SMART GRID

MODULE-III

Department of Electrical Engineering

PREPARED BY- Dr. (Prof.) SUBHRANSU SEKHAR DASH

Government College of Engineering, Keonjhar

At-Jamunalia, Po. –Oldtown, Dist- Keonjhar

PIN-758002, Odisha

Web- gcekjr.ac.in

CONTENTS

VARIABLE SPEED WIND GENERATORS

- WIND ENERGY CONVERSION SYSTEMS
  - Wind turbine development has become an attractive research topic in renewable energy resources in recent years.
  - Wind energy conversion systems (WECSS) have been intensively developed to contribute the "green energy" demand up 20% by 2030.
  - Clearly, energy specialists and policy makers have realized the potential importance of wind energy resource in common energy crisis in the world nowadays.
  - For technical aspects, many of opportunities being pursued through advanced control techniques are utilized to achieve higher contribution of wind energy.
  - Wind turbine is a device that converts mechanical energy from wind into electrical energy to be used in stand-alone grid or to be connected with the grid.
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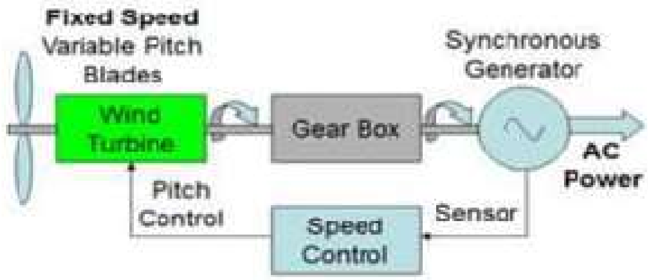
- Configurations in WECS

- There are two basic configurations in WECSS, depending on the electrical machine type.
  - Fixed-speed WECS
  - Variable-speed WECS
- Wind turbines convert the kinetic energy present in the wind into mechanical energy by means of producing torque.
- Large scale wind power projects are an attractive alternative to conventional capacity expansion.
- In the present scenario, most wind turbine manufacturers now equip power generating units by induction generators.
- They are operated either at fixed speed or variable speed.
- Generators driven by fixed speed turbines can directly be connected to grid.

- Variable speed generators need a power electronic converter interface for interconnection with the grid.
- Variable speed generation is preferred over fixed speed generation.
  - <u>Fixed-speed WECS</u>
  - This wind power system operates at a constant rotor speed regardless of the wind speed variations. The rotor speed is controlled according to the grid frequency.
  - The electrical machine equipped with such wind turbines is squirrel-cage induction generator. Sometimes a permanent-magnetic synchronous generator can be used.
  - Fixed-speed WECSS have advantage of being simple, robust, and reliable with a low-cost generator and easy control. However, such wind power systems also have drawbacks due to limited control when wind speed changes continuously.
  - In early prototypes of fixed-speed wind turbines synchronous generators have been used, but the induction machine appeared to be more widely adopted because of its lower cost, better environmental durability and superior mechanical compatibility with rapid wind changes.
  - That is why in fixed-speed wind turbines the generator used is the induction generator type, directly connected to the grid.
  - In the majority of wind turbines designs the generator is connected with the hub with blades via a gearbox. They are placed in a nacelle on the top of the turbine tower.
  - The gearbox is needed to change the low rotational speed of the turbine to a high rotational speed on the generator. The induction generators rotational speed is typically 1000 or 1500 rpm.
  - The speed of the turbine is dependent on its rotor diameter. For example a 330 kW turbine has a rotational speed of approximately 18 - 45 rpm, while the rotational speed of a 1670 kW turbine is approximately 10 - 19 rpm.
  - A fixed-speed wind turbine is designed to obtain maximum efficiency at one wind speed that will give the optimum tip speed to wind speed ratio for the rotor airfoil. In order to be able to capture more wind energy, some fixed-speed wind turbines have two different rotational speeds.

- This can be achieved either by placing two generators in the nacelle or by one generator having two separate windings.

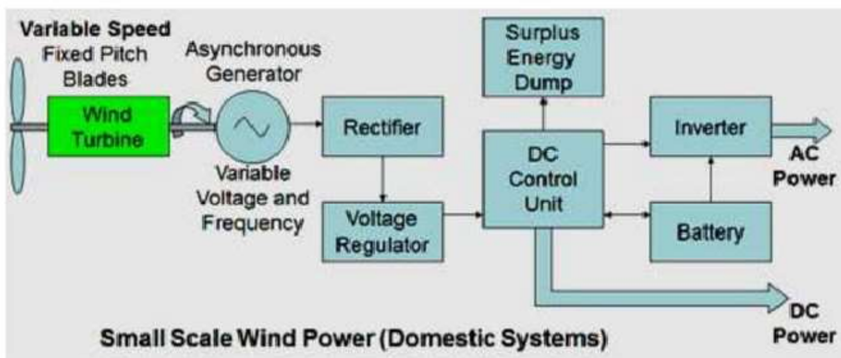


Large Scale Wind Power (Grid Systems)

- <u>Variable-speed WECS</u>

- Comparing with fixed-speed wind turbines, variable-speed WECSS based on a doubly-fed induction generator (DFIG) offer a number of merits such as simple control, four-quadrant active and reactive power regulation, and low cost converter.
- With a DFIG-based wind system, the stator side is directly connected to the grid, whereas the rotor side is connected to a back-to-back voltage source inverter. The stator outputs power into the grid.
- The rotor is capable of delivering or absorbing power to/from the grid, depending on the rotor speed.
- With a PMSG-based wind system, the generator output voltage and frequency are proportional to the rotor speed and the current is proportional to the torque on the shaft.
- The output is rectified and fed through a buck-boost regulator to an inverter which generates the required fixed amplitude and frequency AC voltage.
- There are many similarities in major components construction of fixed-speed wind turbines and wind turbines operating within a narrow variable-speed range.
- Fixed-speed wind turbines operating within a narrow speed range usually use a double-fed induction generator and have a converter connected to the rotor circuit.
- The rotational speed of the double-fed induction generator equally 1000 or 1500 rpm, so a gearbox implementation is required.

– To simplify the nacelle design a direct-driven generator is used. A direct-driven generator using a large turbine blades diameter can operate at very low speeds and does not need a gearbox installed to increase to speed.
– The usage of frequency converter is needed to use a direct-driven generator, so wind turbines operating within a broad variable-speed range are equipped with a frequency converter.
– In a conventional fixed-speed wind turbine, the gearbox and the generator have to be mounted on a stiff bed plate and aligned precisely in respect to each other.
– A direct driven generator can be integrated with the nacelle, so the generator housing and support structure are also the main parts of the nacelle



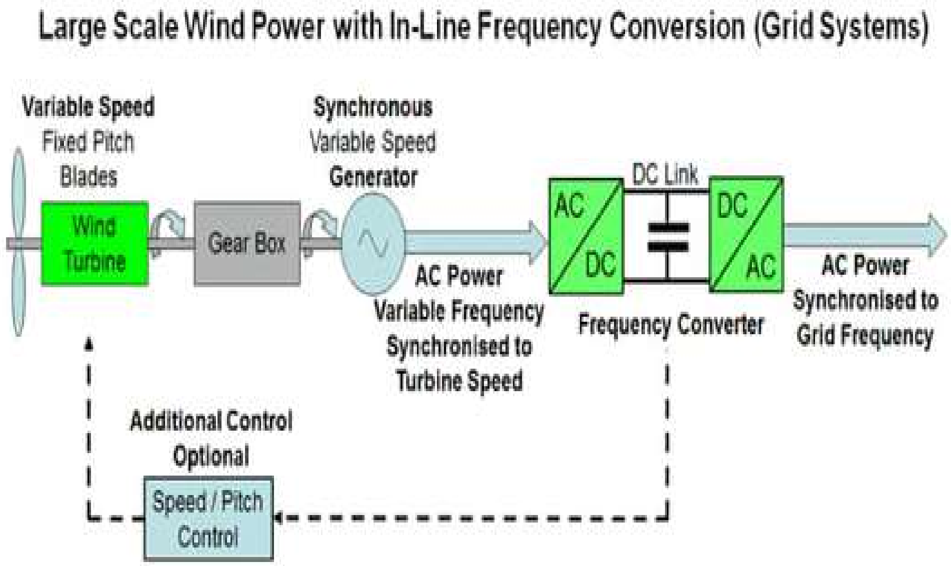
construction.

- <u>Synchronous Generator with In-Line Frequency Control</u>

– Rather than controlling the turbine rotation speed to obtain a fixed frequency synchronized with the grid from a synchronous generator, the rotor and turbine can be run at a variable speed corresponding to the prevailing wind conditions.
– This will produce a varying frequency output from the generator synchronized with the drive shaft rotation speed. This output can then be rectified in the generator side of an AC-DC-AC converter and the converted back to AC in an inverter in grid side of the converter which is synchronized with the grid frequency.
– The grid side converter can also be used to provide reactive power (VARs) to the grid for power factor control and voltage regulation by

varying the firing angle of the thyristor switching in the inverter and thus the phase of the output current with respect to the voltage.

– The range of wind speeds over which the system can be operated can be extended and mechanical safety controls can be incorporated by means of an optional speed control system based on pitch control of the rotor vanes as used in the fixed speed system described above.
– One major drawback of this system is that the components and the electronic control circuits in the frequency converter must be dimensioned to carry the full generator



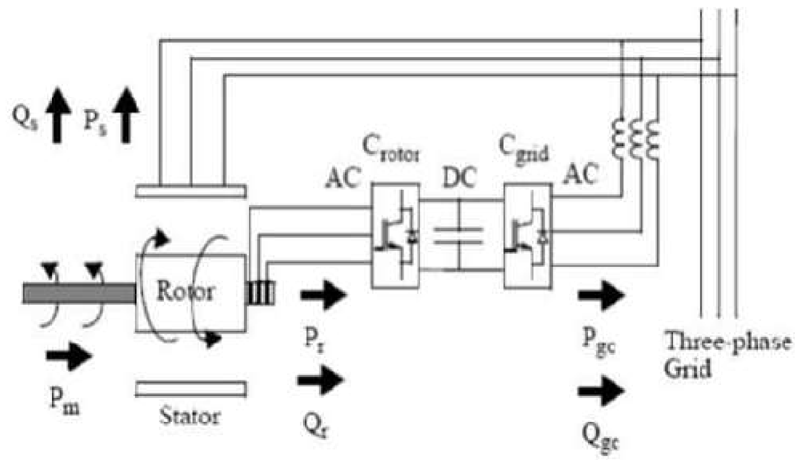
- <u>Doubly Fed Induction Generator</u>

– Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor, induction generator and an AC/DC/AC IGBT-based PWM converter.
– The stator winding is connected directly to the grid while the rotor is fed at variable frequency through the AC/DC/AC converter.
– Vr is the rotor voltage and Vgc is grid side voltage.
– The AC/DC/AC converter is basically a PWM converter which uses sinusoidal PWM technique to reduce the harmonics present in the wind turbine driven DFIG system.
– Crotor is rotor side converter and Cgrid is grid side converter.
– To control the speed of wind turbine gear boxes or electronic control can be used.

Operating Principal of DFIG

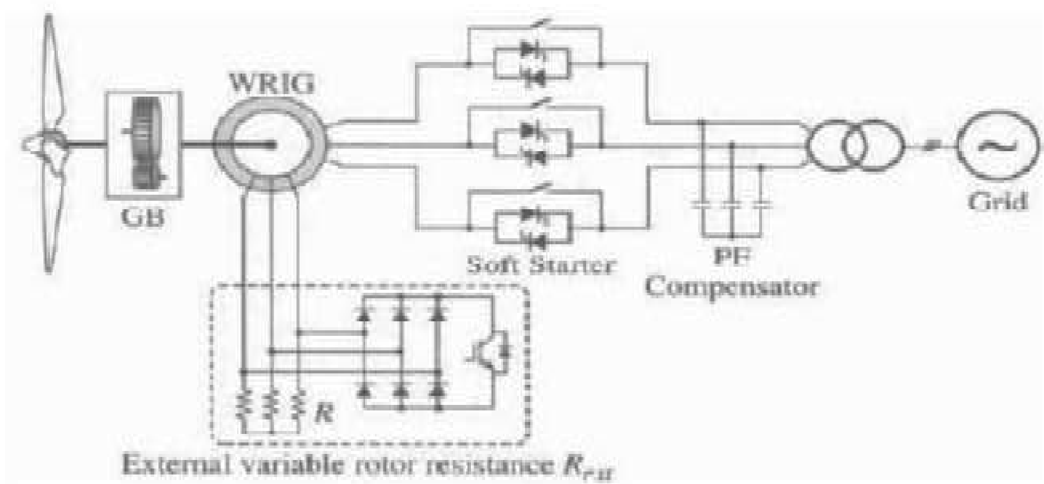
- Below the synchronous speed in the motoring mode and above the synchronous speed in the generating mode, rotor-side converter operates as a rectifier and stator-side converter as an inverter and where slip power is returned to the stator.
- Below the synchronous speed in the generating mode and above the synchronous speed in the motoring mode, rotor-side converter operates as an inverter and stator side converter as a rectifier, where slip power is supplied to the rotor.
- For super synchronous speed operation, Pr is transmitted to DC bus capacitor and tends to rise the DC voltage. For sub-synchronous speed operation, Pr is taken out of DC bus capacitor and tends to decrease the DC voltage.
- Cgrid is used to generate or absorb the power Pgc in order to keep the DC voltage constant.
- In steady-state for a lossless AC/DC/AC converter Pgc is equal to Pr and the speed of the wind turbine is determined by the power Pr absorbed or generated by Crotor.
- The phase-sequence of the AC voltage generated by Crotor is positive for sub synchronous speed and negative for super synchronous speed.
- Crotor and Cgrid have the capability for generating or absorbing reactive power and could be used to control the reactive power or the

voltage at the grid terminals.



Power flow diagram of DFIG

- <u>Wound-Rotor Induction Generator (WRIG) with External Rotor Resistances</u>



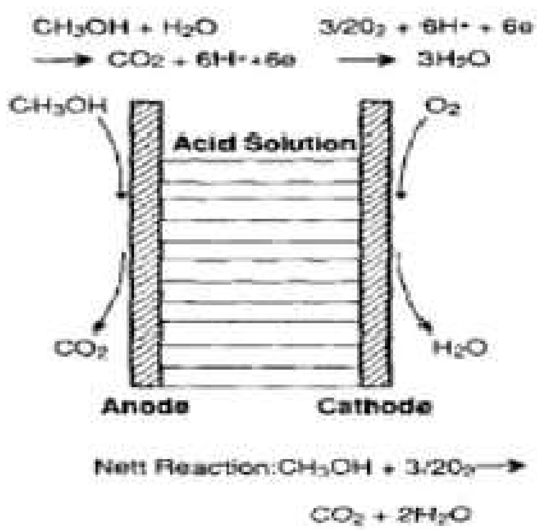
  - The system configuration is the same as that of the fixed-speed wind energy system except that the SCIG is replaced with the WRIG. The external rotor resistance, is made adjustable by a converter composed of a diode bridge and an IGBT chopper. The equivalent value of R, seen by ex the rotor varies with the duty cycle of the chopper.
  - Slip rings and brushes of the WRIG can be avoided in some practical WECS by mounting the external rotor resistance circuit on the rotor shaft. This reduces maintenance needs, but introduces additional heat dissipation inside the generator.

- The main advantage of this configuration compared to the variable-speed WECS is the low cost and simplicity.
- The major drawbacks include limited speed range, inability to control grid-side reactive power, and reduced efficiency due to the resistive losses.

FUEL CELLS

- A fuel cell is an electrochemical device that converts energy produced from a chemical reaction into electrical energy.
- More specifically it is an electrochemical device that combines hydrogen and oxygen to produce electricity, with water and heat as its by- product.
- Chemical Energy → Electrical Energy.

- CONSTRUCTION



- Anode- Negative post of the fuel cell. Conducts the electrons that are freed from the hydrogen molecules so that they can be used in an external circuit. Etched channels disperse hydrogen gas over the surface of catalyst.
- Cathode- Positive post of the fuel cell. Etched channels distribute oxygen to the surface of the catalyst. Conducts electrons back from the external circuit to the catalyst Recombine with the hydrogen ions and oxygen to form water.
- Electrolyte- Proton exchange membrane. Specially treated material, only conducts positively charged ions. Membrane blocks electrons.

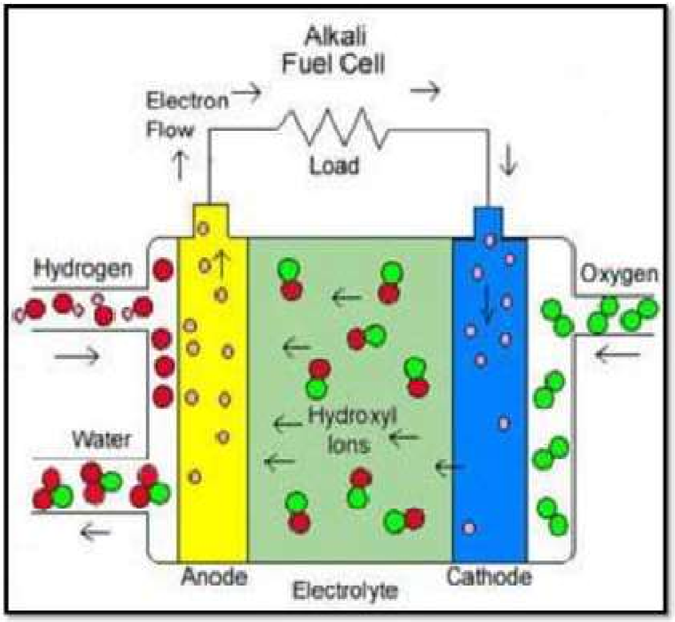
- Catalyst- Special material that facilitates reaction of oxygen and hydrogen Usually platinum powder very thinly coated onto carbon paper or cloth. Rough & porous maximizes surface area exposed to hydrogen or oxygen The platinum-coated side of the catalyst faces the PEM.

  - <u>WORKING</u>
  - A fuel cell generates electrical power by continuously converting the chemical energy of a fuel into electrical energy by way of an electrochemical- reaction. The fuel cell itself has no moving parts, making it a quiet and reliable source of power. Fuel cells typically utilize hydrogen as the fuel, and oxygen (usually from air) as the oxidant in the electrochemical reaction. The reaction results in electricity, by-product water, and by-product heat.
  - When hydrogen gas is introduced into the system, the catalyst surface of the membrane splits hydrogen gas molecules into protons and electrons. The protons pass through the membrane to react with oxygen in the air (forming water). The electrons, which cannot pass through the membrane, must travel around it, thus creating the source of DC electricity.

    - <u>TYPES OF FUEL CELL</u>

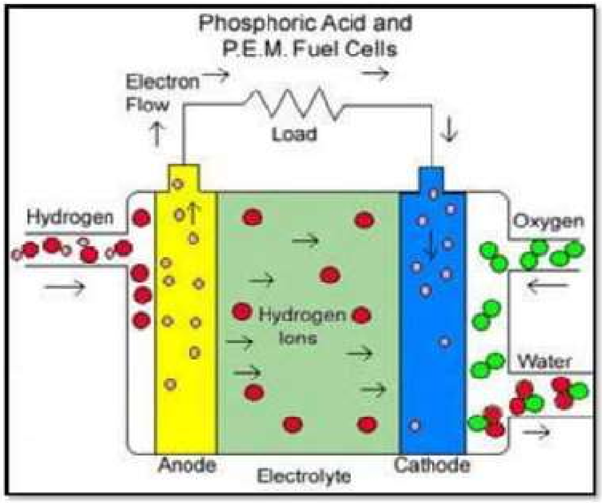
    1. Alkaline FC (AFC)
    2. Phosphoric Acid FC (PAFC)
    3. Molten Carbonate FC (MCFC)
    4. Solid Oxide FC (SOFC)

1. <u>Alkaline FC (AFC)</u>



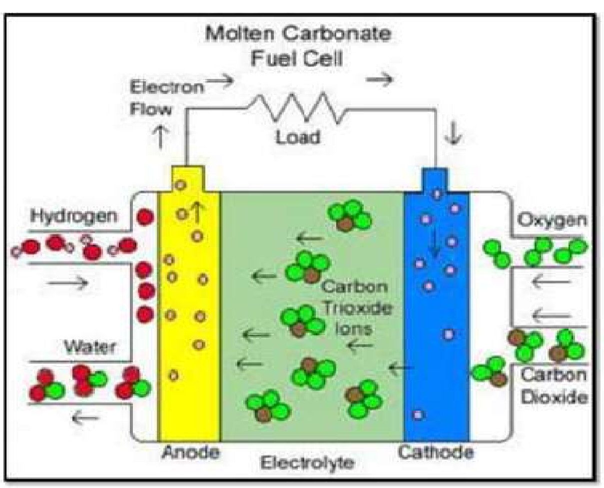
- This type of fuel cell was been introduced in the early 1960's. As the electrolyte used for this device is aqueous alkaline solution like potassium hydroxide, the procedure for electricity consumption is rather expensive.
- It has;
  - compressed hydrogen and oxygen fuel.
  - potassium hydroxide (KOH) electrolyte.
  - -70% efficiency.
  - 150°C-200°C operating temp.
  - 300W to 5kW output requires pure hydrogen fuel and platinum catalyst.

2. Phosphoric Acid FC (PAFC)



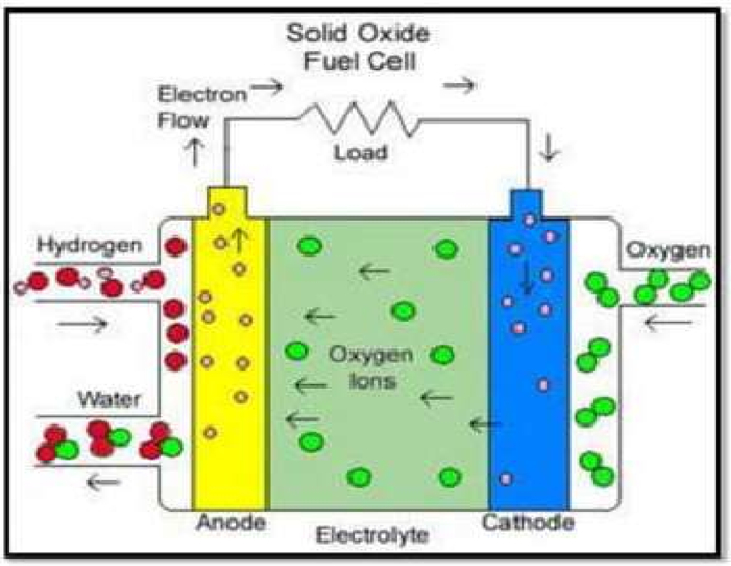
– Molten phosphoric acid is the electrolyte used in this type of fuel cell. It operates at high temperature up to 200 degree Celsius. It has an efficiency of up to 55%. This type of fuel cell is most commonly used in commercial cars.
– It has;
- phosphoric acid electrolyte.
- 40-80% efficiency.
- 150°C-200°C operating temp.
- 11 MW units have been tested.
- sulphur free gasoline can be used as a fuel.
- The electrolyte is very corrosive.
- Platinum catalyst is very expensive.

3. Molten Carbonate FC (MCFC)



Molten alkaline carbonate like sodium bicarbonate is used as the electrolyte. They can produce high powers up to 100 Mega Watts. Thus they can be used as high power generators. They can also be operated at high temperatures up to 650 degree Celsius. They are not so expensive in production and hence can be used for commercial uses. It has an efficiency of almost 55%.

4. Solid Oxide FC (SOFC)



- This is one of the most commercially used fuel cell as they have the highest operating life. It has a very high operating temperature of 1,000 degrees Celsius. But other parts of the fuel cell may not be able to withstand at this temperature making it highly unstable. But, when used in a continuous state they can be highly reliable. At high temperatures the device can produce water in the form of steam which can be easily transported through steam turbines to produce more electricity, thus increasing the efficiency of the system. This device is also special in the case where a wide variety of fuels can be used. Most of the petroleum products can be used as the fuel. The electrolyte used in the cell is called yttria stabilized zirconia (YSZ). This electrolyte is good for large scale power generation and has the same characteristics as all the other electrolytes.
- As the device has a very high operating temperature, there are some disadvantages as well. There may be unwanted number of reactions taking

place inside the cell due t the high temperature. As a result of these reactions carbon dust and also graphite may be built up on the anode making it insufficient from reacting with the catalyst.

- ADVANTAGES

– Water is the only discharge (pure H_2)
– Higher efficiency than conventional engines.
– Excellent part load characteristics.
– Zero emission.
– Long operating period between failures.
– No rotating parts in the main hard ware components.
– Negligible noise pollution.

- DISADVANTAGES

– CO_2 discharged with methanol reform.
– Little more efficient than alternatives.
– Technology currently expensive. Many design issues still in progress.
– Hydrogen often created using "dirty" energy (e.g., coal).
– Pure hydrogen is difficult to handle.

- APPLICATIONS
  - Can be used as power sources in remote areas.
  - Can be used to provide off-grid power supplies.
  - Can be applicable in both hybrid and electric vehicles.
  - Waste water treatment plant and landfill.
  - Cellular phone, laptop and computers.
  - Hospitals, credit card centres and police stations.
  - Buses, Car, Planes, Boats, Fork lift, Trains
  - Vacuum cleaner.
  - Telecommunication, MP3 players, etc.

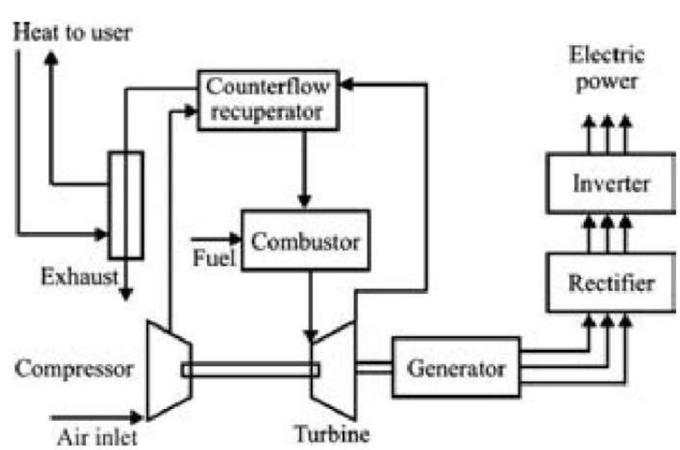
MICRO-TURBINES

- Micro Turbines are new type of combustion turbine used for energy generation.
- They provide not only electricity, but also the thermal energy for heating needs.
- They typically have power outputs in the range of 25 to 300kW.

- Need of Micro turbines
- Demand of alternate energy sources
- Need of energy in Remote locations
- Need of compact & portable power generator
- Better efficiency and require infrequent maintenance.
- Need of clean energy generating device

- Components of Micro turbine
  - Compressor
  - Combustor
  - Generator
  - Recuperator (Heat Exchanger)
  - Turbine
  - Power Electronics (Rectifier & Inverter)

- Working Principle



- Micro turbines are small gas turbines, most of which feature an internal heat exchanger called a recuperator.
- In a micro turbine, a radial flow (centrifugal) compressor compresses the inlet air that is then preheated in the recuperator using heat from the turbine exhaust.
- Next, the heated air from the recuperator mixes with fuel in the combustor and hot combustion gas expands through the expansion and power turbines. The expansion turbine turns the compressor and, in single-shaft models, turns the generator as well.
- Finally, the recuperator uses the exhaust of the power turbine to preheat the air from the compressor.
- Single-shaft models generally operate at speeds over 60,000 revolutions per minute (rpm) and the permanent magnet generator generates electrical power of high frequency, and of variable frequency (alternating current- AC). This power is rectified to direct current (DC) and then inverted to 50/60 Hz for commercial use.

- Features of Micro-turbine

(1) Size They are relatively smaller in size as compared to other DERS.

(2) Fuel-to-electricity conversion They can reach the range of 25-30%. However, if the waste heat recovery is used for CHP applications, energy efficiency levels are greater than 80%.

(3) NO, emissions - These are lower than 7 ppm for natural gas machines.

(4) Operational life- They are designed for 11,000 hours of operation between major overhauls with a service life of at least 45,000 hours.

(5) Economy of operation System costs are lower than $500 per kW. Cost of electricity is competitive with alternatives including grid power for market applications.

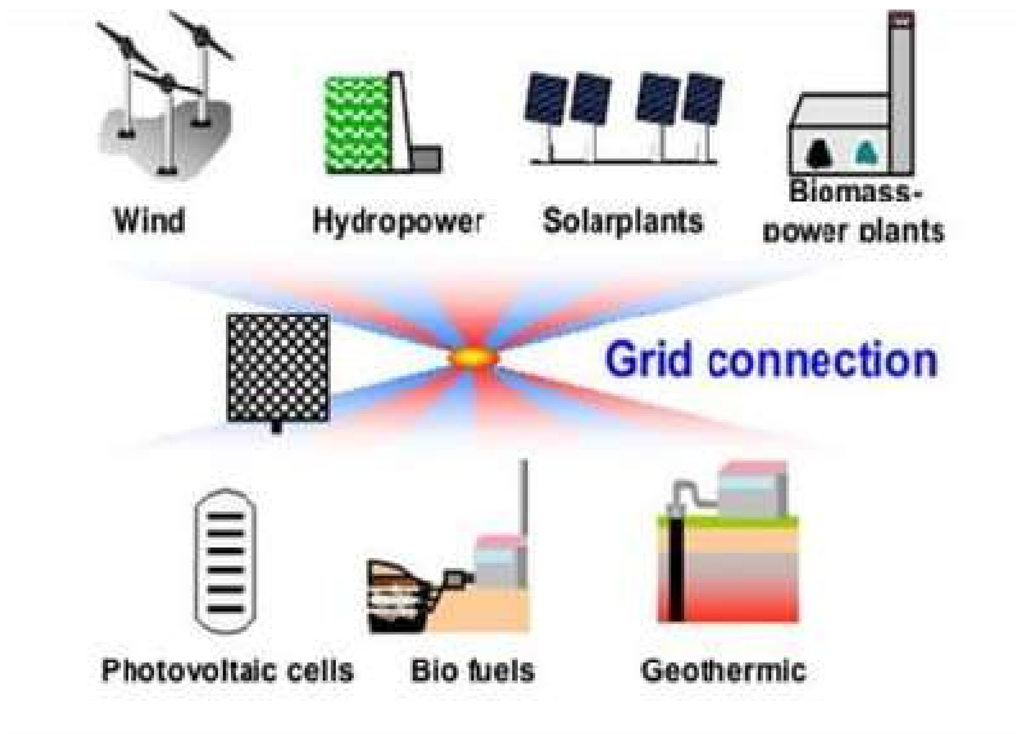
(6) Fuel flexibility-It is capable of using alternative fuels, like natural gas, diesel, ethanol and landfill gas, and other biomass-derived liquids and gases.

(7) Noise level-It has reduced level of noise and vibrations.

(8) Installation - It has simpler installation procedure.

- <u>Application of Micro-turbine</u>
  - Small scale power generation
  - In Automobiles (turbocharger)
  - Auxiliary power unit for air planes

INTEGRATION OF RENEWABLES AND ISSUES INVOLVED



- <u>Reasons for Renewable Energy</u>
- – Declining Fossil Fuel Supplies
- – Environmental Concerns
- – Increasing Cost of Fossil Fuels
- – Business Opportunities
- – Energy Security
- – Energy independence

- <u>CHALLENGES WITH INTEGRATING INTO ELECTRICAL POWER SYSTEMS</u>

– Most RE resources are location specific.

➢ Renewable-generated electricity may need to be transported over considerable distances.

➢ Beneficial combinations of renewable sources may not always be practicable.

– Lack of flexibility

➢ Balancing supply and demand

➢ Uncertainty in predicted out-put.

<u>Advantages and Disadvantages of Distributed Generation</u>

Distributed or dispersed generation may be defined as a generating resource, other than central generating station, that is placed close to load being served, usually at customer site.

- <u>Advantages</u>

– Concern about climate change.

– Improve power quality and system reliability.

– Reduce transmission and distribution line losses.

– Constraints on construction of new transmission lines.

– Relatively low capital cost compared to centralized generation due to avoided T&D capacity upgrades.

- <u>Disadvantages</u>

– With faults in system, DG has to be disconnected from grid. Loads will be cut off from power.

POWER QUALITY

- The quality of electrical power supply is a set of parameters which describe the process of electric power delivery to the user under normal operating conditions, determine the continuity of supply (short and long supply interruptions) and characterize the supply voltage (magnitude, asymmetry, frequency, and waveform shape).
- Power quality phenomena can be divided into two types :-
- ➢ A characteristic of voltage or current (e.g., frequency or power factor) is never exactly equal to its nominal and desired value. The small deviations are called voltage variations or current variations.
- ➢ When the voltage or current deviates significantly from its normal or ideal wave shape. These sudden deviations are called events. Power quality events are the phenomena which can lead to tripping of equipment, to interruption of the production or of plant operation, or endanger power system operation. This includes interruptions, under voltages, overvoltage, phase angle jumps and three phase unbalance.

- CAUSES OF POOR POWER QUALITY
- Variation in voltage magnitude and frequency.
- Variation in magnitude can be due to sudden rise or fall of load, outages, repetitive varying loading pattern in rolling mills, power electronic converters, inverters, lightning..etc
- Variation in frequency can rise of out of system dynamics or harmonics injection.

- SOURCES OF POOR POWER QUALITY
- Non linear loads
- Arcing loads
- Switching operation
- Reactive loads

- Atmospheric condition
- Unstable loads
- Neighboring unbalance system

EMC – Electromagnetic Compatibility

- The IEC – International Electrotechnical Commission defines Electromagnetic Compatibility as “the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment”.
- The satisfactory function of electrical and electronic equipment with respect to electromagnetic disturbances is the aim of EMC.
- Electromagnetic disturbances may be radiated or conducted and electrical/electronic equipment potentially sensitive to any or to both of these types of disturbances. Disturbances are in turn subdivided into a number of low and high frequency phenomena.

- <u>Relation between Voltage Quality and EMC</u>
- Conducted low-frequency phenomena:
  - Harmonics, interharmonics
  - Signals superimposed on power lines
  - Voltage fluctuations
  - Voltage dips and interruptions
  - Voltage unbalance
  - Power frequency variations
  - Induced low frequency voltages
  - DC component in AC networks
- Conducted high-frequency phenomena:
- Induced voltages or currents
- Unidirectional transients
- Oscillatory transients

- Voltage Quality can be seen as an umbrella name for deviations from ideal voltage conditions at a site in a network. This is equivalent to electromagnetic disturbances of the voltage at the site. With no disturbances the Voltage Quality is perfect, otherwise not. Electromagnetic disturbances are defined as electromagnetic phenomena that may degrade the performance of equipment .
- Adequate Voltage Quality contributes to the satisfactory function of electrical and electronic equipment in terms of Electromagnetic Compatibility.

- EMC DIRECTIVE AND ELECTRICAL NETWORKS
  - Manufacturers of equipment intended to be connected to networks should construct such equipment in a way that prevents networks from suffering unacceptable degradation of service when used under normal operating conditions.
  - Network operators should construct their networks in such a way that manufacturers of equipment liable to be connected to networks do not suffer a disproportionate burden in order to prevent networks from suffering an unacceptable degradation of service.
  - The European standardization organizations should take due account of that objective (including the cumulative effects of the relevant types of electromagnetic phenomena) when developing harmonized standards.
  - This means that both parties responsible for networks (being equipments) as well as for equipment connected to networks are supposed to contribute to EMC.

- ELECTROMAGNETIC COMPATIBILITY IN POWER SYSTEMS

- Applying the concept of fixed installation, there is principally no difference between electrical networks or connected equipment in terms of electromagnetic disturbances. Both networks and connected equipment can emit electromagnetic disturbances and immunity is similarly relevant in this context. A network may well be connected to other network(s) which may emit disturbances or be affected by disturbances in terms of imperfect Voltage Quality. Lack of immunity can also degrade the very basic function of the grid of energy transfer. One such case is where energy transfer is interrupted due to interference caused by geomagnetically induced currents.

- Disturbances can propagate from a network to connected equipment or *vice versa.* Disturbances may also propagate between networks and emission from a network may be seen as a cumulative effect of emissions from a large number of connected equipment in terms of imperfect Voltage Quality at a specific site.

POWER QUALITY ISSUES OF GRID CONNECTED RENEWABLE ENERGY SOURCES

- For grid connection of renewable energy sources we use Grid Integration – Grid-tie Inverter. The use of Inverter is to take energy from grid when renewable energy is insufficient. And supply energy when more power is generated. The connection of grid with renewable energy and disconnection is done in 100ms.
- There are several technical issues associated with grid connected systems like Power Quality Issues, Power and voltage fluctuations, Storage, Protection issues, Islanding.
- Power Quality issues are harmonics and voltage and frequency fluctuations.

- Harmonics

- Harmonics are currents or voltages with frequencies that are integer multiples of the fundamental power frequency. Electrical appliances and generators all produce harmonics and in large volumes (eg. computers and compact fluorescent lamps), can cause interference that results in a number of power quality problems.
- Most grid-connected inverters for DG applications put out very low levels of harmonic current, and because of their distribution on the network are unlikely to cause harmonic issues, even at high penetration levels.
- While the most common type of inverters (current-source) can not provide the harmonic support required by the grid, voltage-source inverters can, but

do so at an energy cost and there are a variety of harmonic compensators that are likely to be cheaper.

- Frequency and Voltage Fluctuations

Frequency and voltage fluctuation again classified as

1. Grid-derived voltage fluctuations
2. Voltage imbalance
3. Voltage rise and reverse power flow
4. Power factor Correction

1. Grid-derived voltage fluctuations
    - Inverters are generally configured to operate in grid 'voltage-following' mode and to disconnect DG when the grid voltage moves outside set parameters, This is both to help ensure they contribute suitable power quality as well as help to protect against unintentional islanding. Where there are large numbers of DG systems or large DG systems on a particular feeder, their automatic disconnection due to the grid voltage being out of range can be problematic because other generators on the network will suddenly have to provide additional power
    - To avoid this happening, voltage sag tolerances could be broadened and where possible, Low Voltage Ride-through Techniques (LVRT) could be incorporated into inverter design. LVRT allows inverters to continue to operate for a defined period if the grid voltage is moderately low but they will still disconnect rapidly if the grid voltage drops below a set level.
    - Inverters can also be configured to operate in 'voltage-regulating' mode, where they actively attempt to influence the network voltage. Inverters operating in voltage-regulating mode help boost network voltage by injecting reactive power during voltage sags, as well as reduce network voltage by drawing reactive power during voltage rise. Thus, connection standards need to be developed to incorporate and allow inverters to provide reactive power where appropriate, in a manner that did not interfere with any islanding detection systems.

2. Voltage imbalance

- o Voltage imbalance is when the amplitude of each phase voltage is different in a three-phase system or the phase difference is not exactly 120°.
- o Single phase systems installed disproportionately on a single phase may cause severely unbalanced networks leading to damage to controls, transformers, DG, motors and power electronic devices. Thus, at high RE penetrations, the cumulative size of all systems connected to each phase should be as equal as possible.
- o All systems above a minimum power output level of between 5-10kW typically should have a balanced three phase output.

3. Voltage rise and reverse power flow
    - o Traditional centralized power networks involve power flow in one direction only: from power plant to transmission network, to distribution network, to load.
    - o In order to accommodate line losses, voltage is usually supplied at 5-10% higher than the nominal end use voltage.
    - o Voltage regulators are also used to compensate for voltage drop and maintain the voltage in the designated range along the line.

4. Power factor Correction

- o Because of poor power factor line losses increases and voltage regulation become difficult.Poor power factor on the grid increases line losses and makes voltage regulation more difficult.
- o Inverters configured to be voltage-following have unity power factor, while inverters in voltage-regulating mode provide current that is out of phase with the grid voltage and so provide power factor correction. This can be either a simple fixed power factor or one that is automatically controlled by, for example, the power system voltage.

POWER QUALITY CONDITIONERS

- A power conditioner (also known as a line conditioner or power line conditioner) is a device intended to improve the quality of power that is delivered to electrical load equipment.

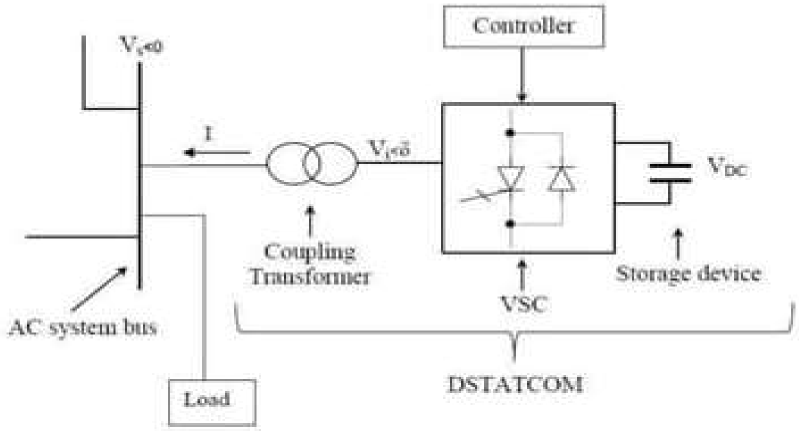
- In a smart grid the role of a power quality conditioner is to:-
  - Deliver voltage & current of the proper level and characteristics to enable load equipment to function properly.
  - Ensure efficient power transfer between utility grid & micro grid.
  - Isolate each micro grid and the utility grid from there respective noises and disturbances.
  - Energy creation i.e. to convert DC power generated by Solar panels to AC.
  - Integration with energy storage system.

- <u>TYPES OF POWER QUALITY CONDITIONERS</u>

- Distribution Static Compensator (DSTATCOM)
- Active power filters
  - Shunt active power filters
  - Series active power filters
  - Hybrid Active Power Filters
- Unified Power Quality conditioner (UPQC)

- <u>DISTRIBUTION STATIC COMPENSATOR (DSTATCOM)</u>

- The DSTATCOM is a custom power device based on a voltage Source Converter (VSC) shunt connected to the distribution networks.
- A DSTATCOM is normally used to precisely regulate system voltage, improve voltage profile, reduce voltage harmonics and for load compensation.
- D-STATCOM can also mitigate voltage dips and can compensate both magnitude and phase angle by injecting reactive or reactive power to the point of connection with the grid.
- The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes: voltage regulation and compensation of reactive power, correction of power factor, and elimination of current harmonics.



- The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the coupling transformer. Such configuration allows the device to absorb or generate controllable active and reactive power.

- <u>ACTIVE POWER FILTERS</u>

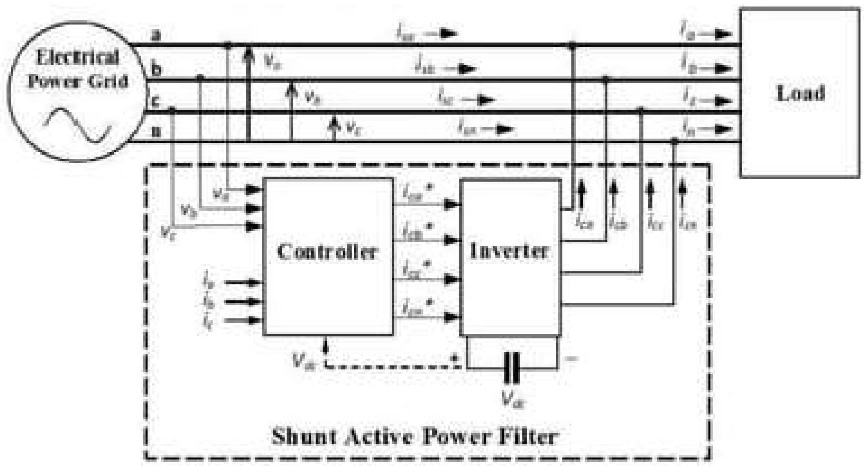
– Active power filter technology has evolved in the past quarter century with varying configurations and control topologies as a full fledged technique for providing compensation for reactive power, harmonics and neutral current in ac networks. Active filters are also used to terminate the voltage harmonics, to regulate terminal voltage, to inhibit voltage flicker and to advance voltage balance in 3- phase systems.

– Generally there are three configurations in which they are connected in power system :-

➢ Shunt active power filters
➢ Series active power filters
➢ Hybrid Active Power Filters

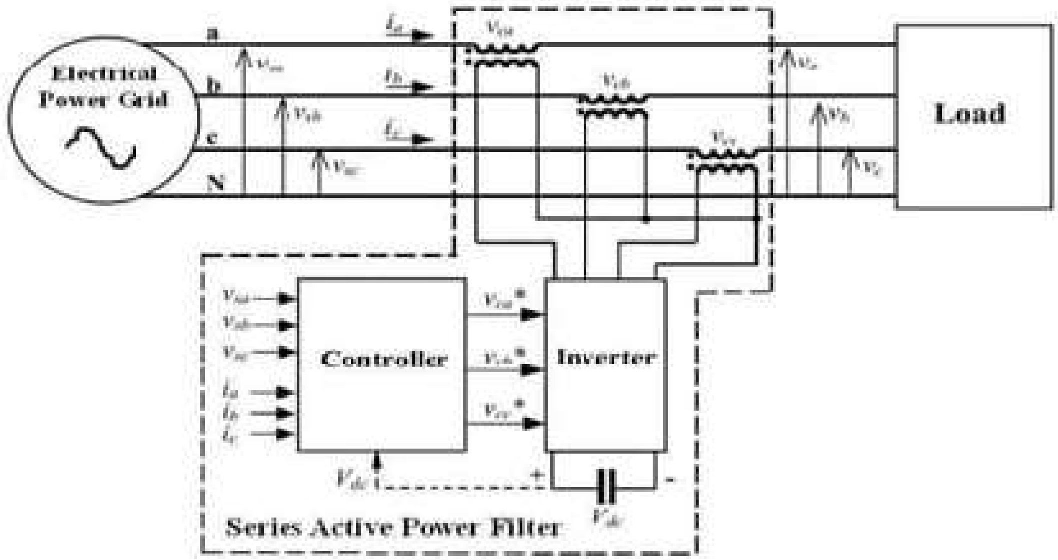
- <u>SHUNT ACTIVE POWER FILTERS</u>
  - It compensate current harmonics by injecting equal-but-opposite harmonic compensating current.

- It operates as a current source injecting the harmonic components generated by the load but phase shifted by 180deg.
- They are usually connected across the load to compensate for all current related problem such as reactive power compensation, power factor correction, current harmonics and load unbalance compensation.



- <u>SERIES ACTIVE POWER FILTERS</u>

  - It compensate current system distortion caused by non-linear loads.
  - The high impedance imposed by the series APF is created by generating a voltage of the same frequency as that of harmonic component that needs to be eliminated.
  - It act as a controlled voltage source and can compensate all voltage related problems such as voltage harmonics, voltage sags & swells, voltage flicker etc.



- <u>HYBRID ACTIVE POWER FILTERS</u>

  – By controlling the amplitude of the voltage fundamental component across the coupling transformer, the PF of the power distribution system can be adjusted.
  – The control of the load power factor imposed a higher voltage across the filter capacitor.
  – This type of configuration is very convenient for compensation of high power medium voltage non linear loads

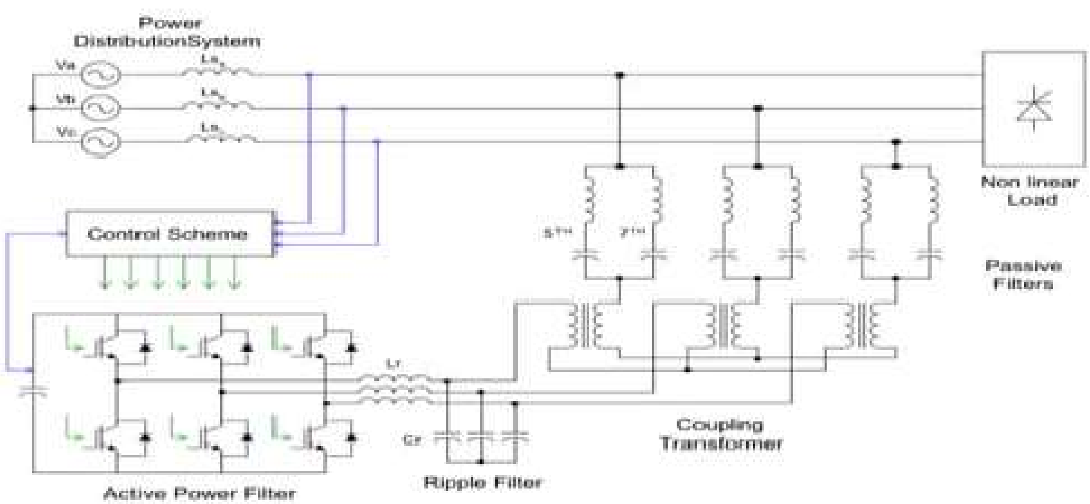
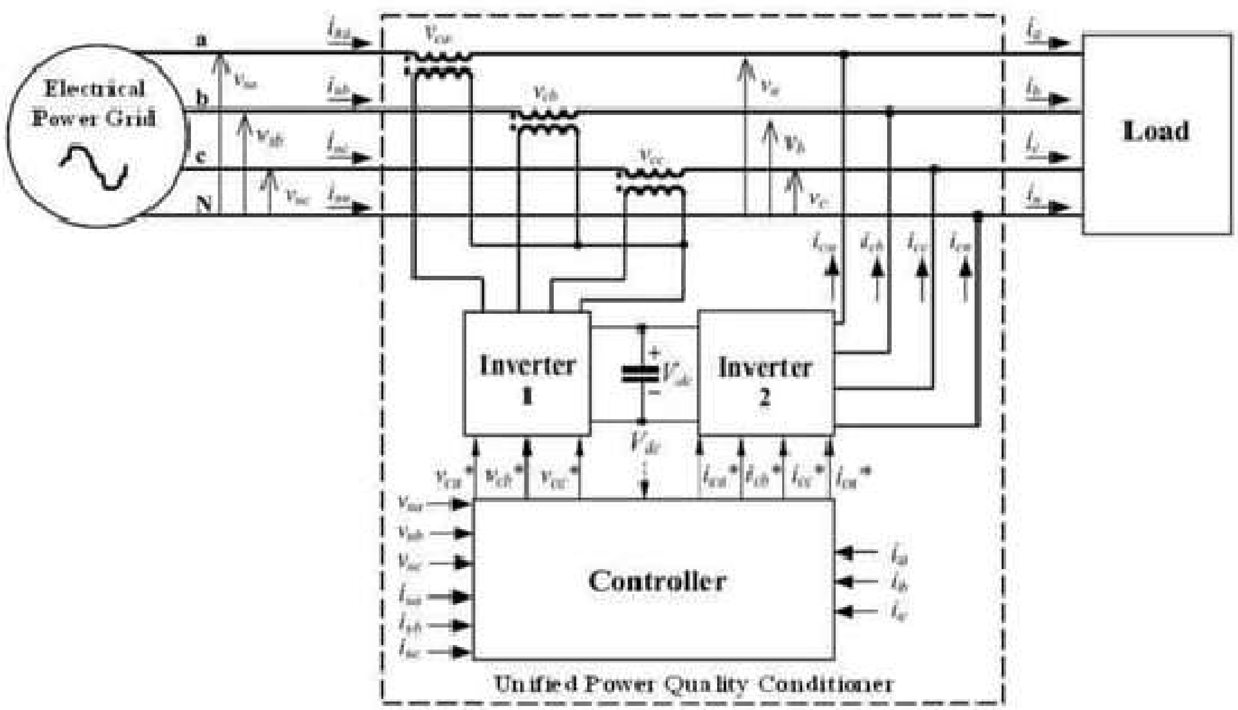


Fig. Hybrid Active power filter

- UNIFIED POWER QUALITY CONDITIONER (UPQC)

  – The Unified Power Quality Conditioner (UPQC) combines the Shunt Active Power Filter with the Series Active Power Filter, sharing the same DC Link, in order to compensate both voltages and currents, so that the load voltages become sinusoidal and at nominal value, and the source currents become sinusoidal and in phase with the source voltages.
  – UPQC can compensate both voltage related problems such as voltage harmonics, voltage sags/swells, voltage flicker as well as current related problems like reactive power compensation, power factor correction, current harmonics and load unbalance compensation.
  – There is a significant increase in interest for using UPQC in distributed generation associated with smart grids because of availability of high frequency switching devices and advanced fast computing devices (microcontrollers, DSP, FPGA) at lower cost.



<u>WEB BASED POWER QUALITY MONITORING</u>

- <u>POWER QUALITY MONITORING</u>
  - It is a multi-pronged approach to identifying, analyzing and correcting power quality problems.
  - Helps to identify the cause of power system disturbances.
  - Helps to identify problem conditions before they cause interruptions or disturbances, in some cases.
  - Objectives for power quality monitoring are generally classified into:
  - ➢ Proactive approach
  - o Intended to characterize the system performance.
  - o Helps to understand and thus match the system performance with customer needs.
  - ➢ Reactive approach
  - o Intended to characterize a specific problem.
  - o Performs short term monitoring at specific customers or at different loads.

- <u>REAL TIME (POWER QUALITY) MONITORING SYSTEM</u>

This permanent monitoring system has the following components:

1) Measurement instruments

- ➢ Involves both the voltage recorder and disturbance analyser.
- ➢ Has a trigger circuit to detect events.
- ➢ Includes a data acquisition board to acquire all the triggered and sampled data.

2) Monitoring workstation

- ➢ Used to gather all information from the measuring instruments.
- ➢ Periodically send information to a control workstation.

3) Control workstation

- This station configures the parameters of measuring instruments.
- Gathers and stores the data coming from the remote monitoring workstations.
- Does the data analysis and export.

4) Control software

- This software drives the control workstation.
- Does the analysis and processing of data.
- Algorithms used for processing varies according to the system used.
- Algorithms used may be based on wavelet transforms or expert systems or some other advanced technique.

5) Database server

- Database management system should provide fast and concurrent access to many users without critical performance degradation.
- Also, it should avoid any form of unauthorized access.

6) Communication channels

- Selection of communication channel strongly depends on monitoring instruments, connectivity functions and on their physical locations.
- Some of the possible channels are fixed telephone channels by using a modem and mobile communication system by using a GSM modem.

- <u>DATA ANALYSIS OF POWER QUALITY MEASUREMENTS</u>

- Analysis is done by the control software and the method of analysis depends on the type of disturbance.
- Main objective of an analyser is to identify the type of event.
- Analyser looks for parameters in the measured data to characterise the waveform.

- Since individual inspection of all wave shapes is not easy due to the large size of database, a few characteristics are extracted from the measured data, mainly magnitude and duration.
- Since database has a lot of information and recorded data, analyser extracts only the relevant disturbances.
- Analyser groups the captured events in a number of classes.
- These classes are made by comparing the captured waveforms with the ideal waveforms.
- This classification is called disturbance classification.
- By comparing the captured events with libraries of power quality variation characteristics and correlating with system events, causes of variations can be determined.
- Every electrical disturbance has an associated waveform which describes its characteristics, which provides important clues to locate the source of electrical problem.

- <u>BENEFITS OF POWER QUALITY MONITORING</u>
- Ensures power system reliability.
- Identify the source and frequency of events.
- Helps in the preventive and predictive maintenance..
- Evaluation of incoming electrical supply and distribution to determine if power quality disturbances are impacting.
- Determine the need for mitigation equipments.
- Reduction of energy expenses and risk avoidances.
- Process improvements-monitoring systems allow identifying the most sensitive equipments and installing power conditioning systems wherever necessary.

POWER QUALITY AUDIT

- A power quality audit is a new technique that is deployed to accomplish various objectives such as better performance, control and minimum power consumption of the loads.

  - An intensive analysis and reporting of power quality problems are stated through power quality audit.
  - The audit reveals deficiencies and risk present in the power system and ways to overcome the major power quality issues.
  - The power quality audit can be defined as a systematic study of the
  - ➢ incoming raw power,
  - ➢ the measurement of the extent of distortion in the incoming raw power,
  - ➢ the identification of the causes of distortion and
  - ➢ the various recommendations for seeking to solve these power quality problems,
  - ➢ a facility will realize the cost-saving benefits.

- Power quality audit measures the various features of power namely
- Active Power
- Apparent Power
- Kilo watt hour
- Phase angle & Power Factor
- Telephonic interference factor
- Under voltage & Over voltage
- Short-Term Voltage Fluctuations
- Voltage Sags & Swells
- Imbalance
- Flickers
- Imbalanced Voltage
- Unbalanced load
- RMS Value
- Harmonics
- Frequency & interruptions etc.

- NEED FOR A POWER QUALITY AUDIT
- Improves the power quality and brings in efficiency

- Helps to identify and eradicate harmonics which minimizes line losses and minimize reduction in the equipment lifetime due to harmonics.
- Helps to identify and eradicate transients to avoid short- duration change in voltage
- Helps to identify and eradicate hours-long voltage sags. caused by system overload
- Improve and maintain continuous supply of quality electricity supply

- <u>POWER QUALITY AUDIT PROCESS</u>

- Planning
  - Focus on objectives
  - Identify risks
- Site Audit
  - Site Visit
  - Gather real time data
- Analysis & Reporting
  - Draft report
  - Recommendation based on standards
  - Comprehensive final report