CONSTANT POWER GENERATION BY GRID CONNECTED PV SYSTEMS USING DIFFERENT POWER CONTROL TECHNIQUES

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ABSTRACT: This paper proposes a stable constant power generation in PV systems connected to the grid by using improved control strategies like Maximum Power Point Technique(MPPT), Constant Power Generation (CPG) control. These involve in high accuracy, stable transitions, fast dynamics. Control strategy is implemented the incremental method of the maximum power which is feed to the PV systems and it is proposed to make sure about the smooth and fast transition between Constant Power Generation (CPG) and maximum power point tracking. Control strategy involves in stable operation regardless of solar irradiance levels and high performance. These control strategies can regulate by the PV output power according to any set-point, and it also force the PV systems to operate at the left side of the maximum power point without any stability problems. Simulation results have been verified in the effectiveness manner by using the proposed CPG control.

I. INTRODUCTION

Currently, Maximum Power Point Tracking (MPPT) operation is mandatory for grid-connected PV systems in order to maximize the energy yield. Catering for more PV installations requires to advance the power control schemes as well as the regulations in order to avoid adverse impacts from PV systems like overloading the power grid . For instance, in the German Federal Law: Renewable Energy Sources Act, the PV systems with the rated power below 30 kWp have to be able to limit the maximum feed-in power (e.g. 70 % of the rated power) unless it can be remotely controlled by the utility . Such an active power control is referred to as a Constant Power Generation (CPG) control or an absolute power control like described in the Danish grid code . Fundamentals of the CPG concept reveals that the most cost-effective way to achieve the CPG control is by modifying the MPPT algorithm at the PV inverter level. Specifically, the PV system is operated in the MPPT mode, when the PV output power Ppv is shown in below equation the setting-point Plimit in the following equation.

$$P_{\text{pv}} = \begin{cases} P_{\text{MPPT}}, & \text{when} \quad P_{\text{pv}} \leq P_{\text{limit}} \\ P_{\text{limit}}, & \text{when} \quad P_{\text{pv}} > P_{\text{limit}} \end{cases} \tag{1}$$

Moreover, whenever the output power reachesthe Plimit, then the output power of the PV systemwill be kept constant, i.e., Ppv = Plimit, whichleading to the constant active power which is injectedasshown in (1) and it also illustrated in Fig. 1 Interms of the algorithms and the CPG which is basedupon the Perturb and Observe (P&O-CPG) algorithmwhich was introduced by the single stage PVsystems. Moreover, during the operating area of the CPGcontrol. Which is limited at the right side of theMaximum Power Point (MPP) of the PV arrays(CPP-R), due to its single-stage configuration. Unfortunately, it will reduce the robustness of thecontrol algorithm when the PV systems is experiencewith the fast decrease during the irradiance time.

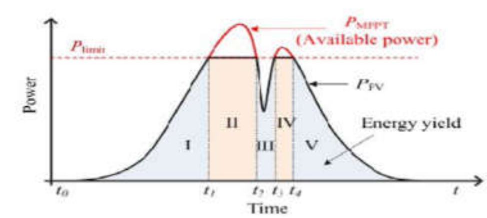


Fig. 1. Constant Power Generation (CPG) concept: 1) MPPT mode during I, III, V, and2)CPG mode during II, IV [6].

The operating point may go thought the open-circuit condition which is illustrated and shown in the Fig. 2. The drawback is also applies to the other CPG algorithms which have been proposed here all the control algorithms is regulate along with the PV power Ppv at the right side of the MPP. Here to graph the above issues, a two-stage grid-connected PV is implemented to extend the operating area of the P&O-CPG algorithm. And also by regulating the PV output power which at the left side of the MPP (CPPL) as shown in Fig. 2, where the stable CPG operation is always achieved by the operating point which will never "fall off the hill" during a fast reduce in the irradiance.The operating point may go thought the open-circuit condition which is illustrated and shown in the Fig. 2. The drawback is also applies to the other CPG algorithms which have been proposed here all the control algorithms is regulate along with the PV power Ppv at the right side of the MPP. Here to graph the above issues, a two-stage grid-connectedPV is implemented to extend the operating area of the P&O-CPG algorithm. And also by regulating the PV output power which at the left side of the MPP (CPPL) as shown in Fig. 2, where the stable CPG operation is always achieved by the operating point which will never "fall off the hill" during a fast reduce in the irradiance.

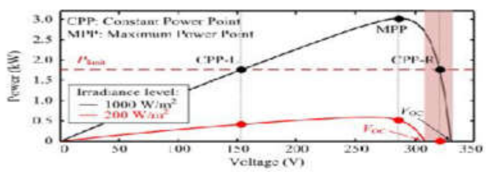


Fig.2.Stability issues of the conventional CPG algorithms, when the operating point is normally located at the right side of the MPP.

Both the P&O-CPG algorithm can beapplied to any two-stage single-phase PV system.This paper is organized as follows: the operationalprinciple of the P&O-CPG algorithm is discussed inSection II, where the dynamics of the P&O-CPGalgorithm are analysed. In Section III, a high-performanceCPG algorithm is proposed. Both theconventional and the proposed P&O-CPG algorithmsare verified and compared respectively.

II.CONVENTIONAL CPG ALGORITHM

A. System Configuration

As shown in the Fig. 3 shows the basic hardware configuration of the two-stage single-phase grid-connected PV system and its control structure. The CPG control is developed in the boost converters, which have been explained in the next section.

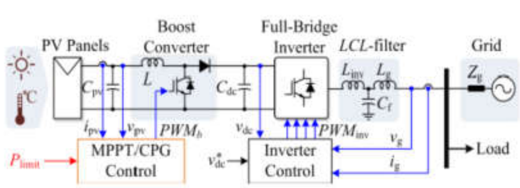


Fig. 3. Hardware schematic and overall control structure of a two-stage single-phase grid-connected PV system

The full-bridge inverter control is realized by the cascaded control; here the DC-link voltage is kept constant throughout the control of the AC grid current, which is an inner loop. An active power is injected to the grid, which meaning that the PV system operates at a unity power factor. Not only that have been mentioned above and 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 (e.g., at the left side of the MPP), and then it can be stepped up by the boost converter to match the required DC-link voltage (e.g., 450 V) [10]. This is not the case for the single-stage configuration, where the PV output voltage Vpv is directly fed to the PV inverter and has to be higher than the grid voltage level (e.g., 325 V) to ensure the power delivery.

B. Operational Principle

The operational principle of the conventional P&O-CPG algorithm is illustrated in Fig. 4. It can be divided into two modes: a) MPPT mode (Ppv Plimit), where the P&O algorithm should track the maximum power; b) CPG mode(Ppv > Plimit), where the PV output power is limited at Plimit.

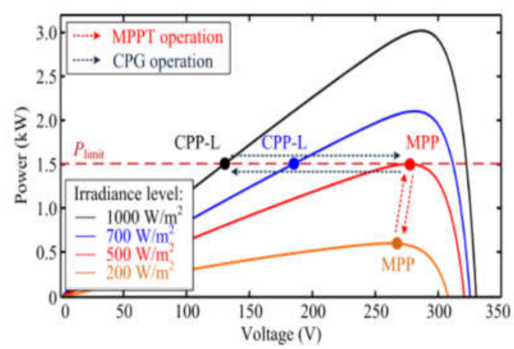


Fig. 4. Operational principle of the Perturb and Observe based CPG algorithm (P&O-CPG), where the operating point is regulated to the left side of the MPP considering stability issues.

During the MPPT operation, the behaviour of the algorithm is similar to the conventional P&O MPPT algorithm - the operating point will track and oscillate around the MPP [13]. In the case of the CPG operation, the PV voltage Vpv is continuously perturbed toward a point referred to as Constant Power Point (CPP), i.e., Ppv = Plimit. After a number of iterations, the operating point will reach and oscillate around the CPP. Although the PV system with the P&O-CPG control can operate at both CPPs, only the operation at the left side of the MPP (CPP-L) is focused for the stability concern. The control structure of the algorithm is shown in Fig. 5, where v* pv can be expressed as

$$v^{*}_{PV} = \begin{cases} v_{MPPT}, & \text{when } P_{PV} \leq P_{limit} \\ v_{pv,n-v_{step}} & ,\text{when} P_{PV} > P_{limit} \end{cases} \quad (2)$$

Where Vmppt 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.

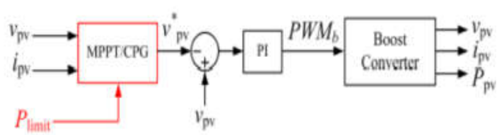
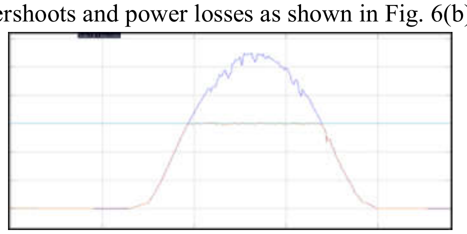


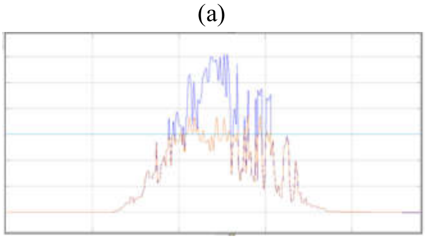
Fig. 5. Control structure of the Perturb and Observe based CPG algorithm (P&O-CPG), where a Proportional Integrator (PI) is adopted.

C. Issues of the P&O-CPG Algorithm

The P&O-CPG algorithm has a satisfied performance under slow changing irradiance conditions, e.g., during a clear day, when the operating point is at the left side of the MPP, as shown in Fig. 6(a). However, irradiance fluctuation that may happen in a cloudy day will result in overshoots and power losses as shown in Fig. 6(b).



(a)



(b)

Fig. 6. Simulation results of the Perturb and Observe based CPG algorithm (P&O-CPG) under two daily conditions: (a) clear day and (b) cloudy day.

This can be further explained using the operation trajectory of the PV system presented in Fig. Assuming that the PV system is operating in MPPT mode initially and the irradiance level suddenly increases, the PV power Ppv is basically lifted by the change in the irradiance, as it can be seen from the black arrow trajectory (i.e., A!B!C). As a consequence, large power overshoots may occur. Similarly, if the PV system is operating in the CPG operation (e.g., at CPP-L) and the irradiance suddenly drops, the output power Ppv will make a sudden decrease, as shown in Fig. (i.e., C! D). It will take a number of iterations until the operating point reaches the new MPP (i.e., E) at that irradiance condition (i.e., 200 W/m2), and resulting in loss of power generation.

III.HIGH-PERFORMANCE P&O-CPG ALGORITHM

According to the above, two main tasks exist - minimizing the overshoots and minimizing the power losses during the fast-changing irradiance condition which has to be addressed in the case of CPG operation. The proposed high-performance P&O-CPG algorithm can effectively solve those issues.

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. Notably, the step size modification should be enabled only when the algorithm detects a fast increase in the Irradiance Condition (IC), which can be illustrated as

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

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.

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

Where Vpv 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. Is a constant which can be used to tune the speed of the algorithm.

B.Minimizing Power Losses

As explained in Fig. 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. In fact, 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. 8. Notably, the detection of the decreased IC as well as the Previous Operating Mode (POM) is also important for minimizing the power losses:

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

$$\mathrm{POM} = \begin{cases} \mathrm{CPG}, & \text{when } \left|\mathrm{P_{limit}} - \mathrm{P_{PV,n-1}}\right| > \varepsilon_{\mathrm{ss}} \\ \mathrm{MPPT}, & \text{when} \left|\mathrm{P_{limit}} - \mathrm{P_{PV,n-1}}\right| \le \varepsilon_{\mathrm{ss}} \end{cases} \quad (6)$$

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. For example, the value of "ss can be chosen as 1-2 % of the rated power of the PV system, which is normally higher than the steady-state error in the PV power of the P&O-CPG algorithm. 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. 7.

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

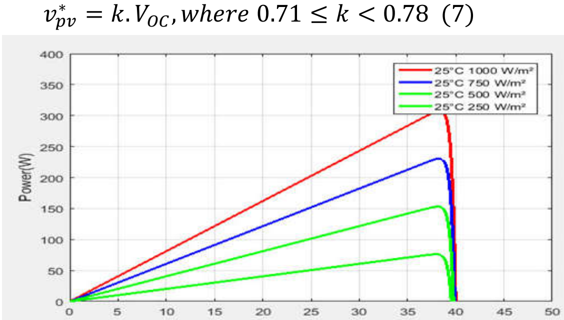


Fig. 7. Power-voltage (P-V) curves of the PV arrays, where the voltage at the MPP is almost constant especially at a higher irradiance level.

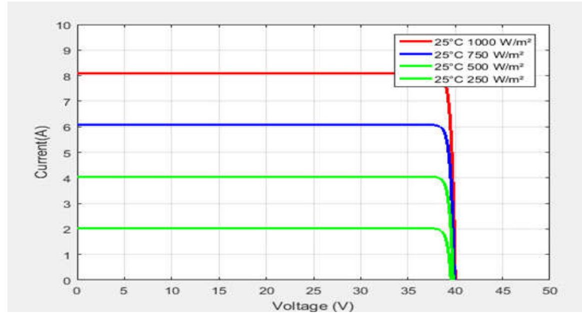


Fig.8.Current- voltage (I-V) curves of the PV arrays

By doing so, the operating point can be instantaneously moved close to the MPP 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.

C. Simulation Verification

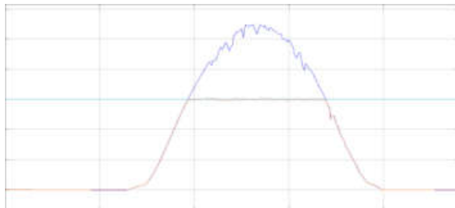
Solutions to improve the dynamic performance of the P&OCPG algorithm have been discussed above. Parameters of the proposed high-performance P&O-CPG algorithm are designed as: = 10, k = 0.715, "Inc = 50 W, "dec = 100 W, and "ss = 30W.Simulation is carried out referring to Fig. 3, and the system parameters are given in Table I.

Table I Parameters of the Two-Stage Single-Phase PV System

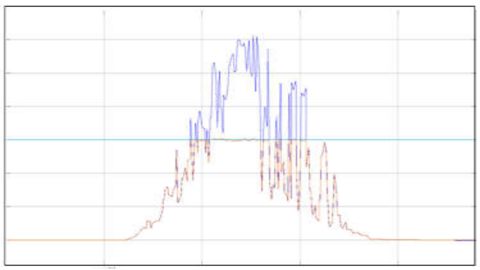
Boost converter inductor	$L = 1.8$ mH
PV-side capacitor	$C_{pv} = 1000\ \mu$F
DC-link capacitor	$C_{dc} = 1100\ \mu$F
LCL-filter	$L_{inv} = 4.8$ mH, $L_g = 4$ mH, $C_f = 4.3\ \mu$F
Switching frequency	Boost converter: $f_b = 16$ kHz, Full-Bridge inverter: $f_{inv} = 8$ kHz
DC-link voltage	$V_{dc} = 450$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

In the simulation, a 3-kW PV simulator has been adopted, where real-field solar irradiance and ambient temperature profiles are programmed. Fig. 8 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 (shown in Fig. 6), 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 behaviour to only react, when the fast irradiance condition is detected. This can be seen from the performance under clear irradiance conditions in

Fig. 8(a), which is similar to the conventional P&O-CPG algorithm (shown in Fig. 6(a)).



(a)



(b)

Fig. 9. Simulation results of the proposed high-performance P&O-CPG algorithm under two daily conditions: (a) clear day and (b) cloudy day.

CONCLUSION

In this paper observed that a high-performance active power control scheme been limiting the maximum power which is feed tothe PV systems which is proposed there. The proposed solutions make sure about the stable constant power generation operation. When compared with the traditional methods. Here the proposed control strategy will force the PV systems to operate at the left side of the maximum power point, and which make to achieve a stable operation along with smooth transitions. Simulation has verified the effectiveness of the proposed control solution in order to minimized power losses, reduced overshoots and also fast dynamics. Moreover, for single-stage PV systems, same concept of CPG is also applicable. Therefore, in such case, the PVvoltage operating range will limited and some small changes in the algorithms which are necessary to make sure for a stable operation.

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