

# **Implementation of Voltage Regulation using Adaptive Voltage Control by Reducing Capacitor Size in PV System**

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**ABSTRACT:** This paper deals with the implementation of voltage regulation in PV system. In the photovoltaic systems, the PV voltage regulation is necessary in order to both maximize and limit the power. So, in traditional method large input capacitor was used. The proposed voltage regulation method uses adaptive voltage control method and reduces the capacitor's size. Therefore the non-linear characteristic of PV array is modified into linearization by using small input capacitor and boost converter. After reducing the size of the capacitor it also performs the original system as in large capacitor. Then suggests an Adaptive control, which allows the use of a small input capacitor at the same time, the power conservation of the original system with a large capacity. The proposed control method is designed and modelled and its performance is evaluated in Matlab-simulation. Simulated results are presented to validate the performance of the proposed system.

**KEYWORDS:** Adaptive voltage control, photovoltaic converters, photovoltaic power systems, voltage regulation.

## **I. INTRODUCTION**

Due to the power crescent demand and environment condition power sectors are looking towards the renewable energy sectors. Some examples of renewable energy sources are low power wind turbine, PV modules and other applications such as fuel cells, embedded systems, portable electronic equipment, UPS, and battery powered equipment. Photovoltaic (PV) source is one of the significant players in the world's energy portfolio, by 2040 and it will make one of the biggest contributions to electricity generation among all the renewable energy candidates by, because it will be a clean, emission-free, and renewable electrical generation source with high reliability. When the PV array can connect to the grid it can be operated at maximum power point tracking MPPT. It can lead to develop the micro grids. Reference power can be used to function the MPP technique. LPPT is another technique to track the limited power .PV usually operated in the MPPT. When the storage element is full and demand is low LPPT can be used to limit the power and switches to LPPT [2].

Many MPPT algorithm are used to perform the solar system in efficient manner, commonly the perturbation and observation (P&O) [4], [27], hill-climbing [3], [6], fractional open-circuit voltage, and incremental conductance[7], [12].these algorithm are used and also modified it possible to operate both in MPPT and LPPT[2],[9]. PV voltage [9]-[13], PV current [14] or duty cycle [2]of the DC-DC converter are used as reference for these algorithm. Best option for the control is PV voltage because it varies slowly and more stable but it can be used for the low power application only. Due to voltage drop during transient PV current controlling is not effective one and controlling by the duty cycle leads an inappropriate control of PV voltage and PV current and also more stress and losses in the converter [10]-[12], [15], [16].

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In PV voltage controlling technique, reference voltage can be continuously updated for the MPPT and LPPT. Thus, a fast and stable regulation in the entire operating range is obtained by proper tracking [11], [12]. Where PV voltage is very closer to the MPP voltage during MPPT operation and varies from MPP to open-circuit voltage during the LPPT operation. The non-linearity of the PV system cause the performance can be change with the operating point. This nonlinear characteristic can lead to great variations in the dynamics and can even put the stability at risk [11], [12], [17], [18].

In the PV voltage control method, system voltage can be varied due to the dynamic resistance which can be obtain form the slope of its V-I curve [19], [20]. This parameter depends on the characteristics of the PV array. And it is highly variable with the temperature, irradiation, and especially with the PV voltage. Then the voltage regulation performance can be diminished when operating under MPPT due to the irradiation and temperature change, and it become worse when operating under LPPT since the PV voltage also changes.

The dynamic resistance of the PV voltage control for buck converter, single and cascade feedback loops proper control is guaranteed in whole operation due to high cut off frequency and big input capacitor [12].An in-depth analysis of the cascaded control technique is developed in [21] and [22].It shows that system become unstable when capacitor sizing and correct regulation are not carried out properly.In [11], duty cycle can be used to regulate the PV voltage, i.e., without inner current loop. These control schemes are normally applied to small PV generators (e.g., 50 W in [11]).

For higher power boost converters (typically over 1 kW), the PV voltage is usually controlled by means of an inner inductor current loop. The cascaded control avoids current transients and reduces failure rates. In these systems, the influence of the dynamic resistance has not been traditionally taken into account. The current to voltage transfer function has been considered as  $1/Cs$ , where the PV array is taken as a current source [13], [23].Initially, the dynamic resistance effect was hidden by the use of large input capacitors.In recent years, these large electrolytic capacitors are being replaced by smaller polypropylene ones, which are much cheaper and more reliable [25]. However, this capacitor reduction makes the dynamic resistance not negligible anymore. This renders necessary the analysis of the dynamic resistance effect and the design of new control techniques capable of compensating this effect.

In this paper, the Dynamic resistance can be obtained from V-I slope of the PV array. The adaptive control obtain the PV voltage regulation with the cut-off frequency and phase margine that remain almost for the whole operating range, with a small input capacitor.The adaptive control can be done by estimate the PV voltage and inductor current.

## II. MODELLING OF PV SYSTEM

The analysed system is shown in fig 1 is the circuit diagram .It consists of PV panel ,input capacitor, a boost converter ,bus capacitor,and a single phase inverter and PID controller.The grid current is controlled by inverter with the desired power factor and constant bus voltage is maintained.

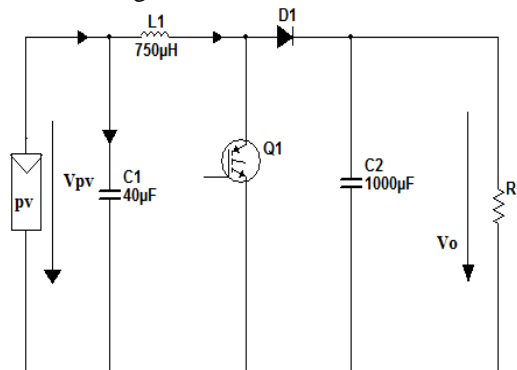


Fig. 1 PV single-phase conversion system.

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## A. Inductor current control

The control must be able to handle both the continuous conduction mode (CCM) and the discontinuous conduction mode (DCM). Since it might be necessary to operate in LPPT with low inductor current. The current control is based on the technique for this purpose. It is valid for both conduction modes. By using that strategy, the input impedance has no influence on the current control.

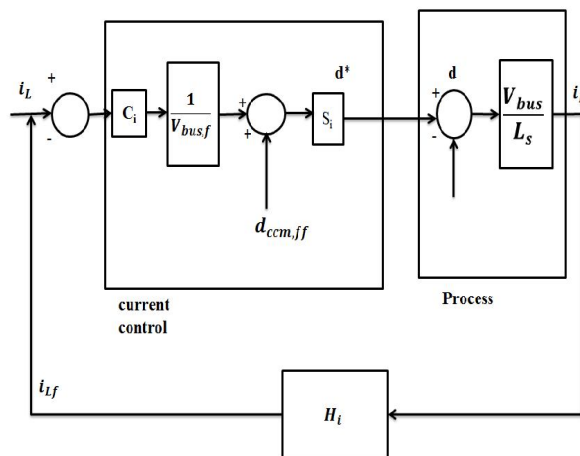


Fig.2 Inductor current control loop for CCM

From Fig .1 considering average values for all variables in a commutation period, the CCM and Kirchoff's law is as follows:

$$V_{pv} - (1-d) \cdot V_{bus} = L di_L / dt \quad (1)$$

Where d is the duty cycle.

Dividing (1) by  $V_{bus}$  and recognizing the equation, one finds

$$d - (1 - V_{pv}/V_{bus}) = d - d_{ccm} = L \cdot di_L / dt \cdot 1/V_{bus} \quad (2)$$

$$\text{where } d_{ccm} = 1 - V_{pv}/V_{bus} \quad (3)$$

As can be observed in (2) and (3), the influence of the PV array in this process is included in  $d_{ccm}$ . By using PV voltage and bus voltage, the value of  $d_{ccm}$  is calculated which are measured variables. The obtained value,  $d_{ccm,ff}$ , can be used as feedforward compensation.

In fig 2 it shows the it shows the loop for inductor current regulation in CCM, by making use of (2) and (3). Here  $C_i$  represents the controller,  $S_i$  represents the digital sampler,  $H_i$  represents inductor current sensing. Being  $T_{si}$  the current sample time, the digital sampler  $S_i$  can be approximated as

$$S_i = \frac{1}{1.5T_{si}s + 1} \quad (4)$$

The inductor current sensing transfer function is expressed as

$$H_i(s) = \frac{K_i}{T_i s + 1} \quad (5)$$

where  $\tau_i$  is the time constant of the inductor current sensing and  $K_i$  is the scaling constant of the inductor current sensing. In order to simplify it will be taken as 1. Because of the sampler and the retard in the measurements of  $v_{pv}$  and  $v_{bus}$ , the forwarded duty cycle  $d_{ccm,ff}$  does not eliminate the effect of the PV generator for high frequencies. However, it is removed below the sample and sensing frequencies, and thus around the current control cut off frequency.

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The process seen by the regulator can therefore be considered as  $1/Ls$  for the controller design. A simple PI controller can then be used, obtaining a regulation independent of the dynamic resistance. For the DCM, a similar analysis is carried out in [26], obtaining the same schemes of Fig. 2 but with a different equation for the duty cycle  $d_{dcm}$  and for its estimation  $d_{dcm,ff}$ . In this case, only known variables of the system are also required for the estimation. Since the boost converter can function in both conduction

modes, the strategy constantly estimates both duty cycles  $d_{ccm}$ . The authors prove that when operating in CCM,  $d_{ccm} < d_{dcm}$  whereas in DCM,  $d_{dcm} < d_{ccm}$ . In other words, the lowest duty cycle corresponds to the actual mode of conduction. As a result, the technique for both conduction modes uses

The same schemes of Fig. 2 but choosing the minimum between  $d_{ccm,ff}$  and  $d_{dcm,ff}$  as feed forward compensation.

### III. PROPOSED CONTROL

#### A. Block diagram

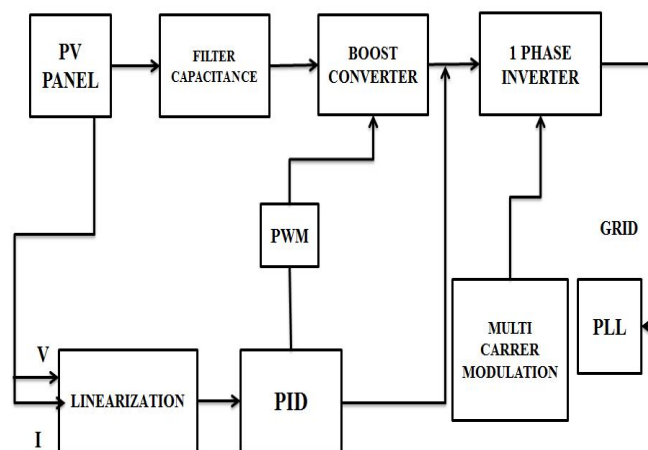


Fig.3 Block diagram of proposed control

In this figure it explains the working of proposed control. It consists of PV panel, filter capacitance, Boost converter and single phase inverter, PID controller, multicarrier modulation, PLL. It has two sides. One side is converter side and another side is inverter side. The voltage and current from the PV panel is taken and it is given to the MPPT linearization. The PV panel output is always linear. So to obtain stable output from solar panel we need to connect large capacitance in parallel with PV panel. By calculating linear equation we can reduce the capacitor size. From the solar panel output linear characteristics is calculated and is given to the PID controller. According to the linear characteristics, PID controller calculates the PWM. The PWM output is given to the boost converter. The boosted output is given to the single phase inverter. Multi carrier modulation is used to increase the output quality.

#### B. Perturb and Obserb algorithm

The P&O MPPT algorithm is mostly used, due to its ease of implementation. It is based on the following criterion: if the operating voltage of the PV array is perturbed in a given direction and if the power drawn from the PV array increases, this means that the operating point has moved toward the MPP and, therefore, the operating voltage must be further perturbed in the same direction. Otherwise, if the power drawn from the PV array decreases, the operating point has moved away from the MPP and, therefore, the direction of the operating voltage perturbation must be reversed.

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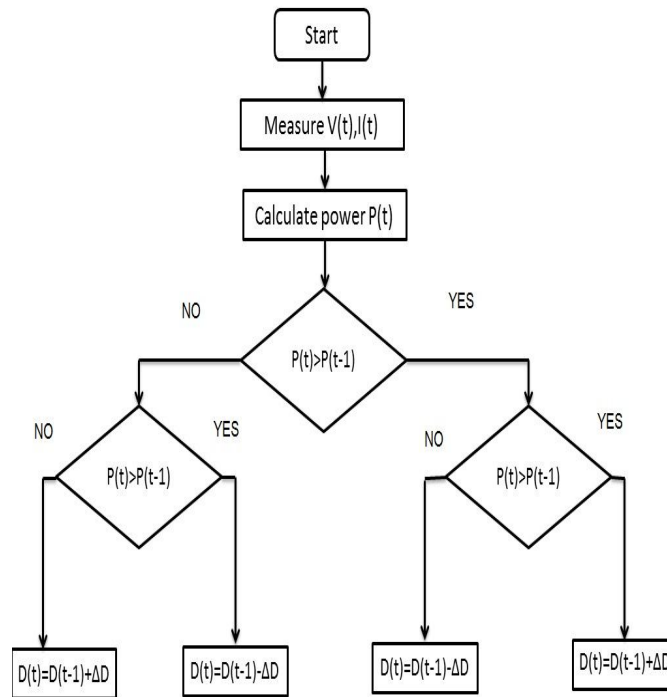


Fig.4 Flow chart for P&O algorithm.

A drawback of P&O MPPT technique is that, at steady state, the operating point oscillates around the MPP giving rise to the waste of some amount of available energy. Several improvements of the P&O algorithm have been proposed in order to reduce the number of oscillations around the MPP in steady state, but they slow down the speed of response of the algorithm to changing atmospheric conditions and lower the algorithm efficiency during cloudy days.

To solve the problems of the dynamic resistance variation, an adaptive control is proposed in this paper. For each voltage sample time  $T_{sv}$ , the control estimates the dynamic resistance and uses this value in order to adapt one parameter of the controller according to the dynamic resistance variation. In this way, the nonlinear system variability is compensated. In this paper P&O algorithm is used among all the MPPT. It is one of the simplest method of algorithm. The current and voltage generates output by using P&O algorithm.

### C. Dynamic resistance estimation

If a short period is considered, the linear model of the PV array is applicable (18). It can be seen that the  $i_{pv}$  variation is caused by both  $v_{pv}$  and  $g$  variations. The irradiance variation is unknown but can have an important effect on the current during a cloud passage. This fact hinders the estimation of the dynamic resistance, which represents the current variation caused by the voltage variation. For this reason, an intrinsic feature of single-phase inverters, particularly its 100 Hz ripple, is used. In real systems, the irradiance component around the 100 Hz is negligible. As a result, the evolution of the 100 Hz ripple of  $i_{pv}$  is exclusively provoked by the 100 Hz ripple of  $v_{pv}$ . Furthermore, the product  $C_v(s) \cdot G_v(s)$  remains now the same as with a PI and the traditional model, and therefore  $K_p$  and  $T_n$  can traditionally be calculated. In the proposed control including the  $R_{pv}$  estimation is shown.

This control has been validated by simulation with PSIM. The features of the simulated system are identical to the traditional control, excluding the proposed control which is now being used. In addition, the design cut off frequency for the voltage control is  $f_{vc} = 20$  Hz and the phase margin is  $PM_v = 55^\circ$ . The cut off frequency is chosen quite lower than 100 Hz in order to avoid interactions with the 100 Hz ripple of the single-phase converters. Given that the bigger

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the PV array, the slower the average irradiance variation in the whole PV array, this cut off frequency is high enough to perform a fast MPPT/LPPT and reject the irradiance variations.

The performance is for the same conditions of the test (note that the time scale is different). The real dynamic resistance and its estimation are also represented in the figure. Given that the design cut off frequency is 20Hz, the rise time of the voltage response should be constant and close to 23.9 ms (using  $3/\omega_{vc}$ ). However, during the transient from 260 to 250 V, i.e., near to open-circuit, the rise time is 18.4 ms, whereas from 220 to 210 V, around the MPP, it is 15.1 ms. This deviation of the actual cut off frequency from the design value is caused by the misestimation of  $R_{pv}$ . As can be observed in the misestimation only occurs in transients due to a retard in the estimation of  $R_{pv,est}$ . In any case, when using the proposed control, the rise time is much closer to the design time than in the case of the traditional control, where it was expected to be 9.5 ms but varies from 730 ms near to open-circuit to 108ms around the MPP. Furthermore, the rise time obtained with the proposed control is much lower despite having a lower design cut off frequency (20 Hz versus 50 Hz). Thus, thanks to the proposed control, the MPPT/LPPT controller period can be considerably reduced, which leads to an improvement of its performance. More precisely, on account of the analysis of [29] for the stabilization time, the traditional control requires an MPPT/LPPT cycle of about 1 s, whereas the proposed control can reduce this time up to about 40 ms.

### IV. EXPERIMENTAL RESULTS

In this section, the modeling is validated and the traditional and proposed control strategies are tested using the commercial single-phase converter. Its input is connected to the PV array, and its output to the grid.

Modelling is first validated, the theoretical current reference to PV voltage transfer function  $G_v^*$  can be obtained as follows:

$$\mathbf{G}_v(\mathbf{s}) = \mathbf{G}_{i_{ref}}(\mathbf{s}) \cdot \mathbf{G}_v(\mathbf{s}) = - \frac{\mathbf{1}}{\frac{\mathbf{s}}{\omega_{ic}} + \mathbf{1}} \cdot \frac{\mathbf{R}_{pv}}{\mathbf{R}_{pv} \cdot \mathbf{C} \cdot \mathbf{s} + \mathbf{1}} \quad (35)$$

For a sunny day, a current reference composed by a constant and a small-signal sinusoidal term is introduced. The constant component is adjusted in order to set the desired  $v_{pv}$  operating point, i.e., the desired dynamic resistance. With the sinusoidal term, a frequency range is swept for that operating point. Then, the small-signal PV voltage response is measured, obtaining the gain for each frequency. To validate this model control loop is activated.

The experimental gain diagram for one operating point in each of the three different regions of the  $I-V$  curve: Constant current (CC), maximum power point (MPP), and constant voltage (CV). The lines represent the theoretical response given by and the points represent the experimental values. As can be observed, the experimental points match the theoretical model carried out in Section II.

The effect of the dynamic resistance on the plant can also be observed. In fact, the gain at low frequencies is equal to  $R_{pv}$  itself. In addition, the influence of the  $G_v$  transfer function pole, which is located at a frequency of 200 rad/s in the CC, 1250 rad/s in the MPP, and 10000 rad/s in the CV can be observed. The pole due to the current closed-loop is common and equal to 2850 rad/s.

The traditional control is now tested by maintaining the original configuration of the converter; that is, with the design values of  $f_{vc} = 50$  Hz and  $PM_v = 40^\circ$ . The PV voltage and the PV current are depicted for steps of the voltage reference. This deviation of the actual cut off frequency from the design value is caused by the misestimation of  $R_{pv}$ . As can be observed in the figure, the misestimation only occurs in transients due to a retard in the estimation of  $R_{pv,est}$

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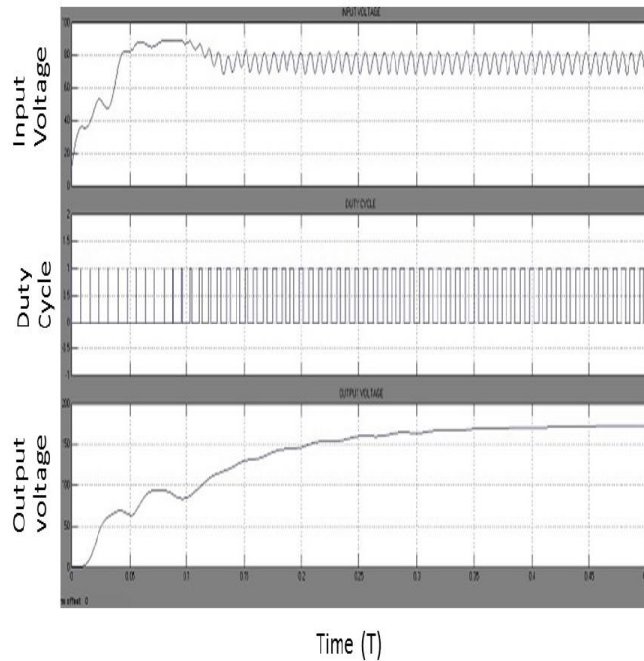


Fig.5 Duty cycle variation in output

At the moment of this test, the conditions were:  $g = 820 \text{ W/m}^2$ ,  $T = 51^\circ \text{C}$ , and  $V_{OC} = 227 \text{ V}$ . It can be observed that the regulation speeds up when reducing the volt-age since it increases the dynamic resistance. More precisely, the rise time is 660ms near to the open-circuit, then 470ms, 310ms, and finally 130ms around the MPP. Similarly to the simulation results these rise times validate the slowing down of the control for high values of the PV voltage.

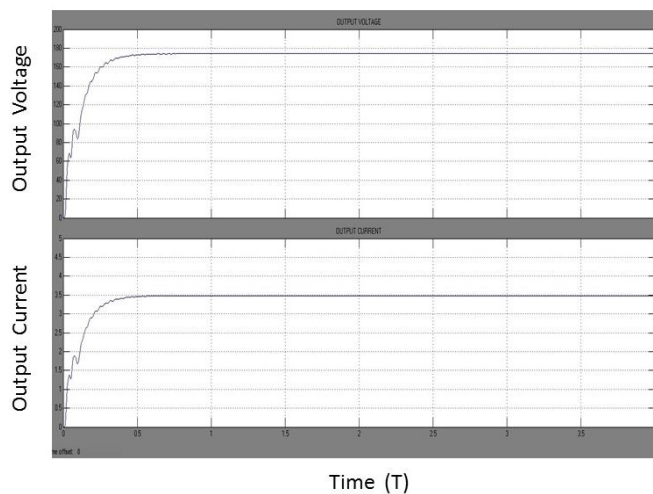


Fig .6 Proposed output voltage and current waveform

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## V.CONCLUSION

In PV systems, the PV voltage regulation depends on the dynamic resistance, which changes with the characteristics of the PV array and is highly variable with the irradiation, the temperature, and especially with the PV voltage. The large input capacitors are reduced to small input capacitor, in order to reduce costs. Its output is mainly depends upon operating point. Adaptive control is proposed in order to avoid variability. Here proposed control is tested by using 40  $\mu$ F.

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