Technical Aspects of Grid Connected PV Array

Gaurav Chauhan, Sakshi Bangia
Department of electrical engineering, J.C. Bose University of Science and Technology, YMCA, Faridabad, Haryana, India.
Chauhangaurav2050@gmail.com, sakshibangia@gmail.com

Abstract. Solar PV energy is a form of renewable energy which uses free and abundant energy from sun and gives an environmental friendly cyclic operation. The output of a PV system is fluctuating in nature which in turn reduces its reliability and do not provide the continuous power to the end users. The solar PV array can be directly connected to the grid or can have a standalone (off grid) connection. Due to seasonal and periodic variation the off grid connection does not provide the continuous supply of energy and hence is not reliable. So grid connected PV systems are required in order to satisfy the load demand. In this work the performance analysis of grid connected PV array has been carried out. The simulation is done in MATLAB and power profile is estimated with different load conditions and different problems associated with grid connected PV array have been identified.

Keywords: Standalone, off-grid, MATLAB, PV array, MPPT.

1. Introduction
The demand of electricity is increasing day by day in today’s world, which motivated the use of renewable sources of energy. PV generation system and wind energy are most commonly used renewable sources of energy. Total installed capacity of PV system in the world is 512GW and installed capacity of solar power in India is 33.73GW as of 31 December 2019 and capital cost per MW is lowest in India. As of January 2019, 3.4% of total electricity generation is done by solar PV array.

Table 1. Annual solar power generation (as per ministry of power)

| Year  | Solar power generation(TWh) |
|-------|-----------------------------|
| 2013-14 | 3.35                        |
| 2014-15 | 4.60                        |
| 2015-16 | 7.45                        |
| 2016-17 | 12.09                       |
| 2017-18 | 25.87                       |
| 2018-19 | 39.27                       |

The first PV cell was developed by Becquerel in 1839. According to him, there are some materials which produce electricity when exposed in sunlight PV. The power generated by a PV array is clean, quiet and reliable. PV array consist of photovoltaic cells which directly generates electricity from light energy. A DC voltage is generated by PV array which is then converted into AC by using inverters and then supplied to the consumers. There are fluctuations in the power output of PV array due to the change in the environmental conditions which
degrade the output of inverter which may cause to degrade the performance of utility. Block diagram of grid connected PV array is shown in fig.-1.

![Block diagram of grid connected PV array](image)

**Figure 1.** Grid interconnected PV array

It consists of:
- PV array that gives PV voltage and current output depending on solar irradiance.
- Inverter which converts DC into 3-phase AC.
- Filters to reduce the harmonic distortion.
- A control unit which synchronizes the output of inverter to the grid.

In this paper: Section II describes the mathematical modelling of single diode PV cell and MPPT by incremental conductance method. The results obtain with and without grid connection to the PV array are discussed in Section III. Conclusion is presented in Section IV.

### 2. Mathematical modelling

#### 2.1. PV array

A PV cell is a semiconductor device which produces electrical current when its p-n junction is exposed in light [1]. Different kind of semiconductors can be used for the manufacturing of a PV cell. At present time monocrystalline and polycrystalline silicon cells are mainly used. When solar radiations strike on p-n junction it generates charge carriers as a result electrical current start flowing due to the short circuit in the cell [1].

![Single diode PV cell](image)

**Figure 2.** Single diode PV cell

A single diode PV cell model is shown in figure 2 [2]. Some authors used an extra diode which makes the model more sophisticated but present better accuracy and can be used for different purposes [3] & [4]. Some authors proposed three-diode model as well which gives better accuracy and includes the effect of recombination [5]. In this paper a single diode model is used for simplicity [6].

A diode in parallel with current source is used here and many authors used this model in previous work with some simplification but the basic structure remains the same [7], [8] and [9]. The photovoltaic current is given by the equation (4).
2.2. MPPT and Controller

Here incremental conductance method for maximum power point tracking has been used which increases the accuracy of MPPT and is advantageous overcome to perturb and observe (P&O) method. The IC method of power point tracking stops after determining that the MPPT[10] has reached the MPP. Figure-3 shows the MPPT algorithm using incremental conductance method [10]

\[
I = I_t - I_d  \hspace{1cm} (1) \\
I_d = I_s (e^{\frac{qv}{NKT}} - 1)  \hspace{1cm} (2) \\
I = I_t - I_d - I_{sh} \hspace{1cm} (3) \\
I_s = I_s N_p - N_p [I_s (e^{\frac{(V_s + I_s R_s N_p)}{N_p}} - 1)] - \frac{(V_s + I_s N_p R_s)}{N_p} \hspace{1cm} (4)
\]

**Figure 3.** Flow chart of MPPT using incremental conductance method
3. Simulation Models

Maximum of 100 kW is delivered by PV array at 1000W/m² sun irradiance. A DC-DC boost converter is used to step up the natural PV output voltage from 270 V DC to 500V DC.

3.1. Simulation Model of Incremental conductance

MPPT controller optimizes the duty cycle which uses the incremental conductance technique. Maximum power is extracted automatically by MPPT system and the required voltage is generated by varying the duty cycle.

3.2. Simulation model of VSC controller

500 V DC link voltage is converted into 260 V AC by using VSC control. It also helps in keeping the unity power factor. VSC controller not only regulates DC link voltage but also generates active and reactive grid current components. A time of 100 micro seconds is used by the current and voltage controller.
3.3. Grid connected PV array

![Grid connected PV array model](image)

**Figure 6.** Grid connected PV array model

| Component                  | Description                                           |
|----------------------------|-------------------------------------------------------|
| PV array                   | 100 kW at 1000W/m² irradiance                        |
| 5-kHz DC-DC boost converter| 275 V DC to 500V DC                                   |
| 3-level 3-phase VSC        | Converts 500 V DC to 260 V AC                        |
| 10-kvar capacitor bank     | Filter harmonics produced by VSC                      |
| 3-phase coupling transformer| 100-kVA, 260V/25KV                                   |
| Utility grid               | 25-kv distribution feeder +120 Kv equivalent feeder   |

**Table 2.** Various components of simulink model
4. Results and Discussion

Figure 7. Variation in temperature and irradiance

4.1. PV array connected to grid (on load)

Figure 8. Power absorption by grid

Fig.8 shows the power absorbed by the grid. Due to the variability in atmospheric condition the wave shape is not smooth. Dependency of inputs (irradiation and temperature) on time is major cause of output fluctuations.

Figure 9. Phase-a voltage and current

Phase-a voltage waveform and current waveform are shown in above figure. It is clear from the waveforms that there are lots of harmonic content due the presence of nonlinearity in the input. These harmonics affects the overall performance of the system.
Fig. 10 shows the VSC output of line voltage Vab. The primary function of VSC is used to convert the dc output of PV array into ac. Multi stage converter is used which reduces the total harmonic distortion at the ac side of the system which can be further reduces by using suitable AC filter.

For the functioning of VSC the two important parameters are modulation index and $V_{\text{ref}}$ for dc to ac conversion which are shown in above figure. These come out from the 3-level PWM generator and the reference generator providing the $V_{abc}$ as the input of reference generator.

Fig 12 shows the various atmospheric conditions like irradiance and temperature as the function of time. Change in atmospheric conditions affects the mean value of voltage, power and duty cycle, which are finally used for MPPT.

4.2. PV array disconnected to grid (no load)
The behaviour of the system when it is on no load is shown by results below:

![Figure 13. Power absorbed by grid](image)

It is clear from the fig. 13 that the isolation of the grid from PV array results in zero power drawn. The output power and the load current come to zero as load is removed from common bus bar.

![Figure 14. Phase-a voltage and current](image)

Fig. 14 shows phase a waveforms at no load. The removal of load from common ac bus bar results in zero current (due to an open circuit) and some fluctuating no load phase voltage.

![Figure 15. Output voltage (Vab) of VSC](image)

DC to AC converted output by VSC is shown in Fig. 15. There will be some transients at the starting of no load operation that will die out with time. These fluctuations can damage the VSC components so proper care should be taken at the starting of no load operation.
Variation in irradiance, temperature, Pmean, Vmean and duty cycle

The time dependent waveforms of irradiance and temperature (inputs of PV array) are shown in Fig.16. Mean value of power, voltage and duty cycle (depends on the atmospheric conditions) used for MPPT.

5. Conclusion
In this paper, MATLAB/SIMULINK is used for the modelling and simulation of PV array. The performance of the PV array has been studied with and without grid connection. The MPPT by ‘incremental conductance’ method is used for tracking maximum amount of power from solar radiations as the output of the PV array is fluctuating and hence not reliable (can be seen from waveforms) with grid connection and there is no power drawn from the PV array if grid is not connected which further reduces the performance of PV array.

6. References

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