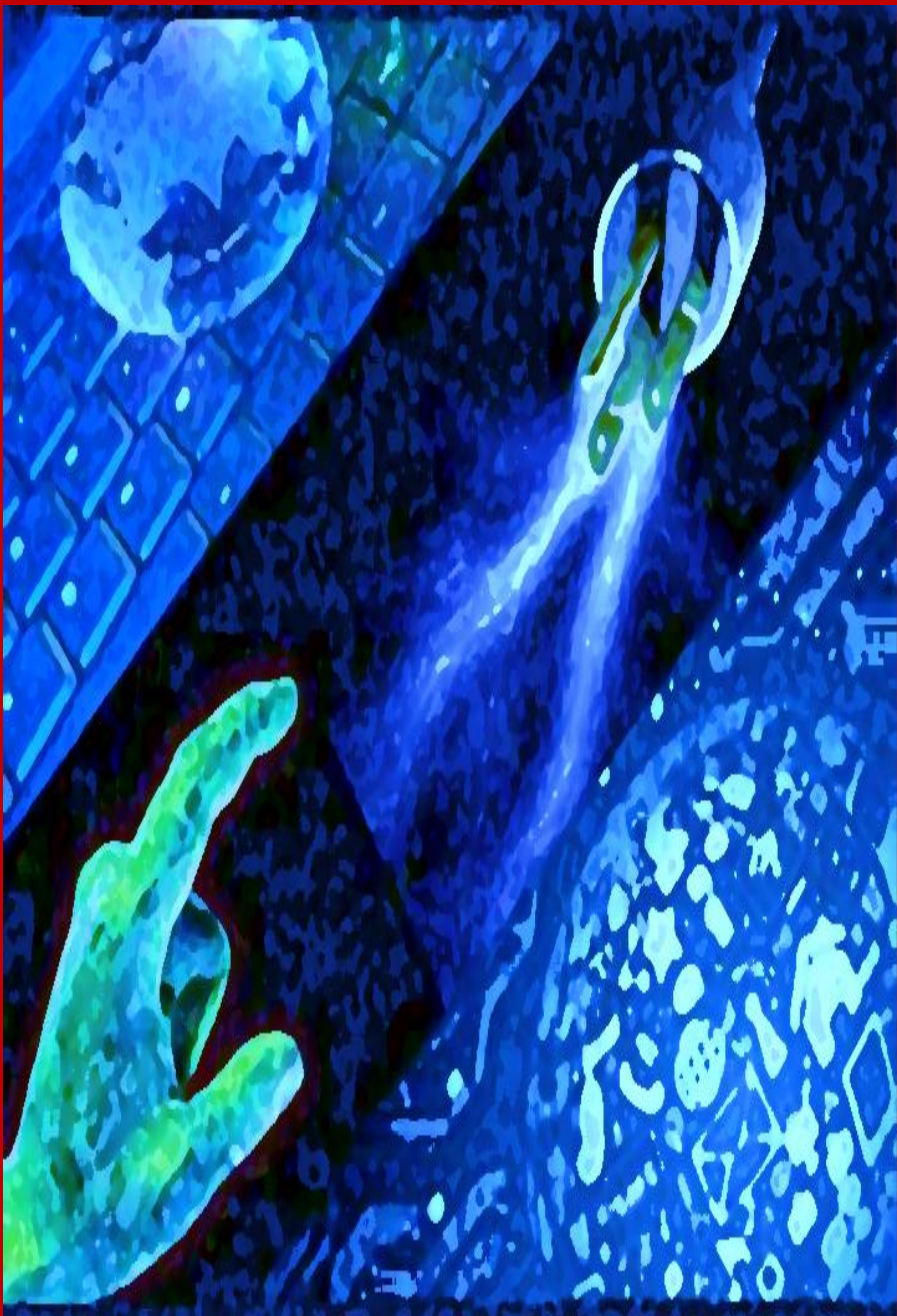
VOLTAFFAIR – 2015

DEPARTMENT OF ELECTRICAL ENGINEERING



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EDITORIAL

In the process of continuous improvement, we are progressing in leaps & bounce. The consecrated approach has been attempted to ascertain in minute efforts towards discussion of technical progressions. It is elating to see the dynamic participation from the students. It is clearly a sign that they are no longer contented being mute auditors anymore; rather they are indoctrinating a full-duplex partaking.

We are looking forward for the moment our students will get their works published in international journals adding further feathers to the crown of the Department of Electrical Engineering.

INTRODUCTION

The way technology is evolving, it is too perilous to brag about the information one gained since he has signed off from the student life. This is the area where the necessity to gather beyond. In various segments of Electrical Engineering, a lot of innovations have already been achieved and sarcastically the process is a quite greedy one. Pointing out all of them is practically impossible. Bounded by the scope of the magazine, a few among them have been presented in the annual magazine of the department. With a hope to enrich our students and also us here we present the second volume of "VOLTAFFAIR"

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SLIDING MODE CONTROLLER DESIGN

RAJEEV KUMAR

Lecturer of Electrical Engineering Department

Technique Polytechnic Institute, Hooghly, West Bengal, India

Email id: rajeev88@gmail.com

A. INTRODUCTION:

Sliding mode control (SMC) is a nonlinear control technique featuring remarkable properties of accuracy, robustness, and easy tuning and implementation.

SMC systems are designed to drive the system states onto a particular surface in the state space, named sliding surface. Once the sliding surface is reached, sliding mode control keeps the states on the close neighborhood of the sliding surface. Hence the sliding mode control is a two part controller design. The first part involves the design of a sliding surface so that the sliding motion satisfies design specifications. The second is concerned with the selection of a control law that will make the switching surface attractive to the system state.

B. ADVANTAGES:

There are two main advantages of SMC. These are

- The dynamic behavior of the system may be tailored by the particular choice of the sliding function.
- The close loop response becomes totally insensitive to some particular uncertainties. This principle extends to model parameter uncertainties, disturbance and nonlinearity that are bounded.

From a practical point of view SMC allows for controlling nonlinear processes subject to external disturbances and heavy model uncertainties.

C. DESCRIPTION:

Let us consider the nonlinear SISO system

$$\dot{x} = f(x,t) + g(x,t)u$$

$$y = h(x,t)$$

Where y and u denote the scalar output and input variable, and $x \in R^n$ denotes the state vector.

The control aim is to make the output variable y to track a desired profile y_{des}, that is, it is required that the output error variable $e=y-y_{des}$ tends to some small vicinity of zero after a transient of acceptable duration.

As mentioned, SMC synthesis entails two phases

Phase 1 (Sliding surface design)

Phase 2 (Control input design)

The first phase is the definition of a certain scalar function of the system state, says $\sigma = \sigma(e, \dot{e}, \ldots e^k)$

The function σ should be selected in such a way that its vanishing, $\sigma = 0$, gives rise to a stable differential equation any solution $e_y(t)$ of which will tend to zero eventually.

The most typical choice for the sliding manifold is a linear combination of the following type

$$\sigma = \dot{e} + c_0 e$$

$$\sigma = \ddot{e} + c_1\dot{e} + c_0 e$$

$$\sigma = e^k + \sum_{i=0}^{k-1} c_i e^i$$

The number of derivatives to be included (the k coefficient should be $k=r-1$, where r is the input output relative degree.

With properly selected c_i coefficient, if one steers to zero the σ variable, the exponential vanishing of the error and its derivatives is obtained.

If such property holds, then the control task is to provide for the finite time zeroing of *σ,* forgetting any other aspects.

From a geometrical point of view, the equation $\sigma = 0$ defines a surface in the error space, that is called "sliding surface". The trajectories of the controlled system are forced onto the sliding surface, along which the system behavior meets the design specifications.

A typical form for the sliding surface is the following, which depends on just a single scalar parameter, p.

$$\sigma = \left(\frac{d}{dt} + p\right)^k e$$

K=1 $\sigma = \dot{e} + pe$

K=2 $\sigma = \ddot{e} + 2p\dot{e} + p^2 e$

The choice of the positive parameter *p* is almost arbitrary, and defines the unique pole of the resulting "reduced dynamics" of the system when in sliding.

The integer parameter k is on the contrary rather critical; it must be equal to r-1, with r being the relative degree between y and u.

This means that the relative degree of the σ 3
variable is one.

4

The successive phase (Phase2) is finding a control action that steers the system 5
trajectories onto the sliding manifold, that is, in other words, the control is able to steer the σ variable to zero in finite time.

There are several approaches based on the sliding mode control approach:

- standard (or first-order) sliding mode control
- high-order sliding mode control

The control is discontinuous across the manifold $\sigma = 0$.

$$u = -U\, sgn(\sigma)$$

That is

$$u = \begin{cases} -U, & \sigma > 0 \\ U, & \sigma < 0 \end{cases}$$

U is a sufficiently large positive constant.

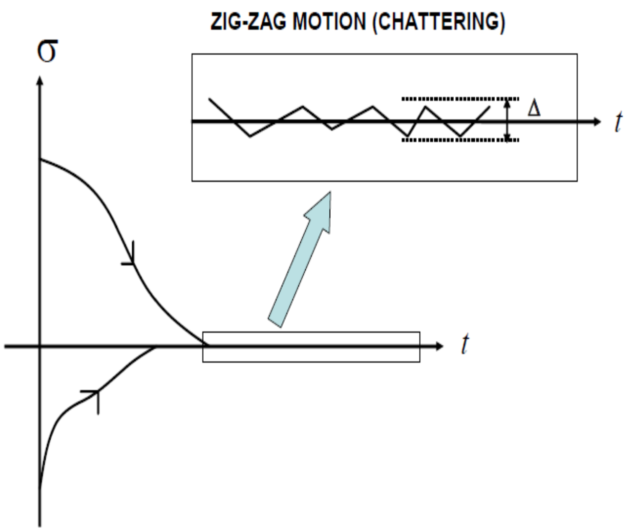


Fig.1 Typical evolution of the σ variable starting from different initial conditions

In steady state the control variable u will commute at very high (theoretically infinite) frequency between the values $u = U$ and $u = -U$ as it is seen Fig 2

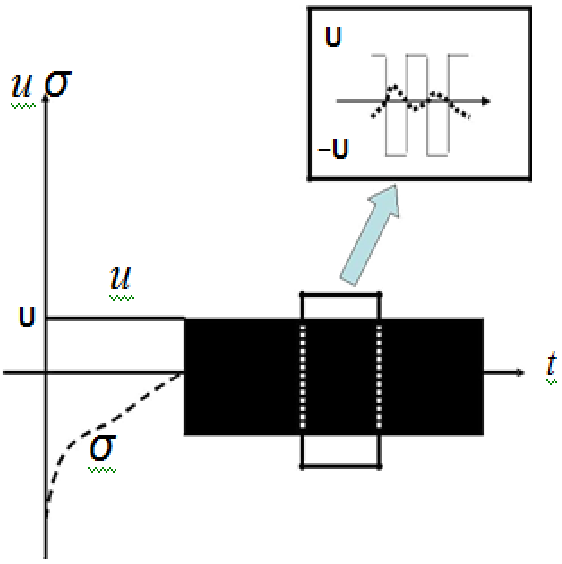


Fig.2 Typical evolution of the control signal u (the dashed line represents σ)

The discontinuous high frequency switching control as shown Figure 2 is appropriate in "electrical" applications (where PWM control signals are normally employed) but gives rise to oscillations and many problems in different areas like, e.g., the control of mechanical systems.

In order to solve the above problem (referred to as "**chattering phenomenon**") approximate (smoothed) implementations of sliding mode control techniques have been suggested where the discontinuous "sign" term is replaced by a continuous smooth approximation. Two examples follow:

$$SAT \quad u = -U sat(\sigma, \varepsilon) \equiv -U \frac{\sigma}{|\sigma| + \varepsilon} \qquad \varepsilon > 0 \quad \varepsilon \approx 0$$

$$TANH \quad u = U \tanh\left(\frac{\sigma}{\varepsilon}\right) \qquad \varepsilon > 0 \quad \varepsilon \approx 0$$

D. CONCLUSION:

Unfortunately this approach is effective only in specific case, which is when hard uncertainties are not present and the control action that counteracts them can be set to zero in the sliding mode.

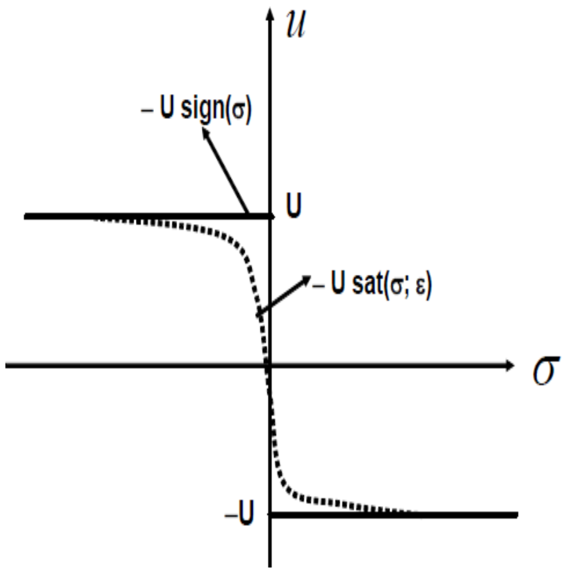


Fig.3 Smooth approximations of sliding mode control

TO STUDY DIFFERENT LIGHTING CONTROL STRATEGIES

AVIJIT KARMAKAR

Lecturer of Electrical Engineering Department

Technique Polytechnic Institute, Hooghly, West Bengal, India

Email id: avijit.karmakar.ee@gmail.com

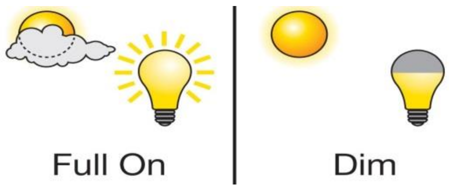
A. INTRODUCTION:

Lighting controls are devices and systems that regulate the output of lamps and luminaires. They either turn the lights on and off using a switch or adjust light output using a dimmer. Growing demands for energy savings and flexibility to support visual needs have given lighting control much greater prominence. In particular, commercial building energy codes are driving demand for more sophisticated, detailed and layered control systems. The digital revolution in lighting control technology has enabled manufacturer solutions to keep pace with these demands.

A good lighting design requires a good controls design. A good controls design, in turn, ensures that the lighting system produces the right amount of light where and when it is needed. Benefits of a good control design include reduced energy costs and flexibility, which can support the user's visual needs and create a desired mood or ambience. This article provides a brief introduction to how lighting controls work, resulting control strategies and how those strategies are applied to projects.

B. DAYLIGHT HARVESTING:

A system that can dim or adjust lighting levels in response to the amount of daylight that's available in a space can save a significant amount of energy. A daylight harvesting system uses photo sensors to detect the amount of available daylight in a space. The devices then signal the lighting control system to dim the lamps at an appropriate level when the daylight levels increase.



Potential savings: 25% to 60% lighting load

Most estimates cite lighting load in a commercial building to be somewhere in the 20% to 40% range of the total building load. This means whatever methods you might employ to target a reduction of this load should result in a fairly strong financial payoff when it comes to the monthly energy bill. These seven lighting control strategies offer potential savings of anywhere from 5% to 60% of total lighting load.

- **DEMAND RESPONSE**

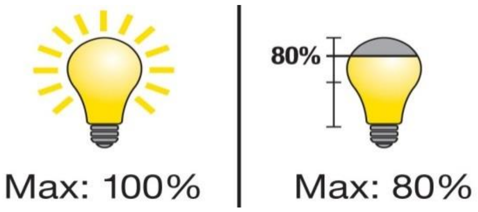
Receiving devices can be set up in a building to pick up an electric utility demand reduction signal sent out during peak electric usage periods. The building control system will then respond by turning off a portion of the lighting system to reduce overall lighting load.

Potential savings: 30% to 50% lighting load during peak demand periods

Most estimates cite lighting load in a commercial building to be somewhere in the 20% to 40% range of the total building load. This means whatever methods you might employ to target a reduction of this load should result in a fairly strong financial payoff when it comes to the monthly energy bill. These seven lighting control strategies offer potential savings of anywhere from 5% to 60% of total lighting load.

- **HIGH-END TUNING**

Lighting levels in a space can be trimmed or tuned to less than 100%. Studies have shown that the human eye can barely perceive a reduction of up to about 20%.

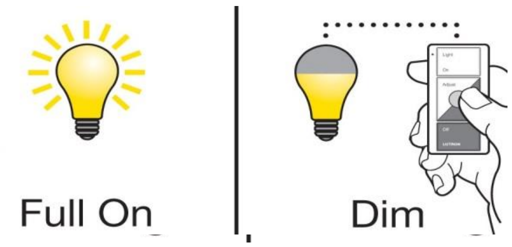


Potential savings: 10% to 30% lighting load

Most estimates cite lighting load in a commercial building to be somewhere in the 20% to 40% range of the total building load. This means whatever methods you might employ to target a reduction of this load should result in a fairly strong financial payoff when it comes to the monthly energy bill. These seven lighting control strategies offer potential savings of anywhere from 5% to 60% of total lighting load.

- **HVAC INTEGRATION**

Integrating lighting and HVAC controls in a single platform can also lead to reduced energy use. Shared sensors can detect room occupancy and automatically adjust the lighting and temperature levels to match the situation.

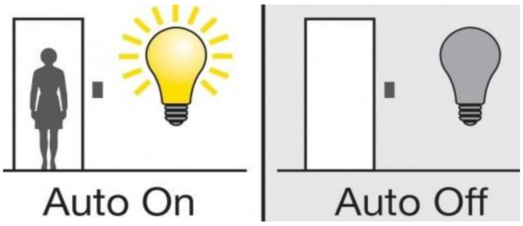


Potential savings: 5% to 15% HVAC load

Most estimates cite lighting load in a commercial building to be somewhere in the 20% to 40% range of the total building load. This means whatever methods you might employ to target a reduction of this load should result in a fairly strong financial payoff when it comes to the monthly energy bill. These seven lighting control strategies offer potential savings of anywhere from 5% to 60% of total lighting load.

- **OCCUPANCY / VACANCY SENSING**

This is the most common control method employed today. Sensors automatically turn lights off in a space when it's unoccupied and turn them on when occupied.

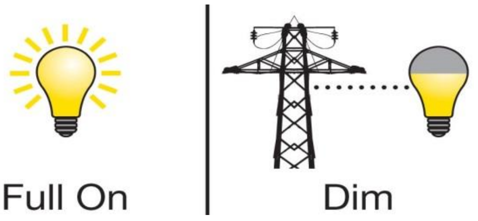


Potential savings: 20% to 60% lighting load

Most estimates cite lighting load in a commercial building to be somewhere in the 20% to 40% range of the total building load. This means whatever methods you might employ to target a reduction of this load should result in a fairly strong financial payoff when it comes to the monthly energy bill. These seven lighting control strategies offer potential savings of anywhere from 5% to 60% of total lighting load.

- **PERSONAL DIMMING CONTROL**

Personal dimming control allows individuals to control light levels in their own office space. Studies have shown that giving workers this type of control can not only lead to reduced energy use but it can also improve their productivity level.



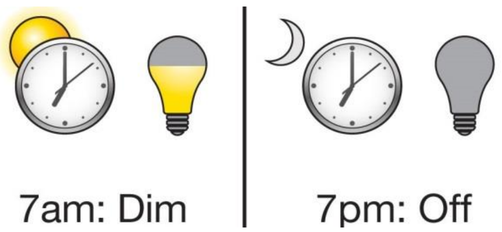
Potential savings: 10% to 20% lighting load

Most estimates cite lighting load in a commercial building to be somewhere in the 20% to 40% range of the total building load. This means whatever methods you might employ to target a reduction of this load should result in a fairly strong financial payoff when it comes to the monthly energy bill. These seven lighting control strategies offer potential savings of anywhere from 5% to 60% of total lighting load.

C. CONCLUSION:

- **SCHEDULING**

Many lighting control systems offer some type of scheduling option. This means the system can be set up to turn lights off automatically after normal business hours. More advanced systems offer the capability to set schedules around time of day, day of week, holidays, and more.



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STAND-BY GENERATOR MAINTENANCE PROGRAM FOR DIESEL

KAUSTAV MALLICK

Lecturer of Electrical Engineering Department

Technique Polytechnic Institute, Hooghly, West Bengal, India

Email id: kaustavmallick91@gmail.com

A. INTRODUCTION:

Today's electrical grid delivers reliable electricity to millions of homes and businesses. However, electrical failures that affect large geographic areas do happen on a recurring basis due to hurricanes, floods, or major equipment failures. Local outages that affect smaller numbers of people happen much more often. For individual households, such power outages are often just an inconvenience. But for hospitals and other healthcare facilities, however, they can be life threatening. For businesses like data centers, these outages can be extremely costly. Having a well-designed and well maintained standby power system is the best protection against utility power outages. Diesel powered generators provide the most reliable form of emergency backup power, and can start/assume full rated load in less than 10 sec. While backup generators typically can go 30,000 hr or more between major overhauls, even the best system needs to be exercised and maintained on a regular basis to make sure it operates properly when needed. When standby Generators fail to start or perform as designed; it is usually due to faulty maintenance procedures or neglect.

- **MAIN REASON OF FAILURE:**

In fact, the top three reasons standby generators fail to automatically start or run are:

• The generator START switch was left in the OFF position instead of AUTO.

• Starting batteries were dead or insufficiently charged.

• The fuel filter was clogged due to old or contaminated fuel.

All of these common issues can be eliminated with a regular generator maintenance routine performed by properly trained personnel.

- **PREVENTIVE MEASURES:**

Because of the durability of diesel engines, most maintenance is preventive in nature and consists of the following operations:

• General inspection
• Lubrication service
• Cooling system service
• Fuel system service
• Servicing and testing starting batteries
• Regular engine exercise

It is generally a good idea to establish and adhere to a schedule of maintenance /service based on the specific power application and the severity of the environment.

- **GENERAL INSPECTION:**

When the generator set is running, operators need to be alert for mechanical problems that could create unsafe or hazardous conditions. Following are several areas that should be inspected frequently to maintain safe and reliable operation.

• ***Exhaust system***: With the generator set operating, inspect the entire exhaust system, including the exhaust manifold, muffler, and exhaust pipe. leaks at all connections, welds, gaskets, and joints should be checked and it is to be made sure that the exhaust pipes are not heating surrounding areas excessively. Repair any leaks immediately. Immediate checking for excessive smoke upon starting should be done: It can indicate possible performance and air quality issues that may require immediate attention.

• ***Fuel system*:** With the generator set operating, inspect the fuel supply lines, return lines, filters, and fittings for cracks or abrasions. It is to be made sure the lines are not rubbing against anything that could cause an eventual failure. Instant Repairing of any leaks or altering line routing is required to eliminate wear immediately.

• *DC electrical system*: Check the terminals on the starting batteries to make sure the connections are clean and tight. Loose or corroded connections create resistance, which can hinder starting.

• ***Engine***: Monitor fluid levels, oil pressure, and coolant temperatures frequently. Most engine problems give an early warning. Look and listen for changes in engine performance, sound, or appearance that will indicate that service or repair is needed. Be alert for misfires, vibration, excessive exhaust smoke, decreases in power, or increases in oil or fuel consumption.

• ***Control system***: Inspect the control system regularly, and make sure it is logging data properly during engine exercise. Be sure to return the control system back to normal automatic standby (AUTO) when testing and maintenance are completed.

- **LUBRICATION SERVICE:**

Check the engine oil level when the engine is shut down at the interval specified in the Table. For accurate readings on the engine's dipstick, shut off the engine and wait approximately 10 min. to allow the oil in the upper portions of the engine to drain back into the crankcase. Follow the engine manufacturer's recommendations for API oil classification and oil viscosity. Keep the oil level as near as possible to the "full" mark on the dipstick by adding the same quality and brand of oil. Change the oil and filter at the intervals. Check with the engine manufacturer for procedures for draining the oil and replacing the oil filter. Used oil and filters must be disposed of properly to avoid environmental damage or liability.

- **COOLING SYSTEM SERVICE:**

Check the coolant level during shutdown periods at the interval specified in the Table. Remove the radiator cap after allowing the engine to cool, and, if necessary, add coolant until the level is about 3/4 in. below the radiator cap's lower sealing surface. Heavy duty diesel engines require a balanced coolant mixture of water, antifreeze, and coolant additives. Use the coolant solution recommended by the engine manufacturer. Inspect the exterior of the radiator for obstructions, and remove all dirt or foreign material with a soft brush or cloth. Use care to avoid damaging the fins. If available, use low pressure compressed air or a stream of water in the opposite direction of normal air flow to clean the radiator. Check the operation of the coolant heater by verifying that hot coolant is being discharged from the outlet hose.

- **FUEL SYSTEM SERVICE**

Diesel is subject to contamination and deterioration over time, and one reason for regular generator set exercise is to use up stored fuel before it degrades. In addition to other fuel system service recommended by the engine manufacturer, the fuel filters should be drained at the. Water vapor accumulates and condenses in the fuel tank — and also must be periodically drained from the tank along with any sediment present. Bacterial growth in diesel fuel can be an issue in warm climates. Consult the generator set manufacturer or dealer for recommendations on treating stored fuel with a biocide. Regular testing and fuel polishing may be required if the fuel is not used and replenished in three to six months. The charge air cooler piping and hoses should be inspected regularly for leaks, holes, cracks, or loose connections. Tighten the hose clamps as necessary. In addition, inspect the charge air cooler for dirt and debris that may be blocking the fins. Check for cracks, holes, or other damage. The engine air intake components should be checked at the interval indicated in the Table. The frequency of cleaning or replacing air cleaner filter elements is primarily determined by the conditions under which the generator set operates. Air cleaners typically contain a paper cartridge filter element that can be cleaned and reused if not damaged.

- **STARTING BATTERIES:**

Weak or undercharged starting batteries are a common cause of standby power system failures. Even when kept fully charged and maintained, lead acid starting batteries are subject to deterioration over time and should be replaced approximately every 24 to 36 months — or when they no longer hold a proper charge. NiCad starting batteries require less maintenance than lead acid and are often used in mission critical applications. However, they are also subject to deterioration and need to be regularly tested under load. See the Table for the recommended inspection interval for lead acid batteries and the charging system.

• ***Testing batteries***: Merely checking the output voltage of the batteries is not indicative of their ability to deliver adequate starting power. As batteries age, their internal resistance to current flow goes up, and the only accurate measure of terminal voltage must be done under load. On some generators, this diagnostic test is performed automatically each time the generator is started. On other generator sets, use a manual battery load tester to verify the condition of each starting battery.

• ***Cleaning batteries***: Keep the batteries clean by wiping them with a damp cloth whenever dirt appears excessive. If corrosion is present around the terminals, remove the battery cables and wash the terminals with a solution of baking soda and water (¼ lb baking soda to 1 quart of water). Be careful to prevent the solution from entering the battery cells, and flush the batteries with clean water when finished. After replacing the connections, coat the terminals with a light application of petroleum jelly.

• ***Checking specific gravity***: In open cell lead acid batteries, use a battery hydrometer to check the specific gravity of the electrolyte in each battery cell. A fully charged battery will have a specific gravity of 1.260. Charge the battery if the specific gravity reading is below 1.215.

• ***Checking electrolyte level***: In open cell lead acid batteries, check the level of the electrolyte at least every 200 hr of operation. If low, fill the battery cells to the bottom of the filler neck with distilled water.

Maintenance items	Service time				
	Daily	Weekly	Monthly	6 months	Yearly
Inspection	X				
Check coolant heater	X				
Check coolant level	X				
Check oil level	X				
Check fuel level	X				
Check charge-air piping	X				
Check/clean air cleaner		X			
Check battery charger		X			
Drain fuel filter		X			
Drain water from fuel tank		X			
Check coolant concentration			X		
Check drive belt tension			X		
Drain exhaust condensate			X		
Check starting batteries			X		
Change oil and filter				X	
Change coolant filter				X	
Clean crankcase breather				X	
Change air cleaner element				X	
Check radiator hoses				X	

B. CONCLUSION:

Generator sets on continuous standby must be able to go from a cold start to being fully operational in a matter of seconds. This can impose a severe burden on engine parts. However, regular exercising keeps engine parts lubricated, prevents oxidation of electrical contacts, uses up fuel before it deteriorates, and, in general, helps provide reliable engine starting. Periods of no load operation should be held to a minimum because unburned fuel tends to accumulate in the exhaust system. Whenever possible, test the system with actual building loads in order to exercise the automatic transfer switches and verify performance under Real world conditions. If connecting to the normal load is not convenient for test purposes, the best engine Performance and longevity will be obtained by connecting it to a load bank of at least one third the nameplate rating. Be sure to return the generator control to AUTO at the conclusion of any maintenance.

BASICS OF PHOTO VOLTAIC CELLS AND SYSTEMS

ANJANA SENGUPTA

Lecturer of Electrical Engineering Department

Technique Polytechnic Institute, Hooghly, West Bengal, India

Email id: @gmail.com

A. INTRODUCTION:

The ability of certain materials to convert sunlight to electricity was first discovered by Becquerel in 1839, when he discovered the photo galvanic effect. A number of other significant discoveries ultimately made way for the fabrication of the first solar cell in 1954 by Chapin, Fuller & Pearson. This cell had a conversion efficiency of 6%. Within 4 years, solar cells were used on the Vanguard I orbiting satellite. The cost then was quite high.

Space applications eventually led to improved production efficiencies, higher conversion efficiencies, higher reliability & lower cost of PV cells. By the 1980s, PV cells were introduced for terrestrial use where conventional electrical sources were expensive & gradually PV cells have become cost effective in a wide range of utility interactive & standalone applications. In the 90's, conversion efficiency ranged from just under 10% for thin film modules to over 30% for gallium arsenide (GaAs) concentrating cells.

- **CONVERSION OF SUNLIGHT TO ELECTRICITY:**

Till date, the most popular materials for direct conversion of sunlight to electricity have been crystalline Silicon (Si, amorphous Si (a-SiH), Copper Indium diselenide (CIS), Cadmium telluride (CdTe) & gallium arsenide (GaAS). All of these semiconductor materials have band gap energies between 1 & 2 eV. The band gap of a semiconductor is the energy required to excite an electron from the valence band to the conduction band of the semiconductor. Transferring the negative electron to the conduction band creates a positive hole in the valence band. Both charge carriers are then available for electrical conduction. The solar spectrum is at levels higher than the band gap energies for PV materials. Once the electron hole pairs are generated, the electrons & holes must flow in opposite directions. The separation is achieved by using pn- junction. The electron rich p-side & hole rich n-side produces electric field at the junction, directed from n-side to p-side. This field separates the electron hole pairs. But if electron hole pair is generated too far from the junction, electron & hole recombines before being separated. If produced near pn junction, electron is swept into n-region & hole is swept into p-region. Electrons diffuse towards the top of the cell and holes (+) diffuse towards bottom of the cell. Reaching the surface electrons continue to flow in the external circuit, thus, producing flow of current. And because of pn- junction, voltage appears between the bottom and top of the cell.

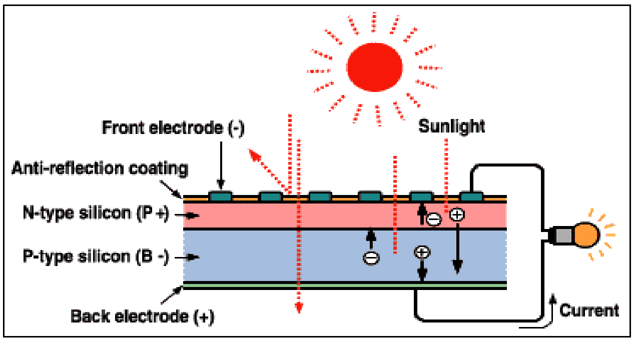


Fig 1. Working of a PV cell

Depending upon cell materials the voltage generated ranges from very small to 1 V. To have higher voltages, cells must be connected in series. The series arrangement is called module. When voltages or currents beyond the capability of an individual module are desired, modules are connected in arrays.

Most cells produce only a few watts, most modules produce 10 to 300W, most arrays produce few thousand watts. And few large systems have been designed for power in MW range.

Cell Performance- The equivalent circuit diagram of a PV cell is as shown-

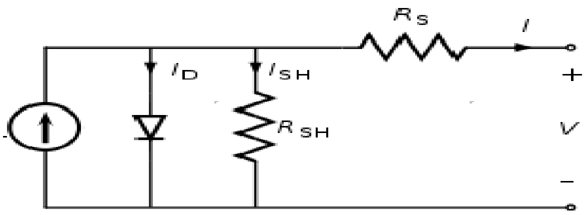


Fig.2 equivalent circuit diagram of PV cell

Where the current source along with diode in parallel represents the ideal PV cell

Since no PV cell is ideal the series and shunt resistance component are added.

The ideal solar cell operates as a diode when in the dark & operates almost as an ideal current source when operated under short circuit conditions. The short circuit current of the cell is almost directly proportional to the intensity of sunlight intensity on the cell.

It is important to note here why PV cells are called Current source. It is because the current generated does not depend upon the load connected but depends solely on illumination conditions.

The photocurrent is related to sunlight intensity by the relationship-

$I_1 = I_1(G_0).[G/G_0]$, where, G= sunlight intensity (W/m^2)

$G_0 = 1000W/m^2$

I_1= Short circuit current of PV cell, I_{sc}

The I-V relationship for the ideal PV cell is given by-

$I = I_1 - I_0\{e^{(qV/kT)} - 1\}$ where,

I_1= Photon generated current component

I_0=cell reverse saturation current.

kT/q= 25.7 mV at 25 degree Celsius.

The open circuit voltage of the cell, Voc decreases with temperature rise. For eg. For Simcells, rate of decrease is 2.3mV/◦C/cell.

Let a 36 cell module produces 20 V. when temperature rises 25◦C above ambient temperature, the loss in voltage is 36x2.3x25=2070mV=2.07V. This makes nearly 10% voltage loss, this results in 10% power loss, current being independent. The V-I characteristic and V-P characteristics are as follows-

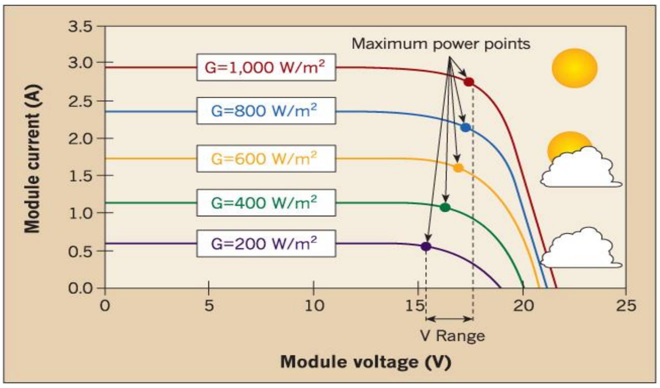


Fig 3. Variation of V-I characteristics with irradiation

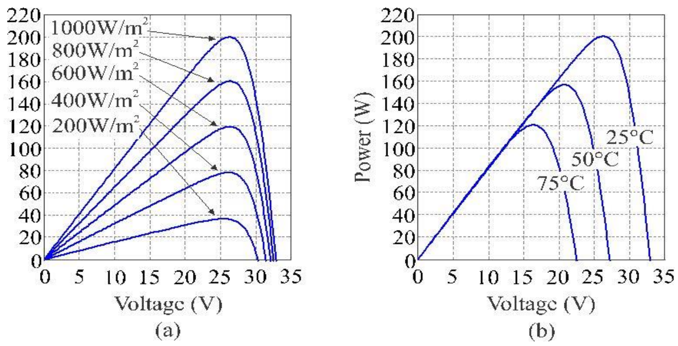


Fig 4a. Variation of V-P characteristics with irradiation

Fig 4b. Variation of V-P characteristics with temperature

The departure of the V-I characteristics of a real cell from that of a perfect cell is measured by the fill factor (FF) or cell.

Fill Factor $=(I_{mp}xV_{mp})/(I_{sc}xV_{oc})$

Where $I_{mp}xV_{mp}$= MPP
Isc= short circuit current
Voc= open circuit voltage

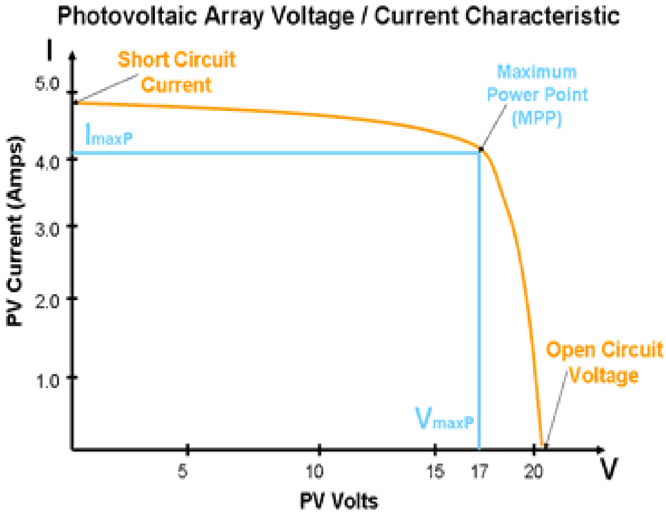


Fig. 5. The maximum power point of V-I curve of PV cell

The general constraint considered during design and set up of a system is the problem of Shading. It may be due to clouds, leaves, dust or any other foreign materials.

At a certain point of shading, the polarity of the cell voltage reverses to enable the cell to carry the current generated by the unshaded cells in the module. The cell then dissipates power and can overheat to the point of cell degradation. To protect the module against cell degradation, bypass diodes are normally incorporated into module design to shunt current away from shaded cells.

If voltage of module drops below voltage of other modules connected in parallel, it is possible for the current produced by the higher voltage modules to flow in the reverse direction of the lower voltage module. To prevent reverse flow of current through a module, a blocking diode is used in series with the module.

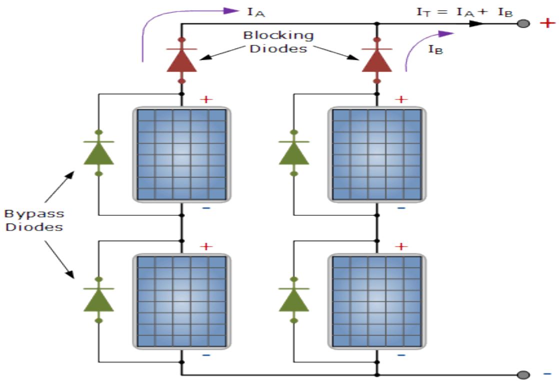


Fig.6. Arrangement of bypass diodes and Blocking diodes

Other components of solar photovoltaic power generation-

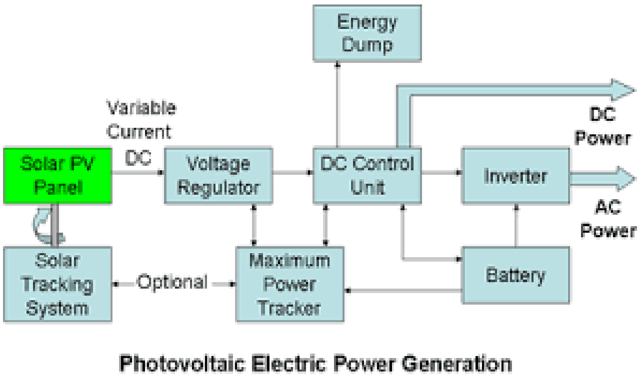


Fig.7. Components of photo voltaic power generation system

Basic Design Aspects:

Of the shown components the most interesting application of power electronics are Inverter and Maximum power point tracker. Design of battery is also important for the system.

The **Inverters** used are better known as Power conditioning unit (PCU). It forms the most sophisticated piece of power electronics equipment. Since arrays are still relatively costly, it is important for the PCU to extract the maximum power from the array. This is done by incorporating Maximum power point tracking circuitry. The design challenge of this circuitry is the variation of PCU input resistance, defined as the ratio of Input voltage to input current, while sampling the PCU output power. When the PCU output power reaches the maximum level the input resistance is fixed at the value that produces this level. This process resembles the Maximum power transfer theorem performed in laboratories.

The PV system is also provided with **battery backup** in order to provide emergency power in the event of grid failure. The designing of battery requires the identification of the energy requirements in such emergencies. Since the storage batteries are normally rated in ampere hours (Ah), the energy requirements of the load are normally converted to Ah at the voltage of the storage battery system.

The design of a system with storage involves determining the daily or weekly system load in Ah, determining the no. of storage days required, determining system losses, determining battery requirements & array requirements. The design also requires selecting appropriate charge controller, PCU or other power electronic components, switches, fuses, wires & surge protectors.

The **Connected load** is calculated as Ah load of the standalone system that must be delivered to the load.

The **Corrected load** is the Ah load of PV system that must be supplies to the batteries to overcome battery losses & wiring losses & still supply the connected load. The Corrected load is generally 12% higher than connected load.

Once the Corrected load is known-

$$Ah=(Ah/day)(days/ D_t x D_{ch(disch)})$$

Where, Dt= temperature correction factor (1 at 80 degree Fahrenheit, 0.72 at 32 degree Fahrenheit)

Dch= discharge correction factor (1 till discharge rate is less than rated discharge rate)

Rated array current is given by,

$$I=\{Ah/(PSH_{min} x n)\}$$

Where, PSH= peak sun hour measured in daily kWh/m^2 incident upon the array

Ah = system corrected load

PSH_{min} = min PSH for PV system

n=array degradation factor.

The **Charge controller** is designed to perform the following characteristics-

1. Monitor battery voltage & divert array current output when battery voltage reaches specified limit.
2. Monitor battery temperature & compensates the array disconnect voltage & load disconnect voltage for temperature.
3. Employs maximum power tracking to ensure maximum transfer of charge from array to batteries.
4. Provides for diversion of PV output to an alternate load.

B. CONCLUSION:

The design of a PV power generation system has many design constraints and many design aspects. When all the components function properly only then a PV system can be synchronized with the grid.

VARIOUS NUCLEAR REACTORS

SNEHASHIS DAS

Lecturer of Electrical Engineering Department

Technique Polytechnic Institute, Hooghly, West Bengal, India

Email id: snnehashis@gmail.com

A. INTRODUCTION:

Many factors influence the development and deployment of nuclear reactors. Six of such reactors has been discussed based on cost-effectiveness, safety, security and nonproliferation features, grid appropriateness, commercialization roadmap (including constructability and licensability), and management of the fuel cycle. The nonproliferation benefits of future designs remain unclear, however, and more research will be required. Investment barriers have been overcome in different ways by different countries, but identifying investment priorities and investors will determine, in general, the extent to which nuclear power remains a viable wedge of the global energy future. Geopolitical factors may tip the scales in favor of a country investing in nuclear energy. These factors include the obvious hedging strategies (i.e., using nuclear power as a hedge against an uncertain natural gas supply and price outlook, as well as an uncertain climate policy), as well as more-subtle strategies, such as using nuclear power to demonstrate technological prowess or as a future bargaining chip in a security context.

B. THE KEY REACTOR FACTORS:

Nuclear reactor designs are usually categorized by "generation"; that is, Generation I, II, III, III+, and IV. The key attributes characterizing the development and deployment of nuclear power reactors illuminate the essential differences between the various generations of reactors. The present analysis of existing reactor concepts focuses on six key reactor attributes:

1. *Cost-effectiveness.* From the customer's perspective, a nuclear kilowatt- hour is, aside from its cost, indistinguishable from a renewable or fossil-fired kilowatt-hour. Nuclear power must therefore be economically competitive. Accounting for the life-cycle costs actually paid by the retail electricity customer has proven to be far from trivial and is one of the more controversial elements in the discussion of competing energy technologies. Fossil-fired power, without carbon controls, sets the market price today and will likely continue to do so over the next decade.

2. *Safety.* Several nuclear systems are incorporating passive design features to ensure the safe operation of nuclear reactors, as compared to active safety systems requiring intervention by human agents. This is due to a variety of technical and public policy reasons, including quantitative risk reductions

3. Security and nonproliferation. Nuclear power systems must minimize the risks of nuclear theft and terrorism. Designs that will play on the international market must also minimize the risks of state-sponsored nuclear weapons proliferation. Concerns about dual-use technologies (i.e., technologies that were originally developed for military or other purposes and are now in commercial use) are amplifying this threat.

4. *Grid appropriateness.* The capabilities of both the local and national electric grid must match the electric power a proposed reactor will deliver to the grid. Grid appropriateness is determined by a combination of nameplate capacity and externalities defined by the extant electrical grid

5. *Commercialization roadmap.* Historically, the displacement of a base power source by an alternative source has been an evolutionary process rather than a sudden, disruptive, and radical shift. Attempting to "push the envelope" by forcing the shift is typically economically infeasible because investors are rarely willing to bear, for example, the capital costs associated with the deployment of alternative technology into the existing grid architecture.

C. THE HISTORY OF REACTOR GENERATIONS:

Three generations of nuclear power systems, derived from designs originally developed for naval use beginning in the late 1940s, are operating worldwide today (Figure 1).

Generation I

Gen I refers to the prototype and power reactors that launched civil nuclear power. This generation consists of early prototype reactors from the 1950s and 1960s, such as Shipping port (1957–1982) in Pennsylvania, Dresden-1 (1960–1978) in Illinois, and Calder Hall-1 (1956–2003) in the United Kingdom. This kind of reactor typically ran at power levels that were Reprinted from U.S. Department of Energy, Office of Nuclear Energy, "Generation IV Nuclear Energy Systems: Program Overview" (Department of Energy, n.d.), http://nuclear.energy.gov/genIV/neGenIV1.html.

Generation II

Gen II refers to a class of commercial reactors designed to be economical and reliable. Designed for a typical operational lifetime of 40 years,2 prototypical Gen II reactors include pressurized water reactors (PWR), CANada Deuterium Uranium reactors (CANDU), boiling water reactors (BWR), advanced gas-cooled reactors (AGR), and Vodo-Vodyanoi Energetichesky Reactors (VVER). Gen II reactors in the United States are regulated by the NRC pursuant to 10 CFR Part 50.

Gen II systems began operation in the late 1960s and comprise the bulk of the world's 400+ commercial PWRs and BWRs. These reactors, typically referred to as light water reactors (LWRs), use traditional active safety features involving electrical or mechanical operations that are initiated automatically and, in many cases, can be initiated by the operators of the nuclear reactors. Some engineered systems still operate passively (for example, using pressure relief valves) and function without operator control or loss of auxiliary power. Most of the Gen II plants still in operation in the West were manufactured by one of three companies: Westinghouse,3 Framatome4 (now part of AREVA5), and General Electric (GE).

The Korean Standard Nuclear Power Plant (KSNP), which is based on Gen II technology developed by Combustion Engineering (now Westinghouse) and Framatome (now AREVA), is now recognized as a Gen II design and has evolved to become the KSNP+. In 2005 the KSNP/KSNP+ was rebranded as the OPR-1000 (Optimized Power Reactor) for Asian markets, particularly Indonesia and Vietnam. Six OPR-1000 units are in operation, and four are under construction. China's existing and planned civilian power fleet is based on the PWR. Two important designs used in China are the improved Chinese PWR 1000 (the CPR-1000), which is based on Framatome's 900 megawatt (MW) three-loop Gen II design, and the standard PWR 600 MW and 1,000 MW designs (the CNP series).

Generation III

Gen III nuclear reactors are essentially Gen II reactors with evolutionary, state-of-the-art design improvements.7 These improvements are in the areas of fuel technology, thermal efficiency, modularized construction, safety systems (especially the use of passive rather than active systems), and standardized design.8 Improvements in Gen III reactor technology have aimed at a longer operational life, typically 60 years of operation, potentially to greatly exceed 60 years, prior to complete overhaul and reactor pressure vessel replacement. Confirmatory research to investigate nuclear plant aging beyond 60 years is needed to allow these reactors to operate over such extended lifetimes. Unlike Gen I and Gen II reactors, Gen III reactors are regulated by NRC regulations based on 10 CFR Part 52.9

Generation III+

Gen III+ reactor designs are an evolutionary development of Gen III reactors, offering significant improvements in safety over Gen III reactor designs certified by the NRC in the 1990s. In the United States, Gen III+ designs must be certified by the NRC pursuant to 10 CFR Part 52. Examples of Gen III+ designs include:

• VVER-1200/392M Reactor of the AES-2006 type

• Advanced CANDU Reactor (ACR-1000)

• AP1000: based on the AP600, with increased power output

• European Pressurized Reactor (EPR): evolutionary descendant of the Framatome N4 and Siemens Power Generation Division KONVOI reactors

• Economic Simplified Boiling Water Reactor (ESBWR): based on the ABWR

• APR-1400: an advanced PWR design evolved from the U.S. System 80+, originally known as the Korean Next Generation Reactor (KNGR)

• EU-ABWR: based on the ABWR, with increased power output and compliance with EU safety standards Manufacturers began development of Gen III+ systems in the 1990s by building on the operating experience of the American, Japanese, and Western European LWR fleets. Perhaps the most significant improvement of Gen III+ systems over second-generation designs is the incorporation in some designs of passive safety features that do not require active controls or operator intervention but instead rely on gravity or natural convection to mitigate the impact of abnormal events. The inclusion of passive safety features, among other improvements, may help expedite the reactor certification review process and thus shorten construction schedules.14 of these reactors, once on line, are expected to achieve higher fuel burn up than their evolutionary predecessors (thus reducing fuel consumption and waste production).

D. NEXT STEPS:

After enduring the usual reliability growing pains, Gen I and Gen II nuclear reactors have proven to be economically successful. According to the Nuclear Energy Institute, U.S. nuclear power plants in 2006 supplied the second highest amount of electricity in the industry’s history while achieving a record-low average production cost of 1.66 cents/kWh. Because the capital costs of many Gen I and Gen II reactors have been paid off, average production costs have been below 2 cents/kWh for the past seven years. Capacity factors have remained higher than 90 percent. Self-financing (essentially paid off the balance sheet) is a key factor, leading to not having to pay any capital charges and resulting in very low costs to operate these plants. Power upgrades and improvements in operational efficiency over the past decade have yielded the equivalent of multiple new nuclear plants. Whether this performance platform can be extrapolated to the Gen III and III+ designs is uncertain19 because of the significant overnight cost20 investment for the GEN III/III+ plants.

E. CONCLUSION:

Gen IV reactors are two-to-four decades away, although some designs could be available within a decade. As in the case of Gen III and Gen III+ designs in the United States, Gen IV designs must be certified by the NRC pursuant to 10 CFR Part 52, based on updated regulations and regulatory guides. The U.S. Department of Energy (DOE) Office of Nuclear Energy has taken responsibility for developing the science required for five Gen IV technologies. Funding levels for each of the technology concepts reflects the DOE's assessment of the concept's technological development stage and its potential to meet national energy goals. The Next Generation Nuclear Plant (NGNP) project is developing one example of a Gen IV reactor system, the Very High Temperature Reactor, which is configured to provide high-temperature heat (up to 950°C) for a variety of co-products, including hydrogen production. The NRC is working with DOE on a licensing approach. The earliest potential date for a COL application is the middle of this decade.

F. THE FUTURE:

Public Acceptance and Concerns about Nuclear Waste.

Public attitudes will be crucial in determining whether nuclear technologies are part of the portfolio of energy technologies on which the world relies to confront the challenges of the twenty-first century. Two persistent questions are "What is safe enough?" and "What are we going to do about the waste?" Switching from active to passive safety features is a key component of addressing the safety question. Long-term dry cask storage addresses the second question. However, in the very long-term, we will need to develop and nuclear fuel. Thus, for the next few decades, the long-term waste issue will remain a nettlesome problem for nuclear energy.

The Investment Barrier

In a highly stressed credit market, the price tag for nuclear construction— at least in the Western world—is too high. The latest overnight cost estimates for a dual-unit nuclear plant with an aggregate capacity of 2,236 MW is $5700 per kilowatt,28 a doubling in estimated overnight costs over the last 3-4 years. The investment community has shown an increasing interest in SMR designs because of these escalating costs and related financial challenges. The study team will use cost estimates for factory-produced modular units and compare this methodology to construction practices used in building larger units. A detailed sensitivity analysis will be performed on the key design and manufacturing parameters. This task requires collaboration with vendors to obtain data on

a. modularization practices;

b. factory designs and manufacturing;

c. factory assembly versus field assembly; and

d. learning-by-doing in both manufacturing and construction.

Nuclear Energy Demand in Asia

In Asia, 115 nuclear power reactors are in operation, 39 are under construction, and firm plans exist to build an additional 87. If an additional 185 proposed reactors are eventually deployed, this would represent an aggregate electrical capacity of more than 400 GWe in the region. In 2010 alone, this region has exhibited four out of the five units connected to the grid and seven out of the ten where construction has been initiated. Much of the expansion of nuclear power in this region is driven by concerns about energy security, and thus the financing concerns that dominate in the Western world are not as prominent and determinative here.

The Emerging Roles of China, Russia, the Republic of Korea, and India

The future economics of nuclear energy will be determined, in part, by the tooling up and supply chain improvements currently underway in Russia and several non-Western states. Russian and Chinese suppliers will soon meet the needs of their domestic markets and are beginning to ramp up in the expectation of large-scale exports. Korean industry provides components internationally and by 2013 will possess the capacity to forge even the largest nuclear plant components.30 The Republic of Korea's new very heavy forging capacity will join that of Japan (JSW), China (China First Heavy Industries), and Russia (OMX Izhora). Japan and Korea are already building further capacity (JSW and Doosan, respectively), as is

France (Le Creusot), and new capacity is planned in both the United Kingdom (Sheffield Forgemasters) and India (Larsen & Toubro). GE Hitachi Nuclear Energy (GEH) recently announced it has signed a nuclear power plant development agreement with India's top engineering and construction company, Larsen & Toubro Ltd. The agreement with L&T is an important part of GEH's strategy to establish an extensive network of local suppliers to help build a future GEH-designed Advanced Boiling Water Reactor (ABWR) power station in India. The power station is one of several being planned by India to increase the country's nuclear generation capacity more than tenfold over the next two decades—from 4.1 GW today to 60 GW by 2030. The nuclear power initiative is a key part of India's broader plan to expand its energy infrastructure to meet the country's surging demands for electricity.

SMART TRANSFORMER

AYAN GHOSH

Lecturer of Electrical Engineering Department

Technique Polytechnic Institute, Hooghly, West Bengal, India

Email id: ayan0589@gmail.com

A. INTRODUCTION:

As an integral part of the Smart Grid, smart transformers both work independently to constantly regulate voltage and maintain contact with the smart grid in order to allow remote administration if needed and to provide information and feedback about the power supply and the transformers themselves. Through a process known as voltage optimization, a smart transformer provides the exact amount of power that is needed, and responds instantly to fluctuations within the power grid, acting as a voltage regulator to ensure that the optimized voltage is undisturbed.

Micro grids are future power systems which provide clear and economic power to the utility network. In a micro grid, energy sharing between a producers and consumers is point to point system. Smart transformers are programmed to, as a default provides a voltage optimized power supply that directly addresses their facility's energy needs. Additionally, through their smart grid connectivity, smart transformers can be administered dynamically, allowing facilities to monitor and manage the transformers directly during periods of power fluctuation, and helping them ensure that their power supply remains voltage optimized even when new demands are being placed upon it. Most appliances are designed to work with a percentage of voltage away from the base. A smart transformer delivers voltage directly at the base, which means appliances work at their most efficient – they last longer and use less power. But it requires a large investment on additional communications and also decreases the system reliability. There for to make a system more controllable and less communications a ST concept is introduced. ST is located at the PCC of the system, which controls the voltage in certain limits. ST also mitigating the voltage increases and decreases. Basically a smart transformer is MV/LV transformer which is equipped with electronically operating tap changer. By the help of this it changes its taps position online and with small voltage steps in order to reach at desired value. There for the voltage at LV side is not directly linked with MV micro grid.

B. OVERVIEW OF SMART TRANSFORMER CONCEPT:

In order to reduce the communication data for controlling the power, the ST concept is presented. ST is a device which is the controlled online tap changing transformer that is connected at the point of common coupling of the micro grid, as depicted in fig.1. It is smart in the sense that its control strategy is able to control its micro grid side voltage. In medium-voltage networks, basically on load tap changer transformers (OLTCs) are already in the place so STs require only little modification. But in the low voltage networks, mostly manual tap changer transformers are used, therefore voltage control is offline and not automatically.

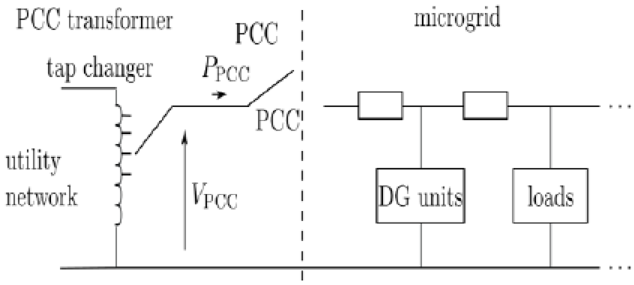


Fig. 1.Smart transformer located at the PCC of the micro grid

And this will increase the system load which makes the system unreliable and less accurate. Therefore many tap changing transformers at the beginnings of the low-voltage lines. By increasing demand of DG units and risk of overvoltage also increased. Therefore ability of automatically tap changing transformer is more interesting and is more effective, faster and cheaper. Hence all manual transformers are upgraded to OLTCs. The OLTCs with smart control strategy, i.e., the ST, controls the PCC power by controlling the micro grid side voltage. If grid is equipped with voltage droop control than these elements automatically change their input/output power. The VBD control strategy, illustrated in Fig. 2, has originally been introduced for a stable operation of low voltage islanded micro grids. For the active power control of the DG units, Vg/Vdc droop controller and P/Vg droop controller combination is consisted in VBD with Vdc the dc-link voltage, where the power of the dc link is provided by the available renewable energy and Vg the terminal voltage of the DG unit. The former enables power balancing of the DG units" ac and dc side and an effective usage of the allowed tolerance on the variations of terminal voltage from its nominal value for grid control. By using P/Vg droop controller voltage limit violations are avoided by changing input power of the unit. It is combined with constant-power bands that delay the active power changes of the renewable (wide constant-power band) compared to those of the dispatchable DG units to more extreme voltages.

C. SMART TRANSFORMER REALISATION:

- **General principle**

Basically the power exchange between the micro grid and utility network is by a ST. with the help of ST we can exchange power bidirectional and also gather information to determine the power set points for power exchange. To control the power of the micro grid ST controls the micro grid side voltage working as an OLTC. Hence the voltage based control of the micro grid DG units is coupled to a voltage based control of the ST.

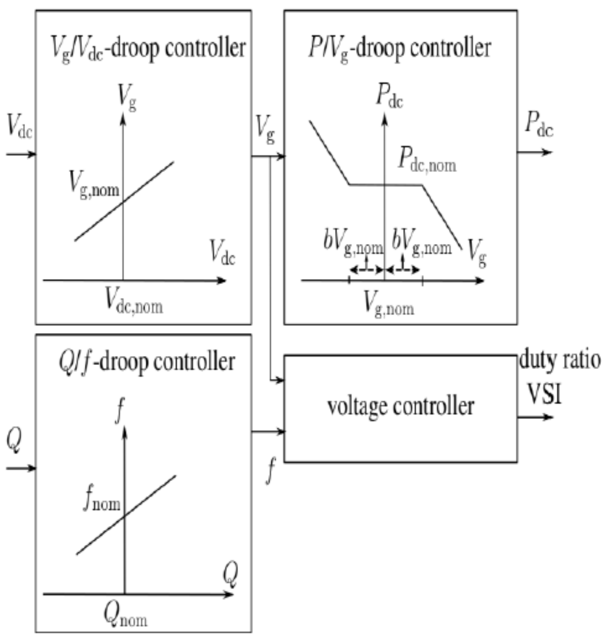


Fig. 2: Voltage based droop control strategy

- **Continuous smart transformer**

To build a continuous transformer first, a variable voltage is obtained by a carbon brush which is rotated on silver plated commutator on the circumference of a ring core transformer. To drive these brushes a motor is connected to brushes and works on a „up" and „down" command. The output voltage is can be adjusted both in positive and negative directions. This involves the use of a additional winding on the side of carbon brush. This configuration provides the control on voltage over a wide range. In practice, however, the transferred power of a transformer is limited due to current limitations in the windings. This causes limitations to the increase of voltage when power is transferred from the side with carbon brush to the side with fixed connection since extremely lowering the brushes can cause a very high current in the side with carbon brush in order to transfer the same power as is desired on the side with fixed connection. In commercially available variable transformers there is fixed number of additional windings above the fixed connection point. There it is difficult to transfer a large voltage from a fixed point to a carbon brush side. And also it is difficult to decrease a large voltage from the side of carbon brush to the side of fixed connections.

Other limitations are occurring from accuracy, due to limited number of turns on a coil. The accuracy of the system can be improved by the use of additional isolating transformer. By the help of this additional isolating transformer we can increase and decrease the voltage. To provide the controlled voltage to primary side of the isolating transformer than variable autotransformer is used. This makes the ST much more accurate for the same accuracy of the brushes drive mechanism. By using double pole change over switch between two transformers will determine if the isolating transformer provides a voltage increase or decrease. Advantage of this is that it makes the system more accurate.

D. CONCLUSION:

As the demand of energy increasing day by day, this result in decreasing the quality of the power and also increase in different type of faults occur on the system. This will make the system unreliable and slowdowns the system. To prevent system from faults and to make the system more reliable smart transformer are used. In this paper, two major concepts, the continuous and the discrete ST, are developed and built with focus on the use of the ST as a power controller between utility grid and micro grid and also focus on the control strategies of smart transformer. The continuous ST has the advantage that the control of power can be more accurate, where the discrete ST has the advantage that the control of power is fast. . It is proven that the power exchange between utility grid and micro grid is being realized by changes in the micro grid-side voltage. A smart transformer attenuates the voltage fluctuations and provides the improved power to the customers.

GRID DISTURBANCE ON 30th JULY 2012

SHAMIK CHATTARAJ

Lecturer of Electrical Engineering Department

Technique Polytechnic Institute, Hooghly, West Bengal, India

Email id: chattaraj.shamik@gmail.com

A. INTRODUCTION:

There was a major grid disturbance at 02.33 hrs. on 30th of July 2012 in Northern region and again at 13.00 hrs. on 31st of July 2012 resulting in collapse of Northern, Eastern, and North-Eastern regional grids barring a few pockets. The first disturbance which led to the collapse of Northern Regional Electricity grid occurred at 02.33 hrs. on 30th July, 2012, in which all states of Northern Region viz. Uttar Pradesh, Uttarakhand, Rajasthan, Punjab, Haryana, Himachal Pradesh, Jammu & Kashmir, Delhi and Union Territory of Chandigarh were affected. Northern Regional Grid's load was about 36,000 MW at the time of disturbance. Small islands which comprised of three units of BTPS with the load of approximately 250 MW in Delhi, NAPS on house load, Area around Bhinmal (Rajasthan) with approximate load of 100 MW connected with Western Region survived the blackout. Restoration was completed by 16.00 hrs. The second incident which was more severe than the previous one occurred at 13.00 hours on

31st of July 2012, leading to loss of power supply in three regions of the country viz. Northern Region, Eastern Region and North Eastern Region affecting all states of Northern Region and also West Bengal, Bihar, Jharkhand, Odisha, Sikkim in Eastern region and Assam, Arunachal Pradesh, Meghalaya, Manipur, Mizoram, Nagaland and Tripura in North-Eastern region. The total load of about 48,000 MW was affected in this black out. Islands comprising of NAPS, Anta GPS, Dadri GPS and Faridabad in Northern Region, Ib TPS / Sterlite, Bokaro steel and CESC survived in Eastern Region. It has been reported that major part of the system could be restored in about 5 hrs., 8hrs and 2 hrs. in Northern, Eastern and North-Eastern regions respectively. This paper represents a case study of grid disturbance on 30th July 2012 and Factors that could have saved the grid from collapse.

B. FACTORS THAT LED TO THE INITIATION OF THE GRID DISTURBANCE ON 30TH JULY, 2012:

(i) Weak Inter-regional Corridors due to multiple outages: The system was weakened by multiple outages of transmission lines in the WR-NR interface. Effectively, 400 kV Bina-Gwalior-Agra (one circuit) was the only main AC circuit available between WR-NR interface prior to the grid disturbance.

(ii) High Loading on 400 kV Bina-Gwalior-Agra link: The over drawl by some of the NR utilities, utilizing Unscheduled Interchange (UI), contributed to high loading on this tie line.

(iii) Inadequate response by SLDCs to the instructions of RLDCs to reduce over drawl by the NR utilities and under drawl/excess generation by the WR utilities.

(iv) Loss of 400 kV Bina-Gwalior link: Since the interregional interface was very weak, tripping of 400 kV Bina-Gwalior line on zone-3 protection of distance relay caused the NR system to separate from the WR. This happened due to load encroachment (high loading of line resulting in high line current and low bus voltage). However, there was no fault observed in the system.

C. FACTORS THAT LED TO THE INITIATION OF THE GRID DISTURBANCE ON 31ST JULY, 2012:

(i) Weak Inter-regional Corridors due to multiple outages: The system was weakened by multiple outages of transmission lines in the NR-WR interface and the ER network near the ER-WR interface. On this day also, effectively 400 kV Bina-Gwalior-Agra (one circuit) was the only main circuit available between WR-NR.
(ii) High Loading on 400 kV Bina-Gwalior-Agra link: The over drawl by NR utilities, utilizing Unscheduled Interchange (UI), contributed to high loading on this tie line. Although real power flow in this line was relatively lower than on 30th July, 2012, the reactive power flow in the line was higher, resulting in lower voltage at Bina end.
(iii) Inadequate Response by SLDCs to RLDCs' instructions on this day also to reduce over drawl by the NR utilities and under drawl by the WR utilities.
(iv) Loss of 400 kV Bina-Gwalior link: Similar to the initiation of the disturbance on 30th July, 2012, tripping of 400 kV Bina-Gwalior line on zone-3 protection of distance relay, due to load encroachment, caused the NR system to separate from the WR system. On this day also the DR records do not show occurrence of any fault in the system.

D. BRIEF SEQUENCE OF EVENTS LEADING TO THE GRID COLLAPSE ON 30TH AND 31ST JULY 2012:

(i) On 30th July, 2012, after NR got separated from WR due to tripping of 400 kV Bina-Gwalior line, the NR loads were met through WR-ER-NR route, which caused power swing in the system. Since the center of swing was in the NR-ER interface, the corresponding tie lines tripped, isolating the NR system from the rest of the NEW grid system. The NR grid system collapsed due to under frequency and further power swing within the region.
(ii) On 31st July, 2012, after NR got separated from the WR due to tripping of 400 kV Bina-Gwalior line, the NR loads were met through WR-ER-NR route, which caused power swing in the system. On this day the center of swing was in the ER, near ER-WR interface, and, hence, after tripping of lines in the ER itself, a small part of ER (Ranchi and Rourkela), along with WR, got isolated from the rest of the NEW grid. This caused power swing in the NR-ER interface and resulted in further separation of the NR from the ER+NER system. Subsequently, all the three grids collapsed due to multiple tripping attributed to the internal power swings, under frequency and overvoltage at different places.
(iii) The WR system, however, survived due to tripping of few generators in this region on high frequency on both the days.
(iv)The Southern Region (SR), which was getting power from ER and WR, also survived on 31st July, 2012 with part loads remained fed from the WR and the operation of few defense mechanisms, such as AUFLS and HVDC power ramping.

E. OVERVIEW OF REGIONAL GRIDS:

- **NORTHERN REGION GRID**

Northern Region is the largest in geographical area amongst the five regions in the country covering approximately 31% of the area and having largest number of constituents. It has largest sized hydro unit (250 MW at Tehri/ Nathpa Jhakri) in the country. Northern Grid has an installed generating capacity of about 56,058 MW as on 30.06.2012 comprising 34608 MW of thermal and 19830 MW of Hydro generation The Thermal-Hydro (including renewable) mix is of the order of 64:36. The installed capacity of nuclear stations is 1620 MW. Major generating stations including Super Thermal Power Stations of NTPC at Rihand and Singrauli are located in the eastern part of the NR grid.

Due to such concentration of generation in the eastern part of the grid and major load Centres in the central and western part of the grid there is bulk power transmission from eastern to western part over long distances. To handle this bulk transmission of power, a point to point high voltage DC line viz. HVDC Rihand-Dadri bipole with capacity of 1500 MW exists and operates in parallel with 400 kV AC transmission network besides under lying 220 kV network. During the month of July, 2012 the Peak demand of Northern Region was 41,659 MW against the Demand Met of 38,111 MW indicating a shortage of 3,548 MW (8.5%). The energy requirement of Northern Region was 29,580 MU against availability of 26,250 MU indicating shortage of 3,330 MU (11.3%).

- **WESTERN REGIONAL GRID:**

The Western Grid has an installed capacity of 66757 MW (as on 30-06-2012) consisting of 49402 MW thermal, 7448 MW hydro, 1,840 MW nuclear and 7909.95 MW from renewable energy sources.

- **EASTERN REGIONAL GRID:**

The Eastern Grid has an installed capacity of 26838 MW (as on 30-06-2012) consisting of 22545 MW thermal, 3882 MW hydro and 411 MW from 6 renewable energy sources. The Eastern Regional grid operates in synchronism with Western, Northern and North-Eastern Regional grids.

- **NORTH-EASTERN REGIONAL GRID:**

The North-Eastern Grid has an installed capacity of 2454.94 MW as on 31-03-2012 consisting of 1026.94 MW thermal, 1200 MW hydro and 228.00 MW from renewable energy sources. The North-Eastern Grid operated in synchronism with Northern Grid, Eastern Grid and Western Grid. North Eastern Regional Grid is connected directly only to the Eastern Regional Grid and any export of power to the other Regions has to be wheeled through the Eastern Regional Grid. The power transfer from North-Eastern Region to Eastern Region is taking place over Bongaigaon – Malda 400 kV D/C lines and Birpara – Salakati 220 kV D/C lines.

F. ANALYSIS OF GRID DISTURBANCE ON 30TH JULY, 2012

- **INTRODUCTION**

On 30th July, 2012 there was a grid disturbance in the NEW grid at 02:33:11 hrs. that led to the separation of the NR grid from the rest of the NEW grid and eventually NR system collapsed. The pre-disturbance conditions, sequence of events and analysis of the disturbance are described below.

- **PRE-DISTURBANCE CONDITIONS**

The details of the generation-demand and power export/import scenario in the four regions of the NEW grid on 30.07.2012 at 02:00 hrs. are given below-

Table-1

Sl	Region	Generation	Demand	Import	Remarks
1	NR	32636 MW	38322MW	5686 MW	
2	ER	12452 MW	12213MW	(-)239 MW	Bhutan import 1127 MW
3	WR	33024 MW	28053MW	(-)6229 MW	
4	NER	1367 MW	1314MW	(-)53 MW	
TOTAL	NEW GRID	79479 MW	79902MW		

A number EHV lines were out prior to the disturbance and the same are listed in the enclosed. The grid frequency, just prior to the disturbance, was 49.68 Hz.

- **SEQUENCE OF EVENTS ON 30TH JULY, 2012**

Following are the sequence of the events, which took place on 30th July, 2012, leading to the Northern Grid blackout:

S.No.	Date & Time	Event
1	30/07/2012 02:33:11.907 AM	400kV Bina – Gwalior-1 Line Tripped, Zone 3 tripping, Main-II
2	30/07/2012 02:34	220 kV Gwalior-Malanpur 1. As per MP SLDC time is 02:34, but is **manual timing**. (This line has tripped probably just prior to Sl no 1 above causing Malanpur and Mehgaon loads to be fed from NR system.)
3	30/07/2012 02:33:13.438 AM	220 kV Bhinmal-Sanchor line, Zone-1 Tripped on Power Swing.++
With the above events, practically all the AC links from the WR to the NR were lost.		
4	30/07/2012 02:33:13:927 AM	400 kV Jamshedpur – Rourkela line-2 tripped on Zone-3
5	30/07/2012 02:33:13:996 AM	400 kV Jamshedpur – Rourkela line-1 tripped on Zone-3
6	30/07/2012 02:33:15:400 AM	400 kV Gorakhpur-Muzaffarpur-2 tripped on Power Swing
7	30/07/2012 02:33:15:425 AM	400 kV Gorakhpur-Muzaffarpur-1 tripped on Power Swing at Gorakhpur end. Line remained charged up to 3.03 am at Muzaffarpur end.
8	30/07/2012 02:33:15:491 AM	400 kV Balia – Biharsharif-2 lines tripped on power swing.
9	30/07/2012 02:33:15:491 AM	400 kV Balia – Biharsharif-1 line tripped on Power swing.

G. FACTORS THAT CONTRIBUTED TO INITIATION OF GRID COLLAPSE:

- **DEPLETED TRANSMISSION NETWORK-**

It is observed that one circuit of 400 kV Bina-Gwalior-Agra section was taken under planned outage by POWERGRID from 11.47 AM of 28.07.2012 for up gradation to 765 Kv level. A number of 400 kV lines were out prior to the incidence on both these days. The outage of 400 kV Bina-Gwalior–Agra for up-gradation work, non-availability of 400 kV Zerda Kankroli and 400 kV Bhinmal-Kankroli due to insulator problems in particular weakened the NR-WR Interface. The availability of 400 kV Zerda-Bhinmal-Kankroli corridor requires to be improved by replacing porcelain insulators by polymer insulators at the earliest.

- **INABILITY TO CONTROL FLOW ON 400 KV BINA-GWALIOR-AGRA LINE**

It is clear from the messages issued by NRLDC to various SLDCs and recorded telephonic conversations that regional load dispatcher had made desperate efforts for reduction of over drawls by various States, which in turn would have led to relieving of loading of 400 kV Bina-Gwalior-Agra line. In spite of records of load shedding in log book of SLDCs, it is evident that there was hardly any reduction in flow on this line. It is observed that NLDC is revising TTC in case of planned outage 35 of transmission elements and not in case of forced outage. During discussions, officials of NLDC had cited few reasons for not revising TTC on the day of disturbance. Firstly, in the opinion of NLDC, declaration of TTC is for the purpose of facilitating organized electricity trading contracts, which are cleared on day-ahead basis and, therefore, revision of TTC in real time would not serve any purpose. Secondly, NLDC pointed out that calculation of TTC requires elaborate studies, which is a specialized task and cannot be performed by operators in real time. Thirdly, NLDC stated that a regulatory provision restrains them from applying congestion charges in case congestion is attributable to forced outage of transmission line in the corridor.

The very fact that provision to apply congestion charge forms part of the regulations on the issue of "*Measures to relieve congestion in real time*" indicates that security of the grid is main objective of such provision. However, the Committee tends to agree that calculation of TTC is a specialized task. However, ways and means can be found out to overcome this problem. The Committee has gone through relevant regulations of Central Commission. However, there is no provision which restrains NLDC from applying congestion charges. Further, para 5.4 of the "Detailed procedure for relieving congestion in real time operation" prepared by NLDC and approved by Central Commission does restrain NLDC from applying congestion charges in such situation but requires curtailment of transactions followed by revision of TTC. Thus, the procedure prepared under the provisions of a Regulation is not consistent with the Regulation. This aspect needs to be reviewed. At present, there is no Automatic Generation Control (AGC)//tie line bias control in the network, which can automatically restrict the tie-line flows to the scheduled limit and also frequency at the nominal value.

- **NON-COMPLIANCE OF DIRECTIONS OF LDCS AND REGULATORY COMMISSIONS**

Non-compliance of instructions of RLDCs has been a problem since long. However, of late a disturbing trend of non-compliance of directions of the Central Commission has been observed. The Committee is of the view that maximum penalty that can be imposed by Regulatory Commissions in accordance with the Electricity Act, 2003 is meager in comparison to damage that such non-compliance can cause to the grid. It is reported that in some cases, the penalty imposed by Central Commission has not been paid. States overdrawing from the grid often do not pay UI Charges which has contributed to infectiveness of ABT.

- **PROTECTION SYSTEM ISSUES**

It is noted that on both days, the grid disturbance was initiated by tripping of 400 kV Bina-Gwalior line on zone-3 of Main-II protection, though there were several other concurrent conditions, which ultimately led to collapse of grid. There is no doubt that this tripping is attributable to load encroachment i.e. the current and voltage conditions were such that the protection system perceived it as fault (during fault, current becomes very high and voltage goes down to very low levels). Thereafter, there were several tripping on load encroachment and power swing. It is also noted that on both days, only Main-II protections operated and Main-I protection did not pick up. It may also be noted that during the disturbances on 30th and 31st July, 2012, the 400 kV Bina-Gwalior line was not thermally overloaded i.e., the current rating (quad Bersimis conductor) of the line was not exceeded. However, the system was “insecure”, i.e., the system was not stable for the loss of this line. System security requires that the system should be able to withstand credible contingencies.

H. FACTORS THAT COULD HAVE SAVED THE GRID FROM COLLAPSE:

- **OPTIMUM UTILIZATION OF AVAILABLE ASSETS**

A large number of high capacity 400 kV lines have been added to the intra-regional and inter-regional systems in the recent past. However, a significant number of lines are generally kept open to contain high voltages. This makes system weak and such system may not be able to cope contingency. The widespread prevalence of high voltages is pointer of insufficient reactive compensation.
Practically all generating units are equipped with Power System Stabilizers (PSS), which can save the grid from several potential destabilizing conditions. However, there is need to tune PSS periodically. Similarly, various devices/equipment available in power system such as HVDC, TCSC and SVC have stability features, which need to be enabled. There is no evidence that these

devices had any stabilizing influence during grid disturbances on 30th and 31st July 2012. The system requires a large of dynamic compensators, which need to be established through detailed study.

Presently, nine numbers of Phasor Measurement Units (PMUs) have been put in place in Northern Region and 3 PMUs have been installed in Western Region. Even these limited numbers of PMUs have been helpful in the past in understanding behavior of the system. Also, these PMUs have been of immense help to this Committee in analysis of grid failures on 30th and 31st July 2012. POWERGRID has plans to install PMUs in a big way, as they are bedrock requirement for development of smart transmission grids. However, it is matter of concern that on the days of disturbances, data from PMUs at Agra in Northern Region and Vindhyachal in Western Region is not available. It appears that the PMUs in Western Region are not time synchronized.

- **OPERATION OF DEFENSE MECHANISM**

Defense mechanisms like load shedding based on under frequency relays (UFRs) and Rate of change of frequency (df/dt) relays have been adopted in all Regional Power Committees (RPCs) in accordance with provisions of IEGC. Similarly, increasing number of Special Protection Schemes is being employed to save system in case of contingencies. However, the experience of the recent grid disturbances reveals that practically there was no load relief from these schemes. The case in point is Northern Region, where UFR based load shedding of 4000 MW (in 3 stages) and df/dt based load shedding of about 6000 MW has been agreed. The Committee is of the opinion that after loss of about 5000-6000 MW to Northern Region, had these relays operated, the grid could have been saved.

- **INTRA-STATE TRANSMISSION PLANNING AND ITS IMPLEMENTATION**

In recent grid disturbances, it has been observed that overloading and consequent tripping of 220 kV systems had pushed the system to the edge. It also appears that though inter-State system is being strengthened continuously, matching strengthening in intra-State transmission system has not been carried out. This not only limits ability of the States to draw power but also causes low voltage problems and unreliable supply to end consumers.

- **NEED OF DYNAMIC SECURITY ASSESSMENT AND REVIEW OF STATE ESTIMATION**

In order to assess the system security in real time and assess the vulnerability condition of the system, dynamic security assessment need to be periodically carried out at the control Centers. A proper review and up gradation of the state estimation procedure is required to improve the visibility and situational awareness of the system.

I. REVIEW OF ISLANDING SCHEMES:

To avoid total blackout following a grid disturbance, a number of defense mechanisms and System Protection Schemes mainly comprising of generation backing down, contingency based load shedding, under frequency load shedding, df/dt load shedding etc. already exist. The success of these schemes in avoiding grid disturbances to a large extent depends upon the severity, area of disturbance and system conditions prior to the disturbance. Also as a last resort some islanding schemes to save the generating stations are also in existence. During the disturbance which took place on 30th and 31st July 2012 some of the generators which survived in NR due to islanding or on house load were NAPP, BTPS, Dadri Gas, and Faridabad Gas. The surviving generating units normally help in meeting essential loads and extending supply to other units within the same generating station and also to the nearby generators thereby helping in restoring the grid in reduced timeframe. The Committee reviewed the existing schemes and explored possibility of formulation of more islanding schemes in the NR.

J. GUIDELINES FOR FORMATION OF ISLANDS:

a) For the success of the islanding scheme, the load and generation of these islands should match and also it is necessary that generators within the island are operated with Governor Action.

b) All control areas should endeavor to operationalize under frequency based load shedding scheme as first defense. Only if this defense mechanism fails and frequency continues its fall to dangerously low levels, formation of islands should be initiated as a last resort.

c) The probability of survival of islands will be realistic only when all the generating units are on free governor or on restricted governor mode in accordance with provisions of Indian Electricity Grid Code.

d) Islanding scheme could be a two-tier scheme. At frequency level of say 47.9 Hz, signal for formation of islands comprising of more than one generating stations along with pre-identified load could be initiated. However, if after the formation of island, frequency continues to fall further to say 47.7 Hz, these islands could be further broken into smaller islands comprising of single generating station with pre-identified loads.

e) For survival of the Islands, they should be created in such a manner that the possibility of generation exceeding load is more.

f) In case of hydro generators with limited pondage, islands should be created keeping peak generation in mind. This is because, in low hydro season, generation will practically be negligible during off-peak hours and hence creation of island may not serve any purpose.

g) Load-generation balance in pre-identified islands may change based on season, there would be need to review the scheme on seasonal basis. Such review should also capture network changes taking place in the interim period.

h) As far as possible, major essential loads such as hospitals etc. should be incorporated in the islands. However, if this was not possible due to some reasons, efforts would be made to extend supply from these islands to essential loads on priority basis.

GREATEST INVENTION IN ELECTRICAL ENGINEERING (of the CENTURY)

ROUNAK SEN

Student of Electrical Engineering Department

Technique Polytechnic Institute, Hooghly, West Bengal, India

Email id: senrounak1996@gmail.com

A. THE TESLA COIL:

A Tesla coil is an electrical resonant transformer circuit invented by Nikola Tesla around 1891. It is used to produce high-voltage, low-current, high frequency alternating-current electricity. Tesla experimented with a number of different configurations consisting of two, or sometimes three, coupled resonant electric circuits.

Tesla used these coils to conduct innovative experiments in electrical lighting, phosphorescence, X-ray generation, high frequency alternating current phenomena, electrotherapy, and the transmission of electrical energy without wires. Tesla coil circuits were used commercially in spark gap radio transmitters for wireless telegraphy until the 1920s, and in medical equipment such as electrotherapy and violet ray devices. Today their main use is for entertainment and educational displays, although small coils are still used today as leak detectors for high vacuum systems.

- **HISTORY**

Tesla invented his "Tesla Coil" around 1891 while he was repeating and then expanding on Heinrich Hertz' experiments that had discovered electromagnetic radiation three years earlier. Tesla decided to power his setup with the high speed alternator he had been developing as part of an improved arc lighting system but found that the high frequency current overheated the iron core and melted the insulation between the primary and secondary windings in the Ruhmkorff coil originally used in Hertz setup. To fix this problem Tesla changed the design so that there was an air gap instead of insulating material between the primary and secondary windings and made it so that the iron core could be moved to different positions in or out of the coil. Tesla also found he needed to put the capacitor normally used in such setups between his alternator and the coil's primary winding to avoid burning out the coil. By adjusting the coil and the capacitor Tesla found he could take advantage of the resonance set up between the two to achieve even higher frequencies. In Tesla's coil transformer the capacitor, upon break-down of a short spark gap, became connected to a coil of a few turns (the primary winding set), forming a resonant circuit with the frequency of oscillation, usually 20–100 kHz, determined by the capacitance of the capacitor and the inductance of the coil. The capacitor was charged to the voltage necessary to rupture the air of the gap during the input line cycle, about 10 kV by a line-powered transformer connected across the gap. The line transformer was designed to have higher than normal leakage inductance to tolerate the short circuit occurring while the gap remained ionized, or for the few milliseconds until the high frequency current had died away. The spark gap is set up so that its breakdown occurs at a voltage somewhat less than the peak output voltage of the transformer in order to maximize the voltage across the capacitor. The sudden current through the spark gap causes the primary resonant circuit to ring at its resonant frequency. The ringing primary winding magnetically couples energy into the secondary over several RF cycles, until all of the energy that was originally in the primary has been transferred to the secondary. Ideally, the gap would then stop conducting (quench), trapping all of the energy into the oscillating secondary circuit. Usually the gap reignites, and energy in the secondary transfers back to the primary circuit over several more RF cycles. Cycling of energy may repeat for several times until the spark gap finally quenches. Once the gap stops conducting, the transformer begins recharging the capacitor. Depending on the breakdown voltage of the spark gap, it may fire many times during a mains AC cycle. A more prominent secondary winding, with vastly more turns of thinner wire than the primary, was positioned to intercept some of the magnetic field of the primary. The secondary was designed to have the same frequency of resonance as the primary using only the stray capacitance of the winding itself to ground and that of any "top hat" terminal placed at the top of the secondary. The lower end of the long secondary coil must be grounded to the surroundings.

- **THE OPERATION**

A Tesla coil is a radio frequency oscillator that drives an air-core double-tuned resonant transformer to produce high voltages at low currents. Tesla's original circuits as well as most modern coils use a simple spark gap to excite oscillations in the tuned transformer. More sophisticated designs use transistor or thyristor switches or vacuum tube electronic oscillators to drive the resonant transformer. These are described in later sections. Tesla coils can produce output voltages from 50 kilo volts to several million volts for large coils. The alternating current output is in the low radio frequency range, usually between 50 kHz and 1 MHz. Although some oscillator-driven coils generate a continuous alternating current, most Tesla coils have a pulsed output; the high voltage consists of a rapid string of pulses of radio frequency alternating current.

Homemade Tesla Coil in operation

- **COMPONENTS OF SPARK EXCITED TESLA COIL**

1. A high voltage supply transformer (T), to step the AC mains voltage up to a high enough voltage to jump the spark gap. Typical voltages are between 5 and 30 kilovolts (kV).

2. A capacitor (C1) that forms a tuned circuit with the primary winding L1 of the Tesla transformer

3. A spark gap (SG) that acts as a switch in the primary circuit

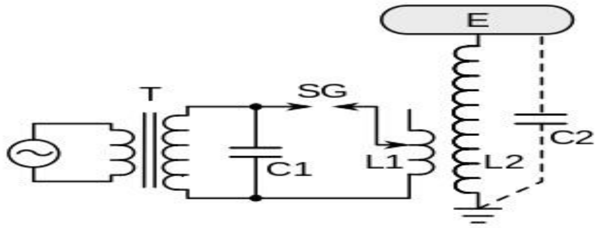
4. The Tesla coil (L1, L2), an air-core double-tuned resonant transformer, which generates the high output voltage.

5. Optionally, a capacitive electrode (top load) (E) in the form of a smooth metal sphere or torus attached to the secondary terminal of the coil. Its large surface area suppresses premature corona discharge and streamer arcs, increasing the Q factor and output voltage.

- **THE RESONANT TRANSFORMER**

The specialized transformer coil used in the Tesla circuit, called a resonant transformer, oscillation transformer, or RF transformer, functions differently from an ordinary transformer used in AC power circuits. While an ordinary transformer is designed to transfer energy efficiently from primary to secondary winding, the resonant transformer is also designed to store electrical energy. Each winding has a capacitance across it and functions as an LC circuit (resonant circuit, tuned circuit), storing oscillating electrical energy, analogously to a tuning fork. The primary winding (L1) consisting of a relatively few turns of heavy copper wire or tubing, is connected to a capacitor (C1) through the spark gap (SG). The secondary winding (L2) consists of many turns (hundreds to thousands) of fine wire on a hollow cylindrical form inside the primary. The secondary is not connected to an actual capacitor, but it also functions as an LC circuit, the inductance (L2) resonates with (C2), the sum of the stray parasitic capacitance between the windings of the coil, and the capacitance of the toroidal metal electrode attached to the high voltage terminal. The primary and secondary circuits are tuned so they resonate at the same frequency; they have the same resonant frequency. This allows them to exchange energy, so the oscillating current alternates back and forth between the primary and secondary coils.

The primary is the flat red spiral winding at bottom, the secondary is the vertical cylindrical coil wound with fine red wire. The high voltage terminal is the aluminum torus at the top of the secondary coil.



Circuit Diagram of an Unipolar Tesla coil circuit. C2 is not an actual capacitor but represents the capacitance of the secondary windings L2, plus the capacitance to ground of the toroid electrode E

- **THE OUTPUT CIRCUIT CAN HAVE TWO FORMS**

UNIPOLAR

One end of the secondary winding is connected to a single high voltage terminal, the other end is grounded. This type is used in modern coils designed for entertainment. The primary winding is located near the bottom, low potential end of the secondary, to minimize arcs between the windings. Since the ground (Earth) serves as the return path for the high voltage, streamer arcs from the terminal tend to jump to any nearby grounded object.

BIPOLAR

Neither end of the secondary winding is grounded, nor are both brought out to high voltage terminals. The primary winding is located at the centre of the secondary coil, equidistant between the two high potential terminals, to discourage arcing.

- **THE OSCILLATION FREQUENCY**

To produce the largest output voltage, the primary and secondary tuned circuits are adjusted to resonance with each other. The resonant frequencies of the primary and secondary circuits, f_1 and f_2, are determined by the inductance and capacitance in each circuit.

$$f_1 = \frac{1}{2\pi}\sqrt{\frac{1}{L_1C_1}} \qquad f_2 = \frac{1}{2\pi}\sqrt{\frac{1}{L_2C_2}}$$

Generally the secondary is not adjustable, so the primary circuit is tuned, usually by a moveable tap on the primary coil L1, until it resonates at the same frequency as the secondary

$$\frac{1}{2\pi}\sqrt{\frac{1}{L_1C_1}} = \frac{1}{2\pi}\sqrt{\frac{1}{L_2C_2}}$$

Thus the condition for resonance between primary and secondary is

$$L_1C_1 = L_2C_2$$

The resonant frequency of Tesla coils is in the low radio frequency (RF) range, usually between 50 kHz and 1 MHz. However, because of the impulsive nature of the spark they produce broadband radio noise, and without shielding can be a significant source of RFI, interfering with nearby radio and television reception.

- **OUTPUT VOLTAGE**

In a resonant transformer the high voltage is produced by resonance; the output voltage is not proportional to the turn's ratio, as in an ordinary transformer. It can be calculated approximately from conservation of energy. At the beginning of the cycle, when the spark starts, all of the energy in the primary circuit W_1 is stored in the primary capacitor C1. If V1 is the voltage at which the spark gap breaks down, this is usually close to the peak output voltage of the supply transformer T.

the energy is given by-

$$W_1 = \frac{1}{2}C_1V_1^2$$

During the "ring up" this energy is transferred to the secondary circuit. Although some is lost as heat in the spark and other resistances, in most modern coils around 80% of the energy ends up in the secondary. At the peak (v2) of the secondary sinusoidal voltage waveform, all the energy in the secondary is stored in the capacitance between the ends of the secondary coil

$$W_2 = \frac{1}{2}C_2V_2^2$$

Assuming no energy losses, $W_2 = W_1$. Substituting into this equation and simplifying, the peak secondary voltage is

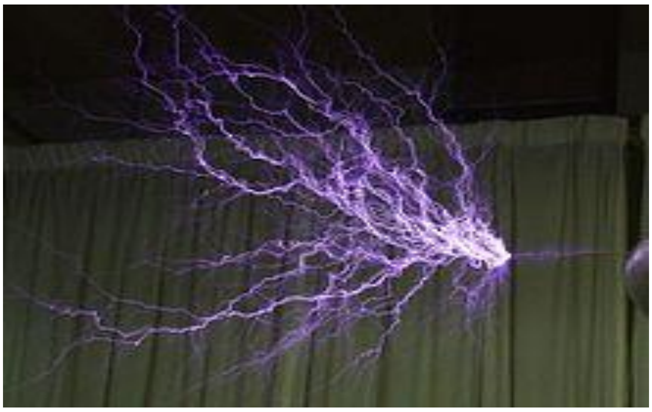
$$V_2 = V_1\sqrt{\frac{C_1}{C_2}} = V_1\sqrt{\frac{L_2}{L_1}}$$

The second formula above is derived from the first using L1C1=L2C2. Since the capacitance of the secondary coil is very small compared to the primary capacitor, the primary voltage is stepped up to a high value. It might seem that the output voltage could be increased indefinitely by reducing C2 and L2. However, as the output voltage increases, it reaches the point where the air next to the high voltage terminal ionizes and corona discharges, brush discharges and streamer arcs break out from the secondary coil. The resulting energy loss damps the oscillation, so the above lossless model is no longer accurate, and the voltage does not reach the theoretical maximum above. Most entertaining Tesla coil designs have a spherical or toroidal shaped electrode on the high voltage terminal. Although the "toroid" increases the secondary capacitance, which tends to reduce the peak voltage, its main effect is that its large diameter curved surface reduces the potential gradient (electric field) at the high voltage terminal, increasing the voltage threshold at which corona and streamer arcs form. Suppressing premature air breakdown and energy loss allows the voltage to build to higher values on the peaks of the waveform, creating longer, more spectacular streamers.

Large coil producing 3.5 meter (10 foot) streamer arcs

B. MODERN DAY TESLA COILS:

Modern high-voltage enthusiasts usually build Tesla coils similar to some of Tesla's "later" 2-coil air-core designs. These typically consist of a primary tank circuit, a series LC (inductance-capacitance) circuit composed of a high-voltage capacitor, spark gap and primary coil, and the secondary LC circuit, a series-resonant circuit consisting of the secondary coil plus a terminal capacitance or "top load". In Tesla's more advanced (magnifier) design, a third coil is added. The secondary LC circuit is composed of a tightly coupled air-core transformer secondary coil driving the bottom of a separate third coil helical resonator. Modern 2-coil systems use a single secondary coil. The top of the secondary is then connected to a top load terminal, which forms one 'plate' of a capacitor, the other 'plate' being the earth (or "ground").



Electric discharge showing the lightning-like plasma filaments from a 'Tesla coil'

The primary LC circuit is tuned so that it resonates at the same frequency as the secondary LC circuit. The primary and secondary coils are magnetically coupled, creating a dual-tuned resonant air-core transformer. Earlier oil-insulated Tesla coils needed large and long insulators at their high-voltage terminals to prevent discharge in air. Later Tesla coils spread their electric fields over larger distances to prevent high electrical stresses in the first place, thereby allowing operation in free air. Most modern Tesla coils also use toroid-shaped output terminals. These are often fabricated from spun metal or flexible aluminum ducting. The toroidal shape helps to control the high electrical field near the top of the secondary by directing sparks outward and away from the primary and secondary windings. A more complex version of a Tesla coil, termed a "magnifier" by Tesla, uses a more tightly coupled air-core resonance "driver" transformer (or "master oscillator") and a smaller, remotely located output coil (called the "extra coil" or simply the resonator) that has a large number of turns on a relatively small coil form. The bottom of the driver's secondary winding is connected to ground. The opposite end is connected to the bottom of the extra coil through an insulated conductor that is sometimes called the transmission line. Since the transmission line operates at relatively high RF voltages, it is typically made of 1" diameter metal tubing to reduce corona losses. Since the third coil is located some distance away from the driver, it is not magnetically coupled to it. RF energy is instead directly coupled from the output of the driver into the bottom of the third coil, causing it to "ring up" to very high voltages.

C. TYPES OF TESLA COILS:

1. Spark excited or Spark gap Tesla Coil.
   - Static Spark gap.
   - Static Triggered Spark gap.
   - Rotary Spark gap.
2. Switched or Solid State Tesla Coil (SSTC).
   - Single Resonant Solid State Tesla Coil.
   - Dual Resonant Solid State Tesla Coil (DRSSTC).
   - Musical Tesla Coil.
3. Continuous Wave.

- **APPLICATIONS**

Tesla coil circuits were used commercially in spark gap radio transmitters for wireless telegraphy until the 1920s, and in electrotherapy and pseudo medical devices such as violet ray. Today, although small Tesla coils are used as leak detectors in scientific high vacuum systems] and igniters in arc welders, their main use is entertainment and educational displays, Tesla coils are built by many high-voltage enthusiasts, research institutions, science museums, and independent experimenters. Although electronic circuit controllers have been developed, Tesla's original spark gap design is less expensive and has proven extremely reliable.

1. Apart from that tesla coils are also used for:-
2. Entertainment purposes.
3. Vacuum System Leak Detectors.
4. Wireless Power Transmission.

SYNCHRONIZATION OF ALTERNATORS IN POWER SYSTEM

ARIJIT MONDAL

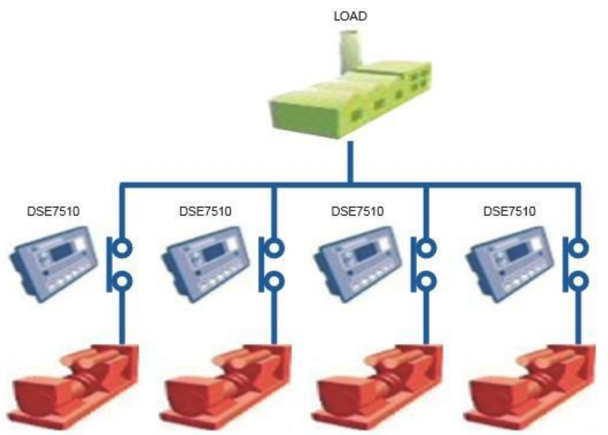
Student of Electrical Engineering Department

Technique Polytechnic Institute, Hooghly, West Bengal, India

Email id: dmondal.95@gmail.com

A. INTRODUCTION:

It is well known that electrical load on a power system or an industrial establishment is never constant but it varies. To meet the requirement of variable load economically and also for assuring continuity of supply the number of generating units connected to a system of bus-bar are varied suitably. The frequency of a large electric power distribution system is established by the speed of rotation of many powerful alternators all connected by various tie-lines in the total network. The collective inertia and power of these generators is so great that there is no single load or disturbance which would be large enough to change their speed of rotation. The frequency of an electric system is, therefore, remarkably stable. A system whose frequency is 50 Hz cannot receive power from an alternator operating at 50.01 Hz. They must both operate at exactly the same frequency. That is why synchronization of alternators plays a very important role in power plants (basically in power system). The method of connecting two or more alternator in parallel to each other or one alternator to the infinite bus-bar is known as synchronization. Electrical power system consist of the interconnection of large numbers of alternator operating in parallel, interconnected by transmission lines and supplying large number of widely distributed loads. The voltage and frequency of the infinite bus-bar is constant. There are many benefits of operating many alternators in parallel to each other like continuity in power supply, reliability, high efficiency, flexibility and expandability. In order to meet the further increasing demand of load more machines can be added without disturbing the original installation. Synchronization which is operated by manually switching is not suitable for the system having large capacity. Thus there comes the need of automatic synchronization system in power plants or in power system where generators are employed.



Schematic diagram of parallel connections among generator sets

B. NECESSITY OF SYNCHRONIZATION:

A stationary alternator is never connected to live bus-bars, because it will result in short circuit in the stator winding (since there is no generated e.m.f. yet). That is why before connecting an alternator into grid, following conditions must be satisfied:

- Equal voltage: The terminal voltage of incoming alternator must be equal to the bus-bar voltage.

- Similar frequency: The frequency of generated voltage must be equal to the frequency of the bus-bar voltage.
- Phase sequence: The phase sequence of the three phases of alternator must be similar to that of the grid or bus-bars.
- Phase angle: The phase angle between the generated voltage and the voltage of grid must be zero.

Synchronization panels are mainly designed and used to the requirements of power system. These panels operate both manually and with an automatic synchronizing function for one or more generators or breakers. They are widely used in synchronizing generators and offering multiplex solutions.

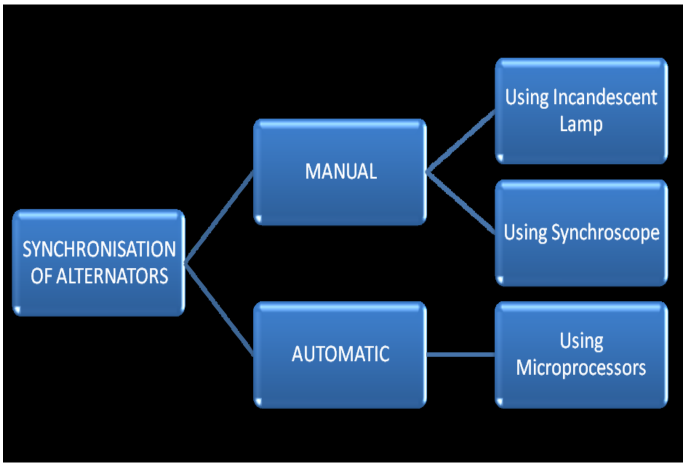
Synchronizing a generator to the power system must be done very carefully. The speed (mainly frequency) and voltage of the isolated generator must be closely matched, and the rotor angle must be close to the instantaneous power system phase angle prior to closing the generator breaker to connect the isolated generator to the power system. Poor synchronizing can:

- Damage the generator and the prime mover because of mechanical stresses caused by rapid acceleration or retardation, bringing the rotating system into synchronism (exactly matched frequency and rotor angle) with the power system.
- Damage the windings of the generator and step-up transformer because of high current.
- Cause disturbances to the power like power oscillations and voltage deviations from nominal.
- Prevent the generator from staying online and picking up load when protective relay elements interpret the condition as an abnormal operating condition and trip the generator.

C. SYNCHRONIZATION OF ALTERNATORS

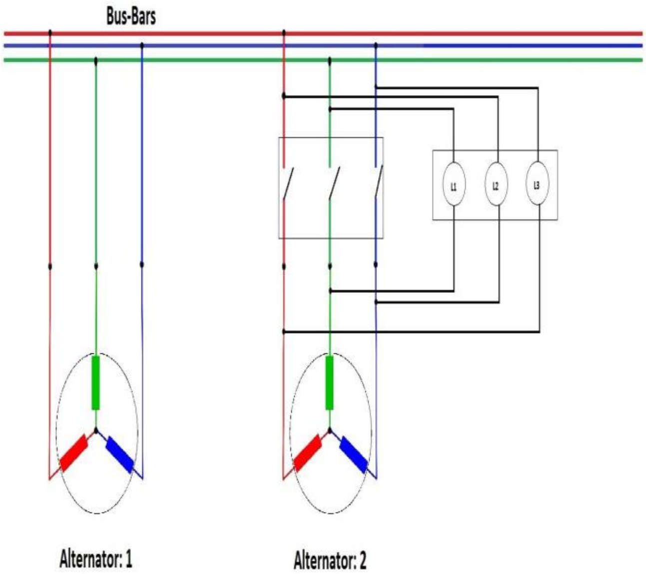
Synchronization of an alternator with a large utility system, or "infinite bus" as it is called is comparable to matching a small gear to another of enormous size and power. If the teeth of both gears are properly synchronized upon contact, then the matching will be smooth. But should the teeth edges meet shock would result with possible damage to the smaller gear. Smooth synchronization of an alternator means first that its frequency must be equal to that of the supply. In addition, the phase sequence (or rotation) must be the same. Returning to our example of the gears, we would not think of trying to mesh two gears going in opposite directions, even if their speeds were identical. The next thing to watch for when we push gears together is to see that the teeth of one meet the slots of the other. In electrical terms the voltage of the alternator must be in phase with the voltage of the supply. Finally, when matching gears we always choose a tooth depth which is compatible with the master gear. Electrically, the voltage amplitude of the alternator should be equal to the supply voltage amplitude. With these conditions met, the alternator is perfectly synchronized with the network and the switch between the two can be turned on. Usually, the condition of terminal voltage is satisfied by using voltmeter.

Synchronization of alternators can be classified as follows:



Manual Synchronizing Systems:
Generators have traditionally been synchronized by manual means. The operator manually adjusts the prime mover speed or the frequency control set point of the governor to match the generator frequency to the system frequency. Similarly, the operator manually adjusts the excitation level or voltage regulator set point of the exciter to match the generator voltage to the system voltage. The operator then initiates closing the breaker when the phase angle between the generator voltage and the system voltage is near 0 degrees. A good operator will judge how fast the phase angle difference is coming together and energize the breaker close coil in advance to account for the closing mechanism delay of the generator breaker so that the main contacts make as close to a zero-degree angle difference as possible.
Instruments that allow the operator to visualize the voltage difference, speed difference (slip), and angle difference of the generator are required for the operator to perform these tasks. These instruments are typically provided on a synchronizing panel in the generator control room.

Synchronization of Alternator Using Incandescent Lamp:



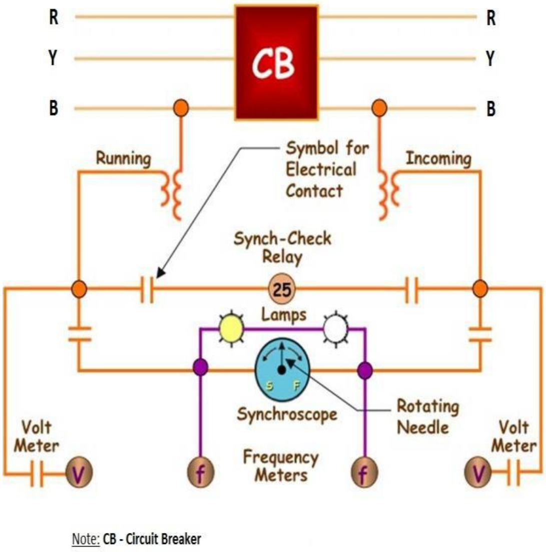
Assuming that, alternator 2 is to be synchronized in a grid and the alternator 1 is already in the grid as shown above in Fig. 3. The alternator 2 is connected to grid through three synchronizing lamps (L1, L2 and L3) as shown in above figure. If the speed of the alternator 2 is not such that the frequency of output voltage is equal to the frequency of the grid, there will also be a phase difference in the voltages, and in this case the lamps will flicker. In this method one lamp is connected between corresponding phases while the other two are cross-connected between the other two phases. Reason behind this setup lies in the fact that if they were connected symmetrically, they would glow or dark out simultaneously at that very moment when the phase rotation becomes same as that of bus-bars. Asymmetrically connected lamps indicate whether the incoming machine is running slower or faster. If the alternator 2 is running slower, the phase rotation of alternator 2 will appear to be clockwise relative to the phase rotation of the grid and the lamps will light up in the order 3, 2, 1; 3, 2, 1.... If the alternator 2 is running faster, the phase rotation of alternator 2 will appear to be anticlockwise relative to the phase rotation of the grid and the lamps will light up in the order 1, 2, 3; 1, 2, 3.... When the speed of the alternator 2 reaches so that, the frequency and phase rotation of output voltage is similar to that of the grid voltage, lamp L1 will go dark and lamps L2 and L3 will dimly but equally glow (as they are connected between different phases and due to this there will be phase difference of 120 degree). The synchronization is done at this very moment. This method of synchronization is sometimes also known as 'two bright and one dark method'.

Drawbacks of 'synchronization using incandescent lamps' method are:

- Synchronization by using incandescent lamps depends on the correct judgment of the operator.
- This method does not tell us how slow or fast the machine is.
- To use this method for high voltage alternators, extra step down transformers need to be added as ratings of lamps are normally low

Synchronization of Alternator Using Synchroscope:

It consists of three coils and one moving vane. A pointer is connected to moving vane. The coils are connected to the bus bar and the alternator which is to be synchronized. The potential transformer is used to measure the voltage difference, the pointer move in clockwise and antic clockwise manner and when speed of incoming machine is same to that of bus bar then pointer will stop at vertical point and relays are closed that connect the alternator to the bus bar.



Synchronizing System for a Substation Breaker

Automatic Synchronizing Systems

Synchronization by means of manually operated switching served well enough when the individual
generators were relatively small, but with the growth of system capacity, it becomes necessary to use automatic devices to ensure the closing of the main switch of the incoming machine at the proper instant.

The scheme introduced here is for the complete automation of synchronization i.e.; the adjustment of magnitude of voltage and frequency of incoming alternator is done automatically. When all the requirements of synchronization are satisfied, closing of the main switch of the incoming machine is done by the automatic synchronizer. In addition, the auto synchronizer has been designed so that the alternator is started with in minimum voltage and minimum frequency conditions.

Synchronization Of alternators Using Microprocessors:

This is generally done by the aid of microprocessor (mainly, 8085 series). The entire setup consists of the following accessories:-

- Frequency control unit
- Voltage control unit
- Potential transformer unit
- Signal conditioning card
- Display card and
- Circuit breaker with the switching circuit.

<u> Frequency Controlling Unit</u>

The frequency of an alternator can be changed by varying the speed of the prime mover which is a DC shunt motor in this case .A rheostat is provided in the field circuit of the motor for this purpose The frequency controlling unit is a lead screw arrangement driven by a stepper motor attached to the variable point on the rheostat the stepper motor (SM1) is controlled by an 8085 microprocessor system through a driver circuit.

<u> Voltage Controlling Unit</u>

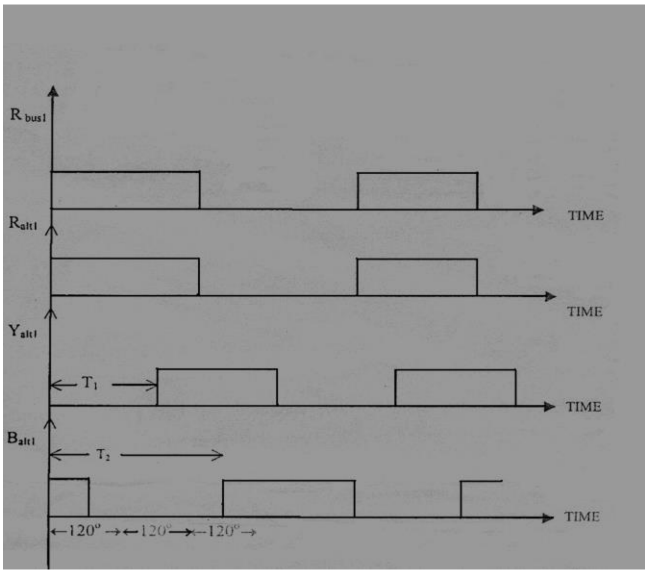
Once frequency of alternator is fixed, or adjusted, its voltage is controlled by variation of excitation current. This excitation current is varied by providing a rheostat in the field circuit of the alternator. The automatic variation of excitation current is obtained by lead screw and stepper motor (SM2) arrangement similar to the one used for frequency control.

<u> Potential Transformer Unit</u>

This unit consists of a bank of four shell type transformer (P.Ts). Out of the four transformers thee are used for stepping down three phase voltages of alternator and the remaining one is used for stepping down the voltage of the phase R of the bus bar. The potential transformers connected to the phase R of the bus bar and the phase R of the alternator are having two secondary windings. Hence one secondary is used for voltage measurement and the other is used for frequency measurement .The potential transformers connected to the Y and B phases have only one secondary each.

□ Signal Conditioning Card

It is subdivided into (i) signal conditioning card and (ii) ADC subunit.
The signal conditioning subunit consists of for identical circuits each of which comprises of a zero crossing detector (ZCD) (for r-alt, y-alt, b-alt and r-bus) two rectifier and filter circuits for r-alt-2 and r-bus-2 and an in-phase sequence detector and an in-phase instant detector.



The ZCD converts sinusoidal output obtained from the secondary side of the potential transformer to square pulses as shown in the above in Fig. 6. These square signals are fed to the microprocessor unit for frequency measurement and detecting the phase sequence by the aid of the developed software.
The AC signal coming from the r-alt-2 and r-bus-2 are converted to DC signals compatible for "ADC 0809" by using rectifiers and filter circuits. Generally, these are used to measure the voltage of alternator and bus.
In-phase instant detector circuit is used for detecting the in-phase instant of signals r-alt-1and r-bus-1 which is the correct instant for synchronization.
The ADC subunit consists of "ADC 0809" interfaced with 8085-microprocessor system. The clock required for this ADC is derived from a frequency divider circuit made up of three 7490 counter ICs. The microprocessor kit provides a clock having frequency of 1.7 MHz, which is further divided by factors 5, 10, 10. Therefore out of the three available outputs, 340 KHz and 3.4 KHz outputs are used respectively for the "ADC 8255". The digital output corresponding to the alternator and bus-bar voltages are obtained using separate channels for alternator and bus-bar voltages.

□ Display Card

The synchronization panel provides a display card that indicates the messages during alternator synchronization process. It uses four seven–segment LED displays to represent the three in-phase synchronization conditions and circuit breaker position. The display card also displays messages like 'HALT','DONE' etc.

□ Circuit Breaker with Switching Circuit

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Its basic function is to detect a fault condition and interrupt current flow. Unlike a fuse, which operates once and then must be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation. The circuit breaker used as a synchronizing switch is in the form of a direct on line starter. The operating coil is generally connected to 230 V DC supply via electromagnetic relay. Microprocessor is used to activate the relay at proper instant so as to keep the circuit breaker closed at the correct in-phase instant.

D. CONCLUSIONS:

The microprocessor based system of automatic synchronizer can be used more effectively compared to conventional methods of synchronization such as dark lamp method, bright lamp method and synchronization using a Synchroscope. This synchronizing system is designed to control the voltage and frequency of the incoming alternator. The frequency can be varied manually as well by increasing or decreasing the speed of the prime mover i.e. DC shunts motor. It also exploits the advantage of superior performance of the microprocessor like accuracy speed and reliability. It is very challenging to design a robust and fault-tolerant synchronizing system. The system should have no single points of failure or common-mode failure problems. The instrument transformer circuits must have proper insulation and grounding. Similarly, the DC control circuits must also have proper insulation. Usually, the only way to achieve this with conventional technology is with problem-prone auxiliary potential transformers and auxiliary relays. Modern advanced automatic synchronizers with software capable of switching up to six voltage signals and local and remote output contacts simplifies the design process. The synchronizing panel is often the last remaining item that still requires complex synchronizing switch circuits.

The human brain (when awake) produces enough electricity to power a 40 W light bulb for 24 hours

Tim Berners – Lee carried the phrase “World Wide Web” in 1990

A diamond cannot be dissolved in acid. The only thing that can destroy it is intense heat

Marie Curie was the first person to win two Nobel Prize for Science

The first handheld mobile phone was demonstrated by John F. Mitchell and Martin Cooper of Motorola in 1973

Golf balls have dimples because they help reduce drag, thus allow the ball to fly further than a smooth ball

India has been celebrated by environmental groups with the announcement of its latest solar power plant in Kamuthi, Tamil Nadu with a capacity of 648 MW

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