Optimized control strategy for a three-phase grid connected inverter using PI controller and DQ frame

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Article Info

Article history:

Received Sep 26, 2023
Revised Mar 8, 2024
Accepted Apr 26, 2024

Keywords:

DQ frame
Grid integration
PI controller
Renewable energy
Three phase inverters

ABSTRACT

This paper provides a proportional-integral (PI) controller and direct-quadrature (DQ) frame transformation-based optimum control method for a three-phase grid-connected inverter. In terms of grid synchronization, voltage regulation, and harmonic abatement, the proposed control technique attempts to improve the inverter's performance. By separating the control of active and reactive power, the control structure is made simpler and independent regulation of these parameters is possible. This improves the inverter's capacity to quickly react to grid disruptions and track reference values accurately. In order to lower carbon emissions and improve grid dependability, it has become vital to integrate renewable energy sources into the current power grid. Grid-connected inverters are essential in this situation because they transform DC electricity from renewable sources into grid-safe AC power. This abstract outline a proportional-integral (PI) controller and direct-quadrature (DQ) frame-based optimal control method for a three-phase grid-connected inverter using a MATLAB simulation.

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1. INTRODUCTION

A crucial component of the global shift to sustainable energy systems is the quick development of renewable energy sources like wind power. The usage of three-phase LCL-type grid-connected inverters is one of the favored methods for integrating renewable energy installations like wind turbines into the public grid. These inverters make it easier to transform variable renewable energy output into a format that can be fed into the grid. Nevertheless, despite their extensive use, these inverters' interface with the grid has inherent stability issues. As a result, it is critical to carefully examine and fix these stability issues [1]. The pursuit of energy efficiency and sustainability is critical in today's society across many businesses. Elevator systems are one key area where energy-saving technology is crucial, particularly with the use of three-phase grid-connected inverters. With the use of this technology, extra DC energy may be converted into AC power and easily incorporated into the power grid, effectively acting as a load [2]. The installation of a grid-connected three-phase inverter system while abiding by industry norms and criteria is the main topic of this article. Average models are used to represent the inverter and LCL filter, and the design of the control scheme in the DQ reference frame is discussed [3]. In order to overcome these difficulties, a proportional-resonant (PR) controller in a stationary coordinate system is offered as a novel solution in this study. Infinite control gain at a particular resonance frequency is one of the PR controller's standout traits. At that frequency point, steady-state error-free control can be achieved thanks to this special characteristic [4]. This study addresses the challenging problems of power coupling and intricate decoupling in the context of a three-phase grid-connected inverter's d-q coordinate system [5]. The gains of the proportional-integral (PI) controllers are improved utilizing a genetic algorithm (GA) through an adaptive online tuning procedure to guarantee the adaptability and efficacy of the control system [6]. An external power loop and an internal current control loop, both implemented using customary PI type controllers, are two crucial parts of the suggested control method [7]. The power generated travels via a three-phase inverter on its way from generation to consumption, operating in accordance with the DQ principle to ensure smooth communication with the grid. This integration not only makes it easier to export excess energy, but it also deals with the crucial problem of poor power quality, which can develop in such intricate systems [8]. These control techniques' main goal is to smoothly transfer all active power produced by non-renewable sources into the grid utility while maintaining the highest standards of power quality and achieving a unity power factor [9]. This paper not only explains the complex design of the controller but also goes into great detail on how it is implemented and evaluates how well it works using a number of simulations [10].

The voltage source inverter (VSI) that powers the DVR uses two PI controllers to carefully control the insulated gate bipolar transistor (IGBT) pulses. These controllers accomplish this by fine-tuning the D-Q axis voltage signals, with each controller handling a single axis component of the load voltage as input and output [11]. A DC-link voltage control loop using a PI controller is cascaded with an internal current loop using PI and proportional-resonant (PR) controllers in the suggested topology. For non-renewable systems, these control techniques are frequently used in a variety of recognized reference frames. The steady-state performance of the proposed system was determined by evaluating key performance indicators, such as total harmonic distortion [12]. The incorporation of micro-sources into microgrids, however, also presents difficulties, particularly in resolving problems with power quality. Non-linear and unbalanced loads in the distribution system might cause disturbances that degrade the microgrid's overall power quality. This paper evaluates the efficiency of the voltage source inverter (VSI) topology and suggests a method for improving stability in the context of current stochastic grid systems by employing a proportional-integral (PI) controller [13]. Power quality issues in smart microgrid networks are caused by the substantial voltage variations that these grid systems frequently suffer [14]. The performance of these techniques is then carefully compared, taking into account elements like grid voltage disturbance rejection and stability under various grid short circuit levels [15]. Voltage stability has been significantly challenged by the rapid expansion of renewable energy sources, notably solar energy systems connected to low and medium voltage networks [16]. Three crucial performance indices are used to assess the effectiveness of the suggested method: the electrical signal's root mean square (RMS) value, total harmonic distortion (THD), and voltage sag compensation [17]-[19]. The form of a modular transformer less grid-connected photovoltaic multilayer inverter, a novel approach is presented in this work [20]-[22]. In this study, we independently set limits for the d-axis and q-axis grid currents using a thorough nonlinear closed-loop system analysis that is based on input-to-state stability theory [23]-[24]. Our study's simulation results will be presented and discussed, shedding light on the possibilities of integrated renewable energy systems as a sustainable and forward-thinking strategy to fulfil our expanding energy needs while preserving our planet's vulnerable ecosystems [25].

2. SYNCHRONOUS REFERENCE FRAME THEORY

In Figure 1 shows P-Q control schemes of a three-phase grid connected inverter in a micro grid. In Figure 1, Lf stands for the equivalent inductance of the LC filter, Rf is the equivalent resistance of the LC filter, and Vdc is the DC voltage supplied by a distribution generation unit. Cd and Cf are the capacitance of the DC side and the LC filter, respectively. The grid-side voltage, a current and phase detector, an inverter-side voltage and current detector, a calculation of active and reactive power, an active power PI controller, a reactive power PI controller, a current PI controller, abc/dq and dq/abc transformations, and space vector pulse width modulation (SVPWM) are the key operations that make up the P-Q control scheme. A control method used in power electronics to manage the flow of electrical energy between a microgrid (a localized collection of distributed energy resources) and the primary utility grid is known as the P-Q control system of a three-phase grid-connected inverter. The active power (P) and reactive power (Q) exchanged between the utility grid and the microgrid are the two main parameters that are the subject of this control scheme's attention. An overview of the P-Q control technique is provided below:

- Active power control (P): The actual work carried out by electrical energy is referred to as active power, also known as real power. The P control in a microgrid makes sure that the inverter can control the transfer of actual power with the utility grid. The inverter modifies its output to deliver active power to the microgrid when the microgrid needs to import power (for instance, during a deficit). On the other hand, the inverter can export extra electricity to the utility grid when the microgrid generates excess power (for instance, from renewable sources like solar panels).

- Reactive power control (Q): Reactive power is not directly used for labour; rather, it is necessary to keep the grid's voltage levels stable. By using Q control, the inverter may control the flow of reactive power and supply or absorb it as necessary. When an inverter is operating in capacitive mode (supplying reactive power), the microgrid's voltage levels are increased, and when it is operating in inductive mode (absorbing reactive power), the voltage levels are decreased.

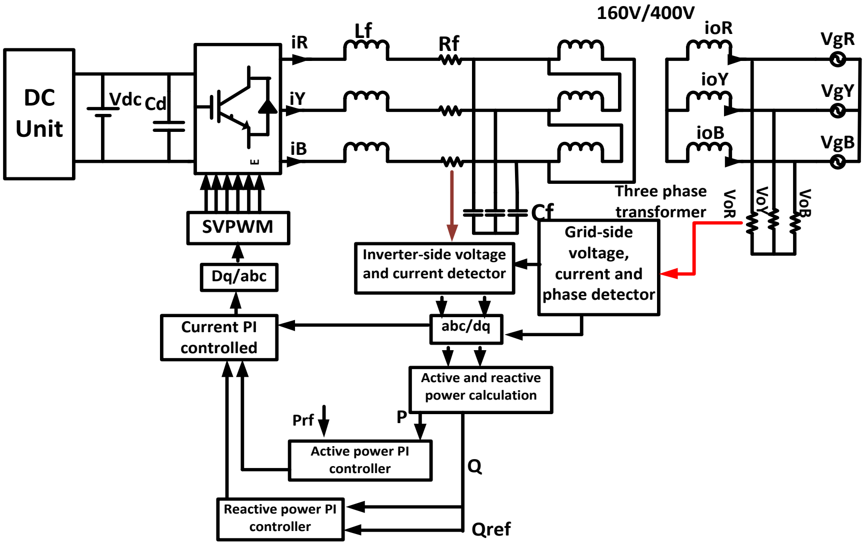

Figure 1. P-Q control schemes of a three-phase grid connected inverter in a micro grid

3. SYSTEM CONFIGURATION

In Figure 2 shows the block diagram of the reference current extraction of PI controller based on instantaneous reactive power (IRP) theory. In Figure 2 the three phase line currents are a, b and c line current; they are connected to 3-phase to 2-phase Clark's transformation and it converts 3-phase to 2-phase represented by α and β currents. The Clarks transformation also to use control the three-phase system. The α and β currents are connected to the active and reactive power component and the power of the equations are p and q are connected, it produces the accuracy and it is gives linear system, this PI controller provides a fast response time, the linear active and reactive powers are connected to the line current of α and β currents, and the line currents are connected reverse Clarks transformation by using reverse Clark's transformation we can convert 2 phases to 3 phase line currents. The line currents are connected to hysteresis based PWM current controller, by using this component to generate controllable frequency and also control ac voltage magnitudes by using pulse width modulation. So, the line currents are connected to voltage source inverter. So, by using filters we can reduce the harmonics. And the three phase voltages are connected input to the three phases to two phase Clark's transformation in reverse supply, and the three phase to two phase Clark's transformation and it will give the output in terms of α and β voltages and it connected to the power components.

3.1. PI controller

Grid inverters and other control systems frequently use the proportional-integral (PI) controller as a control mechanism. API controller is frequently used in the context of a grid inverter to control the electricity flow between renewable energy sources (like solar or wind power plants) and the grid. To reduce errors and keep an output that is accurate and consistent, it makes use of both proportional and integral components. The controller must be properly tuned to work at its best under various operating settings and grid conditions.

- Proportional component (P): The current error, or the discrepancy between the planned setpoint and the actual process variable, is what the proportional component of the controller reacts to. It attempts to lessen the error by producing an output that is proportionate to the error. The magnitude of this response depends on the proportional gain (Kp).
- Integral component (I): The integral component produces an output that acts to correct any steady-state or long-term errors by accumulating the past error over time. It is crucial for getting rid of any bias or offset in the system. How aggressively the controller responds to accumulated error depends on the integral gain (Ki).

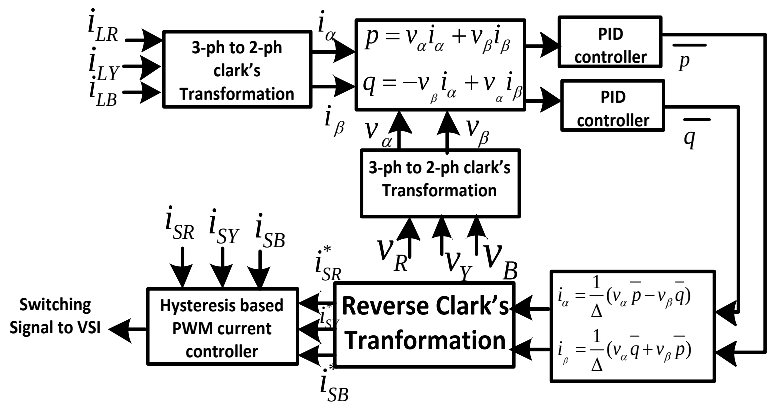

Figure 2. Block diagram of the reference current extraction of PI controller based on IRP theory

3.2. Control algorithms

A DSTATCOM supplies reactive power as needed by the load for reactive power compensation, because only real Power is provided by the source, and load balancing is accomplished. Through balancing the source reference current. Reference source current used to determine when the DSTATCOM will switch on the load current actually has a fundamental frequency component whereby these approaches are used to extracted by ANFIS controller.

IRP theory is based on the calculation of instantaneous active and reactive power in the -frame and the transfer of three-phase quantities to two-phase quantities [3], [4]. Figures 2 displays a block diagram of the reference extraction of using ANFIS controller with IRP theory. He controller receives sensed inputs VR, VY, and VB as well as iLR, iLY, and iLB. These quantities are then processed to create reference current commands (iSR, iSY, and iSB), which are then fed to a hysteresis-based pulse width modulated (PWM) signal generator (shown in Figure 2) to produce final switching signals fed to the DSTATCOM.

The system of the voltages is given by (1).

$$\begin{aligned} v_R &= V_m \, sin(\omega t) \\ v_Y &= V_m \, sin(\omega t - \tfrac{2\pi}{3}) \\ v_B &= V_m \, sin(\omega t - \tfrac{4\pi}{3}) \end{aligned} \tag{1}$$

The load currents are shown in (2).

$$\begin{aligned} i_{LR} &= \textstyle\sum_{i=1}^{n} I_{Lan} \, sin\{ n(\omega t) - \theta_{an}\} \\ i_{LY} &= \textstyle\sum I_{Lbn} \, sin\{ n(\omega t - \tfrac{2\pi}{3}) - \theta_{bn}\} \\ i_{LB} &= \textstyle\sum I_{Lcn} \, sin\{ n\omega t - \tfrac{4\pi}{3}) - \theta_{an}\} \end{aligned} \tag{2}$$

The R, Y, and B axes are fixed on the same plane and spaced out by 2/3 in R-Y-B coordinates. The "R" axis is the location of the instantaneous space vectors VR and iLR, whose amplitudes change with time in both positive and negative directions. This likewise applies to the other two phases. Using Clark's transformation, these phasors can be converted into-coordinates as shown in (3) and (4).

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} v_R \\ v_Y \\ v_B \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} i_{LR} \\ i_{LY} \\ i_{LB} \end{bmatrix} \tag{4}$$

Where α and β are orthogonal coordinates. The power of conventional is defined as (5),

$$p = v_\alpha i_\alpha + v_\beta i_\beta \tag{5}$$

where p equals the standard equation as shown in (6).

$$p = v_a i_a + v_b i_b + v_c i_c \tag{6}$$

Similarly, the IRP q is defined by (7).

$$q = -v_\beta i_\alpha + v_\alpha i_\beta \tag{7}$$

Active and real power can be written as (8).

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{pmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{pmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{8}$$

To find the currents, refer to (9),

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{\Delta} \begin{pmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{pmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \tag{9}$$

where Δ is defined as shown in (10).

$$\Delta = v_\alpha^2 + v_\beta^2 \tag{10}$$

It is possible to separate the instantaneous active and reactive powers p and q into an oscillatory and an average (DC) component.

$$p = \overline{p} + \tilde{p}$$
$$q = \underline{q} + q \tag{11}$$

The reference of currents in R, Y, and B coordinates using reverse Clark's transformation as described in (12).

$$\begin{bmatrix} i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} = \frac{1}{\Delta} \begin{pmatrix} v_\alpha & -v_\beta \\ v_\beta & -v_\alpha \end{pmatrix} \begin{bmatrix} \overline{p} \\ 0 \end{bmatrix} \tag{12}$$

The three phase currents of R, Y, and B are shown in (13),

$$\begin{bmatrix} i_{SR}^* \\ i_{SY}^* \\ i_{SB}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} i_0^* \\ i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} \tag{13}$$

where i_0^* is the zero-sequence component.

4. SIMULATION RESULTS

The Figure 3 shows it is a supply voltage from renewable energy sources that means we give a supply from renewable energy sources to grid through three phase inverters. Inverter converts DC to AC. Voltage. The below figure supply voltage peak voltage is 600 V is supplied voltage, R, Y, and B phase should be amplitude is a 600 V. The phase shift between three phases should be at 120 degrees apart. And the below the supply current is shown figure. At the starting current the fluctuations are occurred at 0 to 0.01 sec after 0.01 sec the currents will continue without fluctuation with help of LCL filter and PI controller. The supply current will change with help of control schemes of active and reactive current control schemes. If we keep 205 at Active current and reactive current is 0 the current start from 0 and the amplitude of current is 205 A. And if we keep active current 0 and reactive current is 150 then graph start at negative and amplitude is 150 A.

The Figure 4 shows the active power and reactive power. active and reactive power from the supply. From Figure 4 powers from 0 to close 0.02 sec will constant and after 0.02 will get sinusoidal wave form of three phase. The Reactive power after 0.02 sec will flow up and move constant till end and R and Y phases will get peak because of PI controller. The Figure 5 is an inverter current. The inverter and supply current are same. The amplitude of current is controlled by the current control schemes. At the starting the phases are get fluctuations after it continues without fluctuations.

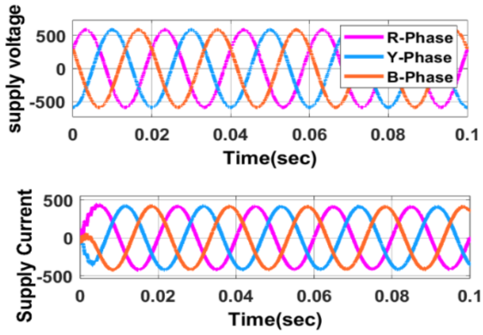

Figure 3. Supply current and supply voltage with respect to time

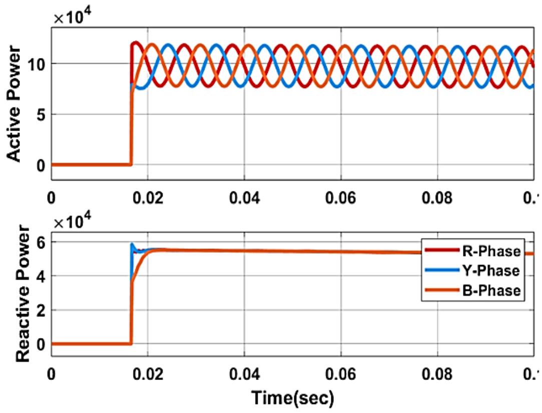

Figure 4. Active and reactive power with respect to time

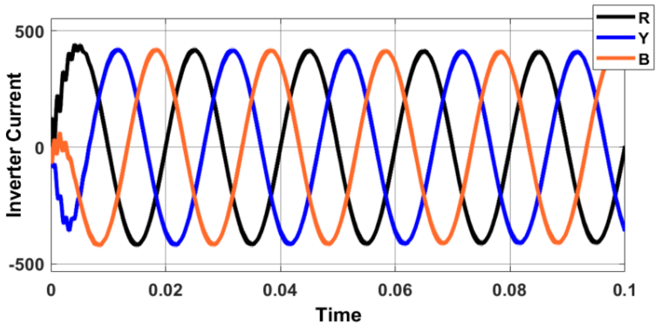

Figure 5. Inverter current with respect to time

5. CONCLUSION

In conclusion, a three-phase grid-connected inverter using an optimal control strategy including a PI controller and the direct-quadrature (DQ) frame offers a reliable and effective solution for contemporary power grid integration. With the help of this sophisticated control system, voltage and current waveforms may be precisely regulated, resulting in smooth communication between utility grids and renewable energy sources like solar or wind turbines. The system performs real-time control parameter modification through the use of the PI controller, improving steady-state performance and transient reactions. The DQ frame transformation also makes it easier to manage three-phase currents, which helps with efficient grid synchronization and power flow control. In the end, this control strategy not only increases energy output from renewable sources but also safeguards the integrity of the grid, providing a promising path for the adoption of sustainable energy solutions and the realization of a more environmentally friendly.

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