surface occurs due to presence of Ozone, Water vapour and Carbon di-oxide.

12- The most important studies to be performed for the wind power plant are site survey, economic, technical, and environmental.

13- The 'maximum power point' on the current-voltage curve for a PV cell is the point at which it produces Maximum voltage× current.

14- Almost 50% of the world's crystalline silicon PV production capacity is located in which country? China

15- The steerable mirrors of a 'power tower' called Heliostats.

16- The two forms of renewable energy that do NOT draw their energy from solar radiation are Tidal and geothermal power.

17- The source of the energy in the wind is the difference in solar heating between the Earth's equator and the poles.
18- The key advantage of vertical axis wind turbines over horizontal axis wind turbines is that VAWTs can harness winds from any direction without having to reposition the rotor.
19- In 1928 Albert Betz showed that there was an upper limit to the fraction of the power in the wind that could be extracted which is 59.3%.

A Renewable Energy Feed-In Tariff is a guaranteed purchase price for renewably-generated electricity.

Question # 2: ***[50 marks]***

a) Define the following terms:

Solidity:

The solidity of a wind rotor is the ratio of the projected blade area to the area of the wind intercepted. The projected blade area does not mean the actual blade area; it is the blade area met by the wind or projected in the direction of the wind. The solidity of the Savonius rotor is naturally unity, as the wind sees no free passage through it. For a multiblade water-pumping windmill, it is typically around 0.7. For high-speed horizontal-axis machines, it lies between 0.01 and 0.1; for the Darrieus rotor also it is of the same order. Solidity has a direct relationship with torque and speed. High-solidity rotors have high torque and low speed, and are suitable for pumping water. Low-solidity rotors, on the other hand, have high speed and low torque, and are typically suited for electrical power generation.

Tip Speed Ratio:

The tip speed ratio (TSR) of a wind turbine is defined as

$$\lambda = \frac{2\pi RN}{V_{wind}}$$

where λ is the TSR (non-dimensional), R is the radius of the swept area (in meters), N is the rotational speed in revolutions per second, and V_{wind} is the wind speed without rotor interruption (in meters per second). The TSRs of the Savonius rotor and the multiblade water pumping windmills are generally low. In high-speed horizontal-axis rotors and Darrieus rotors, the outer tip actually turns much faster than the wind speed owing to the aerodynamic shape. Consequently, the TSR can be as high as 9. It can be said that high-solidity rotors have, in general, low TSRs and vice versa.

Power Coefficient:

The power coefficient of a wind energy converter is given by

$$C_p = \frac{Power\ output\ from\ the\ wind\ machine}{power\ contained\ in\ wind}$$

The power coefficient differs from the efficiency of a wind machine in the sense that the latter includes the losses in mechanical transmission, electrical generation, etc., whereas the former is just the efficiency of conversion of wind energy into mechanical energy of the shaft. In high-speed horizontal-axis machines, the theoretical maximum power coefficient is given by the Betz limit.

Betz limit:

The theoretical maximum power coefficient in high-speed horizontal-axis machines. The graph of the power coefficient against the TSR is a very important yardstick in the characterization of wind energy converters. Typical curves for different types of windmills are shown in the figure below.

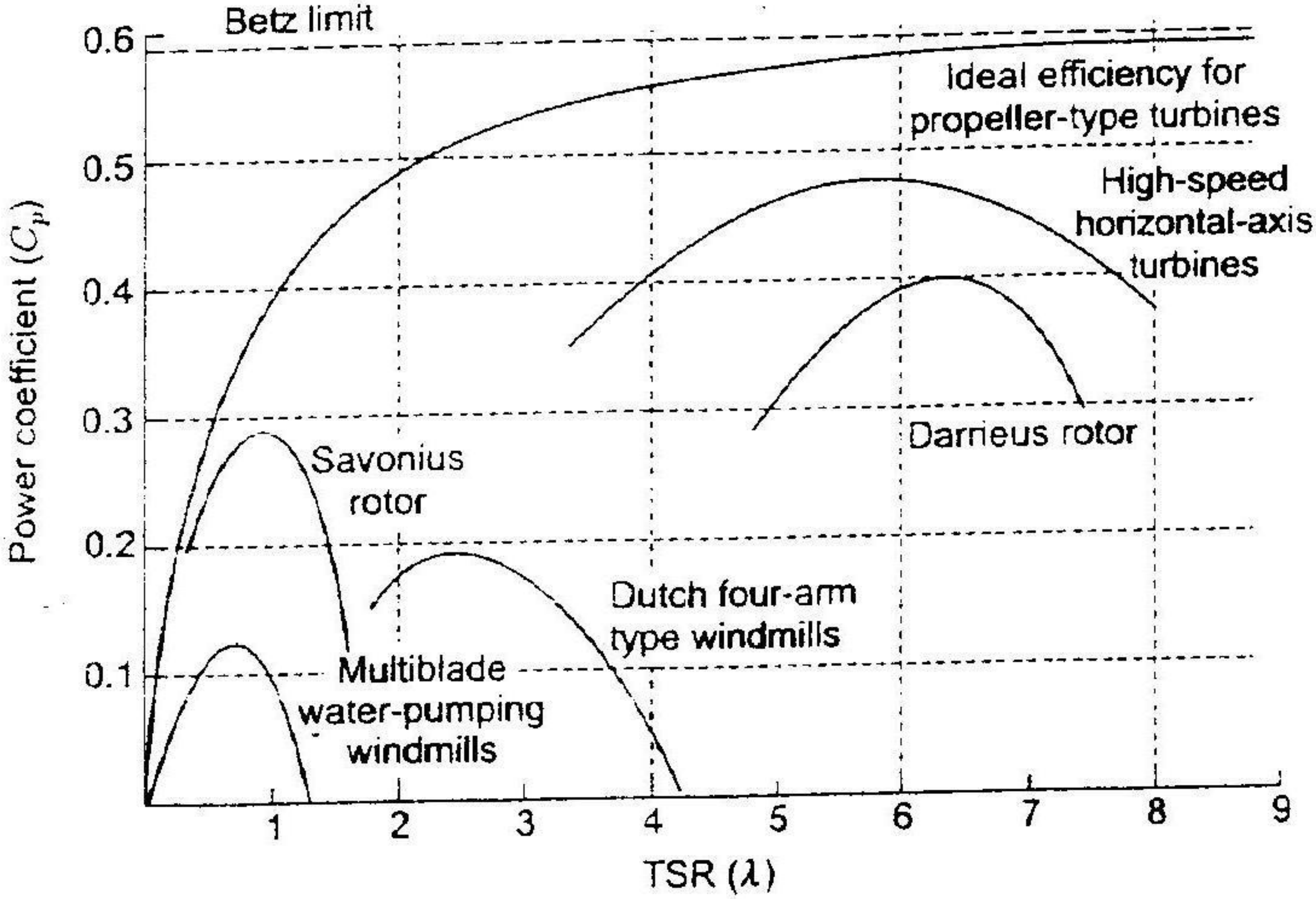

Fig. xx Curves of C_p versus TSR for different types of windmills

b) A horizontal-axis wind turbine generates 100 kW at a wind speed of 8 m/s and a rotor speed of 140 rpm. The power coefficient is 0.43, efficiency of mechanical transmission is 0.9, and efficiency of electrical generator and power conditioning equipment is 0.92.

(30 marks)

i)

$$100 = \frac{1}{8} \times 0.92 \times 0.9 \times 0.43 \times \pi \times 1.25 \times 8^3 \times D^2$$

$D = 33.43\ m$

ii)

$$\lambda = \frac{2 \times \pi \times 16.715 \times \left(\frac{140}{60}\right)}{8} = 30.63$$

iii) If the power is halved, the diameter will be

$$\frac{P_1}{P_2} = \left(\frac{D_1}{D_2}\right)^2$$

$$\frac{100}{50} = \left(\frac{33.43}{D_2}\right)^2$$

$D_2 = 23.64\ m$

To double the output power, the diameter should be increased according to the same relation as mentioned for getting D_2.

c) Wind turbines can have four different types of control mechanisms, as discussed in the following.

1- Pitch Angle Control

This system changes the pitch angle of the blades according to the variation of wind speed. It is possible to achieve a high efficiency by continuously aligning the blade in the direction of the relative wind through pitch control.

On a pitch-controlled machine, as the wind speed exceeds its rated speed, the blades are gradually turned about the longitudinal axis and out of the wind to increase the pitch angle. This reduces the aerodynamic efficiency of the rotor. And the rotor output power decreases. When the wind speed exceeds the safe limit for the system, the pitch angle is so changed that the power output reduces to zero and the machine shifts to the 'stall' mode. After the guest passes, the pitch angle is reset to the normal position and the turbine is restarted. At normal wind speeds, the blade pitch angle should ideally settle to a value at which the output power equals the rated power.

The pitch angle control principle is explained in the following figure. The input variable to the pitch controller is the error signal arising from the difference between the output electrical power and the reference power. The pitch controller operates the blade actuator to alter the pitch angle. During operation below the rated speed, the control system endeavours to pitch the blade at an angle that maximizes the rotor efficiency. The generator must be able to absorb the mechanical power output and deliver to the load. Hence, the generator output power needs to be simultaneously adjusted.

Continuous pitch control is relatively expensive to incorporate, and the cost-benefit trade-off does not justify its use in small wind machines. However, the stalling mechanism must be incorporated to prevent damage of the turbine during turbulent weather conditions.

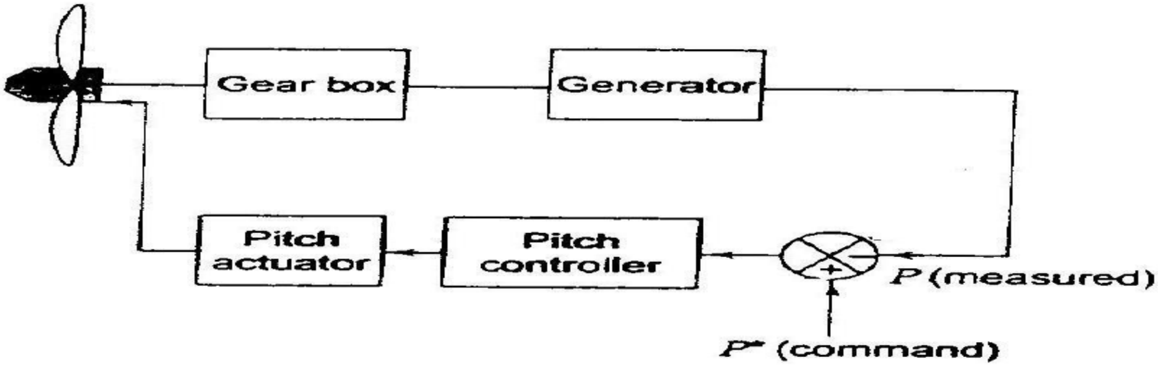

Fig. yy The feedback loop for pitch angle control

2- Stall Control

A- Passive stall control

Generally, stall control to limit the power output at high winds is applied to constant-pitch turbines driving induction generators connected to the network. The rotor speed is fixed by the network, allowing only 1-4% variation. As the wind speed increases, the angle of attack also increases for a blade running at a near constant speed. Beyond a particular angle of attack, the lift force decreases, causing the rotor efficiency to drop. This is an intrinsic property and dispenses with the need for a complex control system and moving parts. The lift force can be further reduced to restrict the power output at high winds by properly shaping the rotor blade profile to create turbulence on the rotor blade side not facing the wind.

B- Active stall control

In this method of control, at high wind speeds, the blade is rotated by a few degrees in the direction opposite to that in a pitch-controlled machine. This increases the angle of attack, which can be controlled to keep the output power at its rated value at all high wind speeds below the furling speed. A passive controlled machine shows a drop in power at high winds. The action of active stall control is sometimes called deep stall. Owing to economic reasons, active pitch control is generally used only with high-capacity machines.

The following figure below presents typical profiles of power curve for pitch control and stall control.

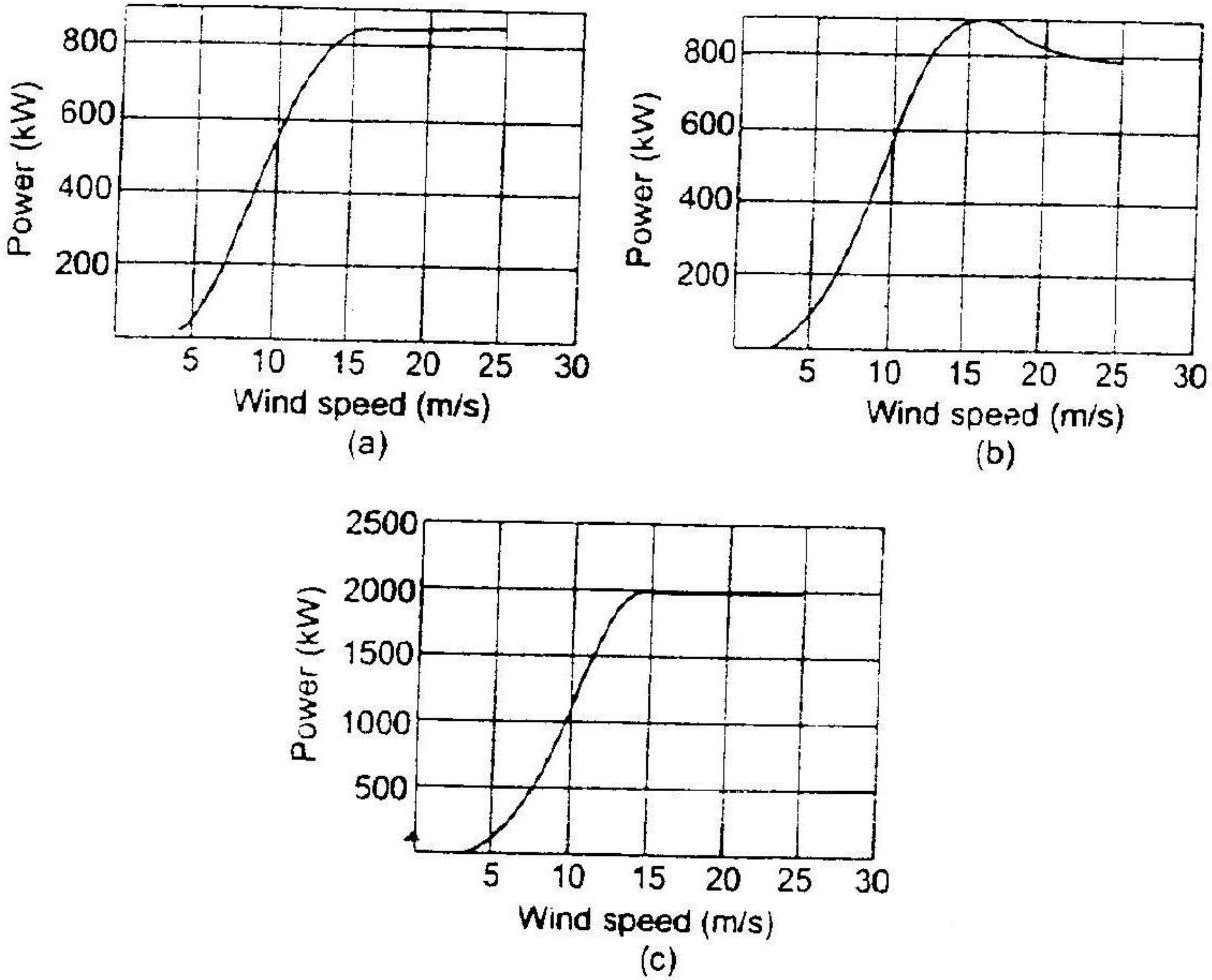

Fig. zz Typical power profiles: (a) pitch control, (b) passive stall control, (c) active stall control

3- Power Electronic Control

In a system incorporating a power electronic interface between the generator and the load (or the grid), the electrical power delivered by the generator to the load can be dynamically controlled. The instantaneous difference between mechanical power and electrical power changes the rotor speed following the equation

$$J\frac{d\omega}{dt}=\frac{P_m-P_e}{\omega}$$

Where J is the polar moment of inertia of the rotor, w is the angular speed of the rotor, Pm is the mechanical power produced by the turbine, and Pe is the electrical power delivered to the load. By integration, we get

$$\frac{1}{2}J(\omega_2^2-\omega_1^2)=\int_{t_1}^{t_2}(P_m-P_e)dt$$

The advantage of this method of speed control is that it does not involve any mechanical action and is smooth in operation. A disadvantage is that fast variation of speed requires a large difference between the input power and output power, which scales as the moment of inertia of the rotor. This results in a large torque and hence increased stress on the blades. Moreover, continuous control of the rotor speed by this method implies continuous fluctuation of the power output to the grid, which is usually undesirable for the power system.

1- Yaw Control

This control orients the turbine continuously along the direction of wind flow. In small turbines this is achieved with a tail-vane. In large machines this can be achieved using motorized control systems activated either by a fan-tail (a small turbine mounted perpendicular to the main turbine) or, in case of wind farms, by a centralized instrument for the detection of the wind direction. It is also possible to achieve yaw control without any additional mechanism, simply by mounting the turbine downwind so that the thrust force automatically pushes the turbine in the direction of the wind.

The yaw control mechanism can also be used for speed control. The rotor is made to face away from the wind direction at high wind speeds, thereby reducing the mechanical power. However, this method is seldom used where pitch control is available, because of the stresses it produces on the rotor blades, Yawing often produces loud noise, and it is desirable to restrict the yawing rate in large machines to reduce the noise.

(20 marks)

Question # 3: ***[50 marks]***

a) Give examples for energy storage systems technologies in general and what are preferred to use with PV systems.

To answer this question, see reference "Wind and Solar Power Systems" chapter 10 pages 173-210 (15 marks)

b) Explain in detail the different wind turbine control systems illustrating your answer if possible with diagrams.

To answer this question, see reference "WIND ELECTRICAL SYSTEMS" chapter 1 pages 42-45 (15 marks)

c) Draw block diagrams for the following hybrid system: ***(20 marks)***

- Stand-alone PV power system with MPPT converter and battery backup.
- Wind-diesel system.

- Wind-PV system.
- PV-diesel system.
- ***To answer this question, see reference "WIND ELECTRICAL SYSTEMS" chapter 7 pages 284-300***

Question # 4: ***[60 marks]***

a) Discuss in details: ***(25 marks)***

- The main factors affecting the electrical design of photovoltaic array system. Discuss the mechanical tracking and MPPT systems of PV arrays and explain two commonly used techniques of the later system.

To answer this question, see reference "Wind and Solar Power Systems" chapter 8 pages 143-155

- Draw the equivalent circuit of PV cells, and then deduce expressions for Vo.c and Is.c.

To answer this question, see reference "Wind and Solar Power Systems" chapter 8 pages 138-150

- Draw the main characteristic of PV arrays (I/V, P/V), showing the effect of intensity of radiation and ambient temperature on their performance.

To answer this question, see reference "Wind and Solar Power Systems" chapter 8 pages 150-151

- Major factors that have accelerated the wind and photovoltaic-power technology development are as follows:

- High-strength fiber composites for constructing large low-cost blades.
- Falling prices of the power electronics.
- Variable-speed operation of electrical generators to capture maximum energy.
- Improved plant operation, pushing the availability up to 95 percent.
- Economy of scale, as the turbines and plants are getting larger in size.
- Accumulated field experience (the learning curve effect) improving the capacity factor.

- The wind power system is comprised of one or more units, operating electrically in parallel, having the following components:

- The tower.
- The wind turbine with two or three blades.
- The yaw mechanism such as the tail vane.
- The mechanical gear.
- The electrical generator.
- The speed sensors and control.

The modern system often has the following additional components:

- The power electronics.
- The control electronics, usually incorporating a computer.
- The battery for improving the load availability in stand-alone mode.
- The transmission link connecting to the area grid.

With our best wishes