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Grid Integration and Application of Solar Energy; A Technological Review

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Abstract – *The author in this paper attempts to present a comprehensive review in the development of technologies to integrate Solar Energy Conversion System (SECS) into the main grid. The applicable solution to overcome intermittent nature of the solar energy has been discussed. Various government and private entities have charted energy policy in a way forward to beat the challenges of grid integrated operation of SECS. The innovation in technologies such as process bus technology, digitizing sub-station, geographical-information system, advanced metering infrastructure has been briefed to mitigate synchronization issues with SECS. The key component of integrated operation of the solar system is inverters. Inverters are the solid technical backbone of smart grid capable of performing multiple functions such as static compensator mitigating harmonics and voltage stability assessment.*

Key Words: Solar Energy, Renewable energy Sources (RES), Single Stage (SS), Dual Stage (DS), Power quality (PQ), Smart Grid (SG).

1.INTRODUCTION

Power quality improvement, synchronization, power flow monitoring and availability of neutral line for harmonics mitigation were there to be addressed[1,2]. The integration of solar energy to the existing grid has a great impact on economy, environment and reliability aspects of the Indian supply system such as low carbon emission, reduced cost of electricity and enhanced reliability and efficient supply system. For efficient grid integration of SECS, several actions need to be taken to address various issues, such as flexible power generation with distributed as well as conventional sources, voltage/frequency control, operating reserve, forecasting and scheduling, deviation settlement mechanism, equalizing mechanism, standardized data telemetry and communication systems, establishment of Renewable Energy Management Centers (REMCs), augmentation and strengthening of transmission system, and compliance to regulations and standards in power generation from renewable sources of energy [3]. At present India is in fifth position in solar power generation with installed capacity as shown in figure 1.

Though the efficiency of electricity production from SECS is lower than conventional resources, it is the need of time to move to a green form of power since conventional resources have high carbon emission which leads to global warming [4]. The adverse effects of climate change are much more discernible than ever before, with a better understanding of the relationship between energy use and poor environmental outcomes. While the global agenda is of common concern, there is a heightened consciousness of the need to fix poor air quality standards in Indian cities, which is being reflected in tough administrative actions and court mandated orders [6].

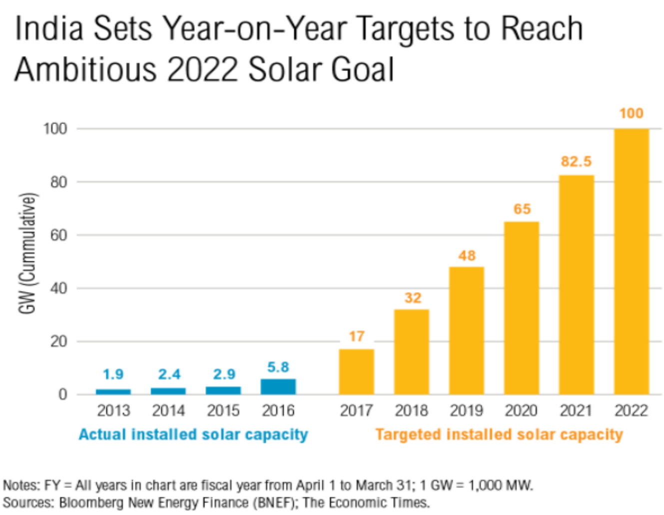

Fig -1: Installed capacity of SECS in India as on march 2022

2. DVR DESIGN AND CONTROL

Large solar plant installation with grid integration is on boom to assist existing utility structure. In order to generate Solar and PV forecasts, diverse resources are used ranging from measured weather and PV system data to satellite and sky imagery observations of clouds, to numerical weather prediction (NWP) models which are presented in figure 2, developed on the basis of modern weather forecasting. The usefulness of these resources varies depending on the forecast horizon considered: very short-term forecasts (0 to 6 hours ahead) perform best when they make use of measured data, while numerical weather prediction models become essential for forecast horizons beyond approximately six hours. The best approaches make use of both data (fig-3) and NWP models.

In literature two types of grid integrated SECS have been reported [7-9]. One is single stage (SS) grid tied [10] SECS and another is dual stage (DS) grid tied SECS. In the SS grid tied system (fig-4) only one converter is designed which functions as both DC-DC and DC-AC converter. The MPPT controller may be within the converter or may be outside the converter a separate controller is designed. In DS grid tied system as shown in figure 5 [11-12] two separate converters for DC-DC output voltage regulation and DC-AC conversion are designed. DC converter incorporates the MPPT controller and AC converter satisfies the grid code requirements. The choice among SS and DS depends upon the efficiency, cost function and complexity.

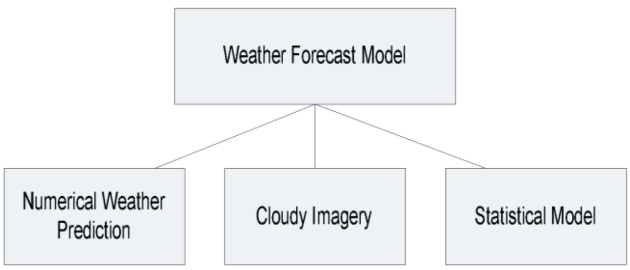

Fig -2: Various forecasting methods

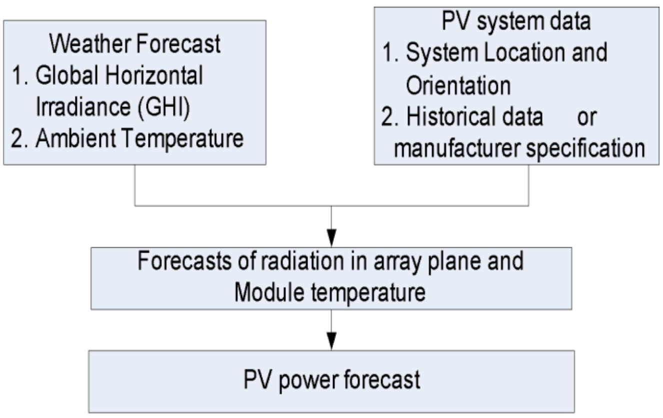

Fig -3: typical physical approach for generating PV power forecast from weather forecasts and PV system data

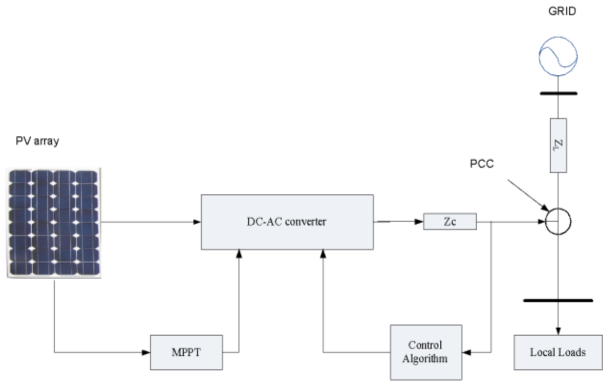

Fig -4: Grid tied Single Stage solar energy conversion system

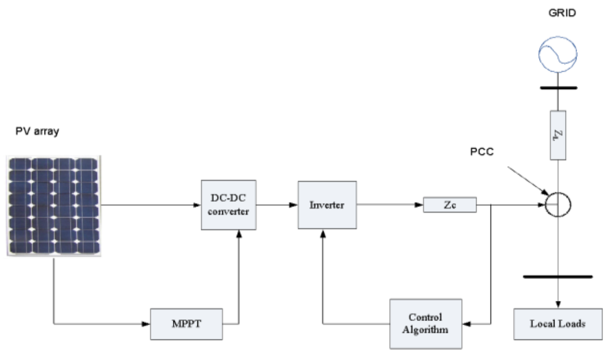

Fig- 5: Grid tied Dual Stage solar energy conversion system

3. Technological improvising for Power quality mitigation of SECS

For harmonic mitigation IEC has initiated standardization in 1995 and 1998 in a draft IEC-61400-21 and 61400-21 [13]. Sensitive loads are affected by voltage instability, in [14] it is compensated using PEC control, [33] employs sequence components to compensate voltage as a complementary control. Reactive power compensation has always been a hot topic for researchers at all operating scenarios. In SECS uncounted literatures [15] are available addressing the real and reactive power management (RRPM) issues. In [16] RRPM is presented as an optimization problem which is formulated using linear programming. A base power reservoir is maintained by adding battery storage in conjunction with the PV, but it adds to the system investment. An optimal solution is searched by forming the cost function (CF) in the form of batteries SOC, SOH (state of charge, state of health, cash received and cash paid) using the following equations;

$$P_{GRID}(t) = P_{pv}(t) + P_{BAT}(t) + P_{LOAD}(t) \quad 1$$

$$SOC^{\min} \leq SOC(t) \leq SOC^{\max} \quad 2$$

$$P_{BAT}^{\min} \le P_{BAT}(t) \le P_{BAT}^{\max} \quad 3$$

$$SOH(t) \ge SOH^{\min} \quad 4$$

$$P_{GRID}(t) \le P_{GRID}^{\max} \quad 5$$

Since load connection is uncontrollable, so the CF for battery storage SECS can be determined as below;

$$\min(CF) = \min \sum_{t=0}^{T} [CR(t) + CP(t)] \quad 6$$

Where CR is the benefit of the system operator and CP is the cost of energy supplied to the load. The SOC of battery is a nonlinear function governed by the power generated by the SECS and supply demand. For excessive power generation, excessive charging of the battery may lead to voltage shot at the battery terminal and when load demand is high the battery bank may suffer the condition of under charging. Over and under charging of batteries may reduce its state of health, hence ESS are designed to coordinate charging and discharging voltages of battery [17-20]. In [20], Designed an adaptive model for battery parameter estimation based on recursive least square and Kalman filter as shown in Fig-6.

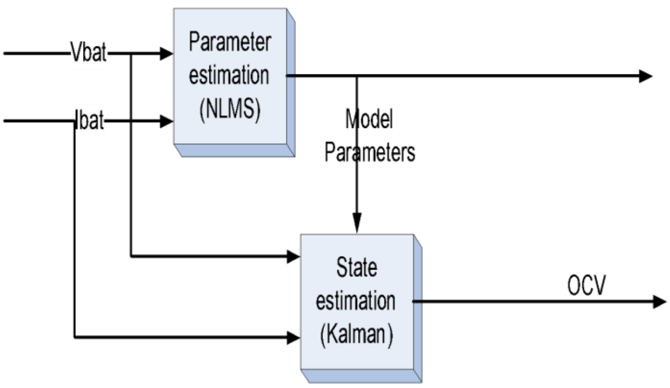

Fig-6 Adaptive EMS for battery parameter estimation [20]

4. CONCLUSIONS

This era witnesses the high penetration of solar in the existing system. There has been several important control complexity with Solar for Power quality such as grid voltage distortion when there are nonlinear loads and/or how to make sure that a balanced neutral line is provided for three-phase loads; operation of inverters in the grid-connected mode or the stand-alone balanced mode; and how to minimize the transient dynamics; how to synchronize inverters with the grid; how to make sure that parallel-operated inverters share power proportionally according to their power ratings to avoid damage; how to operate grid-connected inverters within grid code so that the impact on the grid is minimized, etc. Many research works are available to address these problems over the past 10 years. This work presents the extensive survey of solar generation with technological development.

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