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A Review on High Penetration of PV on Ancillary Services

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Abstract: This paper gives a comprehensive review of the PV technology to be utilized as ancillary services. Fossil fuel based conventional power system provided the necessary inertial support which is required to provide stability during the event of change in operating conditions of the power system. But with the penetration of PV solar farm with the grid, the inertial support is affected due to low inertia, practically no inertia. So there is a dire need to find a viable solution to the problem. This could probably be implemented using various domains like designing efficient engineering system, deeper analysis of energy market and proper scheduling. The authors here have surveyed various aspects which culminates them to a conclusive study to work out solutions in further research using tools like MATLAB, market analysis etc, to improve ancillary services, system response, and stability with the increased PV penetration in particular.

Keywords: Ancillary Services, High PV Penetration, Inertial Support and Solar Energy.

I. Introduction

With the growing power demand, due to increase in global population and their improving life style, there is a tremendous stress on improving the power system structure. This demands for setting up of both the new generation and transmission facilities. But due to socio-economic constraints it is not always feasible to go for the expansion. Also due to the depleting fossil fuel reserves and its harmful effect on environment the objective to make use of the renewable energy resources for power generation. As per the global data more of the stress is on use of wind and solar based electricity generation. The penetration of renewable energy is also increasing significantly. This affects the overall health of the power system. Usually large power was generated using conventional sources of energy. Generators and turbines formed the integral part of the fossil fuel based, hydro based and the nuclear energy based electricity generation. Such systems had high inertia.. Such generators were also used as ancillary source of energy. The prime objective was to maintain balance between generation and load. But due to the high penetration of renewable energy the inertia of the system is affected. So the time response to resolve the generation -load mismatch also gets affected. This paper explores the use of PV system for providing the ancillary services. Besides being inexhaustible, and clean source of energy it has the advantage that it has nearly negligible operational cost and due to rapid technological advancement the cost of generation is decreasing at a good rate. . With the current market scenario by 2050 it will be a major contributor of energy.

This paper has five sections. The first section gives the introduction while section II gives a brief about the principle and working of solar cell followed by a comprehensive detailing of grid connected PV solar system. Section III gives the account of High PV penetration. Use of PV based system for providing ancillary services is given in Section IV and finally the conclusion is drawn in section V.

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II. Solar Photovoltaic : Principle and Working

A. PV Cell

The Rudimentary composition of PV cell includes multifarious layers i.e. metallic contact, p-n doped semiconductor, metallic grid, anti-reflection coating, transparent adhesive, and glass covering, cross-sectional view of PV Cell is shown in Fig. 1 [1].

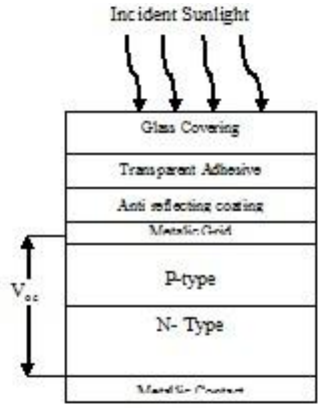

Figure 1: Cross-Sectional View of Solar Cell

With about 90-95% transparency of the layer of glass, the solar cell is fortified from dust and rain. For ensuring maximum absorption and minimizing the reflection of sunlight anti-reflection layer is used. The extraction of photocurrent is done with the help of a metallic grid and metallic contacts. The core of the solar cell is the P-N junction diode; this is the platform wherein the electrical energy is harvested from solar energy. Photons from the sunlight energize P-N doped semiconductor and generate electron-hole pairs which act as charge carriers and subsequently constitute photocurrent. The basic fundamental of such a system is called a solar cell. For silicon based soalr cell , the output is merely 0.8V DC), multiple solar cells are connected to escalate the output to a significant level and is known as Solar panel. The Solar panel in tandem is called solar arrays. The functionality of solar cell pertains to physics of Photovoltaic effect, Fig.2, discovered by Henry Becquerel in 1839 [2-3]. An electron- hole pair in the P- doped semiconductor is formed due to the incident sunlight. Electrons moves from p to n and exit the semiconductor from the metallic contact into the load circuit with the aid of junction potential. Meanwhile, the holes move away from the p-n junction to the metal contact on the p side where it meets the electron which has completed its journey from the load circuit. The above-mentioned electron flow constitutes photocurrent (I_{ph}).

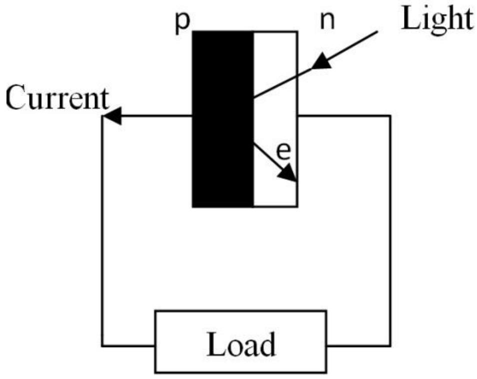

Figure 2: Photovoltaic Effect

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In the presence of a load, a potential difference develops across the terminal of the cell, generating current in the opposite direction to photocurrent termed as dark current (I_d). This gives the output current given by the equation (1).

$$I = I_{PH} - I_D \quad (1)$$

I_d in equation 1 is represented by the Shockley diode equation given by (2).

$$I_D = I_o \left(e^{\frac{qV}{nKT}} - 1\right) \quad (2)$$

From this equation, we equivalent circuit can be constructed as in Fig. 10, recombination losses are accounted by keeping shunt resistance, considering current source to be anti-parallel with diode and metallic contacts are accounted by the series resistance [3].

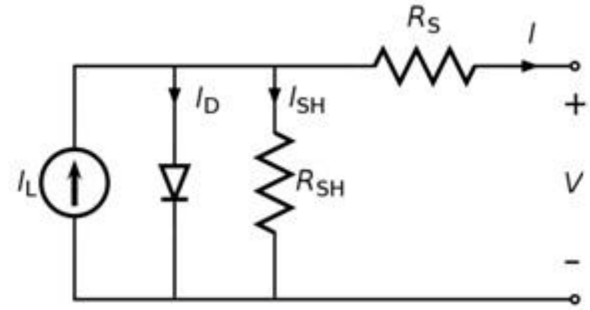

Figure 3: Equivalent Circuit of PV solar cell

B. Grid Connected PV Solar System

These are the power systems interconnected with the utility grid which are energized by photovoltaic panels. System composition includes PV panels, Maximum Power Point Tracking Mechanism (MPPT), inverters, units of power conditioning and grid connection equipment. A block diagram of grid connected interactive SPV system is shown in Fig. 4

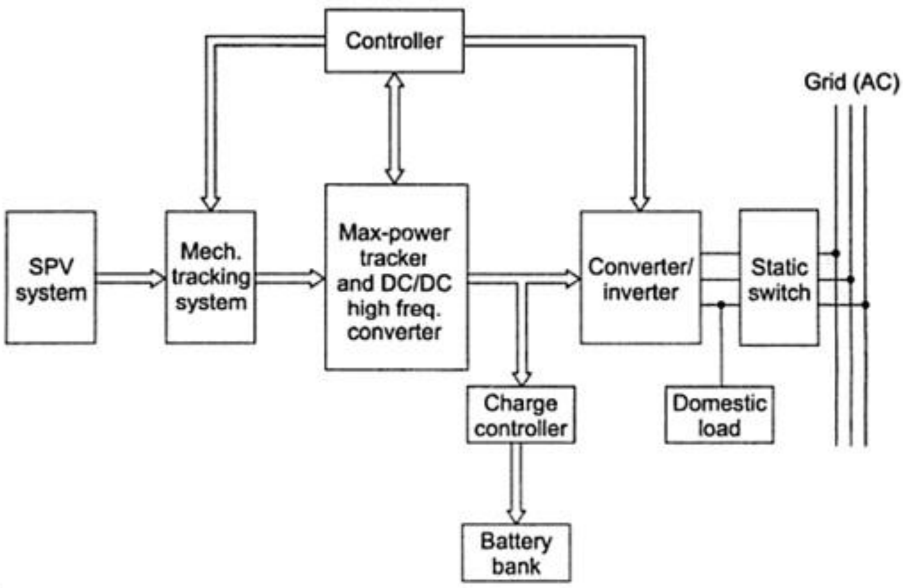

Figure 4: Grid Connected Solar PV

SPV system is not compatible with the grid when directly converted to AC from DC (400V at distribution load). Hence first DC is escalated using DC/DC high-frequency chopping. The combination of converter-inverter is mandatory so that power can flow in, either way, depending upon the amount of solar power availability. The Battery provides back up for any grid outages occurring in the night. For bulk, solar power

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systems basic scheme will be similar except that it would directly feed power into the grid and no power flow in reverse direction. The increase in research and innovation in the field of solar and other factors like the increase in efficiency and decrease in price/Watt increasing trend in solar installation could be seen as in Fig. 14 [4].

III. High PV Penetration

Increase in the PV penetration would lead to contemporary situations for consumers with regards to power supply security and power quality [5,6].Since the traditional power system was designed keeping in view the conventional energy sources, they constitute heavy rotating synchronous generator [7-8]. On the contrary PV sources hardly have the rotating parts in it; the cost of this loss of large synchronous generators is that the inertial support is lost; this inertial support helps to restore system frequency response [6 -9]. Considering power system in UK integration of PV is anticipated to reduce the system inertia by 70% while considering the period 2013/14 to 2033/34 [10]. It was observed in [11] that increase in alteration in PV system causes non-linear variation in frequency dynamics; also a dip in dominant oscillation mode is observed consistently [12]. Hence due to integration of renewable energy the network is dominantly depended on seldom synchronous machine [13]. Increase in PV penetration also increases synchronous reactor which in turn have negative impact on transient system stability [14]. Susceptibility of generator trip/ load trip has seen an increase with the increase in the contribution of photovoltaic in the power generation [7]. With the relegation of conventional power system with wind and solar plants, power system weakens as these resources does not provide inertial response [15]. Primary frequency control reserves displacement, affecting the location of primary frequency control reserves is also raising concerns due to the increase in the PV [7]. If system infallibility or power quality is to be maintained while increasing the PV in system then there lies an inevitable need for an additional control system [16]. With the alteration of renewable energy sources in the European continent the inertia in synchronous area diminishes [17].This might lead to violating boundaries of voltage rise defined by ANSI C84.1 [18]. Apart from the reverse power flow as discussed in [18] two other issues related to high PV penetration include supplementary power flows in the system from distribution link to the transmission link and grid instability due to frequency and voltage [19]. Also energy generated due to solar PV is usually done with the aid of power electronics converter which usually lacks system inertia [20]. The conventional power plant connected to the grid will be more influential while considering power system dynamics in case of lower penetration of PV (Below 50%), and would be primarily responsible for grid control [35]. On the contrary these generators are unable to provide power system stability without the aid of other devices connected to power system [11,21-23]. Besides PV inverter at the point of common coupling must not actively regulate the voltage according to IEEE 1547 and UL 1741 standards. Hence null generation of reactive power from these sources [24]. Effects of PV system transient which are detrimental such as effects of the cloud are not mitigated to a significant amount by the work reviewed in the literature so far, hence it becomes inevitable that power inverters provide to some extent power capability for additional voltage regulation to absorb or generate reactive power [25]. Steady state voltage magnitudes are also affected by high PV penetration. It is evident from [26] that the detrimental or beneficial outcome on small signal stability by solar PV generation may depend on location and penetration level and dispatch of existing synchronous generator, along with the inflating size of PV solar generator and position of point of intersection from the main system transient overvoltage significantly increases [26]. The voltage problem severity caused due to high PV penetration relies on location and relative size of distributed PV generation and loads, topology of the distribution feeder and voltage regulation methods [18]. Traditional power systems pose threat to security with the increase in PV generator which is utilized from highly variable irradiance and connected overpower converter, multiple technologies for energy storage systems having different time constants, power converters are used as an interface few of them to the grid [27]. The equipments and instruments available in the system are required to work on shorter time scales, however said variation in PV an escalation in

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number of operation are observed. These operations are necessary to counteract the variation and would lead to substantial reduction in the life time of switches and tap changers [28]. Renewable energy sources get decoupled from the ac power system that is pre-existing reason being the high power converter used in PV generation. Though the generation due to PV boosts existing power capacity from the installed system but effective system inertia remains unaltered, because power converters inherited within the system creates a decoupling effect of real inertia and AC grid. The Outcome of which is heavy excursions in frequency [27].

IV. Ancillary Services

The Market which is vitally relied upon capacity or energy market serves as principle market. On the contrary the ancillary service market is the fundamental term associated with security, efficient power system, infallibility, and calibration of the power system [7]. These were the activities that were previously considered to be the part of the principle market but with the integration of generation from the distribution side these services are disintegrating gradually [29]. Services that are aided to all the users present in network by the TSO are usually termed as system services, while on the contrary exactly opposite case occurs in ancillary services [30]. However in accordance with [31] services which aid the provision of energy to support infallibility of power system is regarded to be part of ancillary services. While considering overall system, need for voltage control emanates in ancillary service. These services are aided by resources that are proficient of providing the need (voltage control) and imbibing centralized control for directing resource to meet the requirement . Reconciliation of conflict between buyers and sellers for the mutual benefit can be done by propounding market for ancillary services [32-34]. Considering the distribution of these services, unambiguous preference for a particular resource allocation is not available. For instance combining obligatory provisions, auctions, offers which are competitive, distinct duration length and bilateral contracts are not imbibed under a single definition or provision [35].For fortifying supply for short-term and maintaining a balancing demand throughout the power system, frequency control ancillary services are necessitated [20]. These services should not be included as an extension to the energy market, rather distinct mechanisms must be developed for successful deployment for ensuring enactment and proper remuneration for ancillary service market [36].General core areas in ancillary services are composed of voltage support; system restore service, and voltage support, which responds to disturbance or contingencies [7]. Also few of the regions in the world include incentivizing the provision of primary frequency response on to ancillary services [37].While reviewing various regions in the world it would be found that system inertia rules are not enforceable in various countries until now.

a) Africa/Middle East: Frequency regulation, spinning reserves, voltage and reactive power support, black start and load shedding facilities are included in the grid code of Kenya and Nigeria. Operating reserves, black start, and unit islanding, constrained generation, reactive power supply and voltage control from units and regulation are mandated for the system operator by the South African grid code. Though South African grid code requires maintaining the frequency exceeding 49.5Hz after consideration of contingency losses with aid of primary frequency control [7].
b) Asia: CEC India published draft grid code, according to which aiding support for active power, reactive power support, black start etc. Whereas regulation, reserve, reactive support and voltage control, black start service and reliability ‘must run’ services are incorporated in Singapore Electricity Market rules.
c) Europe: Support for voltage, frequency and system restoration is categorization of services in Europe. For maintaining grid security, infallibility, calibration of power, these services are an essential commodity.
d) North America: The United States categorized ancillary system according to US electricity regulation frequency response, spinning reserve, non- spinning reserve, replacement reserve, reactive supply, and voltage control. While in Canada Alberta Electric system Operator ancillary

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services are defined as satisfactory levels of service with acceptable levels of voltage and frequency support, inertia services are not mandatory [7].

V. Conclusion

The current scenario of the world towards increasing pollution, statuary warnings from the scientist and environmentalist all over the world caused serious concerns. These concerns had raised the consciousness of the authors to dig into the reality of the situation. The authors have vindicated these facts with the literature survey. This literature review guided the authors to reach a conclusion that there is an escalation of energy consumption overall the world and this energy is generated generally from resources which have lead to carbon emission in the environment. Hence there is a paradigm shift towards renewable energy is noted overall the world. This shift is aided by technical, political and geopolitical reforms. Authors concluded PV resources as the most promising one among the renewable energy sources considering the present scenario and future investments into the projects. While considering generation with non- conventional energy sources authors raised concerns further. That is the fact that the conventional power system was designed keeping in view the conventional energy sources having a large synchronous generator attached with them. The merit of these generators is that they provide system inertia which helps to restore frequency response during an excursion. But while considering renewable energy source it was found that these are the system with feeble inertia. Also, ancillary service over different regions was reviewed. After reviewing the literature the authors wish to carry out work in system designing to provide additional inertia with the help of MATLAB/PSAT. Also, authors will carry out the study of ancillary services and system optimization using linear optimization techniques.

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