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

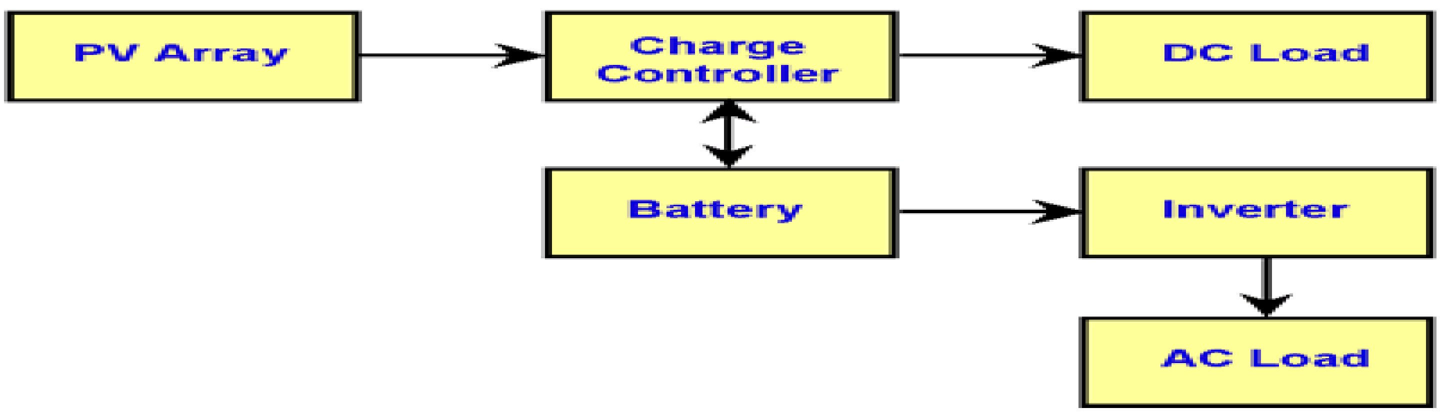
Final Term Exam (Model Answer)
Date: 05/01/2019
Generation of Electrical Power from Renewable Resources
Duration: 3 Hours

- Answer all the following questions.
- Illustrate your answers with sketches when necessary.
- Total mark: 60 marks
- Number of questions: 4
- The exam model answer consists of 12 pages.

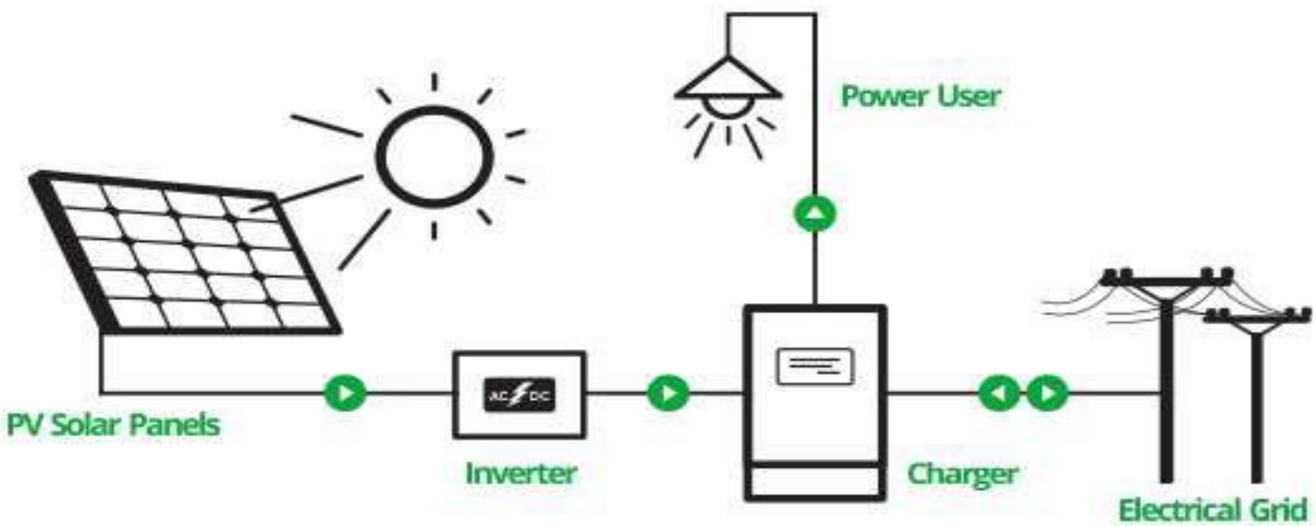
Q.1 **[15 marks]**

a) Explain and draw complete diagrams for stand-alone PV system as well as grid connected PV system. **(3 marks)**

Stand-alone PV system.



Grid connected PV system



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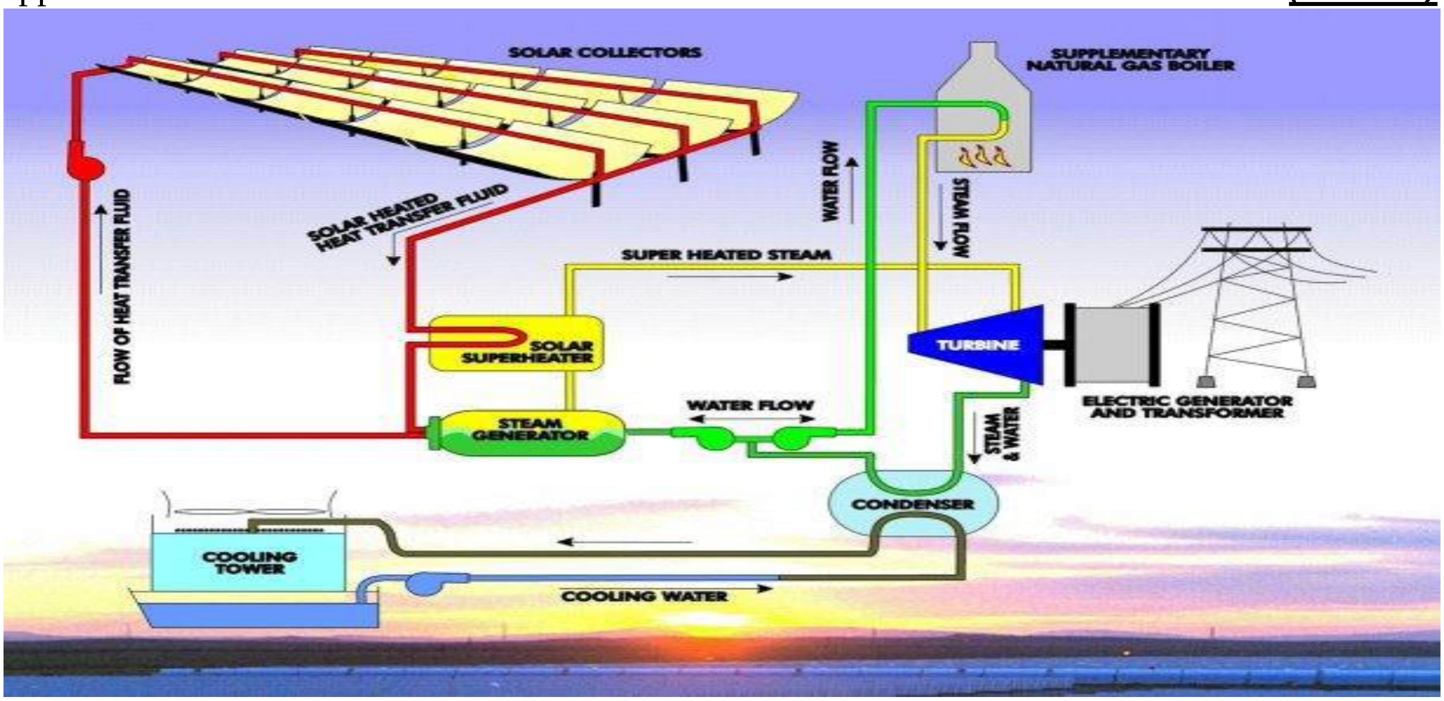
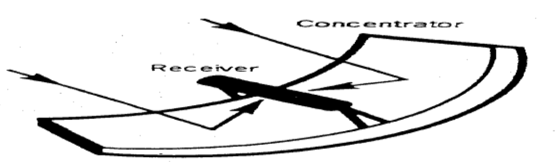
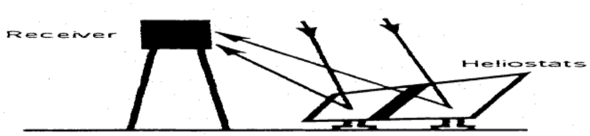
b) Sketch a schematic diagram for solar thermal power plant to generate electricity, mention also the different types of energy collectors and compare between their characteristics and applications. ***(4 marks)***



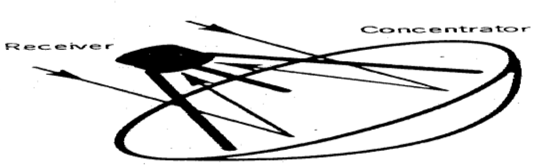
Different types of energy collectors



(a) Trough



(b) Central Receiver



(c) Dish

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c) A 100 cm^2 photovoltaic cell having a reverse saturation current of 10^{-12} A/cm^2. The cell generators have short circuit current of 40 mA/cm^2 at full sun and 25^o C. (i) Sketch I-V and P-V characteristics. (ii) The fill factor. (iii) Operating current and voltage and power delivered from the cell, if it feeds a load of 20 Ω at full sun. (iv) Operating current and voltage of the cell when it supplies a motor at its MPP and also when the motor consumes 3 W. ***(8 marks)***

Q.*2** ***[15 marks]

a) Enumerate the different types of rechargeable batteries and discuss the performance characteristic of the battery which influences the design. Illustrate your answer with necessary curves. ***(4 marks)***

Lead Acid Batteries for Solar Energy

1- Flooded Lead Acid.

2- Valve Regulated Lead Acid:

A- Wet

B- AGM

C- Gel

Another classification for solar energy batteries (flat or tubular plate).

b) Explain briefly the use of the fly wheel and superconducting technologies for storing electricity. ***(4 marks)***

The flywheel stores kinetic energy in a rotating inertia. This energy can be converted from and to electricity with high efficiency. The flywheel energy storage is an old concept, which is getting commercially viable due to advances made in high strength, light-weight fiber composite rotors, and the magnetic bearings that operates at high speeds. The flywheel energy storage system is being developed for a variety of applications and is expected to make significant inroads in the near future. The round-trip conversion efficiency of a large flywheel system can approach 90 percent, much higher than that in the battery. The energy storage in the flywheel is limited by the mechanical stress due to centrifugal force at high speed. Small to medium-size flywheels have been in use for years. Considerable development efforts are underway around the world for high-speed flywheels to store large amounts of energy. The present goal of these developments is to achieve five times the energy density of the currently available secondary batteries. This goal is achievable with the following enabling technologies, which are already in place in their component forms:

• high-strength fibers having ultimate tensile strength of over one million psi.
• advances made in designing and manufacturing fiber-epoxy composites.
• high-speed, magnetic bearings which eliminate friction, vibrations, and noise.

Superconducting Coil

The development efforts to use the superconducting technology for storing electrical energy has started yielding highly promising results. In its working principle, the energy is stored in the magnetic field of a coil, and is given by the following expression:

c) An administration building requires 1 MW electric power for supplying different loads. It is intended to generate 20% of the total load using PV array on the top of the building. The electrical characteristics of solar modules are: cell size: 7.8 × 15.6 cm, number of cells: 120, typical power: 250 Wp, minimum power: 242.5 Wp, voltage at typical power: 31 V, current at typical power: 8.08 A, short circuit current: 8.79 A, open circuit voltage: 37.6 V, module efficiency: 16.4 %, maximum circuit voltage: 1000 V. (i) Design the photovoltaic array system including (modules and inverter sizing). (ii) Design battery system for 6 hours daily. (iii) Estimate the required area for installing this PV system. ***(7 marks)***

(i) PV array system design:

Step (1): find daily energy requirement

1. List all DC loads with their power ratings and daily usage.
2. List all AC loads with their power ratings and daily usage.

In this case study, the customer needs to supply 20% of the electricity consumption.

Total power requirements from PV array system $= \frac{20}{100} \times 1000 \ = 200\ kW$

We will assume that electricity consumption is divided into 20% for DC loads and 80% for AC loads.

DC power requirements $= \frac{20}{100} \times 200 \ = 40\ kW$

AC power requirements $= \frac{80}{100} \times 200 \ = 160\ kW$

We will assume that the daily usage in the administration building is ***10 hours***.

DC energy requirements $= 40\ kW\ \times 10\ h\ = 400\ kWh/day$

AC energy requirements $= 160\ kW \times 10\ h\ = 1600\ kWh/day$

Total energy requirement $= 400 + 1600\ = 2000\ kWh/day$

Step (2): determine critical design month

1. Find monthly mean solar insolation data in kWh/m^2/day or peak sun hours (psh) for installation sites.
2. Divide daily DC energy requirements by available solar insolation values for different tilt angles.
3. The critical design month is the month with the highest ratio of load to solar insolation. It defines the optimal tilt angle that results in the smallest array possible.
4. Since lowest irradiation month mostly falls in the winter solstice, the best tilt angle for constant loads is “Latitude + 15 degree”.

We will assume 5 psh

Step (3): PV array sizing

1. Locate the project site on the sun hours per day maps and list winter and yearly average sun hours per day.
2. Calculate required watt hours you need to generate per hour of full sun = daily demand watt hours / sun hours per day.
3. Estimate the typical power produced by your selected PV = voltage at typical power × current at typical power.

4. Calculate total number of modules in array = required watt hours you need to generate per hour of full sun / selected PV panel typical power.

Using 150 Wp module

The average sun hours per day in Egypt is 7 – 11 hours, we will choose 8 hours.

Required watt hours to generate per hour of full sun = $(2000\ kWh/day)/8\ h = 250\ kW$

Typical PV module power = $31V \times 8.08A = 250.48\ W$

Number of PV modules = $250\ kW\ /\ 250.48\ W\ = 999\ modules$

For 240 system voltage, we will have

<u>Step (3): find energy requirement from battery</u>

1. Assume system wiring losses is typically 2.5 – 7%, we will consider 5%.
2. Assume inverter efficiency is typically 85 – 95%, we will consider 90%.
3. Calculate total energy requirement from battery per day = total DC energy requirement + total AC load energy requirement (through inverter).

Average daily energy consumption = $\left(\frac{400}{1-0.05}\right) + \left(\frac{1600}{0.9}\right)\ = 2199\ kWh/day$

<u>Step (4): Battery bank sizing</u>

1. Determine total daily energy requirement per day.
2. Determine the number of storage days or hours that a fully charged battery system can supply power without further charging (days of autonomy).
3. Calculate daily battery capacity demand = total daily energy requirement / (system voltage × number of storage days or hours.
4. Determine depth of discharge (DoD) factor for selected battery, typically 20 - 80%.
5. Calculate required battery capacity = daily battery capacity demand (line 3) / DoD.
6. De-rate your battery for low temperatures by multiplying (line 5) by 1.2 as a de-rating factor.
7. Find the watt hour capacity of your selected battery = voltage × amp hour capacity.

8. Determine the number of batteries = required battery capacity (line 6) / selected battery watt hour (line 7).
9. Select deep discharge batteries, if possible.

- In this case study, we will consider 5 storage hours, 75% DoD

Total battery capacity demand $= (2199\ kWh/day) \times (\frac{6}{24})\ day \times 1.2/0.75 = 880\ kWh$

We will use deep discharge batteries with 256Ah for each battery

Total number of batteries required $= (880\ kWh)/(256\ Ah) \cong 3436\ battery$

We will use deep discharge batteries, $20 \times$ 12V batteries in series with 256Ah for each battery

The battery bank system will consist of:

- 172 parallel connected groups
- Each parallel group consists of 20 battery connected in series.

<u>Step (4): PV array sizing for battery charging</u>

1. Estimate battery charging efficiency (typically 80 – 90%).
2. Estimate soiling factor for installation (typically 0.9 – 1).
3. Calculate required charging current from PV array = daily demand on battery capacity / critical design month insolation / system voltage / battery charging efficiency / soiling factor.
4. Estimate maximum module temperature & rating reference temperature (typically 25°C).
5. Calculate required charging voltage from PV array = system voltage - (system voltage × temperature coefficient × (maximum temperature - reference temperature)).
6. Calculate required charging power from PV array = 1.2 × required charging voltage from PV array × required charging current from PV array.
7. Select appropriate PV modules, e.g. for 240 V system voltage.
8. Calculate (round up) number of PV modules in series = required charging voltage / module rated voltage.
9. Calculate (round up) number of PV modules in parallel = required charging current / module rated current.

10. Calculate total number of modules in array = number of modules in series × number of modules in parallel.

Using 250 Wp module

Required charging current = $(2199\ kWh/day)/\left(5\frac{psh}{day}\right)/(240V)/(0.9)/(0.95) = 2143.3\ A$

Required charging voltage = $240V - (240V \times -0.004 \times (60°\text{C} - 25°\text{C})) = 206.4\ V$

Required charging power from PV array = $1.2 \times 206.4V \times 2143.3A = 530.85\ kW$

Number of PV modules in series = $206.4V\ /\ 37.6V = 6\ modules$

Number of PV modules in parallel = $2143.3A\ /\ 8.79A = 244\ modules$

Total number of PV modules = $6 \times 244 = 1464\ modules$

<u>Step (6): Charge controller sizing</u>

1. Look up short circuit current of PV module
2. Calculate charge controller minimum power current = short circuit current of PV module × number of modules in parallel × 1.25
3. Select appropriate charge controller

Using 250 Wp module

Required charge controller minimum power current = $(8.79\ A) \times 244 \times 1.25 = 2681\ A$

<u>Step (7): Inverter sizing</u>

1. Calculate inverter minimum power = power of all AC loads × 1.25
2. Select appropriate inverter

Required inverter minimum power = $(160\ kW) \times 1.25 = 200\ kW$

So, we will select 200 kW inverter

1) <u>surface area for installing this system:</u>

Required surface area for installing this system = $(1464\ modules) \times 1.46\ m^2 \times 1.5 = 3207\ m^2$

Q.3 Write true or false with correcting the wrong statement **[50 marks]**

1- Thousands of mirrors or curved metals are used to focus solar energy to make it very hot, in solar cells. (false, solar furnace)

2- Wind is beneficial resource of energy as it doesn't cause pollution. (true)

3- When animals and plants are rotten in absence of air, there produces a gas called bio gas. (true)

4- Black painted panels which are hanged at roofs to trap heat and energy from sun, are solar battery. (false, solar heater)

5- A natural resource that can be replaced in same rate at which it is consumed or used is known as natural resources. (false, renewable resources)

6- Both power and manure are provided by biogas plants. (true)

7- The electricity and heat production sector produces the most Co_2 emissions. (true)

8- The wind turbine is designed to stop operation at cut out velocity to improve the efficiency. (false, to protect wheel against damage)

9- The fraction of time during a given period that the turbine is on line is called availability factor. (true)

10- Organic cells are the most common photovoltaic used today. (False, poly crystalline)

Q.4 **[20 marks]**

a) Discuss in detail: ***(10 marks)***

- Technical factors affecting site selection.
  1- High average annual wind speed.
  2- Low cost of construction.
  3- Close distance from utility line or customers.
  4- Surface roughness.
  5- Prevailing wind direction.

- Different categories of speed control methods for wind turbines.
  The speed control methods fall into the following categories:

* no speed control whatsoever.
* yaw and tilt control.
* pitch control.
* stall control.

The control levels for the wind power plant:

1- The uppermost level is a supervisory controller that monitors the turbine and wind resource to determine when the wind speed is sufficient to start up the turbine and when, due to high winds, the turbine must be shut down for safety.

2- On the middle level is turbine control, which includes generator torque control, blade pitch control, and yaw control.

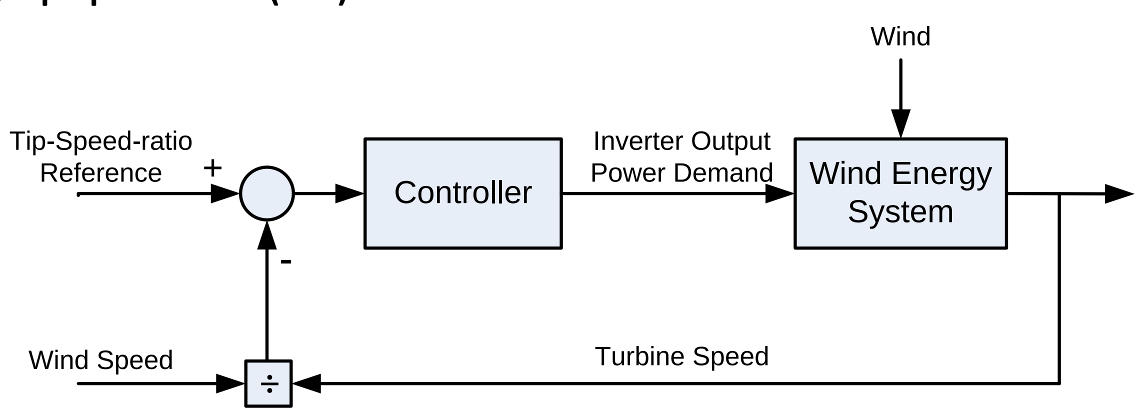
Generator torque control, and pitch control determines how much torque is extracted from the turbine, specifically, the high-speed shaft.

Yaw control, which rotates the nacelle to point into the wind, is slower than generator torque control and blade pitch control.

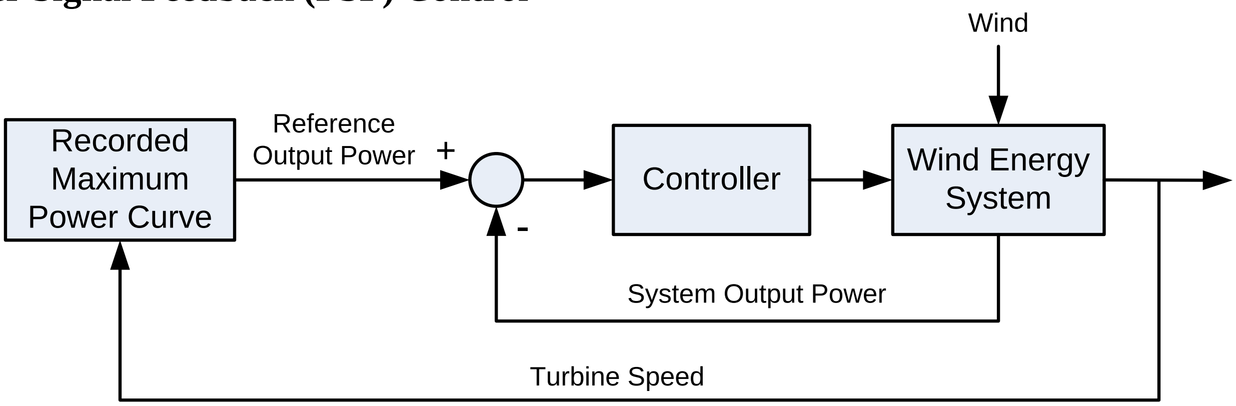
3- On the lowest control level controllers are the internal generator, power electronics, and pitch actuator, which operate at higher rates than the turbine-level control.

- MPPT techniques for wind systems.

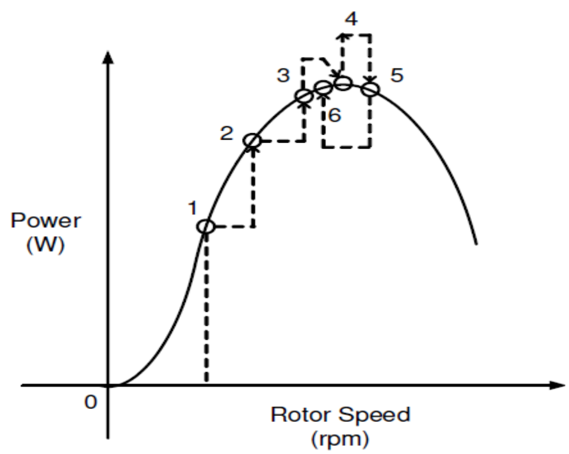
(1) Tip-Speed-Ratio (TSR) Control



(2) Power Signal Feedback (PSF) Control



(3) Hill Climb Search (HCS)



- Different configurations of renewable energy-based hybrid systems.
  1- Wind + diesel + storage
  2- PV + diesel + storage
  3- Hydro + diesel + storage

- Different types of energy storage systems.
  1- Battery Storage
  2- Compressed air storage.

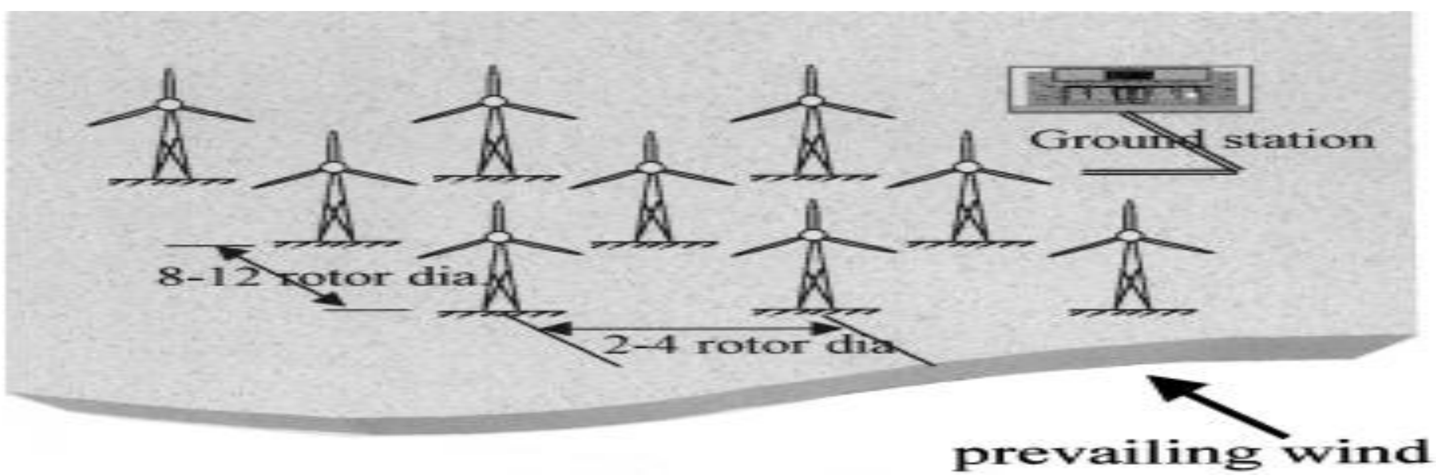
3- Water pump storage.
4- Thermal storage.

b) An Egyptian village plans to get 20% of its electricity using wind energy. The total electrical load is 100MW. Consider that a wind turbine with a rated capacity of 1MW and efficiency factor of 30 % at 12 m/s wind speed, 25^0 C air temperature and the wind availability is 16 hours a day all year around. ***(10 marks)***

(i) Estimate the expected energy produced yearly. (ii) Design the layout of the wind farm considering wake effect. (iii) Suggest how to double the output power.

i) Energy produced yearly $= 365 \times 16 \times 1000\ (\text{kW}) \times 0.3 = 1{,}752{,}000\ \text{kW/ year}$

ii) The layout of the wind farm considering wake effect



iii)

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

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