Unified Control with fuzzy MPPT and PSO based Parameter Optimization for Single Stage PV System based on Energy Saving

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Abstract. This paper presents a unified control for single stage grid-connected system with non-linear load. The proposed control not only ensures power injection into the grid, but also shows its advantage of controlling both active and reactive powers as well as harmonics restraints. This paper explains also the advantage of single stage using quasi-z source inverter (QZSI) which plays the buck/boost operation using space vector pulse width modulation technique (SVPWM) for shoot through insertion during the modulation period. Instantaneous power theory is used to simplify the implementation of the control design for both the inner and outer layer as well as for the reference current generation. To take off the challenge of tracking the maximum power point (MPPT) in any condition, including change in solar irradiance, fuzzy technique is used. Thereby, exhibiting its robustness and adaptability. Besides, to ameliorate the efficiency of the system, the well repute particle swarm optimization algorithm (PSO) is employed to improve the PI controllers’ parameters. Finally matlab/Simulink environment is used to implement and to confirm the effectiveness and the feasibility of the proposed control strategy as well as the optimization method.

Keywords: QZSI, PSO, SVPWM, Fuzzy MPPT, unified control.

1. Introduction

The twenty first century is the one of harnessing clean energy. There is no doubt solar energy is leading in that regard due to many advantages shown so far (pollution free and inexhaustibility). Grid connected photovoltaic system is one of the developing trend in that sense. As such, it has become a target of profound researches in recent years; not only to substitute the conventional sources of energy but also to improve the power quality [1-2]. As the grid connected systems develop, so are the requirements for the control strategy with the development of nonlinear loads. In this regard, this paper presents a unified control with APF which control real and reactive power injection to the grid and improves the THD [3]. To deal with the special feature of QZSI which plays the buck/boost function, SVPWM is used for the purpose of inserting shoot through during modulation period[4]. For efficient use of APF, strong and adaptive MPPT algorithm is of great importance. For these reason this paper utilizes fuzzy logic control technique (FLC) [5]. Research has dealt exhaustively with conventional methods of tuning proportional integral (PI) controller but achieving an optimal solution remains a challenge. Thus, PSO is used in this paper to optimize PI’s parameters since it is faster compare to other intelligent algorithms such as genetic algorithm or artificial neural network.
Moreover, it is easy and simple to implement because there are few parameters to adjust. In this paper, the second section deals with reference current generation and power control. The third section explains PSO method. Next, the fourth section deals with FLC design and the fifth deals with SVPWM and QZSI. The sixth analyses deeply the simulations results and lastly conclusion is made.

2. Reference Current Generation and Power Control
The key point with unified control strategy is to generate exact uniform reference current. Figure1 exhibits the process that leads to the reference current generation. This is done through simultaneous use of dq and α-β transformations. At the beginning, PLL is used to synchronize the inverter with the grid. Then the detected load current is transformed into α-β.

\[
\begin{align*}
C_{dq} & \rightarrow i_{dq} \\
C_{\alpha\beta} & \rightarrow i_{\alpha\beta} \\
C_{\alpha\beta} & \rightarrow i_{\alpha\beta} \\
C_{dq} & \rightarrow i_{dq}
\end{align*}
\]

**Figure1.** Reference current calculation unit.

From α-β to dq coordinates through the block \(C_{dq}\). The DC components with extremely low frequency are filtered out using low pass filter (LPF). These filtered outputs are transformed into fundamental elements \(\alpha_f\) and \(\beta_f\) through the block \(C_{dq}^{-1}\) after which the fundamental components \(i_{aF}, i_{bF}\) and \(i_{cF}\) are produced by retransformation using \(C_{23}\). Finally, the reference currents are calculated by subtracting \(i_a, i_b, i_c\) from \(i_{aF}, i_{bF}\) and \(i_{cF}\) using equation (1).

\[
\begin{align*}
\dot{i}_{a_{ref}} &= i_a - i_{aF} \\
\dot{i}_{b_{ref}} &= i_b - i_{bF} \\
\dot{i}_{c_{ref}} &= i_c - i_{cF}
\end{align*}
\]  

(1)

This paper uses both synchronous frame and static reference frame in order to control both active and reactive power. The grid voltage is transformed into dq components \(e_q\) and \(e_d\). Upon simplification by setting \(e_q\) equals to zero, the equation (4) below is obtained.

\[
\begin{align*}
p &= \frac{3}{2} e_d i_d \\
q &= \frac{3}{2} e_d i_q
\end{align*}
\]  

(2)

Thus, by acting directly on dq components of QZSI output current, real and reactive power can be controlled. This is illustrated through inverter mathematical model as follows [3].

\[
\begin{align*}
e_d &= L_p \frac{di_d}{dt} - \omega L_p i_q + u_d \\
e_q &= L_p \frac{di_q}{dt} + \omega L_p i_d + u_q
\end{align*}
\]  

(3)
Where $u_d$ and $u_q$ as output components of the QZSI, $L_r$ is the reactors’ inductance. Equation (3) shows clearly that the output voltage of the QZSI is coupled with the $i_{dq}$ components. Therefore controllers must be used for decoupling purpose. The decoupling will provide the SVPWM with appropriate signals for triggering the inverter. As for outer layer, fuzzy controller is used to generate duty shoot-through.

3. QZSI Control

This paper uses QZSI to implement single stage PV system. QZSI has a special feature exhibiting shoot-through states\[4\]. This feature occurs when any of the single phase leg, two phase legs or all three phase legs is short circuited which contrarily is not accepted in voltage source inverter. This advantage is seized to boost the DC link voltage as follows.

$$
\begin{align*}
V_{c1} &= \frac{1-D}{1-2D}V_{in} \\
V_{c2} &= \frac{D}{1-2D}V_{in} \\
V_{QZ} &= \frac{1}{1-D}V_{c1}
\end{align*}
$$

(4)

Where D is shoot-through duty, $V_{in}$ is PV voltage ($V_{pv}$), $V_{c1}$ and $V_{c2}$ are elements of quasi z network and $V_{QZ}$ is quasi z network voltage. At the same time as shown in figure 1, a controller is used to control the output of $V_{QZ}$ towards its reference voltage. By adjusting duty shoot-through D, $V_{pv}$ can be controlled up to its reference value.

SVPWM refers to a switching pattern with the aim of producing the reference voltage. This modulation technique divides the space into six active vectors and two zero vectors which are stationary since they don’t move. The motion of the reference vector through all the six sectors can be interpreted as triggering signal since it toggles the switches into ON or OFF state. In every sector, the reference voltage is calculated using two adjacent vectors [3]. The SVPWM has also the advantage of producing fewer harmonic. For boosting purpose, shoot through insertion must be done at the right moment without disturbing the active states. As depicted by figure2 below, shoot through time is divided into six equaled parts and inserted right at the transition states. To avoid redundancy, only sector six will be used. Figure3 shows the reference voltage in sector six which is the projection of vector one and vector six.

$$
V_{ref} = \frac{T_1}{T_{sw}}V_1 + \frac{T_6}{T_{sw}}V_6 + \frac{T_{0.7}}{T_{sw}}V_0
$$

(5)

where $V_{ref}$ is reference voltage, $T_1$ and $T_6$ are operating time of vectors $V_1$ and $V_6$, $T_{sw}$ switching period, $T_{0.7}$ and $V_0$ elements of zero components.

$$
T_{sw} = T_1 + T_6 + T_{0.7} + T_{ST}
$$

(6)
4. Fuzzy Logic Controller Design

This paper uses power-voltage (P-V) curve with its slope and change of slope as fuzzy inputs. These inputs are obtained from the sensed voltage and current of the photovoltaic array. After diving the P-V slope into three regions, five term fuzzy set is used to produce twenty five rules data base. These rules are implemented using toolbox in MATLAB. The change in error shows whether the operating point is on the left or right of the MPP along the P-V curve. Fuzzy technique uses three steps known as fuzzification, rules evaluations and defuzzification. The defuzzification process used is centroid method because of its simplicity. The FLC output which is duty (Do) is fed to SVPWM for MPPT. Figure 4 displays the membership functions realized using twenty five rules shown in table 1.

Table 1. Fuzzy rules.

| Fuzzy Rules | E(k) | CE(k) |
|-------------|------|-------|
| CE(k)       | NB   | NS    | ZE    | PS    | PB    |
|             | NB   | ZE    | PB    | PS    | ZE    | NB    |
|             | NS   | PB    | PS    | ZE    | ZE    | NB    |
|             | ZE   | PB    | PS    | ZE    | NS    | NB    |
|             | PS   | PB    | ZE    | NS    | NS    | NB    |
|             | PB   | PB    | ZE    | NS    | NB    | ZE    |
|             | NB   | NS    | ZE    | PS    | ZE    | NB    |

5. Particle Swarm Optimization

The key point in this algorithm is that, it relays on both personal best position and global best position in order to adjust the next position. The process starts with a random initialization, then followed by the evaluation of the particle position, next is the update then followed again by another evaluation and update again and the process goes on for every iteration till the stop criteria is met or the maximum iteration is achieved [2],[5]. The particle dimension is two, the population of the swarm is ten, the maximum iteration is one hundred. The upper bound is 10 and the lower is 0.01. Both the velocity and the position of the particle are updated using equations (11) and equation (12) respectively.
\[ V_{id}^{n+1} = w V_{id}^n + c_1 r_1 (X_{pbest}^n - X_{id}^n) + c_2 r_2 (X_{gbest}^n - X_{id}^n) \]  \hfill (7)

\[ X_{id}^{n+1} = X_{id}^n + V_{id}^{n+1} \]  \hfill (8)

\( X_{pbest} \) is the best recorded position so far and \( X_{gbest} \) is the global recorded best position. \( c_1 \) and \( c_2 \) are acceleration constants \((c_1=c_2=2)\) and \( r_1 \) and \( r_2 \) random numbers uniformly distributed in the range \([0\ 1]\); \( w \) is inertia weight \((w=4)\). In this paper, the optimal solution is obtained using the function Integral of Time Multiplied by Absolute Errors (ITAE). This function is minimized throughout the iteration process using the above two equations (7) and equation (8).

\[ ITAE = \int_{0}^{T} |e(t)| dt \]  \hfill (9)

Every swarm element has a candidate solution for the proportional integral (PI) parameters \( K_p \) and \( K_i \), expressed by the transfer function of the PI controller as equation (14) below [2].

\[ G_{pi} = K_p + \frac{K_i}{s} \]  \hfill (10)

The output voltage of the inverter being coupled with \( i_d \) and \( i_q \) components, two PI controllers are used for decoupling purpose. The decoupling process is displayed by equation (11).

\[
\begin{align*}
U_d &= -(K_p + \frac{K_i}{s})(i_d^* - i_d) + \omega L_F i_q + e_d \\
U_q &= -(K_p + \frac{K_i}{s})(i_q^* - i_q) + \omega L_F i_d + e_q
\end{align*}
\]  \hfill (11)

With \( K_p \) and \( K_i \) parameters of PI controller to be optimized by PSO, \( U_d \) and \( U_q \) output voltage components of the inverter, \( i_d^* \) and \( i_q^* \) reference currents, \( L_F \) reactors’ inductance. This approach discloses that \( i_d \) and \( i_q \) can be controlled independently from reference currents.

6. Simulations Analysis

To verify the feasibility of the proposed control system, matlab environment is used for simulation. The model is made of three parts. First, PV system of 3127 W; second, quasi z source inverter with \( L=470 \) mH and \( C=470 \) mF and last nonlinear load composed of rectifier with resistance and inductor [3]. The overall model is connected to the grid having 220V as phase voltage and 50Hz as frequency. Figure5 displays the three phase wave shape of the non-linear load current which are not entirely sinuous with their ends chopped off due to the nature of the load. Figure 6 shows the performance of fuzzy logic controller despite the change in solar irradiance change. From zero till one second, the maximum power is kept at around 3100W which is consistent with the reference value of 3127W. From one to two second when the irradiance falls from 1000W/m\(^2\) to 700W/m\(^2\), the designed fuzzy controller is still able to track the maximum power point. Thereby, confirming the performance of fuzzy technique. Figure7 displays phase A grid voltage in phase with current which indicates that the control is effective since both voltage and injected current are entirely in phase. This is obtained by setting reactive current to zero leading to unity power factor. Figure 8 shows grid phase A injected current before harmonics restraints with high THD of 11.45\%. Figure 9 shows the same injected current after harmonics restraints using filter leading to a THD of 4.10\% and THD drops further to 3.50\% after optimization as shown by figure 10. Hence, confirming the efficacy of PSO algorithm.
7. Conclusion
This paper presents a unified control system whose feasibility and efficiency are demonstrated through simulation using MATLAB/Simulink. The efficiency of the proposed control was demonstrated by power injection into the grid and harmonics restraints. This paper also shows that the system can further be improved by using particle swarm optimization (PSO) which ameliorates the grid current harmonics. Compared to other methods that combine intelligent control or classical MPPT algorithm with PSO, this paper uses PSO to optimize PI parameters which not only is simple but also produces good result in term of THD. Besides this paper uses fuzzy techniques for maximum power point tracking (MPPT) whose efficacy is demonstrated under different solar irradiance. The proposed control strategy can be used in distribution network with the aim of power quality improvement.

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