A Multifunctional Single-Phase Grid Integrated Residential Solar PV Systems based on LQR Control

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ABSTRACT - A multifunctional single-stage private photovoltaic force flexibly dependent on Linear Quadratic Regulator. The framework utilizes a solitary stage power converter associated with the lattice through a LCL channel. A vigorous LQRI regulator is intended to consolidate added capacities, for example, power line conditioner, dynamic force controller, and voltage stabilizer. The bother and notice (P&O) calculation is utilized to create the reference signal for the fluctuating DC transport voltage just as to separate the most extreme force from the sun powered boards. Full displaying of the converter in the D-Q reference outline is introduced. A Linear Quadratic Regulator with added Integral activity (LQRI) is intended to accomplish ideal multi-usefulness activity of the private force flexibly. Recreation and test results affirm the normal presentation of the proposed regulator for insolation and burden varieties.

Index Terms - D-Q model, LCL filter, LQRI controller, Maximum power point tracking (MPPT), Perturb and observe (P&O), Solar PV system, single phase.

I. INTRODUCTION

The increasing demand of electric energy in the world has boosted the productivity and the multiple use of renewable energy. The solar photovoltaic (PV) array is among the most important renewable sources used for power generation. Forecasts predict that in 2018 more than 68.6 GW of the electric power will be provided from solar PV systems [1]. Growing interest in grid-integrated PV system is becoming more and more important, where two types of grid connected residential photovoltaic converters are used; the first uses single stage conversion and the second uses a cascaded of two conversion stages [2]. The two stages topology uses a dc to dc followed by a dc to ac converters; whereas the single stage PV systems use a direct dc to ac converter which is assumed to have better performance and higher efficiency than the cascaded converters topologies [3].

Due to the drawbacks of two-stage conversion schemes, the single stage PV systems attracted the attention of many researchers especially for low voltage grid applications meant to distribution systems. Single-stage single phase grid integrated PV system based on fuzzy logic controller has been proposed in [4]; where the control of the active current injected to the grid is realized with a resonant controller (PR). Moreover, in [5] a control scheme based on nonlinear adaptive controller is proposed for single-stage grid integrated PV system; where the study demonstrates similar performance with those obtained using a linear controller. In [6] an MPPT algorithm is proposed based on modified particle swarm optimization (PSO) associated with additional control schemes in order to improve the usability and performance of single stage grid integrated PV system. Furthermore, in [7] the authors proposed a control strategy for single-stage and two-stage grid connected inverters with some modifications in the control to improve the system functionalities under abnormal conditions where the dc bus voltage is regulated naturally in single stage, in contrary to two stage conversion scheme. In [8] a single-stage PV system connected to the grid is proposed with modified variable step size (VSS-LMS) based control to improve the performance of the studied configuration. Moreover, in order to insure power quality enhancement, solar PV system (SPV) in the distributed generation, active power filters [9], and series compensators [10] are used. However shunt active power filters are introduced with SPV systems to deal with power quality issues caused by the constant increase of power converters integrated to the distribution systems. In order to respect grid's connection standards, passive filter is required betweenthe inverter and the network. The passive filter role is to help reduce the amplitude of harmonic currents injected into the grid at the point of common coupling (PCC) [11]. Despite its benefits, LCL filters have their own drawbacks such as resonance and dependence on network and neighboring impedances. To overcome these problems, active and passive damping are usually applied to give better performance to the actual passive configuration. Most of these methods are applied to grid connected converters [12]-[13], and those that are applied to shunt active power filter (SAPF) are barely mentioned and discussed [14], [11], [15]. In most applications targeting SPV connected to the distribution system [2],[22]-[23], where in [24] a unified power quality conditioner (UPQC-SPV) with active power filter (APF) capabilities were presented as independent units not integrated into the system functionality as such. Solar PV system grid connected converters can perform the same functions assigned to those performed by shunt active power filters topologies simply by modifying the control algorithm of the SPV systems [23]. The active power filter APF functionality is introduced when insolation is unavailable as in [23]; an adaptive filter (ALCF) is used in the current control scheme. To reduce power quality issues in the distribution system, several configurations and control schemes have been proposed in the literature [26]. Moreover, most of publications were focused on the three-phase systems as in [27, 28] but those dedicated to single phase are rare. As in [29] the functionalities of SPV systems and APF were combined. On the other hand, [30] proposed a control method based on adaptive neurons detection for single-stage single phase grid interfaced SPV system. Moreover, the single-stage grid interfaced SPV system for power quality enhancement under abnormal conditions is presented in [25].

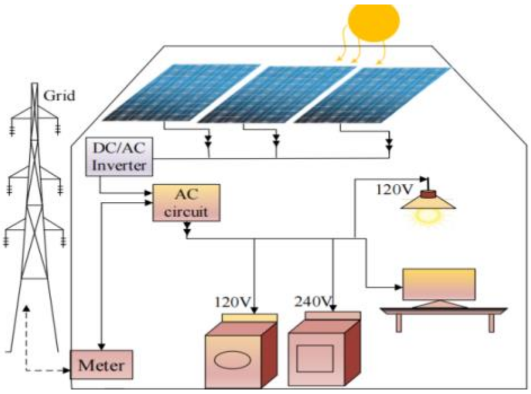

Fig.1. Residential solar photovoltaic systems.

In the system of this examination, the single-stage sun based photovoltaic framework coordinated energy dissemination framework (SPVAPF-LCL) with dynamic force channel abilities for private sun oriented applications is proposed with the utilization of direct current control plot to have similar functionalities as dynamic force channel.

The model in d-q reference outline is done to plan better regulators [16-21], and the proposed regulator is planned to kill music, and guarantee solidarity power factor at the matrix. The LQR regulator is a decent competitor for this application since it guarantees quick powerful reaction, vigor, low THD, unit power factor, and straightforwardness to fine tune its benefits [20]-[31]. The proposed framework incorporates the extra APF capacities in matrix incorporated PV frameworks. A multifunctional lattice interfaced SPV frameworks work as APF at the point when the accessible dynamic force is diminished mostly on account of illumination accessibility; working on thus the force nature of the AC dispersion framework by keeping away from conceivable cooperation and coupling between adjoining establishments. Along these lines fourth commitments are introduced in this work and are as per the following:

- The utilization of direct quadratic controller to track down the ideal regulator gains by picking the ideal upsides of R and Q lattices to limit the control energy and upgrade the dependability of the framework.
- The joining of dynamic damping in the LQR control permits staying away from the utilization of damping resistor of LCL channel furthermore, works on the nature of the remuneration by lessening the current exchanging swells in the framework side.
- The proposed LQR control approach wipes out the utilization of PI regulator for DC-interface voltage.
- The feed-forward regulator is utilized in the immediate currentcontrol plot to safeguard quick unique reaction.

This paper is organized as follows. After full modeling of the converter, the linearized model of single-phase SPV-APF is presented in section II. The design of the LQRcontroller with integral action added is presented in detail in section III. In section four, simulation and experimental results obtained using Matlab/Simulink/SPS and the implementation of LQRI controller in a DS1103 of dSPACE are presented and discussed. Finally, a conclusion along with a discussion is given.

II. MODELING OF SPV-APF-LCL

The single-stage sun powered photovoltaic lattice coordinated private frameworks represented by Fig. 2 comprises of SPV board, a VSI, an LCL channel taking care of direct and nonlinear private burdens.

- The single stage inverter with LCL channel (VSI-LCL) is combined with nonlinear burdens, which comprise of diode spans taking care of inductive burdens and a R-L branches, which addresses the direct burden.
- The latent channel (LCL) is made out of inductance L1, inductance L2 and capacitance C.
- SPV cluster and Cdc is the dc transport capacitor.

A. LCL Filter Design

$$L_1 = \frac{mV_{dc}}{4\,a\,f_{sw}\Delta i_o} = \frac{200}{4\times1.2\times10e3\times1.35} = 3.08mH. \qquad (1)$$

Δo is the maximum ripple that is expected in the current 1, is the switching frequency, and m represents the modulation index. The value of L1 is taken as 2.5mH. The grid side inductance L2 is calculated in the following:

L2=r*L1 **(2)**

The value of**L2** is taken equal to **L1**. Filter capacitor value is calculated as:

$$C = \alpha C_b = 0.01\times212.2\mu F = 2.12\mu F. \qquad (3)$$

Where:

$$C_b = \frac{1}{\omega z_b} = \frac{1}{377\times12.5} = 212.2\mu F.$$

Cb and Zb are the base capacitance and inductance separately. The worth of the channel capacitor is taken as 2.5μF. In three stage framework Park change is by and large utilized to acquire the d-q model that help planning framework regulators utilizing direct or non-straight procedures. To apply this idea to single stage frameworks the nonexistent circuit ought to be made from the genuine factors (Fig.3)as in [16]. The deliberate factors address the genuine circuit and to make the fanciful circuit the factors were moved by 90o to get their comparable segments in the α-β reference outline.

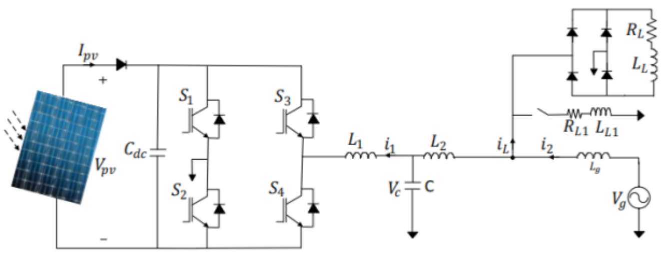

Fig. 2. Electrical scheme of the system under study

$$i_{1\beta}=i_{1\alpha}\,e^{-\pi/2},\ i_{2\beta}=i_{2\alpha}\,e^{-\pi/2},v_{c\beta}=v_{c\alpha}\,e^{-\pi/2},v_{g\beta}=v_{g\alpha}\,e^{-\pi/2} \quad (4)$$

To transform these variables from *α-β* coordinates to *d-r*otating frame, the well-known matrix T given by (5) is used [17].

$$T=\begin{bmatrix}\sin(\omega t) & -\cos(\omega t)\\ \cos(\omega t) & \sin(\omega t)\end{bmatrix} \quad (5)$$

Thereafter, one can obtain the model of the VSC-LCL in *d−q* frame as expressed by (6):

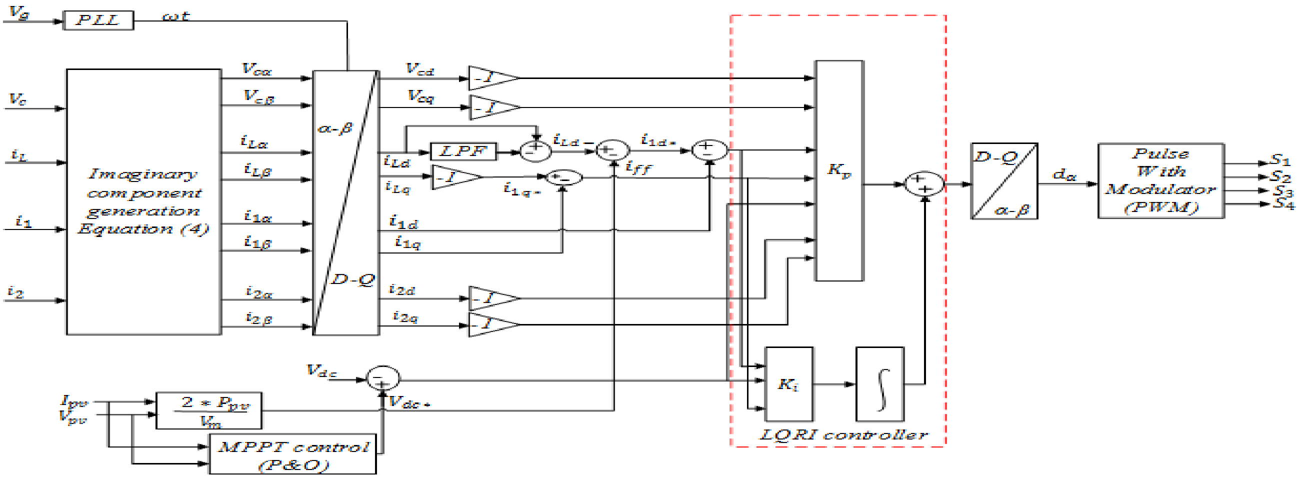

Fig. 3. Implemented controller in Matlab.

$$\frac{d}{dt}\begin{bmatrix}i_{1d}\\ i_{1q}\\ i_{2d}\\ i_{2q}\\ v_{cd}\\ v_{cq}\\ v_{dc}\end{bmatrix}=\begin{bmatrix}-\frac{R_1}{L_1} & \omega & 0 & 0 & -\frac{1}{L_1} & 0 & 0\\ -\omega & -\frac{R_1}{L_1} & 0 & 0 & 0 & -\frac{1}{L_1} & 0\\ 0 & 0 & -\frac{R_2}{L_2+L_g} & \omega & \frac{1}{L_2+L_g} & 0 & 0\\ 0 & 0 & -\omega & -\frac{R_2}{L_2+L_g} & 0 & \frac{1}{L_2+L_g} & 0\\ \frac{1}{C} & 0 & \frac{-1}{C} & 0 & 0 & \omega & 0\\ 0 & \frac{1}{C} & 0 & \frac{-1}{C} & -\omega & 0 & 0\\ \frac{D_d}{C_{dc}} & \frac{D_q}{C_{dc}} & 0 & 0 & 0 & 0 & 0\end{bmatrix}\begin{bmatrix}i_{1d}\\ i_{1q}\\ i_{2d}\\ i_{2q}\\ v_{cd}\\ v_{cq}\\ v_{dc}\end{bmatrix}$$
$$+\begin{bmatrix}0 & 0\\ 0 & 0\\ \frac{-V_{dc}}{L_1} & 0\\ 0 & \frac{-V_{dc}}{L_1}\\ 0 & 0\\ 0 & 0\\ \frac{I_d}{C_{dc}} & \frac{I_q}{C_{dc}}\end{bmatrix}\begin{bmatrix}d_d\\ d_q\end{bmatrix}+\begin{bmatrix}\frac{1}{L_1} & 0\\ 0 & \frac{1}{L_1}\\ 0 & 0\\ 0 & 0\\ 0 & 0\\ 0 & 0\\ 0 & 0\end{bmatrix}\begin{bmatrix}v_{gd}\\ v_{gq}\end{bmatrix} \quad (6)$$

Where, i1d, i1q and i2d, i2q are the APF yield current and lattice current segments, vcd, vcq are the capacitor voltage in d-q outline, vdc is the dc transport voltage, vgd and vgq are the lattice voltage in d-q, dd, dq are the obligation cycle segments. The linearized little sign model around a working point is addressed by (7):

$$\frac{dx_{\sim}}{dt}=A\,x_{\sim}+B\,u_{\sim}+E\,v_{\sim} \quad (7)$$

A,B, and E are the frameworks of the linearized little sign model which address individually the state, control and aggravation lattices of the framework. x, u, and v are the states factors, control input, and unsettling influence vectors of the framework separately.

$$x=\begin{bmatrix}i_{1d\sim} & i_{1q\sim} & i_{2d\sim} & i_{2q\sim} & v_{cd\sim} & v_{cq\sim} & v_{dc}\end{bmatrix}^T,\ u=\begin{bmatrix}d_{d\sim} & d_{q\sim}\end{bmatrix}^T,$$
$$v_g=\begin{bmatrix}v_{gd\sim} & v_{gq\sim}\end{bmatrix}^T.$$

III. SIMULATION RESULTS

Simulation diagram

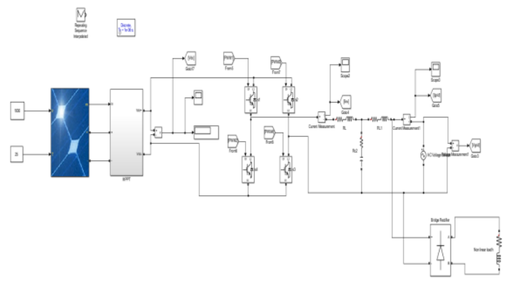

Fig 7: Simulink Design of solar study system Connected to Grid under Non liner load variations

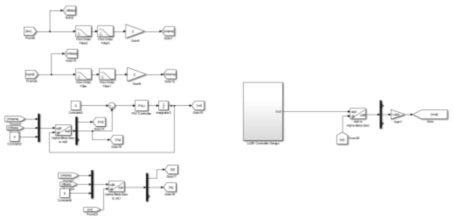

Fig 8 Controller design Of Inverter and Grid system

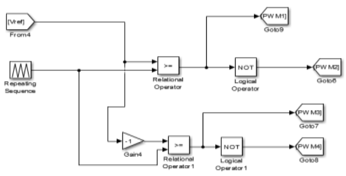

Fig 9 simulink design of SPWM technique for Grid Inverter

Results:

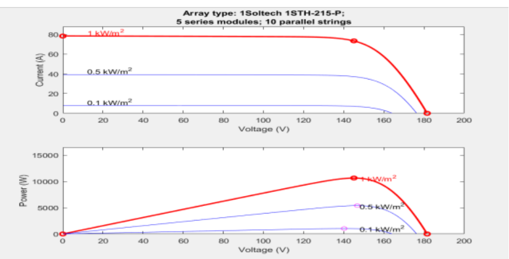

Fig 10 :I-V curve P_V Curve

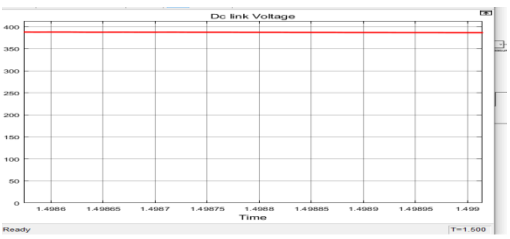

Fig 11: Dc Link Voltage

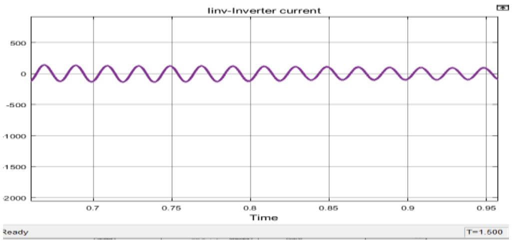

Fig 12: Inverter Current

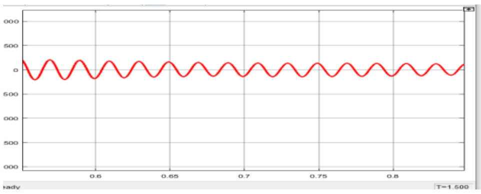

Fig 12: Grid Current

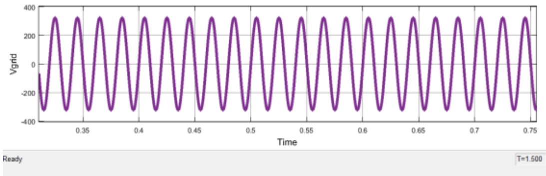

Fig13: Grid Voltage 230V

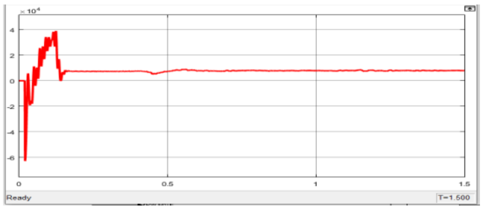

Fig 14 :Active Power

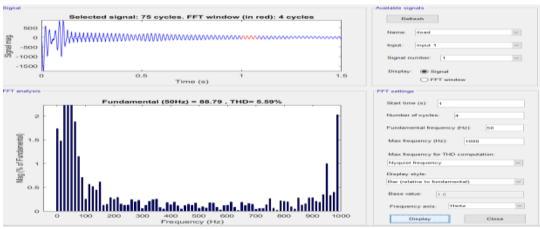

Fig 15: Total Harmonic Distartions THD-5.59%

IV. CONCLUSION

The plan and usage of a powerful Linear Quadratic Regulator conspire for a solitary stage multifunctional SPV-APF-LCL. The proposed powerful regulator is reasonable for single-stage private sunlight based photovoltaic framework applications. Under the keen framework activity, it is illustrated the effectively dealing with the dynamic force created by the sunlight based boards, this single stage setup can repay current that could be symphonious produced by mutilated gracefully voltage, also, nonlinear burdens found in a solitary stage AC dissemination framework. The Simulation and test results show the great execution of the proposed regulator in consistent state and dynamic reaction where a low THD of framework current and little settling time and overshoot are gotten. The SPV-APF to APF mode progress is tentatively executed and demonstrated its viability. Thus, the outcomes did, affirmed the reasonableness and viability of the LQRI as a vigorous sort of regulator which is an incredible possibility for single stage SPVAPF-LCL single stage associated with an AC dissemination framework.

V. REFERENCES

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