Simulation of Optimal Control Strategy for a Solar Photovoltaic Power System

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ABSTRACT

This paper proposes a single-stage PV system based on a linear quadratic regulator (LQR). The system makes use of a single-phase power converter connected to the grid connected system through an LCL filter. The P&O algorithm is used to generate the reference signal for the fluctuating dc bus voltage as well as to extract the maximum power from the solar panels. The proposed work has been carried out in MATLAB, and the results are presented.

KEYWORDS: *linear quadratic regulator, P&O algorithm, LCL filter, PV system*

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I. INRODUCTION

As solar power increases in popularity, the need for this power to become more efficient is evident. The problem that arises is that many of these electronics are quite expensive, and do not necessarily work well outside of a larger system. These systems are often very complex, and not easily repaired or modified.

It is very important with photovoltaic generation to operate the system at high power efficiency by ensuring that, the system is always working at the peak power point regardless of changes in load and weather conditions. In other words, transfer the maximum power to the load by matching the source impedance with the load one. To confirm that, an MPPT system has been implemented which enables the maximum power to be delivered during the operation of the solar array and which tracks the variations in maximum power caused by the changes in the atmospheric conditions. As the solar panel outputs power, its maximum generated power changes with the atmospheric conditions (solar radiation and temperature) and the electrical characteristic of the load may also vary. Thus, the PV array internal impedance rarely matches the load impedance. It is crucial to operate the photovoltaic generation system at the MPP or near to it to ensure the optimal use of the available solar energy. There are two main technologies for the conversion of sunlight into electricity. Photovoltaic (PV) cells depend on the use of semiconductor devices for the direct conversion of the solar radiation into electrical energy. Efficiencies of the typical commercial crystalline PV cells are in the range 12 – 18% although experimental cells have been constructed that are capable of over 30%. In contrast, solar thermal systems depend on intermediate conversion of solar energy into thermal energy in the form of steam, which in turn is used to drive a turbo generator.

To obtain high temperatures, thermal systems invariably use concentrators either in the form of parabolic troughs or thermal towers. At present, generation of electricity by either technology is substantially more expensive than traditional means. Due to the considerable potential of cost reductions in PV systems it is believed that in the future, perhaps in a decade or so from the time of writing, PV systems will be providing a sizeable proportion of the renewable energy contribution.

II. RENEWABLE ENERGY

Renewable energy defines as "energy obtained from natural and persistent flows of energy occurring in the immediate environment". This requires that the flow of energy is passing through the environment irrespective of whether or not some of it is extracted for use. To reiterate, the flow of energy is not manufactured; it is simply tapped (or altered).

Table1: Conventional and Renewable Power Sources

S. No.	Conventional	Renewable
1.	Coal, nuclear, oil, and natural gas	Wind, solar, biomass geothermal, and ocean
2.	Fully matured technologies	Rapidly developing technologies
3.	Numerous tax and investment subsidies embedded in national economies	Some tax credits and grants available from some federal and/or state governments
4.	Accepted in society under the 'grandfather clause' as necessary evil	Being accepted on its own merit, even with limited valuation of their environmental and other social benefits

III. SOLAR PHOTOVOLTAIC

The photovoltaic (PV) system converts the solar radiation into electricity directly. The block diagram of a general PV system is shown in Fig.1. It consists of the following building blocks: The PV array: Its function is the conversion of solar radiation into electricity. It is the major unit in the system; Battery storage: To be available at the absence of the solar radiation, the electric energy produced by the array must be partly stored, normally using batteries. So, the second main unit is the battery storage; Power conditioning circuits: According to the nature of the load, the generated electric power must be conditioned using DC/DC converters and DC/AC inverters.

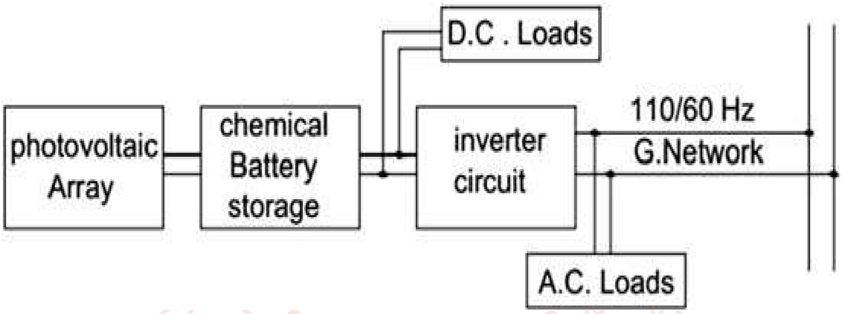

Fig.1: The general photovoltaic system

The PV array is composed of solar modules. Each module contains a matrix of solar cells connected in series and parallel to satisfy the terminal properties of the whole generator. Accordingly, the solar cell is the basic element in the PV generator. This element is the basic solar radiation converter into electricity.

IV. MAXIMUM POWER POINT TRACKING

Perturb and observe is used to control the converter and solar panel, so that the panel operated at its MPP. The logic within these algorithms determines the state of the solar panel's power in relation to its voltage and then decides how to modify the control parameters in order to find the MPP. Once the algorithm determines what needs to be done, there are several variables that can be controlled to force the system to the MPP. For maximum power transfer, the load should be matched to the resistance of the PV panel at MPP. Therefore, to operate the PV panels at its MPP, the system should be able to match the load automatically and also change the orientation of the PV panel to track the Sun if possible (Sun tracking is usually left out of most systems due to the high cost of producing the mechanical tracker). A control system that controls the voltage or current to achieve maximum power is needed. This is achieved using a MPPT algorithm to track the maximum power. A controller that tracks the maximum power point locus of the PV array is known as a MPPT controller. There are several algorithms to track the MPP and a few common maximum power point tracking algorithms have been reviewed. For optimal operation, the load line must match the PV arrays MPP locus and if the particular load is not using the maximum power, a power conditioner should be used in between the array and the load. Basic MPPT system is shown in Fig.2.

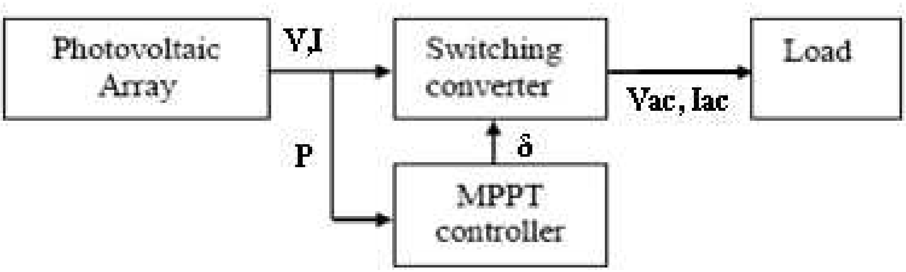

Fig.2: Basic MPPT system

Perturb and observe is probably the most commonly utilized MPPT method. The basic premise for P&O is to continually perturb or alter the power converter's operating point and then to observe or sense the ensuing effects. In other words, the settings within the converter are changed so that the solar panel's voltage and current are changed. Then, the system senses the panel's voltage and current to see if its power has increased or decreased. Subsequently, the algorithm makes a decision on how to further adjust the converter's settings. Typically, the settings that are modified are either a reference voltage or the duty cycle. In Fig.3, the P&O flowchart is presented in order to understand the finer details of this algorithm.

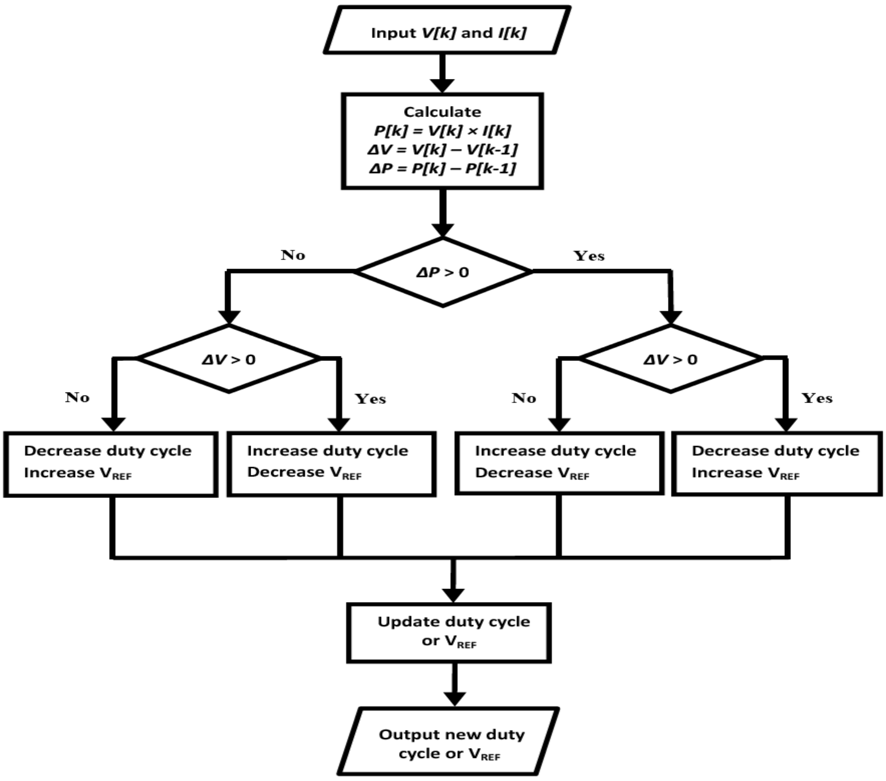

Fig.3: Perturb and observe flowchart

V. SIMULATION RESULTS

Simulations are performed using MATLAB/SIMULINK software for tracking MPPs of the solar PV array whose parameters are in Table 2.

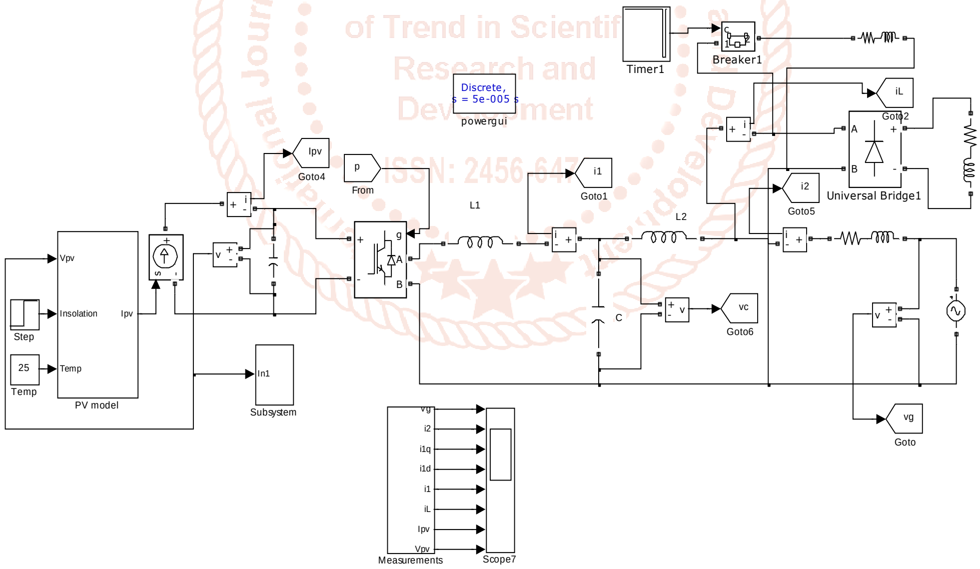

Fig.4: Matlab Simulink model for single stage solar PV system

The solar PV panel provides a maximum output power at a MPP with V_{MPP} and I_{MPP}.

Table2: Simulation parameters

Parameters	Value
DC bus Capacitance	1200e-6F
Switching Frequency	10kHz
Nonlinear load	L=80mH,R=20Ω
Linear load	L=30mH,R=30Ω
Voc	37.7V
Isc	8.85A

The parameters used for the simulations of the power converter and the electrical system are given in Table 2.

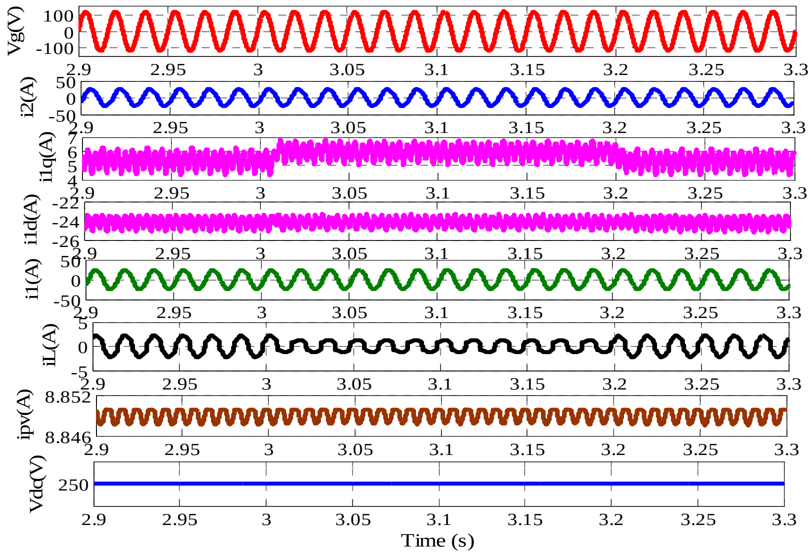

Fig. 5: System response under load power variations

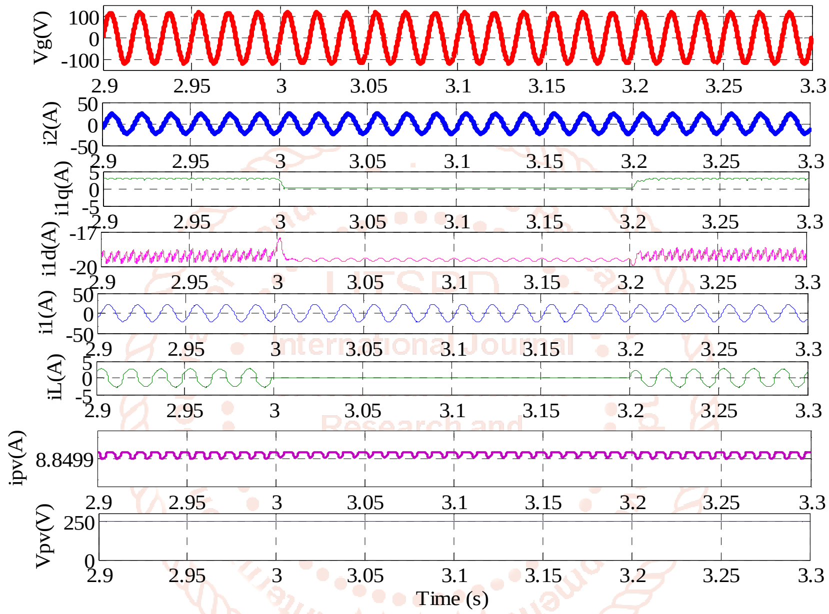

Fig. 6: System response when load is switched ON/OFF and OFF/ON

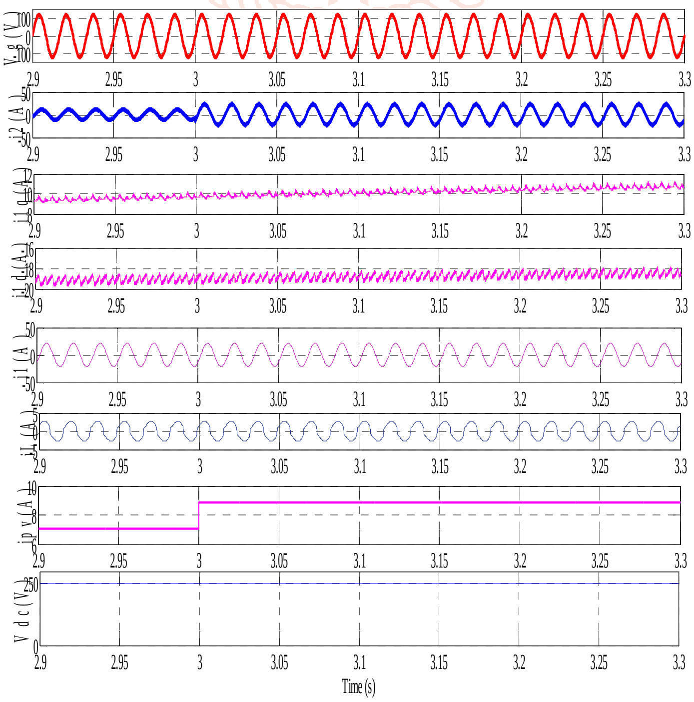

Fig. 7: System response under insolation variations

The simulation results of single-phase grid-integrated SPV systems show different observed variables, namely, grid current i_2, grid voltage v_g, converter current components (i_{1d} and i_{1q}), Load current (i_L), converter current (i_1), dc bus voltage V_{dc}, SPV array current (I_{PV}), and grid power (P_g). Four tests under linear and nonlinear load were carried out, namely, load power variation, insolation variation, load switching ON/OFF and OFF/ON, and SPV-APF to APF transition mode. Figs. 5–9 show the obtained simulation results.

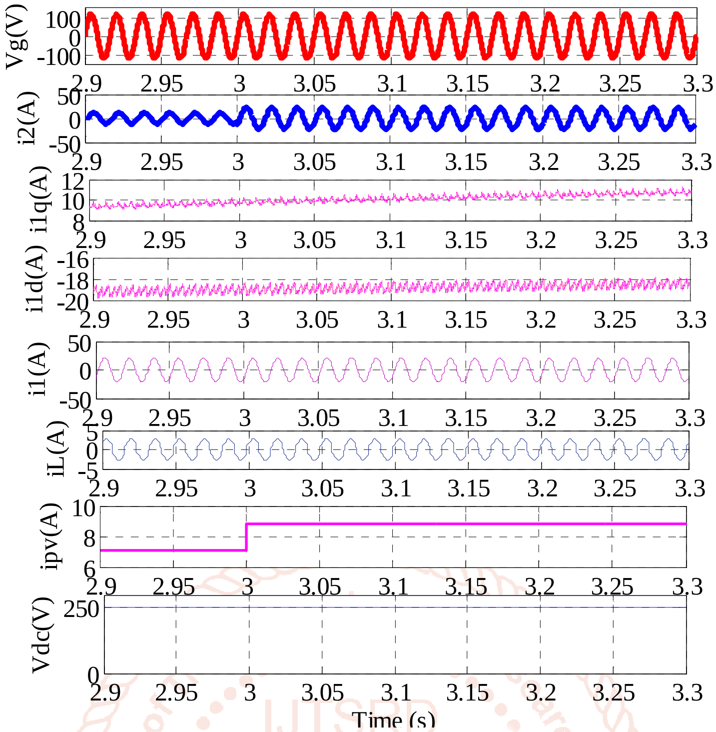

Fig. 8: System response when insolation is switched ON/OFF

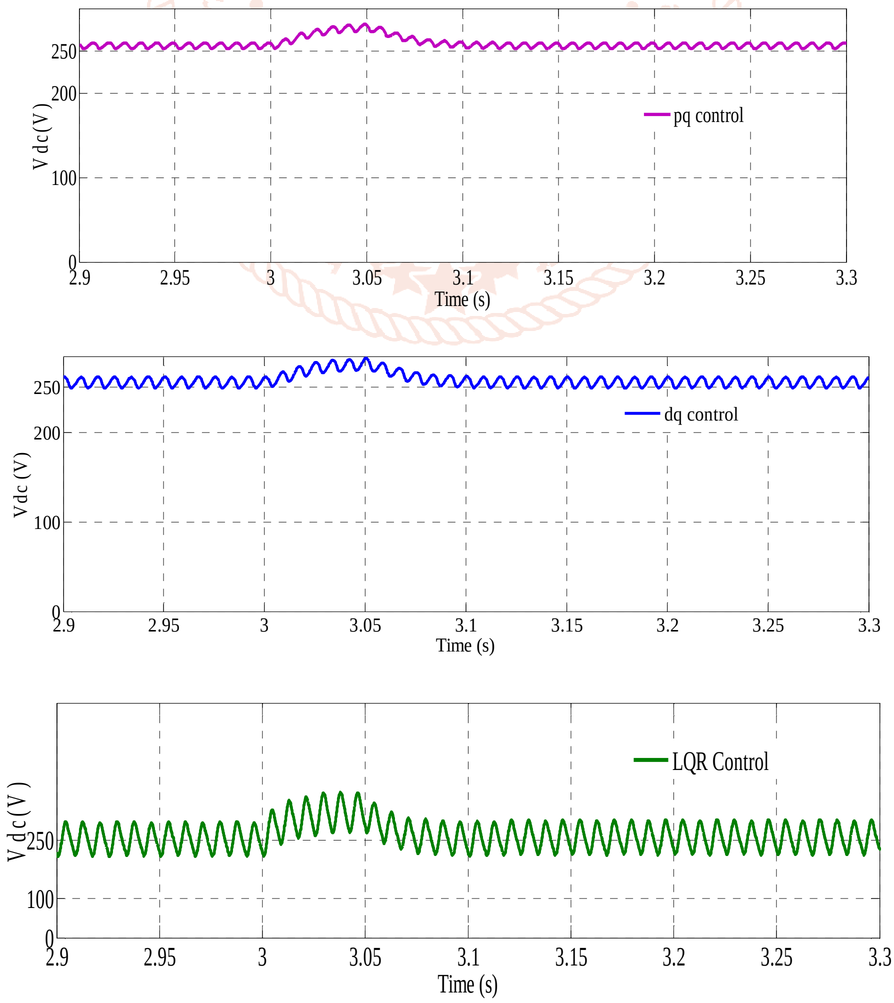

Fig. 9: Dynamic response under insolation variations

VI. CONCLUSIONS

A robust LQR scheme for a single-stage multifunctional SPV-APF-*LCL* is implemented in Matlab simulation. The simulation results show the good performance of the proposed controller in steady state and dynamic response and small settling time and overshoot are obtained.

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