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Stability and Power Quality Improvement in Grid Connected System - A Review

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Abstract: The modern power system is a complex network which contains of numerous generators, transmission lines, loads and transformers etc. There has been exponential increase in the power demand over the last few decades, transmission lines are loaded more than was planned. With the increased loading of long transmission lines, the problem of transient stability, after a major fault becomes a transmission limiting factor. This leads to FACTs devices being installed in the system. The scarcity of power can be met by using renewable sources like Solar Energy, Wind energy etc. The Solar Energy systems also called PV system can be used in isolated or grid connected mode. PV system has numerous benefits and its use has been increasing in recent years. Beside electricity shortage, a more vulnerable issue in modern power system is related to quality of power delivered. A good quality of power ensures smooth operations of electrical utilities. Harmonic distortion in the grid is produced by non-linear loads connected to grid. This reduces the power quality in the system. Good Power Quality is immensely important for both industrial and domestic sectors. In this paper a review of Power Quality problems and FACTs devices is discussed

Keywords: Flexible AC Transmission System (FACTS), Maximum Power Point Tracking (MPPT), PV (Photo Voltaic), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC).

I. INTRODUCTION

Huge influx of energy demand in the developing nations is countered at the cost of natural resources which are depleting at a very fast rate. So there is urgent need to move towards the non-conventional sources of energy like solar, wind energy etc. These power generating systems can be used standalone or can be connected to the grid to meet the increasing load demand [1]. The power quality issues which includes the voltage sag, voltage swell, harmonic distortion, transients, frequency variations, multiple notches, voltage flicker etc are the sensitive energy sources in grid connected renewable energy sources. . [2]. And thus, due to the power quality issues, the grid will experience loss of generation which may cause grid instability. One of the major issues of power quality issues, harmonic distortion is caused by non-linear loads connected to the electrical power system possess a major challenge [3].A harmonic is a voltage or current at a multiple of the fundamental frequency of the system, produced by the action of non-linear loads such as rectifiers, discharge lighting, or saturated magnetic devices. The harmonic current flowing through the power system will cause power loss in transmission lines and reduces its usable load capacity. Harmonic frequencies in the power grid are a frequent cause of power quality problems. Harmonics in power systems result in increased heating in the equipment and conductors, misfiring in variable speed drives, and torque pulsations in motors. FACTS controllers are used for the dynamic control of voltage, impedance and phase angle of high voltage AC transmission lines [4]. In next section a short discussion of Power Quality issues is discussed.

II. POWER QUALITY ISSUES

Following are some major PQ issues in a modern power system [5]:

A. Voltage Sag

When the RMS (Root Mean Square) voltage less than the (0.10-0.90 per unit) nominal voltage at the rated power frequency is termed as voltage swell. Sag is caused by sudden changes in loads such as faults, motor starting and sudden increases in source impedance, usually caused by a connection failure.

B. Voltage Swell

Voltage swell is a rise in voltage (1.10-1.80 per unit) greater than the time range (0.5-30 seconds). The main causes of voltage swells are a sudden reduction in load on a circuit with the damaged voltage regulator.

C. Voltage Interruption (Short & Long)

It refers to loss of system voltage ranging from few cycles to few minutes. An electrical transient is a short term excess of voltage/current (0.10 per unit) in an electrical circuit which only lasts milliseconds, which can occur electrical, data and communication circuits. The transmission line switching, reactor and capacitor bank switching are the causes of power system switching events in voltage transients Frequency variation.

III. POWER QUALITY IMPROVEMENT

Power quality, involves sinusoidal voltage and current of rated frequency. Good power quality can be defined as a steady supply voltage that stays within the prescribed range, steady AC frequency close to the rated value and smooth voltage curve waveform (resembles a sine wave) [5]. An electrical device (or load) may malfunction, fail prematurely or not operate at all. Due to Power Quality issue low power quality leads to number of consequences such as

1) Higher energy usage
2) Higher maintenance costs
3) Equipment instability and failure

A. Introduction to FACTs Devices

Recent evolution in power electronics, the use of Flexible AC Transmission System (FACTS) controllers in power system. These FACTS controllers are capable of controlling the network condition in a quick way and this feature of FACTS can be exploited to improve power quality of the system [6].

1) Static VAR Compensator (SVC): Fig. 1 shows the circuit configuration of a SVC. SVC is a 1st generation FACTS device that can control voltage at the required bus thereby exceed the voltage profile of the system. The primary function of an SVC is to maintain the voltage at a individual bus by means of reactive power compensation (obtained by varying the firing angle of the thyristors) [7]. SVCs have been used for high performance steady state and transient voltage control compared with classical shunt compensation. SVCs are also used to dampen power swings, improve transient stability, and reduce system losses by optimized reactive power control.

$$B_{SVC} = \frac{X_L - \left(\frac{X_C}{\pi}\right)(2(\pi - \alpha) + Sin2\alpha)}{X_C X_L} \ldots . [23]$$

Where,

$$X_{SVC} = \frac{1}{jB_{SVC}} \ldots \ldots \ldots [23]$$

Fig. 1 Static Var Compensator (SVC)

2) *Thyristor Controlled Series Capacitor (TCSC):* Fig. 2 shows the circuit configuration of a TCSC. A TCSC is one of the important members of FACTS family that is increasingly applied with long transmission lines by the utilities in modern power systems. It can have different roles in the operation and control of power systems, such as scheduling power flow, decreasing unsymmetrical components, reducing net loss, assuming voltage support, restricting short-circuit currents, diminishing sub synchronous resonance (SSR), damping the power oscillation and increasing transient stability etc.[8]

$$X_{TCSC} = \frac{X_C X_L(\alpha)}{X_L(\alpha) - X_C} \dots\dots\dots\dots . [24]$$

Fig.2 Thyristor Control Series Capacitor (TCSC)

3) *Statcom (Static Compensator):* Fig. 3 shows circuit Configuration of STATCOM. STATCOM or Static Synchronous Compensator is a power electronic device using force commutated devices like IGBT, GTO etc. to restrict the reactive power flow through a power network and thereby increasing the stability of power network. STATCOM is a shunt device i.e. it is connected in shunt with the line. A Static Synchronous Compensator (STATCOM) is also known as a Static Synchronous Condenser (STATCON). It is a member of the Flexible AC Transmission System (FACTS) family of devices[9].

Fig.3 Static Compensator (STATCOM)

4) *Static Synchronous Series Compensator (SSSC):* Fig 4 shows the circuit configuration of SSSC. The SSSC is one of the most latest FACTS devices for power transmission series compensation. It can be recognised as a synchronous voltage source as it can inject an almost sinusoidal voltage of variable and controllable amplitude and phase angle, in series with a transmission line. The injected voltage is almost in quadrature with the line current. A small part of the injected voltage that is in phase with the line current provides the losses in the inverter. Most of the injected voltage, which is in quadrature with the line current, provides the effect of inject an inductive or capacitive reactance in series with the transmission line. The variable reactance impacts the electric power flow in the transmission line].

Fig. Static Synchronous Series compensator

5) *Unified Power Flow Controller (UPFC):* Fig 5 shows the circuit configuration of UPFC. UPFC is the most versatile one that can be used to enhance steady state stability, dynamic stability and transient stability. The UPFC can independently control many parameters since it is the combination of Static Synchronous Compensator (STATCOM) and Static Synchronous Series Compensator (SSSC). UPFC is an effective FACTS device for transient stability improvement.

Fig. 5 Unified Power Flow Controller (UPFC)

IV. STABILITY AND POWER QUALITY IMPROVEMENT IN GRID CONNECTED PV SYSTEM

Today large number of PV system is connected to the grid. In grid connected PV system during fault in the grid, the grid voltage drops, in an order to protect inverters the PV system voltages drops even more and this creates a huge trouble in the recovery of grid at such low voltages. Hence modification in PV control is necessary. Research on the control strategy of PV Grid connected Inverter upon Grid authors have proposed LVRT (Low Voltage Ride Through) scheme [11]. In this control when different types of faults occur in the power system, and the PCC voltage falls below the rated value still the PV power stations is not disconnected from the power and control technique make us of supressing negative sequence current to achieve stability system.

Grid Connected PV System using a three phase modified dual stage inverter focusing on the application of the three phase isolated DC- DC series resonant converter in a dual stage inverter is shown in [12] . The measured efficiency of the DC-DC stage is limited to 96 - 97.5 % and fewer than 45 to 100 % load condition. In this paper it is shown that inverter is responsible for MPPT as well as grid current. Study on Stability Control of dispatchable grid-connected PV System focuses on requirement of energy storage for improving power quality of system for improving power quality of system [13]. This paper also shows that due to energy storage system, the dispatch able grid-connected PV systems can effectively stabilize the power fluctuations of PV system and improve power quality of the system. Modular Multilevel MMI (HB) Topology for Single-Stage Grid Connected PV paper reviews a fresh new topology for the single-stage grid connection of Photovoltaic (PV) system which include Modular multilevel inverter, MMI (HB) using half-bridge sub modules is latest and a potential candidate for PV application [14].

Study on the impact of PV connection to Grid on power flow based on time output characteristics is shown in [15]. This paper reviews the effect of voltage variation in solar plants due to factors like low sunlight during cloudy days, snowy days, during nights. This paper also analyses the time series output characteristics of grid connected PV power station. The influences of the grid voltage fluctuation and line load rate caused by the change of PV power on the power flow is stimulated and analysed.

Effect of shading on with different array configuration on PV System Connected to Grid and model is discussed in [16] This paper study and analyse the effect of shading with different Photovoltaic (PV) array configurations on a three-phase two-stage grid connected PV system. Total cross Tied (TCT) was better than the SP configuration and the efficiency was increased approximately 4% in TCT configuration. The Importance of cleaning of PV Modules for Grid-Connected PV Systems in a desert environment is shown in [17]. The efficiency of the PV system is analysed in dusty or desert climatic condition. This paper shows the effect of loss of energy generated by dust deposition on the solar panel. In Paper Modelling and Simulation of Grid-connected PV System is performed using DIgSILENT/Power Factory. In this dynamic modelling and control strategy of grid-connected PV power stations is done using following equivalent models for PV power station.

1) Direct modelling of the entire PV station to create a mathematical model with analogous input and output characteristics; however this model cannot reflects the dynamic characteristics of the internal system.
2) Indirect modelling combines the various components within the system, connected through a certain structure, so that the model reflects not only the system's input and output characteristics, but also its dynamic characteristics.

Analysis of Single Phase Grid Connected PV System to identify efficient system configuration is shown by []. This paper primarily reviews the components of the single phase PV system so as to develop a new modified system which is cost effective and efficient.

In paper Simulation of Fuzzy Logic based energy management for the home with grid connected PV-Battery System is presented[20]. The Fuzzy Logic Controller is an effective method to handle the optimization problem such as for minimizing the electricity cost in the grid connected PV-battery system.

The smart grid explained in the paper [] integrates the information communication technology, electronics, sensors, control system, renewable energies into the electricity system. The main components of smart grid are:

a) Power grid
b) Renewable energy generation
c) Energy storage
d) Demand side management.

A Systematic Approach to Grid Connected PV system is presented in [21]. This paper proposed a mathematical model of PV array and a three-level control scheme of a single-phase grid-connected system including maximum power point tracker, voltage source inverter and incorporates the effects of solar irradiation and temperature changes. To extract maximum power from PV arrays and deliver it to the inverter the PI control algorithm is used to control the three-level voltage source inverter which also shows the power-sharing and isolation of PV array. A grid-connected single-phase three-level inverter with its controller for PV application and the load sharing between the PV and the grid is also presented for different combinations of solar insolation and load level.

A new theory of reactive power control of grid connected PV inverter is shown in [22]. Paper provides information to increase the penetration rate and improve the stability of grid voltage in grid connected PV system.

V. CONCLUSION

Solar Energy is a renewable energy source which has the potential to supply future electricity needs and hence great emphasis is being made now a days for increased usage in household as well as for commercial requirements. This paper reviews different techniques available on power quality problems for grid connected solar or PV cells. Power quality is not much deteriorated by issues like voltage sag, voltage swell in PV cells instead it is significantly adulterated due to issues like current harmonics, voltage harmonics. These also adversely affect the grid power quality when PV cells possessing lower quality power are being connected to the grid. The remedies for the above issues are also reviewed in this paper and different analysis of the PV connected to Grid is also reviewed in this paper.

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