High Performance Constant Power Generation for Variable Load Using PV Systems

[1]Ms. Heenali V. Korgaonkar,
Student, (M.E Electrical power system)
YTIET, Karjat.

[2]Prof. Ganesh Mhatre,
Assistant Professor
NHITM, Thane.

(Department of Electrical Engineering, University of Mumbai)

Abstract: A fast and smooth transition between maximum power point tracking and Constant Power Generation (CPG) is ensured which limits the maximum feed-in power of PV systems by using advanced power control strategy. High-performance and stable operation are always achieved regardless of the solar irradiance levels. Without stability problems, the PV output power is regulated to any set-point and operates at the left side of the maximum power point. It describes the operational principle of the P&O-CPG algorithm which is applied to two-stage single-phase grid connected PV system to obtain a stable CPG operation. The effectiveness of the proposed CPG control in terms of high accuracy, fast dynamics, and stable transitions can been verified.

Keywords: **Constant power control, maximum power point tracking, PV systems, power converters.**

1. INTRODUCTION

In order to maximize the energy yield using PV systems, Maximum Power Point Tracking (MPPT) operation is mandatory. Advanced power control schemes as well as the regulations are required to avoid adverse impacts from PV systems like overloading the power due to more PV installations. As stated in the German Federal Law: Renewable Energy Sources Act, the PV systems with the rated power below 30 kWp limits the maximum feed-in power unless remotely controlled by the utility [4]. Such an active power control is referred to as a Constant Power Generation (CPG) control. By modifying the MPPT algorithm at the PV inverter level, CPG control can be achieved. Specifically, when the PV output power P_{pv} is below the setting-point $P_{limit,}$ PV system is operated in the MPPT mode. However, when the output power reaches P_{limit}, the output power of the PV system is constant, i.e., $P_{pv} = P_{limit}$, and leading to a constant active power injection as shown in (1) and illustrated in Fig. 1.1.

$$P_{PV} = P_{MPPT}, \quad \text{when } P_{PV} \leq P_{LIMIT} \quad \text{-------- (1)}$$
$$P_{PV} = P_{LIMIT}, \quad \text{when } P_{PV} > P_{LIMIT}$$

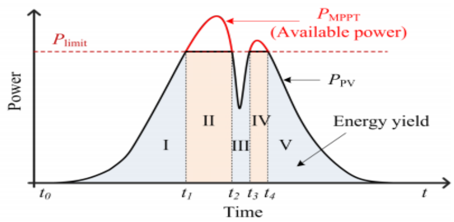


Fig. 1.1 Constant Power Generation (CPG) concept: 1) MPPT mode during I, III, V, and
2) CPG mode during II, IV

2. METHODOLOGY

In single stage grid connected PV systems [7], the CPG based on a Perturb and Observe (P&O-CPG) algorithm was introduced, where the operating area is limited to be at the right side of the Maximum Power Point (MPP) of the PV arrays (CPP-R).When PV systems experience a fast decrease in the irradiance, the robustness of the control algorithm decreases. The operating point may go to the open-circuit condition as shown in Fig. 2.1.

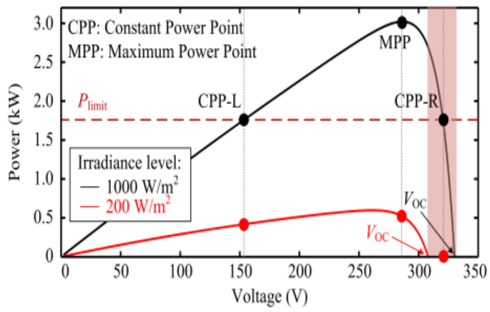


Fig. 2.1 Stability issues of the conventional CPG algorithms, when the operating point is located at the right side of MPP.

The above issues are resolved, by extending the operating area of the P&O-CPG algorithm using two-stage grid connected PV system. By regulating the PV output power at the left side of the MPP (CPP-L), a stable CPG operation can be achieved, since the operating point will never "fall off the hill" during a fast decrease in the irradiance. Thus, the P&O-CPG algorithm can be applied to any two-stage single-phase grid connected PV system.

3. PROPOSED MODEL

3.1 CONVENTIONAL CPG ALGORITHM

3.1.1 System Configuration:

Fig.3.1 shows the basic hardware configuration of a two-stage single-phase grid-connected PV system and its control structure. The CPG control is implemented in the boost converter. The cascaded control of the full-bridge inverter is done where the DC-link voltage is kept constant through the control of the AC grid current, which is an inner loop. The PV system operates at a unity power factor, only when active power is injected to the grid. Here the two-stage configuration can extend the operating range of both the MPPT and CPG algorithms. In the two-stage case, the PV output voltage vpv can be lower (i.e at the left side of the MPP), which is stepped up by using boost converter to match the required DC-link voltage.

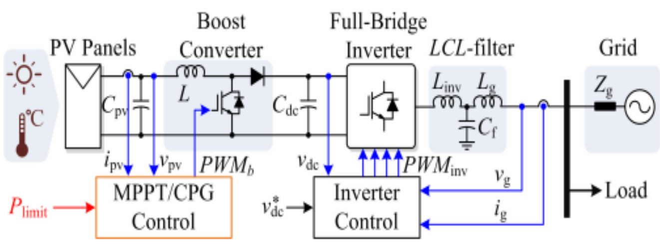


Fig 3.1 Hardware schematic and overall control structure of a two-stage single phase grid-connected PV system.

3.1.2 Operational Principle:

The operational principle of the conventional P&O-CPG algorithm is given in Fig 3.2. It operates into two modes: a) For MPPT mode (Ppv ≤ Plimit), the P&O algorithm should track the maximum power,b) For CPG mode (Ppv > Plimit), the PV output power is limited at Plimit. The behavior of the algorithm is similar to the conventional P&O MPPT algorithm during the MPPT operation. The operating point will track and oscillate around the MPP. For CPG operation, the PV voltage *v*pv is continuously perturbed toward a Constant Power Point (CPP), i.e., $P_{pv} = P_{limit}$. The operating point will reach and oscillate around the CPP, after a number of iterations. Only the operation at the left side of the MPP (CPP-L) is considered for the stability concern, even if the PV system with the P&O-CPG control can operate at both CPPs. The control structure of the algorithm is shown in Fig 3.3. where v^*_{pv} can be expressed as

$$v^*_{pv} = v_{mppt}, \quad when\ P_{pv} \le P_{limit}$$
$$= v_{pv,n} - v_{step}, \quad when\ P_{pv} > P_{limit} \text{ -------(2)}$$

where V_{MPPT} is the reference voltage from the MPPT algorithm (i.e., the P&O MPPT algorithm), vpv,n is the measured PV voltage, and vstep is the perturbation step size.

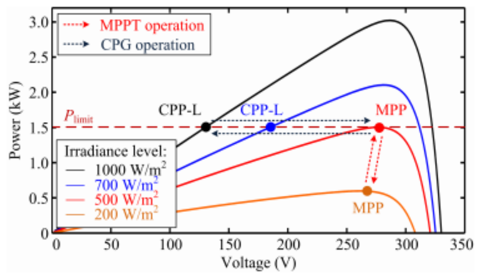


Fig 3.2 Operational principle of the P&O-CPG algorithm with stability issues.

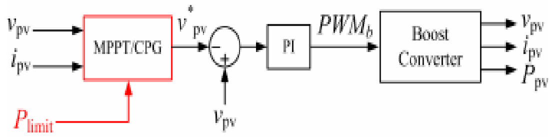


Fig 3.3 Control structure of Algorithm with Proportional Integrator (PI)

3.1.3 Issues of the P&O-CPG Algorithm:

The operation trajectory of the PV system presented in Fig.3.4. Assuming that the PV system is operating in MPPT mode initially and the irradiance level suddenly increases, the PV power P_{pv} increases by the change in the irradiance causing large power overshoots (i.e. A→B→C). Similarly, if the PV system is operating in the CPG operation (e.g., at CPP-L) and the irradiance suddenly drops, the output power *P*pv decreases suddenly, (i.e., C→D). The operating point reaches the new MPP (i.e., E) at that irradiance condition, after undergoing number of iterations, resulting in loss of power generation.

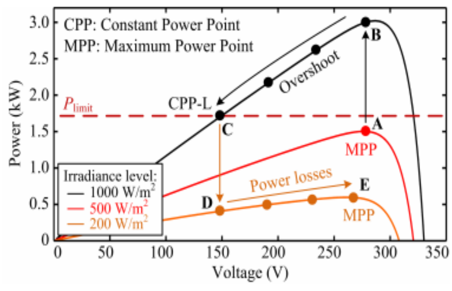


Fig 3.4. Operating trajectory of the algorithm resulting in overshoot and power losses.

3.2 HIGH-PERFORMANCE P&O-CPG ALGORITHM

As addressed in the case of CPG operation, there exist two main tasks - minimizing the overshoots and minimizing the power losses during the fast changing irradiance condition. This issues can be effectively solved using proposed high-performance P&O-CPG algorithm.

A. Minimizing Overshoots

Increasing the perturbation step size is a possibility to minimize the overshoots as the tracking speed is increased. Specifically, a large step size can reduce the required number of iterations to reach the corresponding CPP. When the algorithm detects a fast increase in the Irradiance Condition (IC), then only the step size modification should be enabled which can be given as

$$IC = 1, \quad when\ P_{pv,n} - P_{limit} > \varepsilon_{inc}$$
$$= 0, \quad when\ P_{pv,n} - P_{limit} \leq \varepsilon_{inc} \quad \text{-------- (3)}$$

with Ppv,n being the measured PV power at the present sampling, and "inc being the criterion, which should be larger than the steady-state power oscillation of the PV panels. When a fast increase in the IC is detected (i.e., IC = 1), an adaptive step size is then employed, where the step size is calculated based on the difference between Plimit and Ppv,n as it is given in (4). By doing so, the large step size will be used initially and the step size will continuously be reduced as the operating point approaches to the CPP.

$$v_{pv}^* = v_{pv,n} - \left[\left(P_{pv,n} - P_{limit} \right) \frac{P_{limit}}{P_{mp} \cdot \gamma} \right] . v_{step} \qquad \text{------ (4)}$$

where v*pv is the reference output voltage of the PV arrays, vpv,n and Ppv,n are the measured output voltage and power of the PV array at the present sampling, respectively. Pmp is the rated power. Vstep is the original step size of the P&O-CPG algorithm. The term Plimit /Pmp is introduced to alleviate the step size dependency in the level of Plimit. γ is a constant which can be used to tune the speed of the algorithm.

B. Minimizing Power Losses

As explained in Fig. 3.4, when the CPG operating point is at the left side of the MPP, the P&O-CPG algorithm requires a number of iterations to reach the new MPP during a fast decease in irradiance, leading to power losses. As the operating decrease in irradiance, leading to power losses. As the operating point of the PV system does not change much if the PV system is operating in the MPPT under different irradiance levels as shown in Fig.3.6. Notably, the detection of the decreased IC as well as the Previous Operating Mode (POM) is also important for minimizing the power losses:

$$\begin{aligned} IC &= 1, \quad when\ P_{pv,n-1} - P_{pv,n} > \varepsilon_{dec} \\ &= 0, \quad when\ P_{pv,n-1} - P_{pv,n} \le \varepsilon_{dec} \end{aligned} \qquad \text{-------- (5)}$$

$$\begin{aligned} POM &= CPG, \quad when \left| P_{limit} - P_{pv,n-1} \right| < \varepsilon_{ss} \\ &= MPPT, \quad when \left| P_{limit} - P_{pv,n-1} \right| \ge \varepsilon_{ss} \end{aligned} \qquad \text{-------- (6)}$$

where "dec and "ss are criteria to determine the fast irradiance decrease and the CPG operating mode, respectively. Ppv,n-1 is the measured PV power at the previous sampling. When a fast decrease (i.e., IC = 1) is detected during the CPG to MPPT transition according to (6), a constant voltage given by (7) is applied to the PV system in order to accelerate the tracking speed (i.e., minimize the power losses). The constant voltage can be approximated as 71-78 % of the open circuit voltage VOC, as illustrated in Fig. 3.6.

$$v_{pv}^* = k.V_{OC}\,, \qquad where\ 0.71 \le k < 0.78 \qquad \text{------ (7)}$$

Due to this the operating point can be instantaneously moved close to the MPP (i.e., D!E) in one perturbation, resulting in a significant reduction in the number of iterations until the operating point reaches the MPP. This approach is simple but effective, which is very suitable to be implemented.

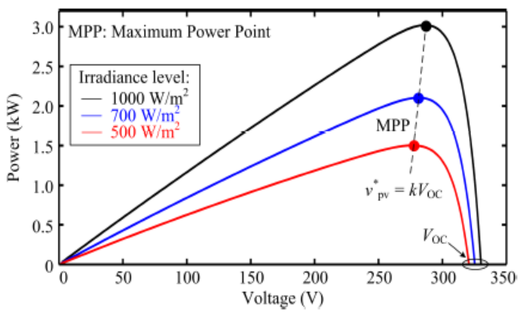


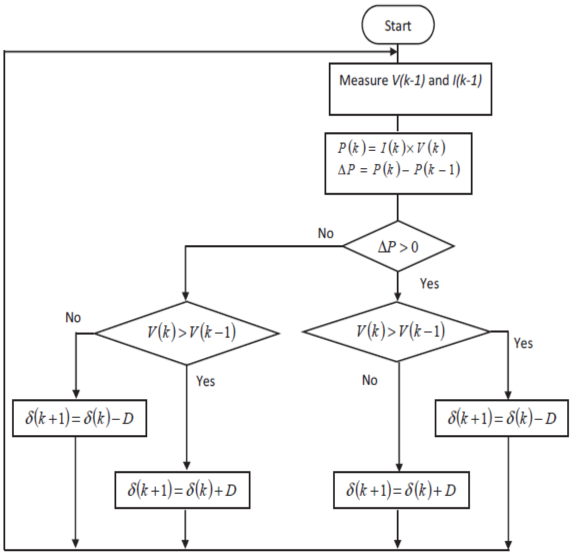
Fig 3.5 Power-voltage (P-V) curves of the PV arrays, where the voltage at the MPP is almost constant especially at a higher irradiance level.

3.3 SELECTION OF DESIRED MPPT

The major characteristics of all MPPT techniques are summarized in one table which gives better understanding with simplicity and comparative analysis. Only those techniques which are applicable for efficient and reliable operation of PV system can be chosen.

3.3.1 Perturb & Observe (P & O) Algorithm:

P&O is widely used due to easy implementation. This technique forces the PV system to approach MPP by increasing or decreasing the panel output voltage.



To check direction change in maximum power, the P&O method perturbs the operating voltage of PV panel. There are two conditions: 1)When power increases; operating voltage perturbs in same direction. 2) When power decreases; operating voltage perturbs in reverse direction. This process will continue until MPP is reached. The oscillations around MPP is minimized by reducing perturbation step size D. MPPT techniques and having good performance characteristic are generally used. When we take parameters in account like efficiency, implementation, sensor, cost and applications etc. The P&O is one of the best conventional technique.

An improved perturbation and observation method (IP&O) based on fixed algorithm is proposed, which is automatically adjusts the reference step size and hysteresis bandwidth for power comparison. It increases the total PV output power at an unsettled weather condition compare to traditional perturbation and observation method (P&O). The tracking response is higher. When IP&O method has rapidly changing atmospheric conditions then there is unpredictable performance with oscillations around maximum power point (MPP). It has high reliability and is very complex. The improved P&O method is introduced, based on hysteresis band and auto-tuning perturbation step. There is trade-off between dynamic response and steady state due to the selection of 'dv" the perturbation step. The system response of the IP&O method has faster dynamic response and higher induced-power than the Perturbation and Observation (P&O) method has.

4. RESULTS AND DISCUSSIONS

4.1 SIMULATION SETUP

Here fusion technique was anticipated where conventional P&O-CPG method and improved P&O-CPG method are applied to obtain the reliable and highly efficient grid operation using Photovoltaic system. By using P&O-CPG method the issues in operation of grid load are caused due fast changing irradiance condition. The problems of overshoots and power losses are solved using improved P&O-CPG method. The proposed method is implemented in MATLAB 2016a. The simulations were carried out on a PC with 2.0 GHz CPU and 4 GB RAM and system type is 64 bit operating system, x64 based processor.

4.1.1 Perturb and Observe based CPG algorithm (P&O-CPG) under clear and cloudy day condition:

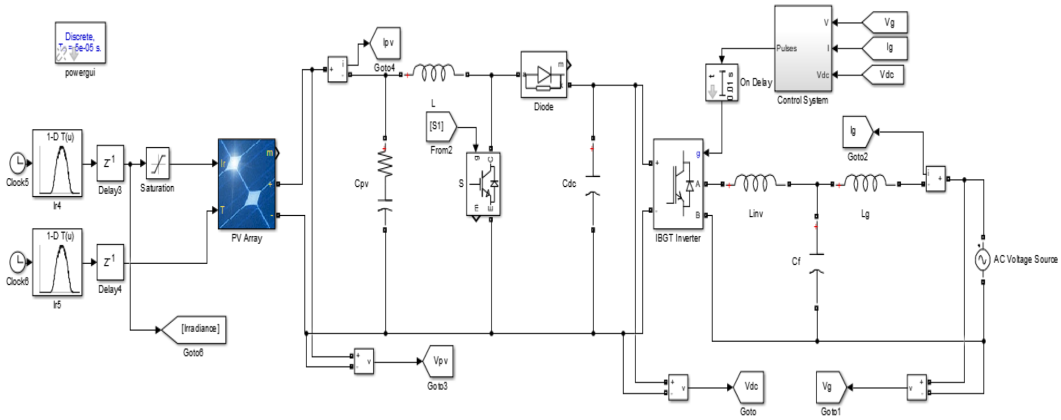


Fig 4.1 Perturb and Observe based CPG algorithm (P&O-CPG) under clear day condition.

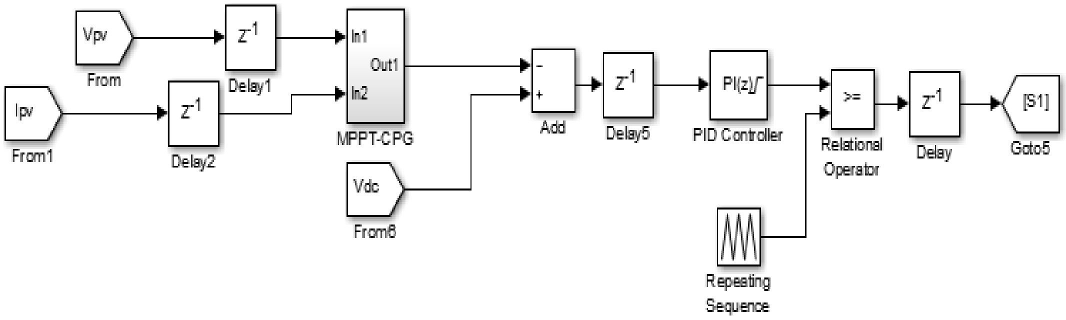


Fig 4.2 Control system for conventional P&O-CPG method.

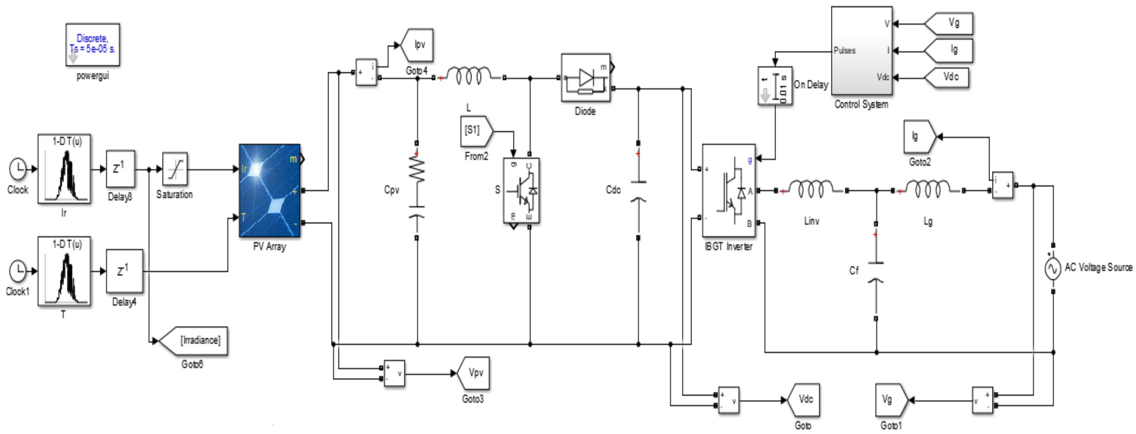


Fig 4.3 Perturb and Observe based CPG algorithm (P&O-CPG) under cloudy day condition.

The P&O-CPG algorithm has a satisfied performance under slow changing irradiance conditions during a clear day, when the operating point is at the left side of the MPP, as shown in Fig.4.4. For a clear day, as the time goes on changing from morning hours, the power to be tracked goes on increasing. When the PV power is less than the limited power, the MPPT mode is operated where P&O algorithm tracks the maximum power. But as the PV power becomes greater than limited power at peak hours, then the CPG mode is operated where PV power equals limited power. Again as the time changes to evening hours, the power decreases below the limited power.

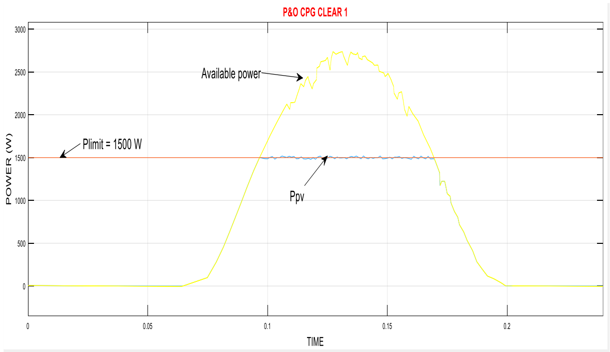


Fig 4.4 Simulation results of the P&O based CPG algorithm under clear day condition.

However, irradiance fluctuation that may happen in a cloudy day will result in overshoots and power losses as shown in Fig.4.5. Initially at MPPT mode, as irradiance level increases, the PV power is lifted by change in irradiance which causes large overshoots during peak hours. As the PV system operates in CPG mode, the irradiance level starts dropping where the PV power decreases suddenly. Now the operating point requires more iteration to reach the new MPP level at that irradiance and thus cause power losses in the system. Hence the PV power is therefore not limited.

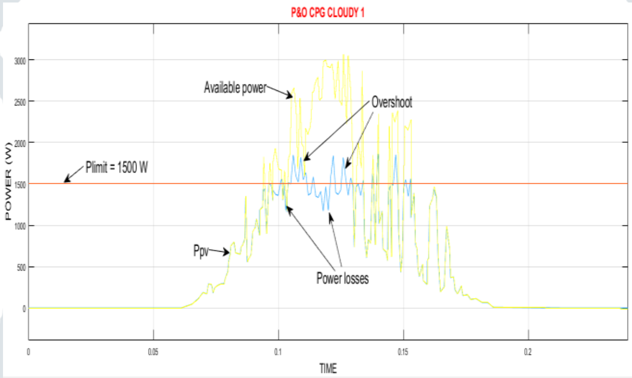


Fig 4.5 Simulation results of the P&O based CPG algorithm under cloudy day condition.

4.1.2 Proposed High-performance Perturb and Observe based CPG algorithm (P&O-CPG) under clear and cloudy day condition:

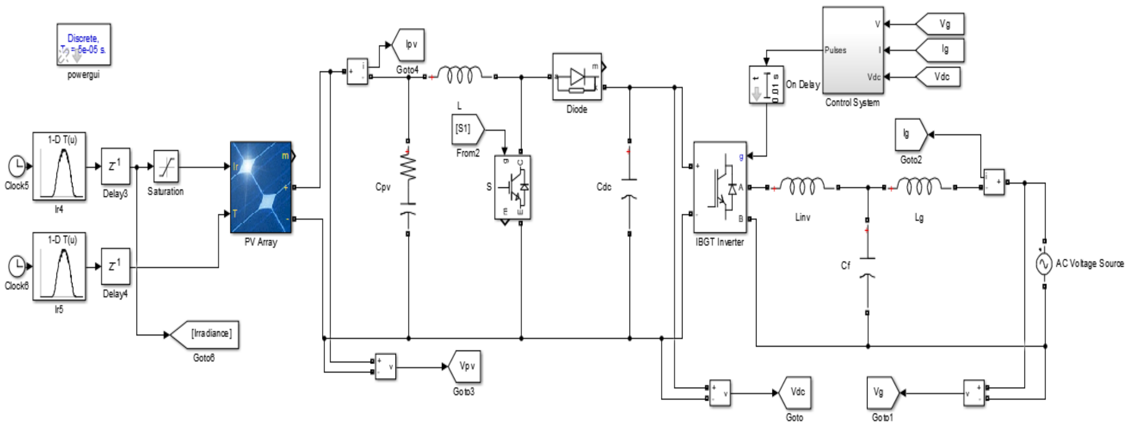


Fig 4.6 Proposed High-performance P&O-CPG algorithm under clear day condition

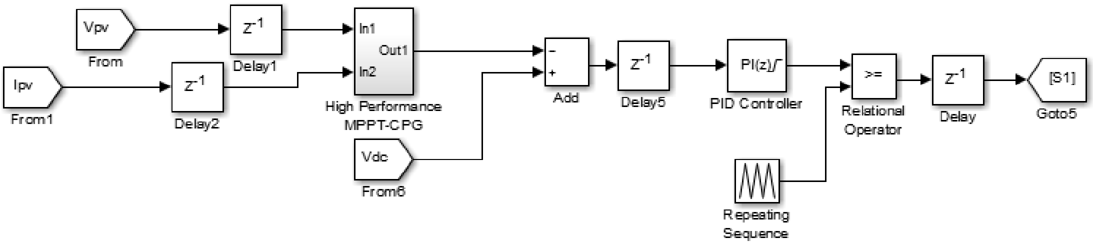


Fig 4.7 Control system for High-performance P&O-CPG method**.**

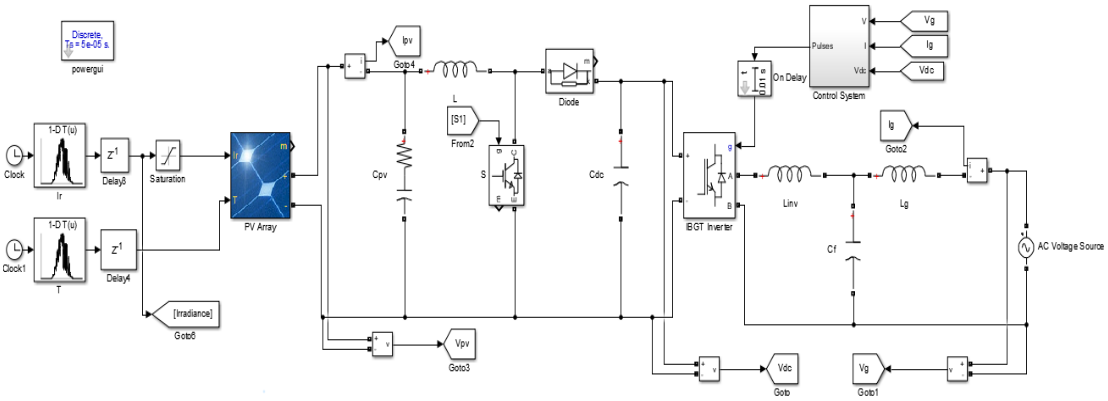


Fig 4.8 Proposed High-performance P&O-CPG algorithm under cloudy day condition.

4.2 SIMULATION VERIFICATION

Solutions to improve the dynamic performance of the P&O CPG algorithm can be clarified by using the above proposed system. Parameters of the proposed high-performance P&O-CPG algorithm are designed as: $\gamma = 10$, $k = 0.715$, "inc = 50 W, "dec = 100 W, and "ss = 30 W. Simulation is carried out referring to Fig.3.1, and the system parameters are given in Table I. In the simulation, a 3-kW PV simulator has been adopted, where real-field solar irradiance and ambient temperature profiles are programmed.

Boost converter inductor	L = 1.8 mH
PV-side capacitor	C_{pv} = 1000 µF
DC-link capacitor	C_{dc} = 1100 µF
LCL-filter	$L_{inv} =$ 4.8 mH, L_g = 4 mH, C_f = 4.3 µF
Switching frequency	Boost converter: f_b = 16 kHz, Full-Bridge inverter: f_{inv} = 8 kHz
DC-link voltage	V_{dc} = 450 V
Grid nominal voltage (RMS)	V_g = 230 V
Grid nominal frequency	$\omega_0 = 2\pi * 50$ rad/s

Table I. Parameters of the Two-Stage Single phase PV system.

Below Figure shows the performance of the proposed high performance P&O-CPG method with two real-field daily conditions. In contrast to the conventional P&O-CPG method, the overshoots and power losses are significantly reduced by the proposed solution and a stable operation is also maintained. The algorithm also has a selective behavior to only react, when the fast irradiance condition is detected. This can be seen from the performance under clear irradiance conditions in Fig.4.9, which is similar to the conventional P&O-CPG algorithm. Fig.4.10 shows that the overshoot and power losses are reduced during cloudy day generating constant power by increasing the perturbation step size.

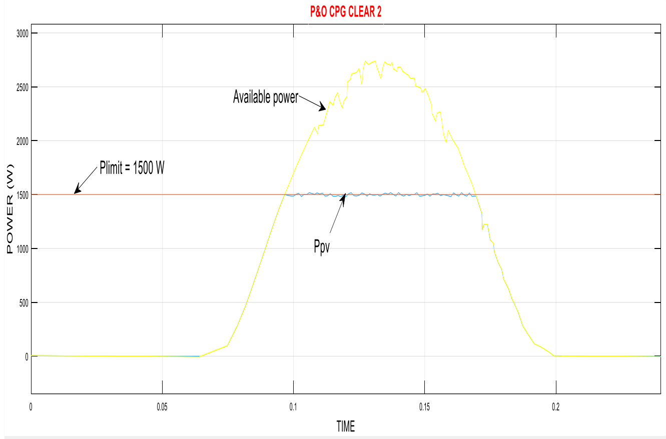


Fig 4.9 Simulation results of the Proposed High-performance P&O-CPG algorithm under clear day condition

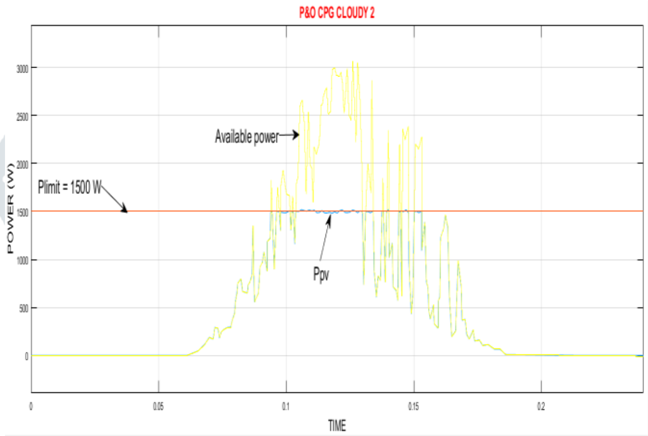


Fig 4.10 Simulation results of the Proposed High-performance P&O-CPG algorithm under cloudy day condition

The below graphs indicate graphical representation of Power Vs Voltage for changing irradiance condition with constant temperature value and I-V graph showing different irradiance condition operating at 25° C. The P-V graph represents different operating modes like maximum power tracking and generation of constant power.

5. CONCLUSION

A high-performance active power control scheme by limiting the maximum feed-in power of PV systems has been proposed in this project. The solution to the proposed system can ensure a stable constant power generation operation. Compared to the traditional methods, the proposed control strategy forces the PV systems to operate at the left side of the maximum power point, and thus it can achieve a stable operation as well as smooth transitions. It uses design of photo voltaic system, simple boost converter, perturbation and observation (P&O), improved perturbation and observation (IP&O) to achieve stable outputs. The PV cell output voltage varies with atmospheric parameters such as temperature and irradiation. P&O method is widely used in photovoltaic (PV) systems because of its simplicity and easily of implementation, which moves the operating point towards the maximum power point and sometimes deviates from the maximum operating point.

The Improved perturbation and observation (IP&O) has the tracking response will be higher. When IP&O method has rapidly changing atmospheric conditions then the unpredictable performance with oscillations around maximum power point (MPP) is reduced. Due to its reliability and complexity, it has advantage to find the real MPP under any working conditions, No oscillation during tracking and steady state operations, Low computational burden required.

Simulation has verified the effectiveness of the proposed control solution in terms of reduced overshoots, minimized power losses, and fast dynamics. Notably, for single-stage PV systems, the same CPG concept is also applicable. However, in that case, the PV voltage operating range is limited and minor changes in the algorithms are necessary to ensure a stable operation.

REFERENCES

[1] T. Stetz, F. Marten, and M. Braun, “Improved low voltage grid integration of photovoltaic systems in Germany,” IEEE Trans. Sustain. Energy, vol. 4, no. 2, pp. 534–542, Apr. 2013.

[2] A. Ahmed, L. Ran, S. Moon, and J.-H. Park, “A fast PV power tracking control algorithm with reduced power mode,” IEEE Trans. Energy Conversion, vol. 28, no. 3, pp. 565–575, Sept. 2013.

[3] Y. Yang, H. Wang, F. Blaabjerg, and T. Kerekes, “A hybrid power control concept for PV inverters with reduced thermal loading,” IEEE Trans. Power Electron., vol. 29, no. 12, pp. 6271–6275, Dec. 2014.

[4] German Federal Law: Renewable Energy Sources Act (Gesetz fur den Vorrang Erneuerbarer Energien) BGBl, Std., July 2014.

[5] Energinet.dk, “Technical regulation 3.2.5 for wind power plants with a power output greater than 11 kw,” Tech. Rep., 2010.

[6] Y. Yang, F. Blaabjerg, and H. Wang, “Constant power generation of photovoltaic systems considering the distributed grid capacity,” in Proc. of APEC, pp. 379–385, Mar. 2014.

[7] R. G. Wandhare and V. Agarwal, “Precise active and reactive power control of the PV-DGS integrated with weak grid to increase PV penetration,” in Proc. of PVSC, pp. 3150–3155, Jun. 2014.

[8] W. Cao, Y. Ma, J. Wang, L. Yang, J. Wang, F. Wang, and L. M. Tolbert, “Two-stage PV inverter system emulator in converter based power grid emulation system,” in Proc. of ECCE, pp. 4518–4525, Sept. 2013.

[9] A. Urtasun, P. Sanchis, and L. Marroyo, “Limiting the power generated by a photovoltaic system,” in Proc. of SSD, pp. 1–6, Mar. 2013.

[10] S. B. Kjaer, J. K. Pedersen, and F. Blaabjerg, “A review of single-phase grid-connected inverters for photovoltaic modules,” IEEE Trans. Ind. Appl., vol. 41, no. 5, pp. 1292–1306, Sept. 2005.

[11] F. Blaabjerg, R. Teodorescu, M. Liserre, and A. V. Timbus, “Overview of control and grid synchronization for distributed power generation systems,” IEEE Trans. Ind. Electron., vol. 53, no. 5, pp. 1398–1409, Oct. 2006.

[12] B. Yang, W. Li, Y. Zhao, and X. He, “Design and analysis of a grid connected photovoltaic power system,” IEEE Trans. Power Electron., vol. 25, no. 4, pp. 992–1000, Apr. 2010.

[13] T. Esram and P. L. Chapman, “Comparison of photovoltaic array maximum power point tracking techniques,” IEEE Trans. Energy Conversion, vol. 22, no. 2, pp. 439–449, Jun. 2007.