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An Audit on Emerging Complexities in Powergrid

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Abstract: *Modern days of power system networks are more polluted and complex in nature, they are inter connected with various levels of voltages and the grid faces exigent operating scenario. The integration of renewable energy sources to utility grid depends on the scale of penetration and the grid operating conditions becomes more complex. Large-scale of wind power penetration impacts the Electricity Supply Industry (ESI) in many aspects such as wind speed uncertainty, high volatility and low predictability reduces the system security. Photovoltaic systems (PV) and their priority are more growing in recent days of power generation. The impact of PV generation at the point of common coupling (PCC) such as voltage profile due to solar radiation, reverse power flow and harmonic distortion. Since wind speed fluctuations reflect on the voltage and active power output of the electric machine connected to the wind turbine. Solar penetration also changes the voltage profile and frequency response of the system and affects the transmission and distribution systems of utility grid. Also, it raises a number of technical challenges for the transmission system operator, distribution system operator.*
Keywords: *Wind power, Photovoltaic (PV) system, stability, power quality, harmonics, flickers, Grid codes, distributed generation, PCC.*

I. Introduction

Over a decade the global warming and energy policies have become a burning theme on worldwide. Developed countries are trying to reduce their greenhouse gas emissions. For example, the EU has committed to reduce the emissions of greenhouse gas to at least 20% below 1990 levels and to produce no less than 20% of its energy consumption from renewable sources by 2020. To solve the problem there are two major Renewable sources for the generation of electric power supply i.e. solar and wind energy.

1.1 Non-RES connected to grids:-

The growing power demand causes to increase the power generation capacity in the recent eras. Power utilities must maintain reserve margins of existing power generation at a sufficient level. Currently, transmission systems are reaching their maximum capacity because of the huge amount of power to be transferred. Therefore, power utilities have to invest a lot of money to expand their facilities to meet the growing power demand and to provide uninterrupted power supply to industrial and commercial customers. Electricity is produced in bulk by using power plants with natural gas, coal or oil as primary sources as shown in Fig 1.1. Combustion of such fuels results in emission of oxides of Carbon, Nitrogen and Sulfur.

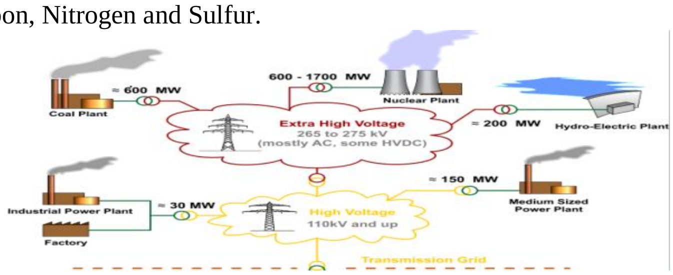

Fig. 1.1 Generation of electrical power by fossil fuels

1.2 Renewable sources connected to grid:-

With the increasing in environmental concerns the generation of electrical energy is mainly with the help of renewable energy source as shown in Fig 1.2. The large-scale integration of renewable energy sources (RES) will drastically contribute to the reduction of greenhouse gases [1].

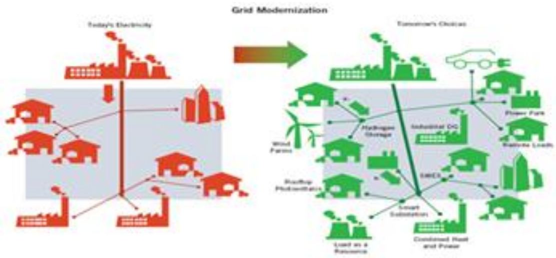

Fig 1.2 Modernization of power system

The integration of wind and photovoltaic (PV) based distributed generation units in the distribution system may lead to several benefits such as voltage support, improved power quality, loss reduction, deferment of new or upgraded transmission and distribution infrastructure, and improved utility system reliability.

Reasons for Renewable Energy ?

- Declining Fossil Fuel Supplies
- Environmental Concerns
- Increasing Cost of Fossil Fuels
- Business Opportunities

II. PQ Issues In Power Grid

IEEE Std 1100-1999 Recommended Practice for Powering and Grounding Electronic Equipment:
– The concept of powering and grounding electronic equipment in a manner that is suitable to the operation of that equipment and compatible with the premise wiring system and other connected equipment.
• Who develops IEEE Std 1100-1999?
– Power Systems Engineering Committee of the
–Industrial and Commercial Power Systems Department of the
– IEEE Industry Applications Society. (1999)

Table 2.1 power quality effects

Power quality problem	Description	Effects
Temporary interruption	Planned or accidental total loss of utility power in a localized area of the community. Duration: sec to min	Equipment's shutdown , loss of work and data, file and hard disk and operating system(OS) corruption, loss of fiber optic, T1 and ISDN connections.
Long –term interruption	Planned or accidental total loss of utility power in a localizes area of the community. Duration : Min to hour	Equipment's shutdown , loss of work and data, file and hard disk and operating system(OS) corruption, loss of fiber optic, T1 and ISDN connections.
Momentary interruption	Very short planned or accidental power loss Duration : Milliseconds to sec	Computer hangs, computer and network equipment reboots or hangs , loss of work and data, file and hard disk and OS corruption
Sag or under-voltage	A decrease in utility voltage Sag Duration - Milliseconds to a few sec Under-voltage- longer than a few sec	Shrinking display screens, equipment hangs or reset, equipment power supply damage. Computer hangs, computer and network equipment reboots or hangs , loss of work and data, file and hard disk and OS corruption
Swell or over-voltage	An increase in utility voltage Swell Duration –Milliseconds to a few sec Over voltage- Longer than a few sec	Permanent equipment damage, Computer hangs, computer and network equipment reboots or hangs , loss of work and data, file and hard disk and OS corruption
Transient, impulse or spike	A sudden change in voltage upto several hundred to thousands of volts Duration :Microseconds	Network error, burned or damaged equipment and circuitry, Computer hangs, computer and network equipment reboots or hangs , loss of work and data, file and hard disk and OS corruption
Harmonic Distortion	An alternation of the pure sine wave (sine wave distortion),due to non-linear such as computer switching power supplies	Causes motors, transformers and writing to overheat, lowers operating efficiency of office equipment

The power quality of power supply of an ideal power system means to supply electric energy with perfect sinusoidal waveform at a constant frequency of a specified voltage with least amount of disturbances. Power quality is an issue that is becoming increasingly important to electricity consumers at all level of usage. Power quality is the combination of voltage quality and current quality as shown in below Fig. 2.1, thus power quality is concerned with deviation of voltage and current from ideal. The widespread use of electronic equipment and electrical equipment susceptible to power quality or more appropriately lack of power quality would fall within a seemingly boundless domain as shown in above Table 2.1 [2]. The electrical device might be an electrical motor, a transformer, a generator, a computer, a printer, communication equipment, or household appliances. During the last few years, power electronic technology plays an important role in distributed generation and integration generation into the electric grid. It is due to the development in fast semiconductor switches, which are capable of switching quickly and handling high power, which has been widely used in wind energy system.

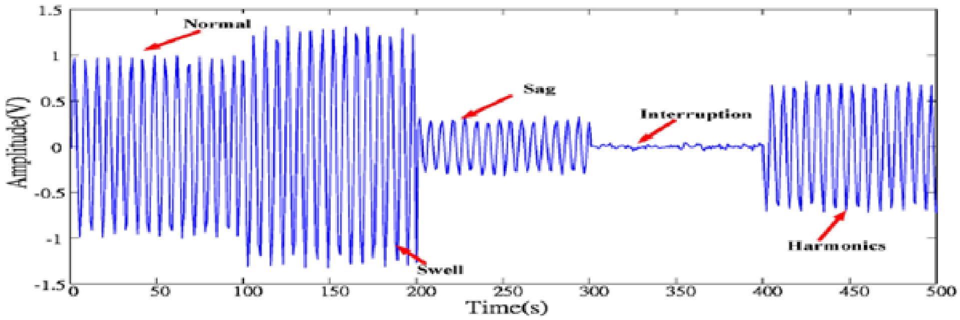

Fig 2.1 various power quality issues

2.1 Wind power generation:

Electricity is produced in bulk by using power plants with natural gas, coal or oil as primary sources. Combustion of such fuels results in emission of pollutants like oxides of Carbon, Nitrogen and Sulfur. Due to availability of wind renewable energy sources abundantly, wind energy generation is increasing day by day to develop rural electrification, increase job opportunities in technology but there are some limitations to the penetrating of wind energy into the grid. Wind speed forecasting has high uncertainty, high volatility and low predictability reduces the system security and wind revenue.

High penetration of wind energy creates stability problem, and possible blackouts thus wind energy penetration is limited by ATC (available transfer capability) of the system. Large wind and solar farms have been installed in power systems around the world due to environmental problems caused by using fossil energy resources as shown in Fig.2.2. The increasing environmental awareness requires that the system operator should supply electricity to consumers with minimum emissions.

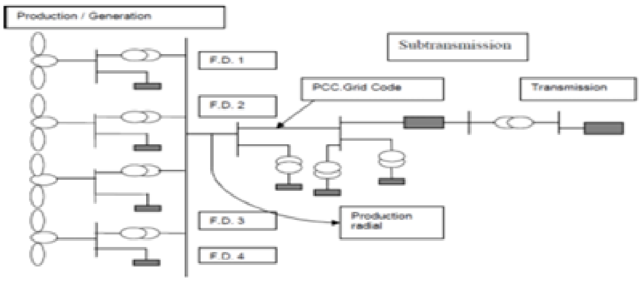

Fig 2.2 Grid Connection of a Wind Farm

2.2 Photo voltaic generation

It is a direct method to convert solar radiations into electricity. Photovoltaic (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect [3]. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Customers are showing interest in solar power due to low cost, eco-friendly, flexible installation and no reactive power consumption by solar panel. Even though installation cost of solar panels are high, solar power generation increases due to government incentives and low production costs with the help of developed PV technology [4].

2.2.1. Schematic of PV connected to Grid

Grid connected PV system which typically consists of a PV array [4], a DC link and a capacitor, an inverter with filter, a step-up transformer, and a power grid as shown in Fig 2.3. The DC power generated from the PV array charges the DC link capacitor. The inverter converts the DC power into AC power, which has a sinusoidal voltage and frequency similar to the utility grid. The diode block is used to prevent reverse current flow through the PV array. The transformer steps up the inverter voltage to the nominal value of the grid voltage and provides electrical isolation between the PV system and the grid.

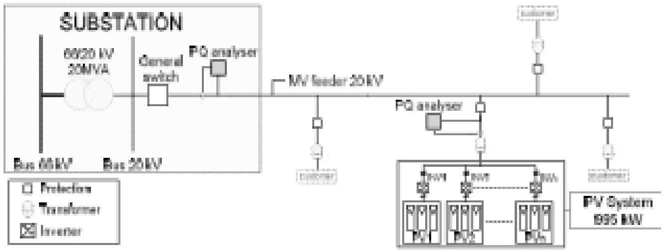

Fig 2.3 PV energy source connected to grid

2.3. Challenges in Grid integration

1. Large Scale Solar integration may introduce new patterns in the flow of power which may cause congestions in transmission & distribution networks in case of a conservative planning.
2. Solar Plants have low development period than transmission strengthening, constraints may arise on account of large difference of developments periods.
3. Solar plants are generally located in remote/concentrated locations. The probability of such area not being a load center is quite high.
4. Solar farms are known to be providing lesser grid support during system disturbances/exigencies than the conventional.

III. Integration Of Res And Their Complexities

The proposed system consists of a wind blade, a variable speed direct-drive wind generator, a wind-side ac/dc converter, a solar array, a dc/dc converter, a common dc capacitor and a grid interface inverter, as shown in below Fig 3.1. Mechanical energy from the wind turbine drives the wind generator to generate AC electric power, which is converted into dc power to form the common dc link. PV array generates dc power. Typically the dc voltage level from the array is low compared with the adequate level of the dc link necessary to guarantee the excellent operation of the grid interface inverter; thus the dc/dc booster raises the array voltage to a higher level, equivalent to the common dc voltage level [5]-[10] as shown in Fig 3.2.

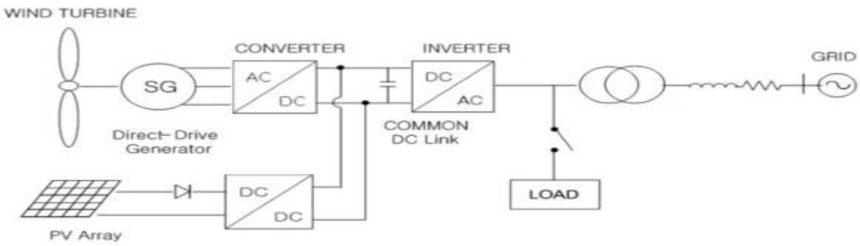

Fig 3.1 wind and PV system connected to grid

3.1. Complexities:-They are classified as follows,

- **Technical**
- ✓ Power Quality
- Harmonics
- Frequency and voltage variation
- ✓ Power fluctuations
- Seasonal power fluctuations
- ✓ Storage
- Protection
- Optimal placement
- **Non-Technical**
- Lack of skilled workers
- Less availability of transmission line accommodate RES

3.2 Integrating renewable sources-Advantages

- Better voltage support
- Peak shaping
- Bidirectional power flow
- Improvement of overall efficiency, reliability and stability
- Load management
- Eco-friendly

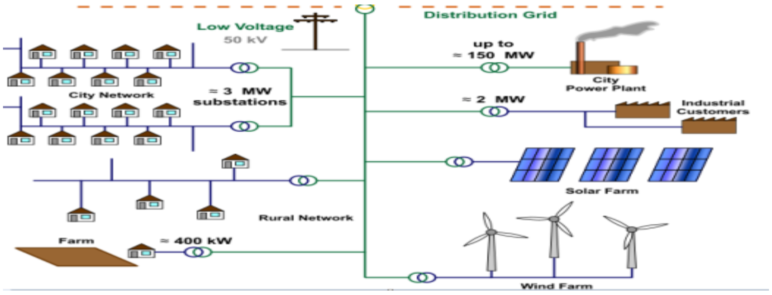

Fig 3.2 Integration of renewable and non-renewable resources to grid

3.3 Grid prospective-Advantages

- Strong interconnection to sustain variability
  - According to frequency point of view strong interconnection can be built between renewable sources and grid
- Strengthen Grid code for RE
  - Voltages, frequency angle these are the grid codes. These codes can be reinforce easily.
- Dynamic control system
  - Load varies on time to time basis, according to load demand these renewable sources can supply power.
- Renewable energy management system

IV. Mitigation Techniques And Control Schemes

The increasing number of renewable energy sources and distributed generators requires new strategies for the operation and management of the electricity grid in order to maintain or even to improve the power-supply reliability and quality. The renewable energy sources such as solar, wind etc [5]-[10] has accelerated the transition towards greener energy sources. Keeping in view of the aforesaid some of the key solutions for RES utilizations are

1. Passive and active filters
2. Unified power flow controller (UPQC)
3. Static VAR compensator (SVC)
4. Interline power flow controller (IPFC)
5. Static compensator (STATCOM)

4.1 Static compensator (STATCOM):-

The **STATCOM** is a shunt-connected reactive-power compensation device that is capable of generating and/ or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system as shown in below Fig 4.1 Specifically, the **STATCOM** considered in this is a voltage-source converter from a given input of dc voltage produces a set of 3-phase ac-output voltages. A STATCOM can improve power-system performances as follows:

1.The dynamic voltage control in Transmission and distribution systems.
2.The power-oscillation damping in power transmission systems.
3.The transient stability.
4.The voltage flicker control.

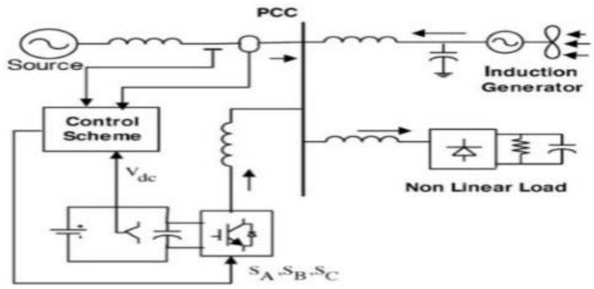

Fig 4.1 STATCOM connected to grid with renewable energy source

4.2 Control schemes for STATCOM are as follows:-

- ✓ *Pi controller*
- ✓ *Hysteresis current controller*
- ✓ *Bang-bang current controller*

4.2.1 PI controller:-

The PI controller is traditionally suitable for second and lower order system. It can also be used for higher order plants with dominant second order performance.[10]. The PI control block diagram is shown in below Fig 4.2. The voltage regulator is of proportional plus integral type. The integral term in a PI controller causes the steady error to zero.

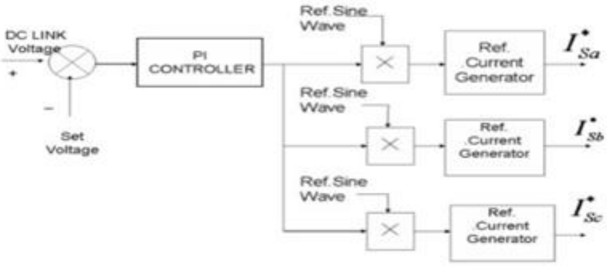

Fig 4.2 PI controller

Reference signal and output of renewable energy sources signal are passed through PI controller as shown in above figure. This PI controller will detect the error signal. This error signal is passed over a reference signal. Reference currents are generated and these currents are directly connected to on and off switches.

- ➢ Without usage of PI controller, THD value will be around ***16.64%***
- ➢ By using the PI controller, THD value will be ***4.09%***

4.2.2 Hysteresis current controller:-

Below Fig 4.3 shows a hysteresis current control for a single phase VSI [9]. Assume the VSI terminal voltage **u** connects to a sinusoidal voltage source **e** through an equivalent inductance L and resistance R. If we want to control APF output current 'i' to track a certain reference current i*, according to below Fig 4.3, we have instantaneous value equation as:

$$L\frac{di}{dt} + Ri = u - e \qquad (1)$$

When the APF output current is equal to reference current i*, the corresponding equation will be L.

$$\frac{di*}{dt} + Ri* = u* - e \qquad (2)$$

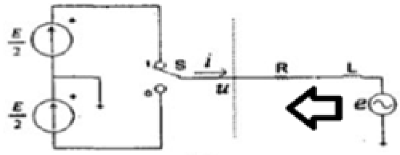

Fig 4.3 Single phase voltage source inverter

Where u* is the reference VSI terminal voltage corresponding to i*, If we define APF current tracking error Δi = i – i*, it is clear that when R=0, we get

$$L.\frac{d\,\Delta i}{dt} = u - u* \quad (3)$$

When Δi is greater than h, s is controlled to be at lower level s=0 and therefore (u-u*) <0
When Δi is less than h, s is controlled to be at higher level s=1 and therefore (u-u*) >0

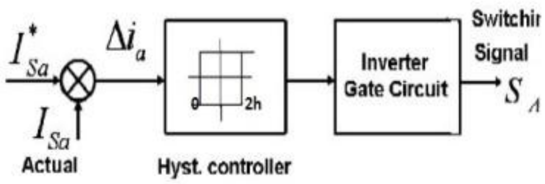

Fig 4.4 Hysteresis current controller

The actual current is detected by current sensor and it is subtracted from desired reference current so that error generated is sent to hysteresis current mode controller to generate the switching pattern as shown in above Fig 4.4. The generated pulse S_A, S_B, S_C control the power semiconductor switches in the inverter.

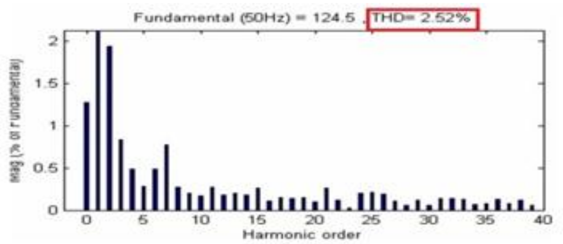

Fig 4.5 THD for hysteresis current controller

By using this hysteresis current controller the total harmonic distortion (THD) will decreases to *2.52%* as shown in above Fig 4.5.

4.2.3 Bang-bang current controller:-

This bang- bang current controller is combination of PI controller and hysteresis current controller as shown in below Fig. 4.6. Bang-Bang current controller is implemented in the current control scheme [8]. There fervency current is generated and actual current are detected by current sensors and are subtracted for obtaining a current error for a hysteresis based bang-bang controller as shown in above Fig 4.6. Thus the ON/OFF switching signals for IGBT of STATCOM are derived from hysteresis controller. THD will be around 0.44% by using bang-bang controller as shown in below Fig 4.7.

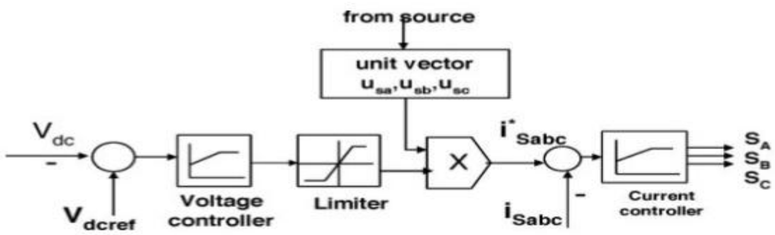

Fig 4.6 Bang-bang current controller

- It also maintains voltage and current in phase
- unity power factor is maintained at the source end
- STATCOM is used for the fast dynamic response
- It is a Regulating device used on AC Transmission networks

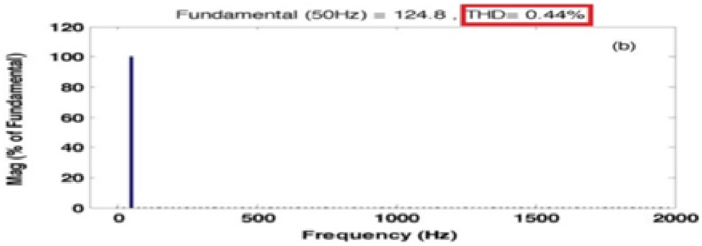

Fig 4.7 THD for Bang-Bang current controller

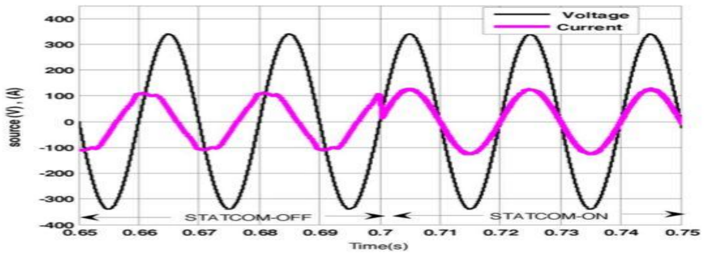

Fig 4.8 Output waveforms of voltage and currents when **STATCOM** connection and not connected to grid

V. Conclusions

- Integration of large penetration of renewable energy systems at the transmission level will require a careful evaluation
- As penetration level of intermittent source increasing ,the grid need to be more smart /should added with advance forecasting tools

The following parameter should be within the range during the integration of solar/wind with Grid.

- ✓ Voltage range for continuous operation
- ✓ Frequency range for continuous operation
- ✓ Active power ramp rate control
- ✓ Reactive power control and voltage regulation
- ✓ Power Quality i.e. flicker ,Harmonics ,Voltage fluctuation

We present the FACTS device (STATCOM) -based control scheme for power quality improvement in wind generating and solar generating system on integration to the grid and with nonlinear load. The power quality issues and its consequences on the consumer and electric utility are presented. It has a capability to cancel out the harmonic parts of the load current. It maintains the source voltage and current in-phase and support the reactive power demand for the wind generator and load at PCC in the grid system, thus it enhance the utilization factor of transmission line.

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