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Development of A Grid Connected Inverter for Solar PV Systems with Energy Capture Improvement Based On Current Control Strategy

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Abstract- In this paper a single stage inverter for solar PV system with energy capture improvement based on voltage control to solve fast changing irradiation problem is proposed. A cascaded control structure with a dc link voltage control loop and a current control loop is used. The maximum power capturing controller is applied to the reference of the outer loop control dc voltage photovoltaic,. without PV array power measurement. In order to generate the correct maximum power point reference voltage under rapidly changing irradiation, a robust maximum power point capturing controller has been proposed. In this controller, the d-axis grid current component reflecting the power grid side and the signal error of a proportional–integral outer voltage regulator is designed to reflect the change in power caused by the irradiation variation. Hence, with this information, the proposed algorithm can greatly reduce the power losses caused by the dynamic tracking errors under rapid weather changing conditions. The superiority of the newly proposed method is supported by simulation and experimental results. The robust tracking capability under rapidly increasing and decreasing irradiance is verified experimentally with a PV array emulator. The performance of the power flow depends largely on the quality of the applied current control strategy.

Index Terms- Fast changing irradiation, maximum power capturing,gridconected PV systems, fast transient response, proportional-integral outer voltage regulator,PV array model.

I. INTRODUCTION

Because of the changes caused by the atmospheric conditions the voltage-power characteristic of a photovoltaic array is nonlinear and time varying. The task of a maximum power capturing in a PV power system is to continuously tune the system so that it draws maximum power from the PV array. The grid connected PV systems have become more popular because they do not need battery backups to ensure maximum power point capturing[1] . The number of power stages undermines the overall efficiency, reliability, and compactness of the system besides increasing the cost[2]. The typical configurations of a grid-connected PV system are single or two stages. In two stages, the first is used to boost the PV array voltage and track the maximum power; the second allows the conversion of this power into high-quality ac voltage[3]. The single stage has numerous advantages, such as simple topology, high efficiency, etc.

The control strategy has to be designed in order to track the maximum available power and to properly transfer it from the PV array to the grid simultaneously. The main component of the single-stage grid connected PV system is the three-phase voltage source inverter . A simple inductors *L* are used as a filter interfacing inverter and mains. This project is based on proposed maximum power point and the performance of the power flow depends largely on the quality of the applied current control strategy. In this paper, the current control has been implemented in a rotating synchronous reference frame *d*, *q* because the controller can eliminate a steady-state error and has fast transient response by decoupling control. Energy-balance modeling and discrete control for single-phase grid-connected PV central inverters[4].is proposed.

In this paper, in order to generate the correct maximum power point reference voltage under rapidly changing irradiation, a robust maximum power point extraction controller has been proposed. In this method the *d*-axis grid current component reflecting the power grid side and the signal error of a proportional–integral outer voltage regulator is designed to reflect the change in power caused by the irradiation variation. Hence, with this information, the proposed a method can greatly reduce the power losses caused by the dynamic tracking errors under rapid weather changing conditions[5-8]. The superiority of the newly proposed method is supported by simulation and experimental results.

II. PHOTOVOLTAIC INVERTER

The inverter is the heart of the PV system and is the focus of all utility-interconnection codes and standards. A Solar inverter or PV inverter is a type of electrical inverter that is made to change the direct current (DC) electricity from a photovoltaic array into alternating current (AC) for use with home appliances and possibly a utility grid. Since the PV array is a dc source, an inverter is required to convert the dc power to normal ac power that is used in our homes and offices. To save energy they run only when the sun is up and should be located in cool locations away from direct sunlight. The PCU is a general term for all the equipment involved including the inverter and the interface with the PV (and battery system if used) and the utility grid. It is very important to point out that inverters are by design much safer than rotating generators.

Maximum power point capturing
Main article: Maximum power point tracker

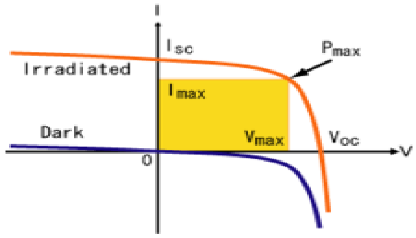

Fig: 1, V-I curve for a solar cell, showing the maximum power point P_{max}.

Maximum power point tracking is a technique that solar inverters use to get the most possible power from the PV array. Any given PV module or string of modules will have a maximum power point: essentially, this defines current that the inverter should draw from the PV in order to get the most possible power .A maximum power point tracker is a high efficiency DC to DC converter that presents an optimal electrical load to a solar panel or array and produces a voltage suitable for the load.

A PV generator is a combination of solar cells, connections, protective parts, supports, etc. In the present modeling, the focus is only on cells. Solar cells consist of a p-n junction; various mode lings of solar cells have been proposed in the literature. Thus, the simplest equivalent circuit of a solar cell is a current source in parallel with a diode. The output of the current source is directly proportional to the light falling on the cell (photocurrent). During darkness, the solar cell is not an active device; it works as a diode, i.e., a p-n junction. It produces neither a current nor a voltage.

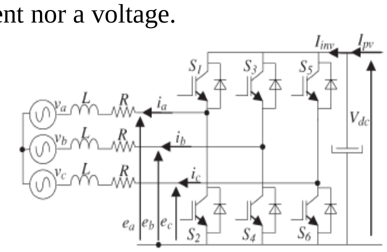

Fig: 2 Three-phase VSI

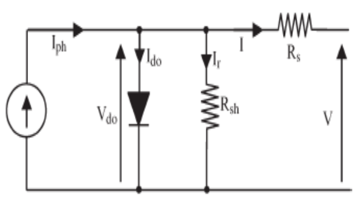

Fig:3 Solar cell electrically equivalent circuit

In general, the output current of a solar cell is expressed by

$$I = I_{ph} - I_o \left(\exp \frac{q}{n.k.T}(V + R_sI) - 1\right) - \left(\frac{V+IR_S}{R_{Sh}}\right) \quad (1)$$

In (3), the resistances can be generally neglected, and thus, it can be simplified to

$$I = I_{ph} - I_o \left(\exp \frac{q}{n.k.T} V - 1\right) \quad (2)$$

If the circuit is opened, the output current I = 0, and the open-circuit voltage V_{oc} is expressed by

$$V_{oc} = \left(\frac{n.k.T}{q}\right) \text{In} \left(\frac{I_{ph}}{I_o} + 1\right) \approx \left(\frac{n.k.T}{q}\right) \text{In} \left(\frac{I_{ph}}{I_o}\right) \quad (3)$$

If the circuit is shorted, the output voltage V = 0, the average current through the diode is generally neglected, and the short circuit current I_{sc} is expressed by using

$$I_{sc} = I = \frac{I_{ph}}{\left(1+\frac{R_S}{R_{Sh}}\right)} \quad (4)$$

Finally, the output power P is expressed by

$$P = VI = \left(I_{Ph} - I_{do} - \frac{V_{do}}{R_{sh}}\right) V. \quad (5)$$

III. CURRENT CONTROLLER

According to(3), V_{oc} strategy guarantees fast transient response and high static performance via internal current control loops.

Current Control

It can be seen that there is cross-coupling between the *d* and *q* components. However, cross-coupling can affect the dynamic performance of the regulator. Therefore, it is very important to decouple the two axes for better performance. This effect can be accomplished with the feed forward decoupling control method. Assuming that

$$V_{rd} = -V_d + d_d V_{dc} + \omega L i_q$$
$$V_{rd} = -V_q + d_d V_{dc} - \omega L i_d \quad (6)$$

where ω is the angular frequency of the utility. Then, the system model is transformed to

$$\begin{cases} \frac{di_d}{dt} = -\frac{R}{L} i_d + \frac{1}{L} v_{rd} \\ \frac{di_q}{dt} = -\frac{R}{L} i_q + \frac{1}{L} v_{rq} \\ \frac{dV_{dc}}{dt} = \frac{I_{pv}}{C} - \frac{V_d + v_{rd}}{CV_{dc}} i_d - \frac{V_q + v_{rq}}{CV_{dc}} i_q \end{cases} \quad (7)$$

The cross-coupling variables are eliminated in the aforementioned model. Hence, the currents i_d and i_q can be controlled independently by acting upon inputs V_d and V_q, respectively. Furthermore, by using PI-type regulators, a fast dynamic response and zero steady-state errors can be achieved. Since the switching frequency is much higher than the line frequency, the sampling and hold delay is neglected.

The diagram is suitable for both i_d and i_q loops. From the diagram, the closed-loop transfer function of the *d*, *q* current loops is

$$\frac{i_q(s)}{I_q^*(s)} = \frac{i_d(s)}{i_d^*(s)} = \frac{k_{ip}}{L}\,\frac{S+\frac{k_{ii}}{k_{ip}}}{S^2+\frac{(k_{ip}+R)}{L}S+\frac{k_{ii}}{L}} \qquad (8)$$

PV Power Calculation

In the synchronous rotating frame *d*, *q*, the active and reactive powers of a three-phase grid-connected VSI are given by

$$\begin{cases} P = \frac{3}{2}(v_d i_{d+v_{di_q}}) \\ Q = \frac{3}{2}(v_d i_{d-v_{qi_d}}) \end{cases}$$
(9)

If the three-phase grid voltage is ideally sinusoidal without any harmonics, then in the *d*, *q* frame, the grid voltage vector is given by (24)

In practice, the grid voltage is non sinusoidal due to harmonics. Therefore, both V_d and V_q will not be constant but have slight ripples whose frequencies and magnitudes depend on the harmonic components. However, in steady state, the average value of V_q is still equal to zero. Consequently, (23) can be rewritten as (25).

Its active power depends on the *d*-axis current, and the reactive power depends on the *q*-axis current. Furthermore, in order to achieve unity power factor fundamental current flow, the *q* component of the command current vector is set to zero

$$\begin{cases} P = \frac{3}{2}(v_d i_d) \\ Q = \frac{3}{2}(v_d i_q) \end{cases} \qquad (10)$$

Thus, the dc bus-voltage control loop under changing irradiation can be modeled with the block diagram, where the current of PV array is an input disturbance.

Between voltage reference V_{dc}^* and voltage measurement V_{dc} is the following:

$\varepsilon(s) = A(s)\, V_{dc}^*(s) + B(s)\, i_G(s)$
(11)

$$A(s) = \frac{CS^2}{CS^2 + d_d k_{up} S + d_d k_{ui}}$$

$$B(s) = \frac{d_d}{C}\,\frac{S}{S^2+\frac{d_d k_{up}}{c}S+\frac{d_d k_{ui}}{c}}$$

If we consider only the impact of perturbation i_G, we can write

$$\varepsilon(s) = \frac{d_d}{C}\,\frac{S}{S^2+\frac{d_d k_{up}}{c}S+\frac{d_d k_{ui}}{c}}\, i_G(s).$$
(12)

IV. SIMULATION RESULTS

This section presents the simulation results of the classical and the proposed methods in order to validate the performance of the control scheme.

Computer simulation has been done using MATLAB/SIMULINK simulation package

The full diagram of the control methodology and the modulation is shown.

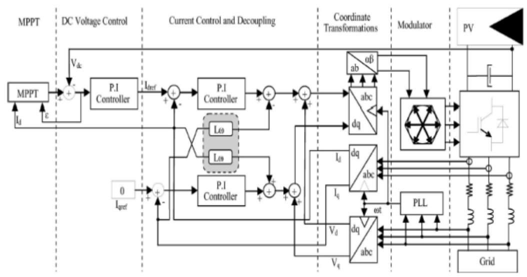

Fig: 4 Grid-connected PV system with the proposed tracker.

PROPOSED MPPT WITH PERTURBATION AND OBSERVATION METHOD.

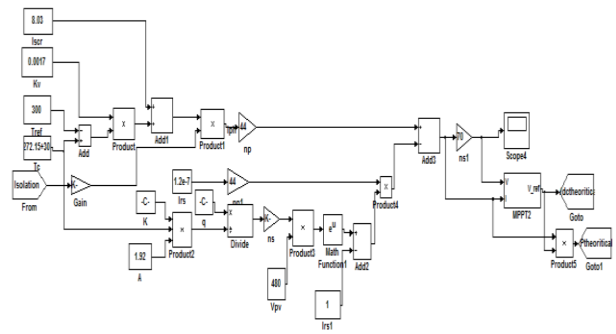

Fig: 5.Theoretical calculations of classical method.

In the conventional method, the MPP is obtained from the PV array power by multiplying the voltage and current of PV arrays and comparing it with the previously measured power.

In the case of a sudden increase in irradiance, the P&O algorithm reacts as if the increase occurred as a result of the previous perturbation of the array operating voltage. The next perturbation, therefore, will be in the same direction as the previous one.

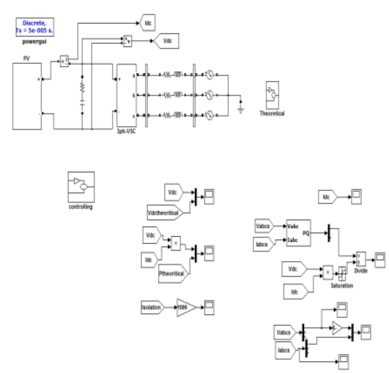

Fig:6 Simulation circuit of classical method

The characteristics of Solar PV module are used for the PV array model in the simulation and experiment. The module provides 60 W of nominal maximum power and a 21.1-V open-circuit voltage at an irradiation of 1 kW/m2 and an ambient temperature of 25◦C.

To compare the performance of the proposed MPPC method with that of the classical method, the simulations are configured under exactly the same conditions to compare the performances. The PV array in simulation is composed of ten series connected Modules.

In order to verify the effect of rapidly changing irradiation, an irradiation ramp change was used. A 25-s period for the increasing and decreasing ramps was selected. This irradiation change starts from 225 W/m2, stops at 1000 W/m2, waits at this level for 25s, and decreases again back to 225 W/m2 with a constant slope. The temperature is considered constant during the simulation.

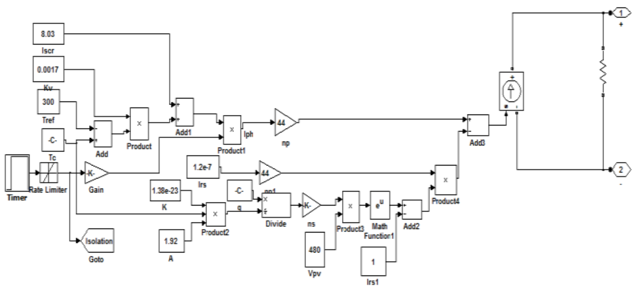

Fig: 7.Designed circuit of photo voltaic system

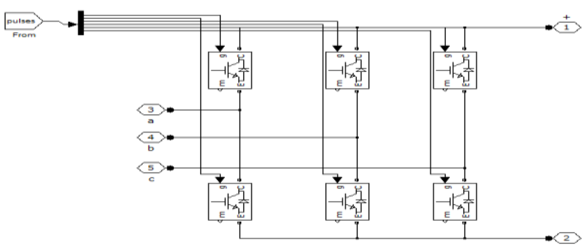

Fig: 8.. Circuit diagram of 3-Ph voltage source converter

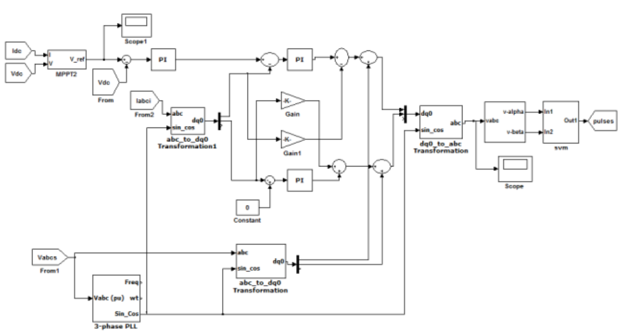

Fig: 9 Controlling circuit of voltage source converter in classical method

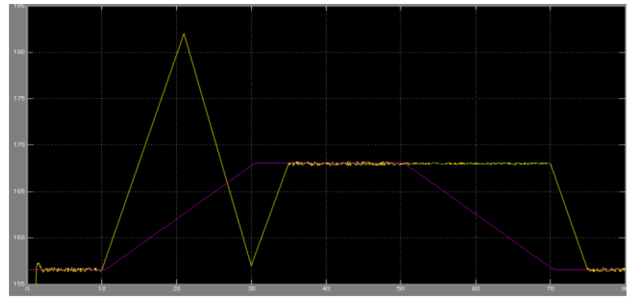

Fig: 10 PV array voltage with classical and theoretical MPP voltage during a trapezoidal irradiation profile.

In above fig. under a decrease of irradiation (60–80 s), we can see that the voltage of PV array varies between V and $V+\Delta v$ since it decreases the PV array power in the two directions of perturbation. This is because the power change caused by irradiation decrease in sunshine is greater than the variation caused by the voltage perturbation.

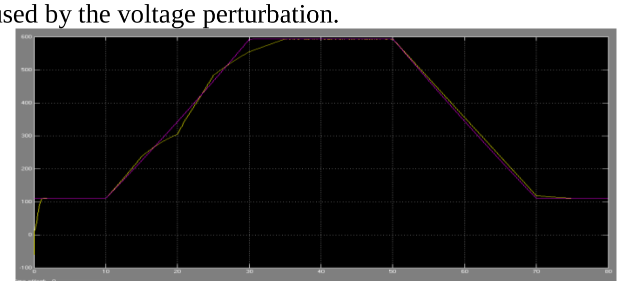

Fig: 11. Simulation measurement of the PV array power during a trapezoidal irradiation profile, using the classical MPPC method, compared to the theoretical MPP power.

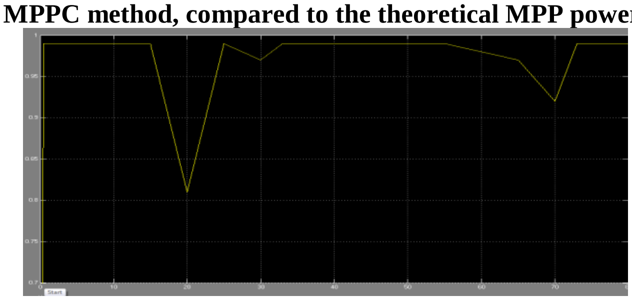

Fig: 12. Simulation measurement of the instantaneous efficiency with classical method

PROPOSED MPPT WITH VOLTAGE-ORIENTED CONTROL METHOD.

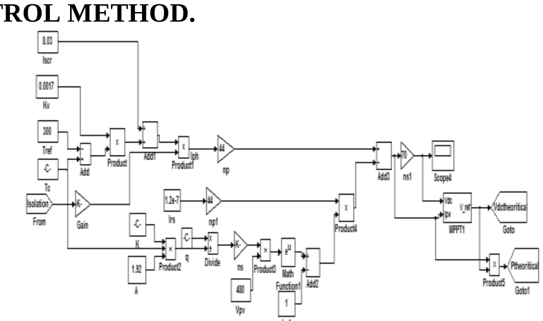

Fig: 13.Theoretical calculations of voltage-oriented control method.

To overcome the limitations of the classical method, the proposed MPPT enables us to decouple the change in power caused by the simultaneous increment perturbation and irradiation variation.

The irradiation variation is estimated by using the signal error of the PI controller of the dc voltage control. The PI regulator is designed to assure zero signal error if the atmospheric conditions are constant and a constant signal error in the opposite case. Hence, the signal error reflects only the change in power caused by the irradiation variation.

After that, in order to calculate the total change in the PV array power, the *d*-axis grid current component is used. Finally, the change in power caused by the previous perturbation is obtained by a simple subtraction; therefore, the correct direction of the MPP can be identified.

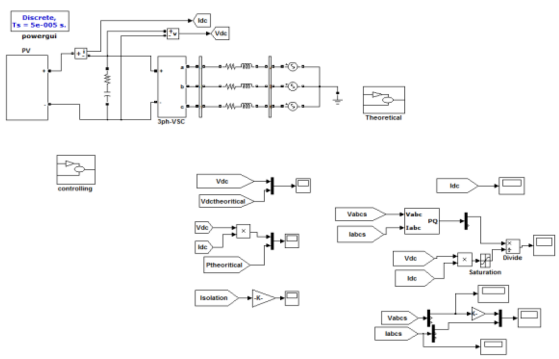

Fig: 14.Simulation circuit of voltage-oriented control method

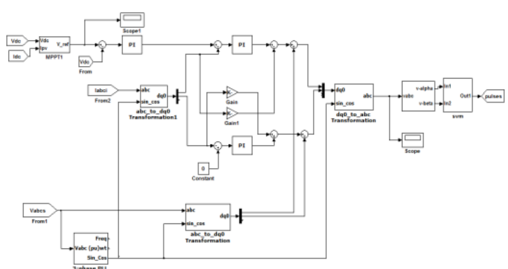

Fig: 15 Controlling circuit of voltage source converter in voltage-oriented control method

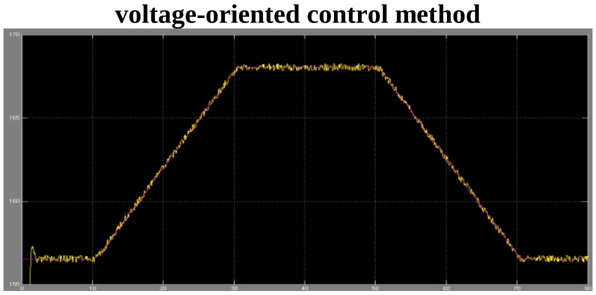

Fig: 16. PV system voltage with the proposed MPPC and theoretical MPP voltage during a trapezoidal irradiation profile.

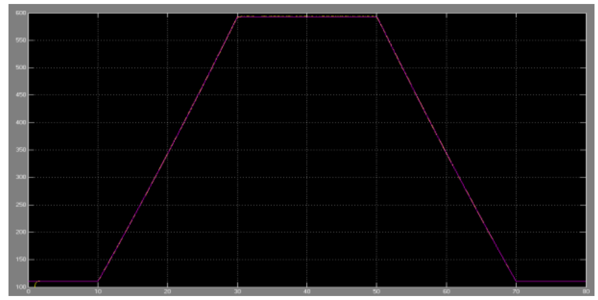

Fig: 17 Simulation measurement of the PV array power during a trapezoidal irradiation profile, using the proposed MPPC method, compared to the theoretical MPP power.

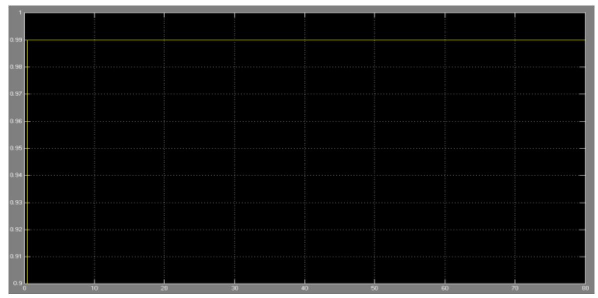

Fig: 18. Simulation measurement of the instantaneous efficiency with proposed MPPC

V. CONCLUSION

1. In order to avoid mistakes in the classical method due to the fast-changing irradiation, this paper has proposed an improved MPPC controller without PV array power measurement. This control scheme uses the *d*-axis grid current component and the signal error of the outer voltage regulator. The robust tracking capability under rapidly increasing and decreasing irradiance is verified experimentally with a PV array emulator.

This MPPC method permits one to differentiate the contribution of increment perturbation and irradiation change in power variation, hence identifying the correct direction of the MPP. In the simulation and experimental results, the robust tracking capability under rapidly increasing and decreasing irradiance has been proved. And overcome the limitations of the classical method. the proposed MPPC enables us to decouple the change in power caused by the simultaneous increment perturbation and irradiation variation. The steady-state and dynamic responses illustrated the perfect desired reference tracking controller. The output power losses caused by the dynamic tracking errors are significantly reduced, particularly under fast changing irradiation. The irradiation variation is estimated by using the signal error of the PI controller of the dc voltage control. The PI regulator is designed to assure zero signal error if the atmospheric conditions are constant and a constant signal error in the opposite case. Hence, the signal error reflects only the change in power caused by the irradiation variation. After that, in order to calculate the total change in the PV array power, the *d*-axis grid current component is used.

Finally, the change in power caused by the previous perturbation is obtained by a simple subtraction; therefore, the correct direction of the MPP can be identified .MPPC method permits one to differentiate the contribution of increment perturbation and irradiation change in power variation, hence identifying the correct direction of the MPP The robust tracking capability under rapidly increasing and decreasing irradiance has been proved.

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