TUTORIAL - 6

Co-Generation of Process and Co-Generation of Steam and Electricity

1. What are the advantages of co-generation power plant?

- ✓ **High fuel efficiency rating**

  The advantage of cogeneration, in accordance with the laws of thermodynamics, lie mainly in the improved utilization of the condensation heat in the steam. Fairly large heating boilers achieve fuel efficiency ratings at least as high as those for district heating power plants.

- ✓ **Simple plant**

  The advantages of this system are operating simplicity, high availability, simplified layout and reduced equipment and construction costs.

- ✓ **Well-suited to low quality fuels**

  It uses fuels of lower quality like coal, lignite, furnace oil, etc. which cannot be directly fired in gas turbines

- ✓ **Good fuel efficiency**

  If plants set up the cogeneration systems with an appropriate power-and-heat balance, they would be able to achieve optimum cogeneration plant efficiency with best possible use of fuel, the primary source of energy

- ✓ **Low civil const. Cost**

  Low civil construction cost due to block type foundations and least nos. of auxiliaries.

- ✓ **Less delivery period**

  Lowest delivery period hence, less generation period. The CET3 consists of three identical combined cycle units capable of delivering more than 500 Mw of electrical power to the national grid

- ✓ **Less impact on environment**

  Less impact on environment (with use of clean fuels).

- ✓ **High flexibility in operation**

  This system ensures a high flexibility in design and operation of the plant, as it is possible to widely vary ratio of steam to power loads without very much affecting the overall plant efficiency.

- ✓ **Optimum fuel efficiency rating**

  Out of all the variants, cogeneration systems based on combined cycle configurations with cogeneration of power and heat permit the optimal utilization of fuel energy in the true sense of Second Law of Thermodynamics

- ✓ **Low relative capital cost**

  With relatively lower capital cost and low operating cost, due to high overall plant efficiency, the cost of power and steam becomes economically quite attractive for the industry.

- ✓ **Less gestation period**

  The gestation period for developing a project is shorter and the equipment can be delivered in a modular manner.

2. Explain co-generation systems.

➢ Cogeneration system:

A cogeneration system is the sequential or simultaneous generation of multiple forms of useful energy (usually mechanical and thermal) in a single, integrated system. CHP systems consist of a number of individual components – prime mover (heat engine), generator, heat recovery, and electrical interconnection – configured into an integrated whole.

The type of equipment that drives the overall system (i.e. the prime mover) typically identifies the CHP system. Prime movers for CHP systems include reciprocating engines, combustion or gas turbines, steam turbines, micro-turbines, and fuel cells.

These prime movers are capable of burning a variety of fuels, including natural gas, coal, oil, and alternative fuels to produce shaft power or mechanical energy. Although mechanical energy from the prime mover is most often used to drive a generator to produce electricity, it can also be used to drive rotating equipment such as compressors, pumps, and fans.

Thermal energy from the system can be used in direct process applications or indirectly to produce steam, hot water, hot air for drying, or chilled water for process cooling.

➢ TYPES OF COGENERATION SYSTEMS

This section includes various types of cogeneration systems:

1) Steam turbine cogeneration system,
2) Gas turbine cogeneration system,
3) Reciprocating engine cogeneration system.

1) Steam Turbine Cogeneration System

The two types of steam turbines most widely used are the backpressure and the extraction-Another variation of the steam turbine topping cycle cogeneration system is the extraction-back pressure turbine that can be employed where the end-user needs thermal energy at two different temperature levels. The full-condensing steam turbines are usually incorporated at sites where heat rejected from the process is used to generate power.

The specific advantage of using steam turbines in comparison with the other prime movers is the option for using a wide variety of conventional as well as alternative fuels such as coal, natural gas, fuel oil and biomass. The power generation efficiency of the demand for electricity is greater than one MW up to a few hundreds of MW. Due to the system inertia, their operation is not suitable for sites with intermittent energy demand.

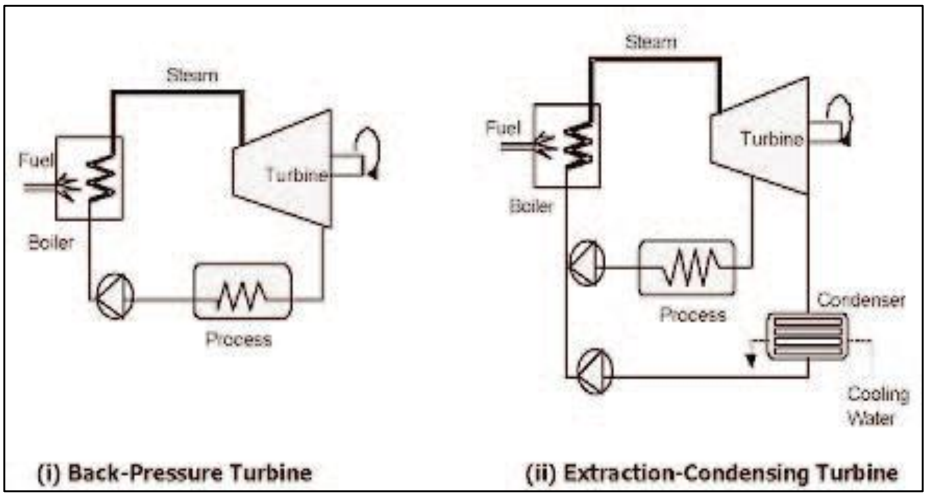

Figure: Schematic Diagrams of Steam Turbine Cogeneration Systems

2) Gas Turbine Cogeneration System

Gas turbine cogeneration systems can produce all or a part of the energy requirement of the site, and the energy released at high temperature in the exhaust stack can be recovered for various heating and cooling applications (see Figure). Though natural gas is most commonly used, other fuels such as light fuel oil or diesel can also be employed. The typical range of gas turbines varies from a fraction of a MW to around 100 MW.

Gas turbine cogeneration has probably experienced the most rapid development in the recent years due to the greater availability of natural gas, rapid progress in the technology, significant reduction in installation costs, and better environmental performance. Furthermore, the gestation period for developing a project is shorter and the equipment can be delivered in a modular manner. Gas turbine has a short start-up time and provides the flexibility of intermittent operation. Though it has a low heat to power conversion efficiency, more heat can be recovered at higher temperatures. If the heat output is less than that required by the user, it is possible to have supplementary natural gas firing by mixing additional fuel to the oxygen-rich exhaust gas to boost the thermal output more efficiently.

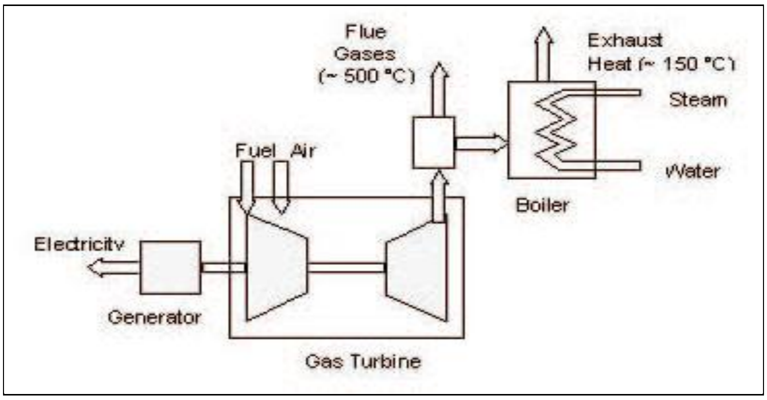

Figure: Schematic Diagram of Gas Turbine Cogeneration

On the other hand, if more power is required at the site, it is possible to adopt a combined cycle that is a combination of gas turbine and steam turbine cogeneration. Steam generated from the exhaust gas of the gas turbine is passed through a backpressure or extraction-condensing steam turbine to generate additional power. The exhaust or the extracted steam from the steam turbine provides the required thermal energy.

3) Reciprocating Engine Cogeneration System

Also known as internal combustion (I. C.) engines, these cogeneration systems have high power generation efficiencies in comparison with other prime movers. There are two sources of heat for recovery: exhaust gas at high temperature and engine jacket cooling water system at low temperature (see Figure). As heat recovery can be quite efficient for smaller systems, these systems are more popular with smaller energy consuming facilities, particularly those having a greater need for electricity than thermal energy and where the quality of heat required is not high, e.g. low pressure steam or hot water.

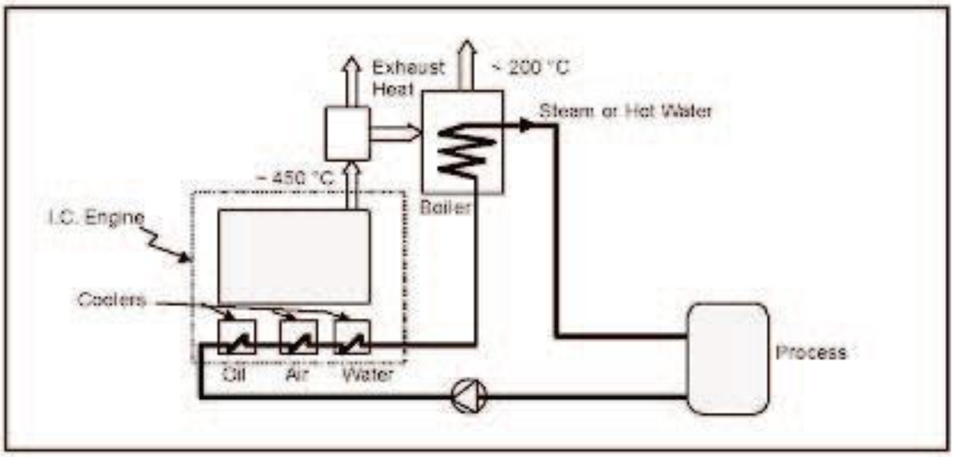

Figure: Schematic Diagram of Reciprocating Engine Cogeneration

Though diesel has been the most common fuel in the past, the prime movers can also operate with heavy fuel oil or natural gas. These machines are ideal for intermittent operation and their performance is not as sensitive to the changes in ambient temperatures as the gas turbines. Though the initial investment on these machines is low, their operating and maintenance costs are high due to high wear and tear.

There are two another types of cogeneration system:

1. The bottoming cycle
2. The topping cycle

1. The bottoming cycle:

Primary heat is used at high temperature directly for process requirements. Waste heat from process is used for electrical power generation. It is difficult to extract power economically in the bottoming cycle plants. It has low efficiency and therefore it is not widely used.

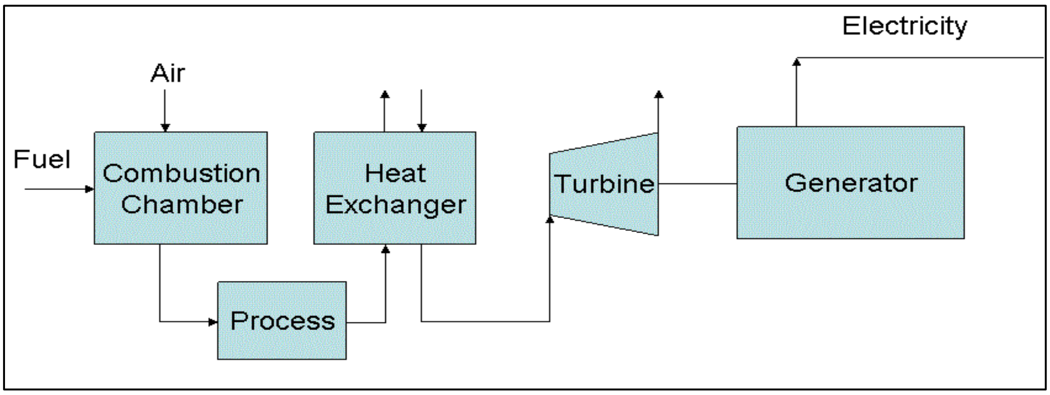

Figure: Bottoming cycle

2. The topping cycle:

First electricity is generated by steam turbine or gas turbine or diesel engine, then exhaust steam or gas is used for process requirements. Process seam at low pressure and temperature is extracted by two ways depending on process requirements.

a) Extracted from turbine at an intermediate stage.
b) Taken at the turbine exhaust.

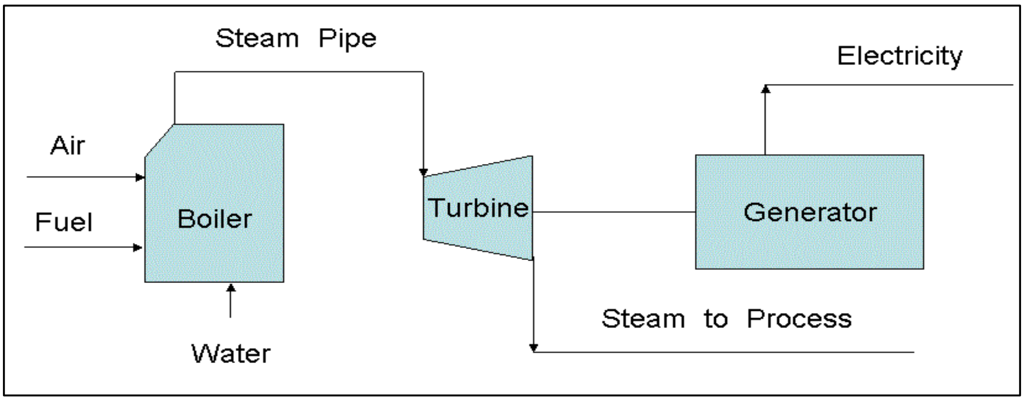

Figure: Topping cycle

Therefore, topping cycle can provide true savings in primary energy. Also process applications require low pressure, low temperature. (Sometimes moderate temperature) steam. Such steam is easily produced in a topping cycle.

3. Discuss advantages and disadvantages of cogeneration systems.

Variant	Advantages	Disadvantages
Back pressure	- High fuel efficiency rating	- Little flexibility in design and operation
Steam turbine & fuel firing in boiler	- Simple plant - Well-suited to low quality fuels	- More capital investment - Low fuel efficiency rating - High cooling water demand - More impact on environment - High civil const. cost due to complicated foundations
Gas turbine with waste heat recovery boiler	- Good fuel efficiency - Simple plant - Low civil const. Cost - Less delivery period - Less impact on environment - High flexibility in operation	- Moderate part load efficiency - Limited suitability for low quality fuels
Combined gas & steam turbine with waste heat recovery boiler	- Optimum fuel efficiency rating - Low relative capital cost - Less gestation period - Quick start up & stoppage - Less impact on environment - High flexibility in operation	- Average to moderate part-load efficiency - Limited suitability for low quality fuels
Diesel Engine & waste heat recovery Boiler & cooling water heat exchanger	- Low civil const. Cost due to block foundations & least no. of auxiliaries - High Power efficiency - Better suitability as stand by power source	- Low overall efficiency - Limited suitability for low quality fuels - Availability of low temperature steam - Highly maintenance prone.

4. Mention three circumstances, where co-generation is likely to be most attractive.

Cogeneration is likely to be most attractive under the following circumstances:

1. The demand for both steam and power is balanced i.e. consistent with the range of steam: power output ratios that can be obtained from a suitable cogeneration plant.
2. A single plant or group of plants has sufficient demand for steam and power to permit economies of scale to be achieved.
3. Peaks and troughs in demand can be managed or, in the case of electricity, adequate backup supplies can be obtained from the utility company.

Cogeneration is simultaneous generation of two different forms of useful energy from a single primary energy source. So it most likely to be attractive where demand for both steam and power is balanced. If it is not balanced then there will not be beneficial to the organization.

The plant should have sufficient demand for steam and power for permitting economics. If the organization grants more rupees for cogeneration and, steam and power is not utilized as much produced, then the rupees spent for implementing the plant will not be utilized properly.

If there is peak and through in demand of steam and power, then there should be the mechanism for managing the needs for cogeneration to be attractive.

5. List out electrical energy parameters required while carrying out cogeneration system performance evaluation.

Required Energy parameters are:

1. Total power generation for the trial period from individual turbines.
2. Hourly average power generation.
3. Quantity of power import from utility.
4. Auxiliary power consumption.

The important technical parameters for cogeneration system are:

- **Heat-to-power ratio**

  Heat-to-power ratio is one of the most important technical parameters influencing the selection of the type of cogeneration system. The heat-to-power ratio of a facility should match with the characteristics of the cogeneration system to be installed.

  It is defined as the ratio of thermal energy to electricity required by the energy consuming facility.

- **Quality of thermal energy needed**

  The quality of thermal energy required (temperature and pressure) also determines the type of cogeneration system. For a sugar mill needing thermal energy at about 120°C, a topping cycle cogeneration system can meet the heat demand. On the other hand, for a cement plant requiring thermal energy at about 1450°C, a bottoming cycle cogeneration system can meet both high quality thermal energy and electricity demands of the plant.

- **Load patterns**

  The heat and power demand patterns of the user affect the selection (type and size) of the cogeneration system. For instance, the load patterns of two energy consuming facilities would lead to two different sizes, possibly types also, of cogeneration systems.

- **Fuels available**

  Depending on the availability of fuels, some potential cogeneration systems may have to be rejected. The availability of cheap fuels or waste products that can be used as fuels at a site is one of the major factors in the technical consideration because it determines the competitiveness of the cogeneration system.

A rice mill needs mechanical power for milling and heat for paddy drying. If a cogeneration system were considered, the steam turbine system would be the first priority because it can use the rice husk as the fuel, which is available as waste product from the mill.

- **System reliability**

  Some energy consuming facilities require very reliable power and/or heat; for instance, a pulp and paper industry cannot operate with a prolonged unavailability of process steam. In such instances, the cogeneration system to be installed must be modular, i.e. it should consist of more than one unit so that shut down of a specific unit cannot seriously affect the energy supply.

- **Grid dependent system versus independent system**

  A grid-dependent system has access to the grid to buy or sell electricity. The grid-independent system is also known as a "stand-alone" system that meets all the energy demands of the site. It is obvious that for the same energy consuming facility, the technical configuration of the cogeneration system designed as a grid dependent system would be different from that of a stand-alone system.

- **Retrofit versus new installation**

  If the cogeneration system is installed as a retrofit, the system must be designed so that the existing energy conversion systems, such as boilers, can still be used. In such a circumstance, the options for cogeneration system would depend on whether the system is a retrofit or a new installation.

- **Electricity buy-back**

  The technical consideration of cogeneration system must take into account whether the local regulations permit electric utilities to buy electricity from the co-generators or not. The size and type of cogeneration system could be significantly different if one were to allow the export of electricity to the grid.

- **Local environmental regulation**

  The local environmental regulations can limit the choice of fuels to be used for the proposed cogeneration systems. If the local environmental regulations are stringent, some available fuels cannot be considered because of the high treatment cost of the polluted exhaust gas and in some cases, the fuel itself.

6. Explain how power factor improvement helps to save energy.

Power factor is the ratio between the KW (Kilo-Watts) and the KVA (Kilo-Volt Amperes) drawn by an electrical load where the KW is the actual load power and the KVA is the apparent load power shown in figure. It is a measure of how effectively the current is being converted into useful work output and more particularly is a good indicator of the effect of the load current on the efficiency of the supply system.

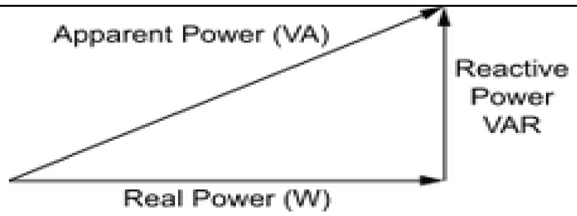

Figure: Power Triangle

All current flow will causes losses in the supply and distribution system. A load with a power factor of 1.0 results in the most efficient loading of the supply and a load with a power factor of 0.5 will result in much higher losses in the supply system. A poor power factor can be the result of either a significant phase difference between the voltage and current at the load terminals, or it can be due to a high harmonic content or distorted/discontinuous current waveform.

Poor load current phase angle is generally the result of an inductive load such as an induction motor, power transformer, lighting ballasts, welder or induction furnace. A distorted current waveform can be the result of a rectifier, variable speed drive, switched mode power supply, discharge lighting or other electronic load.

A poor power factor due to an inductive load can be improved by the addition of power factor correction, but, a poor power factor due to a distorted current waveform requires an change in equipment design or expensive harmonic filters to gain an appreciable improvement. Many inverters are quoted as having a power factor of better than 0.95 when in reality, the true power factor is between 0.5 and 0.75. The figure of 0.95 is based on the cosine of the angle between the voltage and current but does not take into account that the current waveform is discontinuous and therefore contributes to increased losses on the supply.

- **Effects of Power Factor**

With a power factor less than unity, the amount of useful power that can be sup- plied by the supply system's generating plant will be less than its full total power capacity. In other words, although the generators may be delivering their full current capacity, not all of this current results in useful power. Consequently, the electricity supply authorities generally require consumers to restrict their reactive power demand such that their power factor level is maintained above 0.9. Defaulters are subject to significant cost penalties, some of which are reflected in the tariffs customers pay.

- **Effects to the electricity supplier**

Reactive power actually costs something to produce at the generating station since low power factor causes a large drop of voltage in the generators, hence requiring larger exciters. It also increases transmission and distribution losses. The losses in the cables or conductors are proportional to the square of the cur- rent, and consequently they are inversely proportional to the square of the power factor. Thus, for example, the losses in the cable conductors at a power factor of 0.8 are 1.57 times the losses at unity power factor, and the losses at a power factor of 0.4 will be 6.25 times that at a unity power factor.

The ratings of transformers, cables and protective switchgears are proportional to the current and therefore inversely proportional to the power factor. Therefore higher ratings of transformers and cables are required for loads that operate at low power factor.

- **Effects to the consumer**

When there is extensive application of inductive motors and associated devices, consumers will have a low system power factor, which causes a significant volt- age drop across the cables. Low voltage results in inefficient operation of equip- ment such as motors and lighting. Consequently, extra voltage regulating/ stabilizing equipment needs be installed.

When demand charges are based on the total power demand (kVA), electricity costs are inversely proportional to the power factor level and therefore a low power factor results in higher costs. The cost of electricity to consumers whose demand charges are based on their kW or active demand is unaffected by the level of the plant's power factor, unless there is a low power factor penalty provision in the tariff agreement.

- **Additional Material regarding Power Factor.**

- **Methods of Power Factor Correction**

Capacitors connected at each starter and controlled by each starter is known as "Static Power Factor Correction" while capacitors connected at a distribution board and controlled independently from the individual starters is known as "Bulk Correction".

1. Bulk Correction

The Power factor of the total current supplied to the distribution board is monitored by a controller which then switches capacitor banks In a fashion to maintain a power factor better than a preset limit. (Typically 0.95). Ideally, the power factor should be as close to unity (Power factor of "1") as possible. There is no problem with bulk correction operating at unity.

2. Static Correction

As a large proportion of the inductive or lagging current on the supply is due to the magnetizing current of induction motors, it is easy to correct each individual motor by connecting the correction capacitors to the motor starters. With static correction, it is important that the capacitive current is less than the inductive magnetizing current of the induction motor.

In many installations employing static power factor correction, the correction capacitors are connected directly in parallel with the motor windings. When the motor is off-line, the capacitors are also off-line. When the motor is connected to the supply, the capacitors are also connected providing correction at all times that the motor is connected to the supply. This removes the requirement for any expensive power factor monitoring and control equipment.

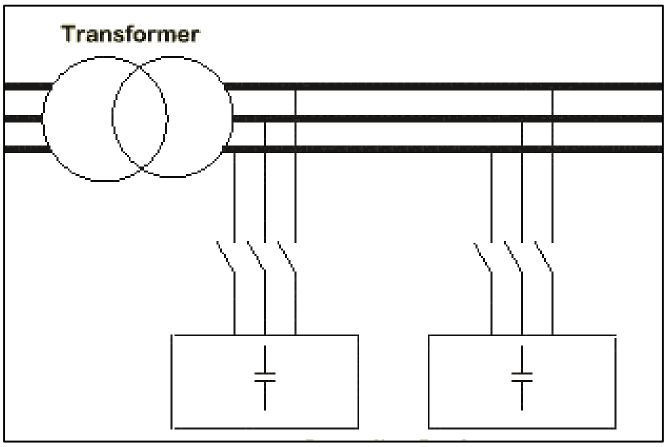

Figure: Static correction by connecting transformer with motor

In this situation, the capacitors remain connected to the motor terminals as the motor slows down. An induction motor, while connected to the supply, is driven by a rotating magnetic field in the stator which induces current into the rotor. When the motor is disconnected from the supply, there is for a period of time, a magnetic field associated with the rotor. As the motor decelerates, it generates voltage out its terminals at a frequency which is related to it's speed. The capacitors connected across the motor terminals, form a resonant circuit with the motor inductance.

If the motor is critically corrected, (corrected to a power factor of 1.0) the inductive reactance equals the capacitive reactance at the line frequency and therefore the resonant frequency is equal to the line frequency. If the motor is over corrected, the resonant frequency will be below the line frequency.

If the frequency of the voltage generated by the decelerating motor passes through the resonant frequency of the corrected motor, there will be high currents and voltages around the motor/capacitor circuit. This can result in severe damage to the capacitors and motor. It is imperative that motors are never over corrected or critically corrected when static correction is employed. Static power factor correction should provide capacitive current equal to 80% of the magnetizing current, which is essentially the open shaft current of the motor.

The magnetizing current for induction motors can vary considerably. Typically, magnetizing currents for large two pole machines can be as low as 20% of the rated current of the motor while smaller low speed motors can have a magnetizing current as high as 60% of the rated full load current of the motor.

It is not practical to use a "Standard table" for the correction of induction motors giving optimum correction on all motors. Tables result in under correction on most motors but can result in over correction in some cases. Where the open shaft current cannot be measured, and the magnetizing current is not quoted, an approximate level for the maximum correction that can be applied can be calculated from the half load characteristics of the motor. It is dangerous to base correction on the full load characteristics of the motor as in some cases, motors can exhibit a high leakage reactance and correction to 0.95 at full load will result in over correction under no load, or disconnected conditions.

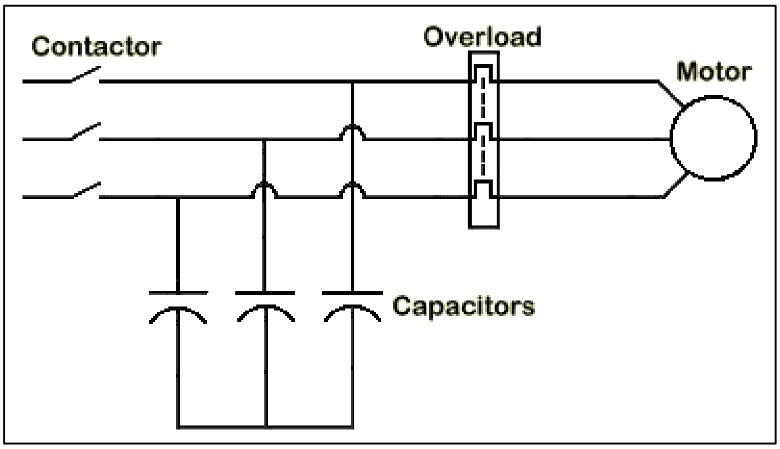

Figure: Static correction using capacitors with motor

Static correction is commonly applied by using one contactor to control both the motor and the capacitors. It is better practice to use two contactors, one for the motor and one for the capacitors. Where one contactor is employed, it should be up sized for the capacitive load. The use of a second contactor eliminates the problems of resonance between the motor and the capacitors.

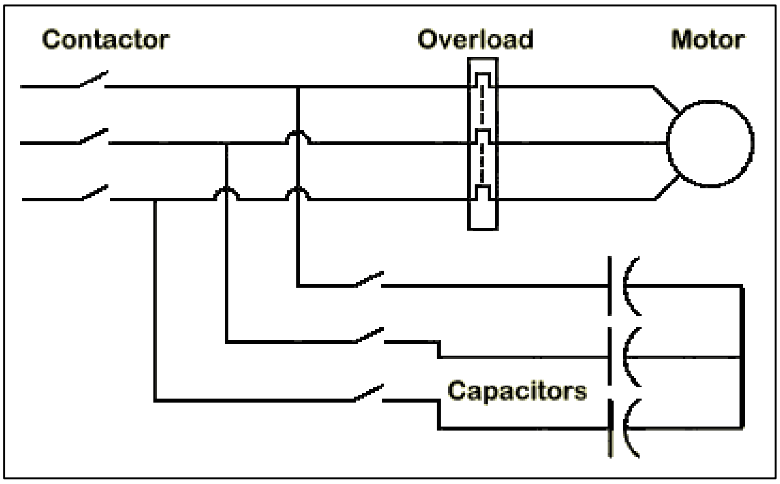

Figure: Static correction by connecting contractor to capacitor

3. Inverter

Static Power factor correction must not be used when the motor is controlled by a variable speed drive or inverter. The connection of capacitors to the output of an inverter can cause serious damage to the inverter and the capacitors due to the high frequency switched voltage on the output of the inverters.

The current drawn from the inverter has a poor power factor, particularly at low load, but the motor current is isolated from the supply by the inverter. The phase angle of the current drawn by the inverter from the supply is close to zero resulting in very low inductive current regardless of what the motor is doing. The inverter does not however, operate with a good power factor.

Many inverter manufacturers quote a cos Ø of better than 0.95 and this is generally true, however the current is non sinusoidal and the resultant harmonics cause a power factor (KW/KVA) of closer to 0.7

depending on the input design of the inverter. Inverters with input reactors and DC bus reactors will exhibit a higher true power factor than those without.

The connection of capacitors close to the input of the inverter can also result in damage to the inverter. The capacitors tend to cause transients to be amplified, resulting in higher voltage impulses applied to the input circuits of the inverter, and the energy behind the impulses is much greater due to the energy storage of the capacitors.

It is recommended that capacitors should be at least 75 Meters away from inverter inputs to elevate the impedance between the inverter and capacitors and reduce the potential damage caused.

Switching capacitors, Automatic bank correction etc, will cause voltage transients and these transients can damage the input circuits of inverters. The energy is proportional to the amount of capacitance being switched. It is better to switch lots of small amounts of capacitance than few large amounts.

4. Solid State Soft Starter

Static Power Factor correction capacitors must not be connected to the output of a solid state soft starter. When a solid state soft starter is used, the capacitors must be controlled by a separate contactor, and switched in when the soft starter output voltage has reached line voltage. Many soft starters provide a "top of ramp" or "bypass contactor control" which can be used to control the power factor correction capacitors. The connection of capacitors close to the input of the soft starter can also result in damage to the soft starter if an isolation contactor is not used. The capacitors tend to cause transients to be amplified, resulting in higher voltage impulses applied to the SCRs of the Soft Starter, and the energy behind the impulses is much greater due to the energy storage of the capacitors.

It is recommended that capacitors should be at least 50 Meters away from Soft starters to elevate the impedance between the inverter and capacitors and reduce the potential damage caused.

Switching capacitors, Automatic bank correction etc., will cause voltage transients and these transients can damage the SCRs of Soft Starters if they are in the off state without an input contactor. The energy is proportional to the amount of capacitance being switched. It is better to switch lots of small amounts of capacitance than few large amounts.

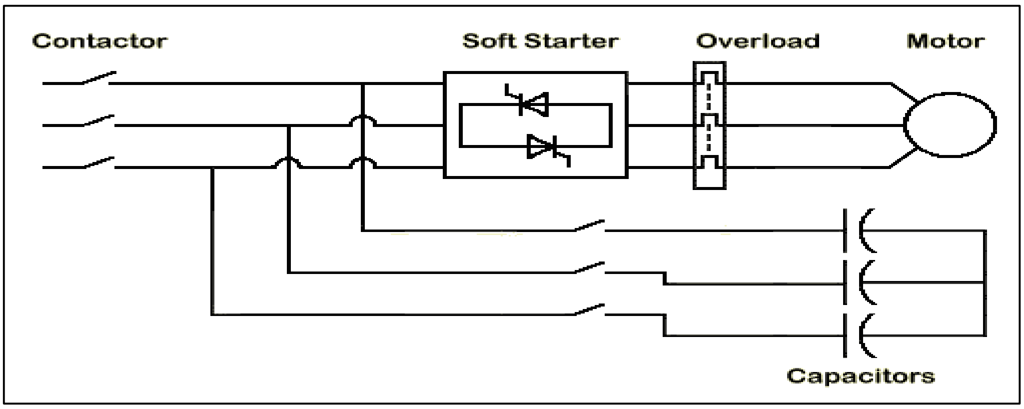

Figure: Solid State Starter

7. Discuss various measures to be taken for reducing electric energy transmission losses.

Transmission and distribution of electrical energy require cables and power transformers, which create three types of energy loss:

- The Joule effect, where energy is lost as heat in the conductor (a copper wire, for example);
- Magnetic losses, where energy dissipates into magnetic field
- The dielectric effect, where energy is absorbed in the insulating material.

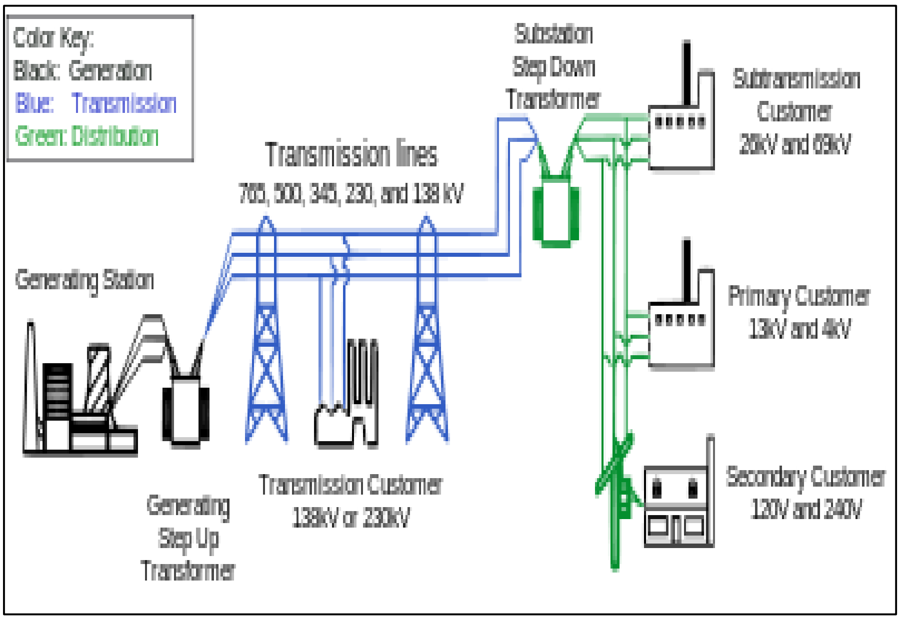

Figure: Transmission & Distribution Of Power

Most transmission lines use high-voltage three-phase alternating current (AC), although single phase. AC is sometimes used in railway electrification systems. High-voltage direct-current (HVDC) technology is used for greater efficiency in very long distances (typically hundreds of miles (kilometers)), or in submarine power cables (typically longer than 30 miles (50 km)). HVDC links are also used to stabilize against control problems in large power distribution networks where sudden new loads or blackouts in one part of a network can otherwise result in synchronization problems and cascading failures.

- Electricity is transmitted at high voltages (120 kV or above) to reduce the energy lost in long-distance transmission. Power is usually transmitted through overhead power lines. Underground power transmission has a significantly higher cost and greater operational limitations but is sometimes used in urban areas or sensitive locations.

- A key limitation in the distribution of electric power is that, with minor exceptions, electrical energy cannot be stored, and therefore must be generated as needed. A sophisticated control system is required to ensure electric generation very closely matches the demand. If the demand for power exceeds the supply, generation plants and transmission equipment can shut down which, in the worst cases, can lead to a major regional blackout, such as occurred in the US Northeast blackouts of 1965, 1977, 2003, and other regional blackouts in 1996 and 2011. To reduce the risk of such failures, electric transmission networks are interconnected into regional, national or continental wide networks thereby providing multiple redundant alternative routes for power to flow should (weather or equipment) failures occur.

- **CONTROL**

To ensure safe and predictable operation the components of the transmission system are controlled with generators, switches, circuit breakers and loads. The voltage, power, frequency, load factor, and reliability capabilities of the transmission system are designed to provide cost effective performance for the customers.

- **Load balancing**

The transmission system provides for base load and peak load capability, with safety and fault tolerance margins. The peak load times vary by region largely due to the industry mix. In very hot and very cold climates home air conditioning and heating loads have an effect on the overall load. They are typically highest in the late afternoon in the hottest part of the year and in mid mornings and mid-evenings in the coldest part of the year. This makes the power requirements vary by the season and the time of day. Distribution system designs always take the base load and the peak load into consideration. The transmission system usually does not have a large buffering capability to match the loads with the generation. Thus generation has to be kept matched to the load, to prevent overloading failures of the generation equipment.

Multiple sources and loads can be connected to the transmission system and they must be controlled to provide orderly transfer of power. In centralized power generation, only local control of generation is necessary, and it involves synchronization of the generation units, to prevent large transients and overload conditions.

In distributed power generation the generators are geographically distributed and the process to bring them online and offline must be carefully controlled. The load control signals can either be sent on separate lines or on the power lines themselves. Voltage and frequency can be used as signaling mechanisms to balance the loads.

In voltage signaling, the variation of voltage is used to increase generation. The power added by any system increases as the line voltage decreases. This arrangement is stable in principle. Voltage-based regulation is complex to use in mesh networks, since the individual components and set points would need to be reconfigured every time a new generator is added to the mesh.

In frequency signaling, the generating units match the frequency of the power transmission system. In droop speed control, if the frequency decreases, the power is increased. (The drop in line frequency is an indication that the increased load is causing the generators to slow down.). Wind turbines, vehicle-to-grid and other distributed storage and generation systems can be connected to the power grid, and interact with it to improve system operation.

- **Failure protection**

Under excess load conditions, the system can be designed to fail gracefully rather than all at once. Brownouts occur when the supply power drops below the demand. Blackouts occur when the supply fails completely. Rolling blackouts (also called load shedding) are intentionally engineered electrical power outages, used to distribute insufficient power when the demand for electricity exceeds the supply.