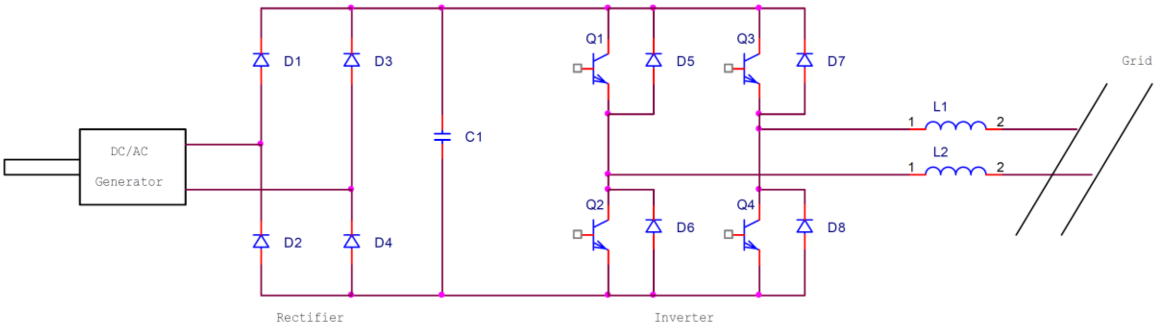
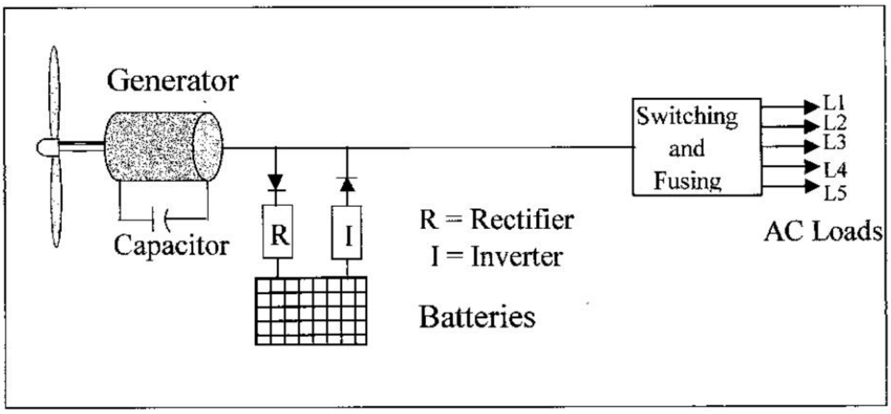
Grid connected Wind-Turbines

We have seen in the previous section the generation of electrical power by the flow of water through turbines. The generated electrical power could be dc or ac depending on the type of generator. After the power is generated, it needs to be transmitted and distributed to consumers by connecting it to the grid. Following figure shows how the grid connection is done. It has the following sections:

1. The rectifier
2. The capacitor
3. Switches
4. Inductor

The rectifier is required if the generated power is ac by alternator or induction generator. The capacitor is required to smooth the generated power. Switches are required to convert the power to ac to match the grid frequency and inductors are required to develop the voltage.



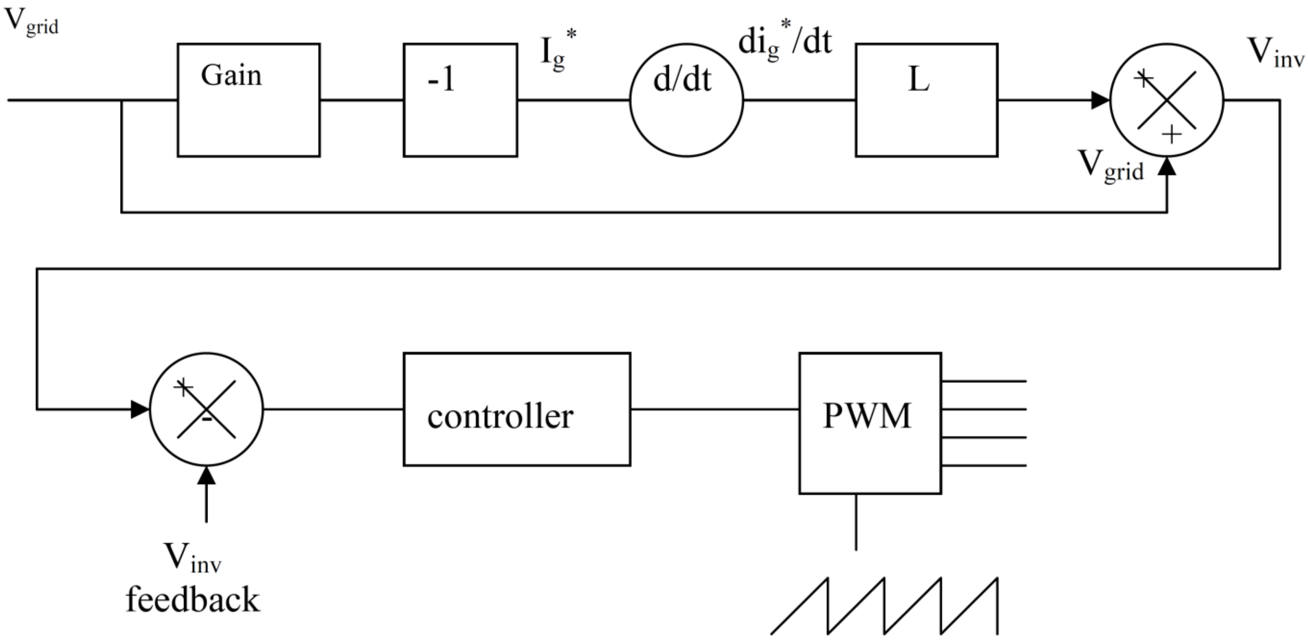


$$i_L = \frac{1}{L} \cdot \int v_L \cdot dt \qquad \text{...} \quad (2)$$

Also

$$\frac{di_L}{dt} = \frac{v_L}{L} = \frac{v_{inv} - v_{grid}}{L} \qquad \text{...} \quad (3)$$

The above equation can be realized as follows:



The starting reference is the grid voltage V_{grid}. The current I_g^* proportional to the grid voltage is fed through a differentiator giving dI_g^*/dt. This is equivalent to a value given in equation (3). Multiplying this value by L gives ($V_{inv} - V_{grid}$). Adding this to V_{grid} taken directly from the grid gives V_{inv}. This is compared to the actual V_{inv} measured at the output of the inverter. If the error is zero, then the voltage across the grid and the voltage at the output of the inverter are same and hence can be connected to each other. If there is an error signal then the controller changes the duty cycle of PWM such that the error signal becomes zero.

Harnessing wind power by means of windmills can be traced back to about four thousand years from now when they were used for milling and grinding of grains and for pumping of water. However there has been a renewed interest in wind energy in the recent years as it is a potential source of electricity generation with minimum environmental impact [1]. According to present growth the accumulated world wide installed wind electric generation capacity will reach to 50GW at the end of year

Wind electric systems directly feeding to the local load are known as the isolated wind energy system but the wind energy system that are connected to grid are known as grid

connected system. Wind is not available all the time for the generation of electric power and power output of wind turbine is proportional to the cube of the velocity of wind and the power output is optimal for a particular wind velocity. So Large wind electric generator (WEG) systems are connected to utility grid where they feed the power to grid.

The connection of cage rotor Induction Generator to grid again cause the problems in terms of drawing large magnetizing current from grid at very low power factor. Under the low wind conditions when the machine draws only reactive power from grid and stator power factor is very poor. Lagging power factor is compensated by connecting capacitor banks across the line. Depending on the active power generated these capacitors are either cut-in or cutout to regulate the power factor. The switching of capacitors may cause the over voltage in power system [1]. So various techniques for connecting the WEG to grid has been proposed [2,5,6]. The stand -alone system can be better utilized by using load-matching techniques [7].

Limitations of Present day WEG 's

Most of the present day WEG 's are the constant speed installations. These WEG'S have some limitations as given below

A- *Poor Energy Capture –*

This is due to low aerodynamic efficiency of WEG and the variation in efficiency over the entire operating range.

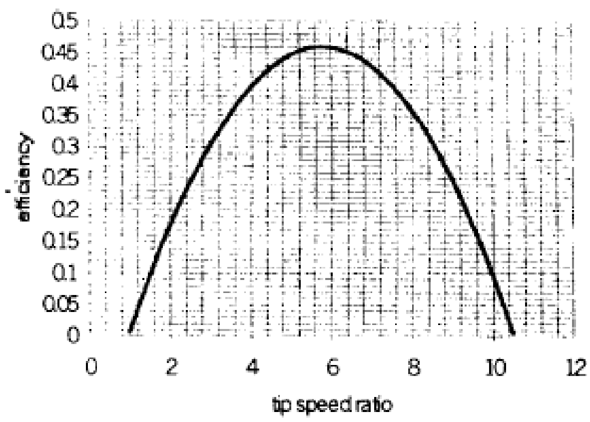
Power output of turbine

$$Pt = .5\ Cp\ \rho\ A\ v^3$$

ρ = Air density, A = swept area, v =wind velocity, Cp is called the power coefficient and is dependent on the linear velocity of the blade tip (Rω) and the wind velocity (v). The ratio, known as the tip-speed ratio, is defined as

$\lambda = R\omega/v$ where R is the radius of the turbine

From fig 1 it is observed that the power coefficient is maximum for a particular tip ratio. So power capture is not optimum at other wind velocity.



Since most WEG 's employ induction generators as electromechanical energy converters these WEG 's draw reactive power from grid for excitation. This leads to additional T&D losses and changes in voltage stability margins.

C- *Unstable grid frequency -*

Most WEG 's have their blade design based on expected speed of the IG (grid frequency). The aerodynamic efficiency greatly reduces when the grid frequency is not maintained a constant at the specified level due to the changes in the tip speed ratio.

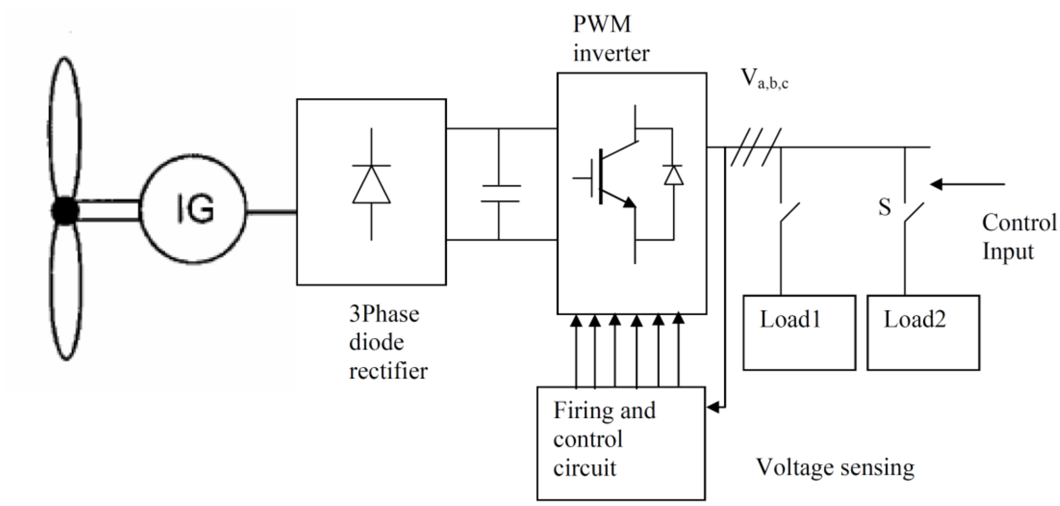
By considering above-mentioned problems it is preferable to run WEG at variable speed. A variable speed WEG enables enhanced power capture as compared to constant speed WEG. The rotor speed can be made to vary with changing wind velocity so the turbine always operates with max Cp within the power and speed limits of the system.

Various control schemes are used for both Isolated WEG and grid connected WEG running at variable speed.

Isolated WEG

A- *Load Matching-*

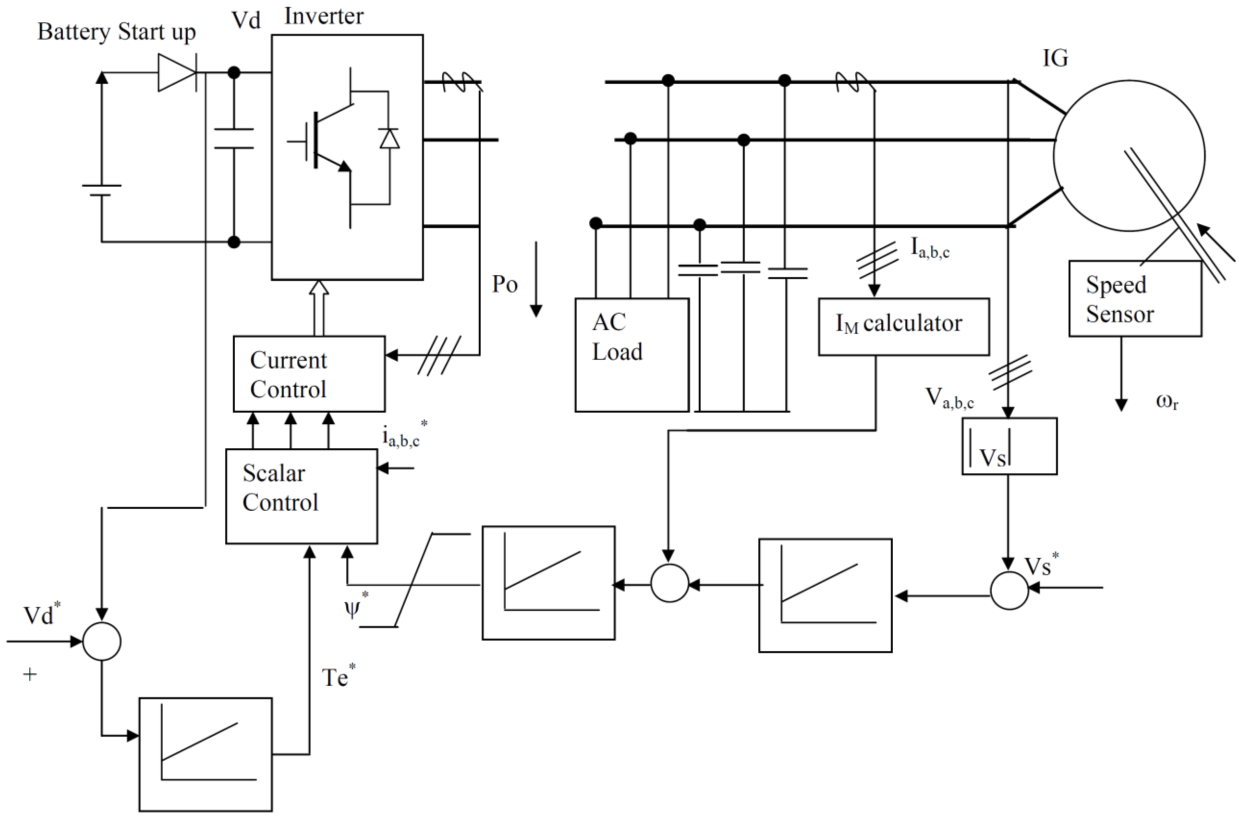
When wind driven self excited Induction generator (SEIG) running at variable
Speed, it is essential that the power output of the generator increase with increasing power input to the prime mover, which in the case of wind turbine varies approximately as the cube of the wind speed. If this load matching is not planned properly, the generator would either over speed at high wind speed or come out of excitation at low wind speeds. Further, since the output voltage and frequency of the generator varies with wind speed for many applications requiring constant voltage, some kind of power electronic controller is needed between the generator and load. Fig shows a scheme employing a PWM inverter to obtain the voltage of required magnitude and frequency at the load terminal. Loads are connected through control switch, which could appropriately be activated by monitoring the wind speed as shown in the fig2.



B- *Scalar Control of IG -*

Scalar control of IG means control of magnitude of voltage and frequency so as to achieve suitable speed with an impressed slip. Scalar control disregards the coupling effect on the generator; that is, the voltage will be set to control the flux and the frequency in order to control the torque.

If the IG is primarily in stand-alone operation, reactive power must be supplied for proper excitation. The overall scheme of control is shown below in fig3.



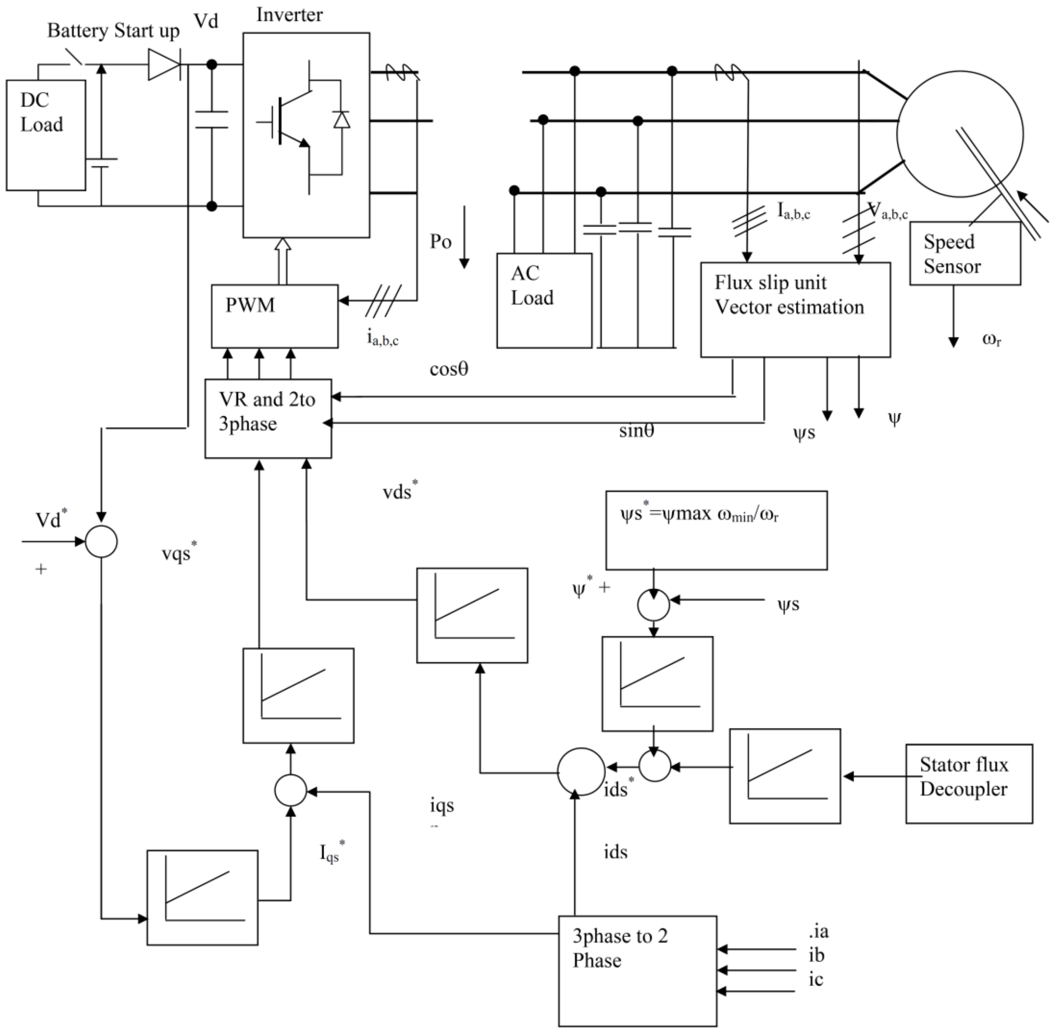
At the generator side terminal current and voltages are measured to calculate the magnetizing current needed for the generator, and the instantaneous peak voltage is compared to the stator voltage reference, which generates a set point for flux through the feedback loops on the inverter side. This system requires a charged battery startup. That can be recharged with an auxiliary circuit after the system is operational. Since stator voltage is kept constant the frequency can be stabilized at about 50Hz for the AC load, but some slight frequency variation is still persists and the range of turbine shaft variation should be within the critical slip in order to avoid instability. Therefore AC loads should not be too sensitive for frequency variation in this stand- alone application.

C- *Vector Control of IG-*

The decoupled flux and torque control of IG is known as vector control.

For an IG operating in stand- alone mode, a procedure to regulate the output voltage is required as shown in the fig4.

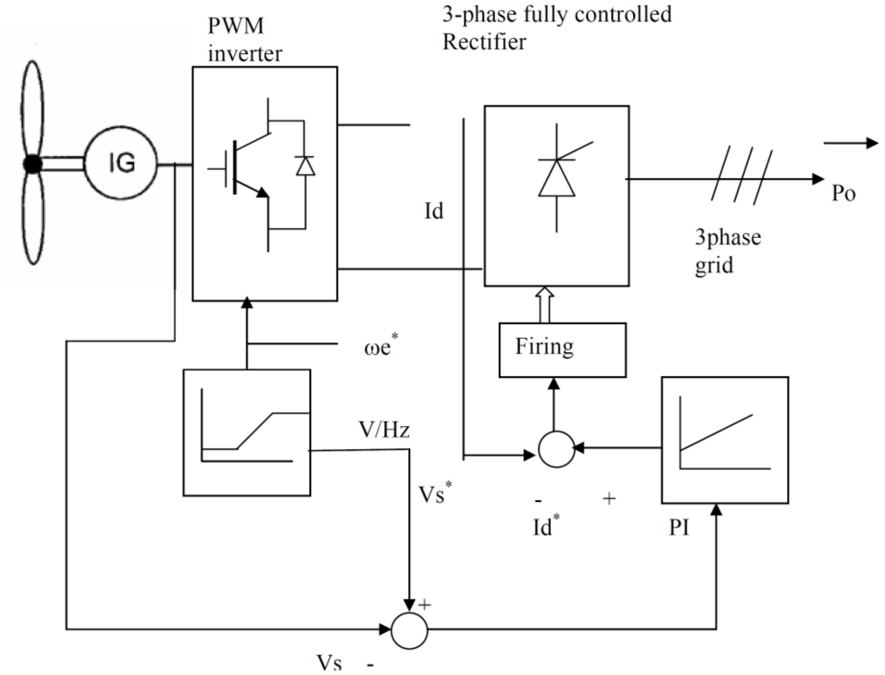
The DC link voltage across the capacitor is kept constant and machine impressed terminal frequency will vary with variable speed.
Since the frequency of generated voltage depends on the wind speed (rotor speed), the product of the rotor speed and the flux linkage should be remain constant so that the terminal voltage will remain constant, where the maximum rotor speed corresponding to maximum saturated flux linkage. The system starts up with a battery connected to the inverter. Then, as the system DC link voltage is regulated a higher value across the capacitor, the battery will be turned off by the diode and the DC load can be supplied across the capacitor. The machine terminals are also capable of supplying the power to an auxiliary load at variable frequency.

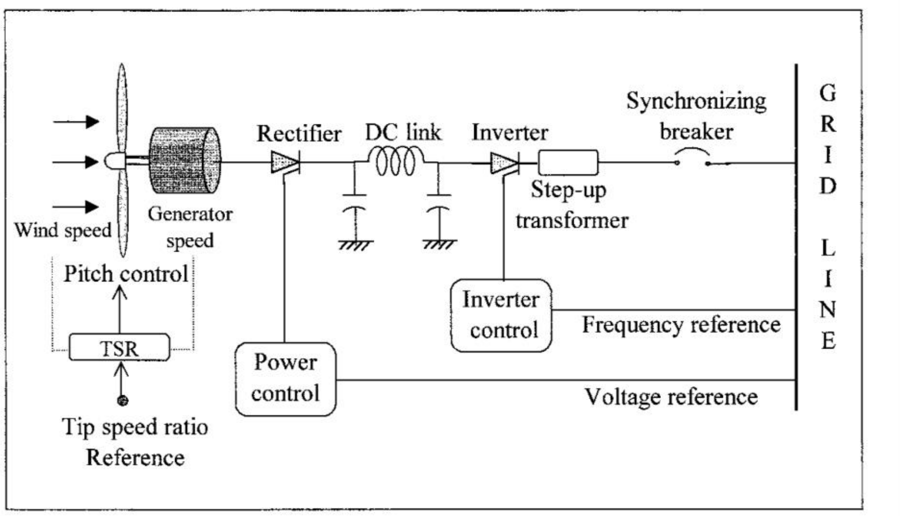


Generator Connected to Grid

A -*Scalar Control*

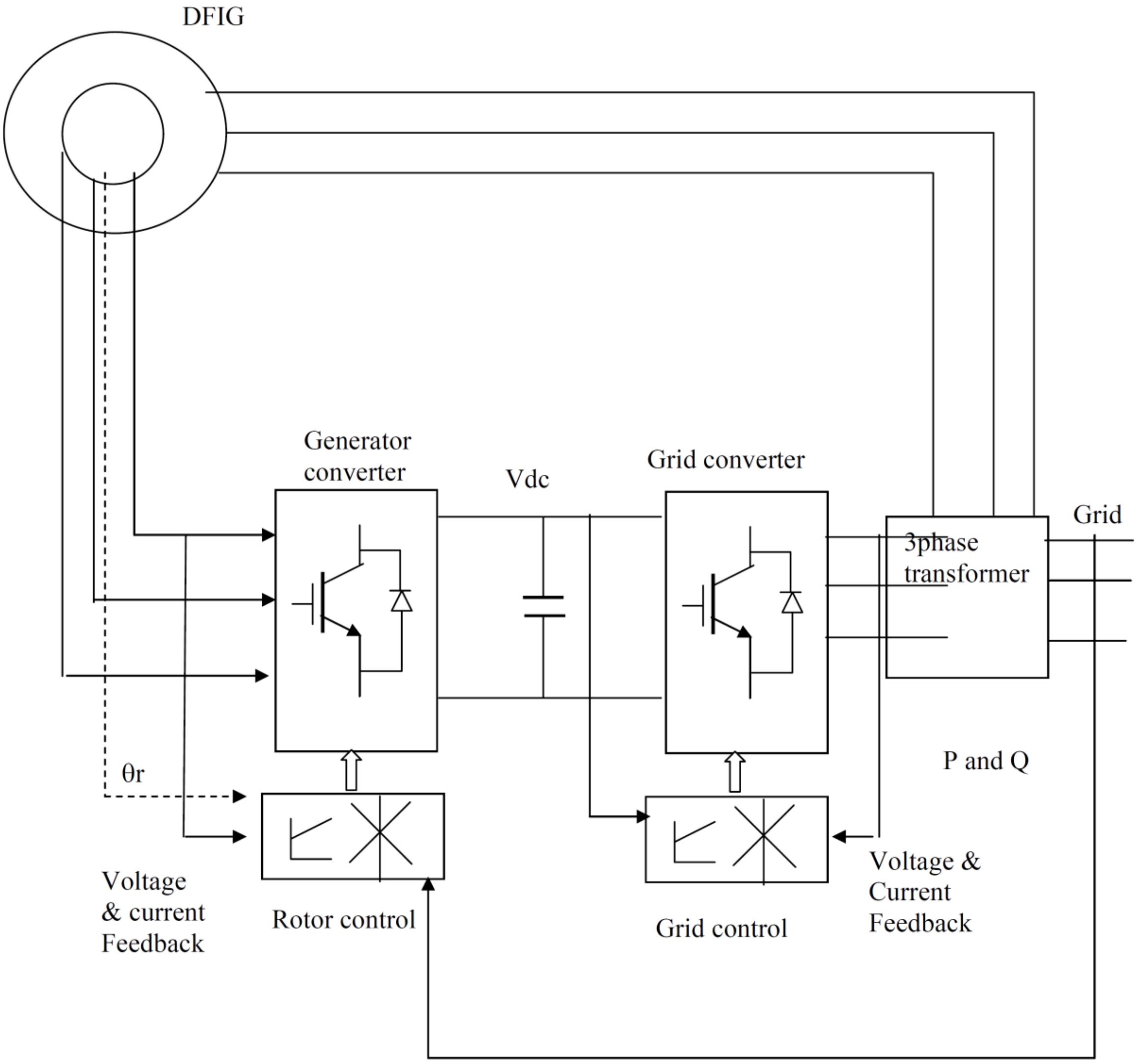
A current –fed link system for grid connection with constant V/Hz is depicted in fig5.
The DC link current allows easy bi-directional flow of power. Although the DC link current is unidirectional, a power reversal is achieved by a change in polarity of the mean DC link voltage and symmetrical voltage and symmetrical voltage blocking switches are required. A thyristor-based controlled rectifier manages the three phase utility side and machine side inverter can use a transistor with a series diode. The system is commanded by the machine stator frequency reference (ω_e). A PI control produces set point for DC link current, and firing for the thyristor bridge controls the power exchange (P_o) with the grid. The stator frequency reference ω^*_e can be varied in order to optimize the power tracking of IG.





Doubly Fed Induction Generator (DFIG)

Compared to the squirrel-cage induction generator, the main difference is that the doubly fed induction generator provides access to the rotor windings, thereby giving the possibility of impressing a rotor voltage. By this, power can be extracted or impressed to the rotor circuit and the generator can be magnetized from either the stator circuit or the rotor circuit. Speed control can be applied to the doubly fed induction generator by slip power recovery scheme. Figure7 slip-power recovery scheme.

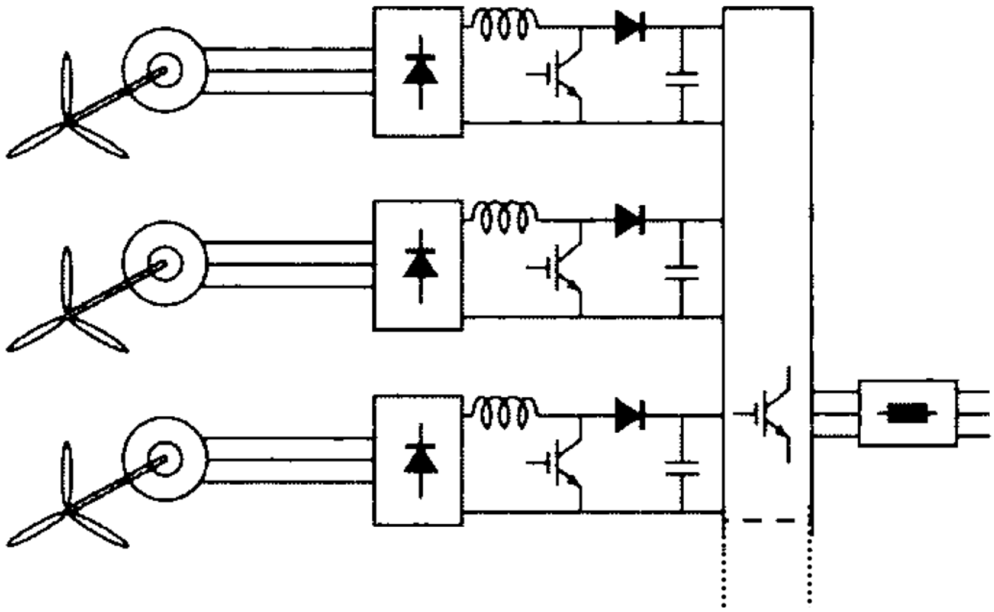


The doubly fed induction generator is controlled by a bi-directional power converter- in the present diagram back-to-back two-level converter. By this scheme, the generator can be operated as a generator at both sub- and super synchronous speed and the speed range depends only on the converter ratings. Besides nice features such as variable-speed operation, active and reactive power control, and fractional power conversion through the converter, the system suffers from the inevitable need for slip rings, which may increase the maintenance of the system and decrease its reliability. Further, the system comprises a step-up gear. The two inverters-the grid side inverter and the rotor side inverter-in Fig. 8 can be controlled independently, and by a proper control the power factor at the grid side can be controlled to unity or any desired value. By more sophisticated control schemes the system can be used for active compensation of grid-side harmonics.

Connection of Large Wind Farm to grid with Asynchronous Link

Previously, wind turbines were sited on an individual basis or in small concentrations making it most economical to operate each turbine as a single unit. Today and in the future, wind turbines will be sited in remote areas (including off-shore sites) and in large concentrations counting up to several hundred megawatts of installed power. For such a large system, using asynchronous link can give the best interconnection to grid especially for weak AC system. HVDC system can give such type of asynchronous link

Today most wind farms and single units are directly connected to the AC-grid. With increasing wind power coming on line, it is today, Already difficult to enter high amount of wind power in often weak Part of the AC-network. The development towards big wind farms will in most cases make it necessary to have an interface between the wind farm and the AC-grid. This is because out-put from a wind generator generates disturbances to the AC-grid, which is not acceptable. In order to maintain power quality and stability, the AC-grid must fulfill certain criteria's, if not, measures have to be taken. If the AC-grid is strong, i.e. the short circuit capacity is high in relation to the capacity of the wind farm; it may be possible to connect the farm directly to the grid. However, wind farms are often located in areas where the AC-grid is very weak, and can therefore not be directly connected. The introduction of HVDC Light now offers an alternative,



The main features are

1- the distance from the farm to the connection point in the AC-grid has no technical limitations.

2- the wind farm is from a disturbance point of view isolated from the AC-grid.

3- HVDC Light generates the reactive power needed by the generators.

4- the power quality at the connection point is improved.

5- Controlled power production. During periods with reduced transmission capacity in the grid, the wind farm must be able to operate at reduced power levels with all turbines running.

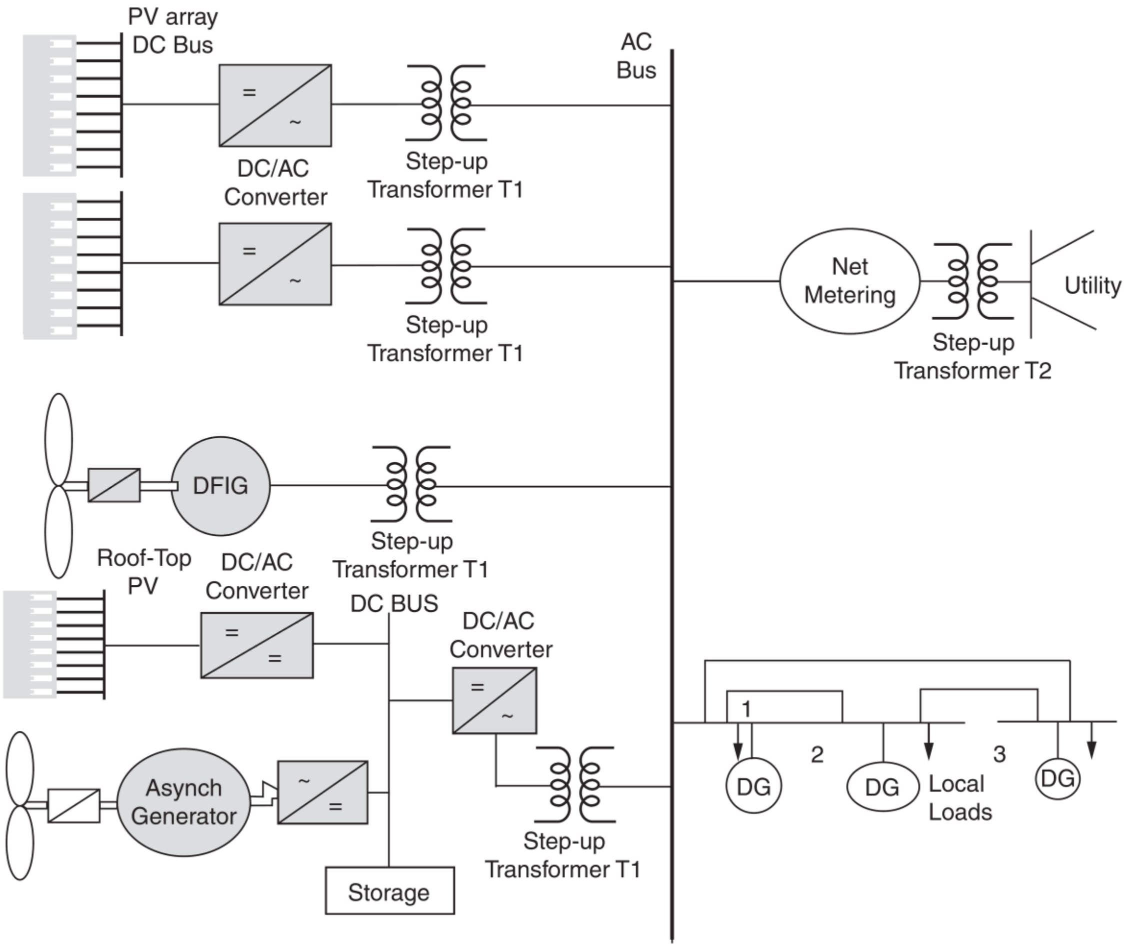


FIGURE 1.3 The Architecture for design of a 2-MVA PV station.