Current Control of Three Phase Grid Connected PV Inverters using Adaptive Controllers

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Abstract- Distributed Generation (DG) is now widely employed in many electricity generation networks. It is mostly based on energy storage and renewable energy sources such as wind turbines (WT), photovoltaic cells (PV) and fuel cells to minimize pollution and greenhouse gas emissions. For large scale installations, a three phase power electronic inverter utilized to interface the source of renewable energy to the utility grid. The inverter and the associated control system are at the core of the energy conversion process and their operation is essential to inject high power quality, low harmonic distortion, current to the grid. For this reason international harmonic and power quality recommendations, such as IEEE Standard 519 and 1547, are often in place to limit the harmonic currents injected into the grid. Typically, 5% current total harmonic distortion (THD) limit is imposed. Numerous inverter current control techniques have been proposed to achieve improved power quality waveforms.

The proportional-integral controller (PI controller) is perhaps the best understood and commonly applied control strategy. In three phase systems, the d-q rotating synchronous reference frame (SRF) approach, based on classic Park transformations, is often applied [4]. As a consequence of the shortcomings of the PI controller such as steady state output error when tracking sinusoidal reference signals [5], alternative control solutions have been presented. Of these, the Proportional Resonant (PR) controller has become a popular strategy in renewable energy applications. For example, in [6], the PR controller is successfully employed in the stationary reference frame of a three phase grid connected system. Significantly, the reported advantages of the PR controller include the capability to remove steady state errors when tracking AC signals by generating an infinite gain at a known resonant frequency of the controlled signal [7], and a highly attenuated gain at other frequencies, such as the harmonic frequencies. Furthermore, the Park transformation is not necessary, and there is less cross coupling of the control axis, hence de-coupling strategies are not required [8]. As a result, in grid connected applications, significant reduction in the harmonic content of the controlled current is possible. Additional elimination of the harmonic content can be achieved by implementing Harmonic Compensation (HC) terms in parallel with the main control effort [9]. However, a sudden drop in the voltage could further increase the error between the reference signal and the controlled signal causing considerable deviation from its nominal value. The performance of the conventional PR controller will not keep up with the increase in the error which weakens the controller performance. To overcome

Key words- Simulink, Wind turbine, provocative cells.

I. INTRODUCTION

Distributed Generation (DG) is now widely employed in many electricity generation networks. It is mostly based on energy storage and renewable energy sources such as wind turbines (WT), photovoltaic cells (PV) and fuel cells to minimize pollution and greenhouse gas emissions [1]. For large scale installations, a three phase power electronic inverter utilized to interface the source of renewable energy to the utility grid. The inverter and the associated control system are at the core of the energy conversion process and their operation is essential to inject high power quality, low harmonic distortion, current to the grid [2]. For this reason international harmonic and power quality recommendations, such as IEEE Standard 519 and 1547, are often in place to limit the harmonic currents injected into the grid [3]. Typically, 5% current total harmonic distortion (THD) limit is imposed. Numerous inverter current control techniques have been proposed to achieve improved power quality waveforms.

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this issue, this project presents an improvement in current control using a novel adaptive PR controller. It demonstrates and compares the performance of the adaptive PR controller during normal and abnormal grid voltage conditions. The proposed control technique is capable of providing low total harmonic distortion (THD) of the injected current even during the occurrence of abnormal grid conditions. The proposed method also achieves lower overshoot, settling time as well as steady-state error.

What's more, this venture shows a straightforward strategy to deteriorate the voltage and the current into their positive and negative grouping segments in view of versatile postponed channel with one-quarter period delay. The execution of the versatile control technique is checked by reproduction. A three stage framework associated inverter is demonstrated and controlled utilizing versatile PR controller procedure in light of the stationary reference outline perspective with space vector balance method (SVM). Thus, a stage bolted circle (PLL) is utilized here in this control to recognize the change point and upgrade the synchronization of the inverter yield current with the matrix voltages accomplished. Two versatile PR current controllers together with symphonious compensators are connected in the present controller. The control conspire does not have any coupling amongst dynamic and receptive segments, and the outcomes demonstrate that it gives astounding dynamic reaction.

As of late, there has been a quick increment in the quantity of matrix associated three stage inverter frameworks being associated with the appropriation arrange. Subsequently, the requirement for excellent, low consonant mutilation, current infusion into the framework is basic. To accomplish this, cautious thought of the inverter controller is fundamental. Many control strategies depend on the conventional corresponding indispensable controller (PI), or the all the more as of late embraced Proportion Resonant controller (PR). This task introduces another strategy of limiting the mistake of the present control in a three stage lattice associated inverter utilizing a promptly implementable Adaptive Proportional Resonance controller.

II. LCL Filter Design
Fig.1 shows a three-phase grid connected inverter with a third order LCL filter. The LCL filters improve the power quality of the current injected to the grid compared to lower order L and LC filters

The differential equation representing of the LCL filter can be found from the single phase equivalent circuit in Fig.2. Here, the filter is defined by the inverter-side inductor L1, filter capacitor C1, grid side inductor L2, and the resistive elements represent the ohmic losses in the passive components.

Since SVM is used in this system, the LCL filter is designed in the stationary reference frame (αβ) using space vectors to make it easier and more convenient. By applying Kirchhoff’s voltage and current laws, the following equations can be used to represent the voltages and currents within the circuit of Fig.2 [11]. Inverter vector equations, dc voltage, capacitor voltage and LCL filter current equations are given by paper [1].

III. Control Scheme
In this work, the applied control system is a cascaded system with an inner current control loop controlled by an outer voltage control loop. The block diagram of the adaptive PR current control scheme is presented in Fig.3. The system consist of PV array with maximum power point comprised of dc-dc converter following by three phase dc-ac inverter [3, 4]. The voltage control loop comprises of two PI regulators; one for the dc link voltage control and the other for the grid
voltage control. The measured dc voltage is compared with the reference dc voltage.

Fig.3: Adaptive PR controller in stationary Reference control

Fig.4: Controller diagram of PR Controller

The measured voltage is converted to the synchronous reference frame, and the q-component, \( v_q \) is compared with the reference \( v_q^* \) which is equal to zero and controlled by a PI controller. The nominal grid frequency \( \omega \) is added to the output of the PI controller, and the sum is integrated to obtain the grid voltage angle \( \theta \).

IV. BRIEF OF THE INSTANTANEOUS POWER THEORY

As the name inferred, the prompt power hypothesis depends on a meaning of momentary genuine and responsive powers in time area. It is exceptionally helpful in the consistent state as well as in the transient state examination for both three-stage frameworks with or without an impartial conductor. To delineate the hypothesis, let consider an arrangement of momentary three stage amount, for example \( a_v, b_v \) and \( c_v \). It begins with changing an arrangement of three-stage factors in the abc into \( q\beta \) 0 facilitates. This change is supposed as the Clark change as portrayed takes after.

\[
\begin{bmatrix}
  v_0 \\
  v_\alpha \\
  v_\beta \\
\end{bmatrix} = \sqrt{2/3} \begin{bmatrix}
  1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\
  0 & 1/\sqrt{3} & 1/\sqrt{3} \\
  0 & 1/\sqrt{3} & 1/\sqrt{3} \\
\end{bmatrix} \begin{bmatrix}
  v_a \\
  v_b \\
  v_c \\
\end{bmatrix} \\
\]

\[\ldots\ldots\ldots\ldots (1)\]

\[
\begin{bmatrix}
  i_0 \\
  i_\alpha \\
  i_\beta \\
\end{bmatrix} = \sqrt{2/3} \begin{bmatrix}
  1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\
  0 & 1/\sqrt{3} & 1/\sqrt{3} \\
  0 & 1/\sqrt{3} & 1/\sqrt{3} \\
\end{bmatrix} \begin{bmatrix}
  i_a \\
  i_b \\
  i_c \\
\end{bmatrix} \\
\]

\[\ldots\ldots\ldots\ldots (2)\]

In three-stage, three-wire frameworks, there is no zero grouping segments. On the off chance that \( 0_v \) and \( 0_i \) are both disregarded, quick voltage, \( v \), and current phasors, \( i \), can be characterized from their relating momentary \( \alpha \) and \( \beta \) segments as takes after

\[
v = v_a + jv_b \ldots \ldots \ldots (3)\]
\[
i = i_a + ji_b \ldots \ldots \ldots (4)\]

From (3) and (4), instantaneous complex powers, \( s \), can be defined as the product of the instantaneous voltage phasor and the complex conjugate of the instantaneous current phasor given in (5).

\[
s = vi^* = (v_a + jv_b)(i_a - ji_b) = p + jq \ldots \ldots \ldots (5)\]

Where,

\[
P = v_a i_a + v_b i_b \] is the instantaneous active power
\[
q = v_a i_b - v_b i_a \] is the instantaneous reactive power

The instantaneous complex power is useful. It can be applied for transient or steady-state analysis. The following equation is a compact form for the instantaneous real and reactive power definition and its inversion.
\[
\begin{align*}
\begin{bmatrix}
p \\ q
\end{bmatrix} &=
\begin{bmatrix}
v_\alpha & v_\beta \\
-v_\beta & v_\alpha
\end{bmatrix}
\begin{bmatrix}
i_\alpha \\ i_\beta
\end{bmatrix} \\
&= v_\alpha^2 + v_\beta^2 \\
\begin{bmatrix}
i_\alpha \\ i_\beta
\end{bmatrix} &= \frac{1}{v_\alpha^2 + v_\beta^2}
\begin{bmatrix}
v_\alpha & -v_\beta \\
v_\beta & v_\alpha
\end{bmatrix}
\begin{bmatrix}
p \\ q
\end{bmatrix} \\
\end{align*}
\]

\[ p = \bar{p} + \bar{p} \quad \text{(8)} \]

\[ q = \bar{q} + \bar{q} \quad \text{(9)} \]

V. Fuzzy Controller

INTRODUCTION:

The word Fuzzy means dubiousness. Fluffiness happens when the limit of snippet of data is not obvious. In 1965 Lotfi A. Zahed propounded the fuzzy set hypothesis. Fuzzy set hypothesis displays tremendous potential for successful settling of the vulnerability in the issue. Fuzzy set hypothesis is an amazing numerical device to deal with the vulnerability emerging because of dubiousness. Understanding human discourse and perceiving manually written characters are some normal occurrences where fluffiness shows.

Fuzzy set hypothesis is an expansion of traditional set hypothesis where components have differing degrees of enrollment. Fuzzy rationale utilizes the entire interim in the vicinity of 0 and 1 to depict human thinking. In FLC the information factors are mapped by sets of enrollment capacities and these are called as "Fuzzy SETS".

Fuzzy set involves from an enrollment work which could be characterizes by parameters. The incentive in the vicinity of 0 and 1 uncovers a level of enrollment to the fuzzy set. The way toward changing over the fresh contribution to a fuzzy esteem is called as "fuzzificaton." The yield of the Fuzzier module is interfaced with the principles. The fundamental operation of FLC is built from fuzzy control rules using the estimations of fuzzy sets when all is said in done for the mistake and the difference in blunder and control activity. Essential fuzzy module is appeared in fig. 5.

VI. SIMULINK DESIGN AND RESULTS

Fig. 5: block diagram fuzzy logic.

Fig. 6: Simulink Block Diagram.
Simulation Results:

Fig 9: Three phase voltage waveform

Fig. 9 and 10 shows the simulation results of the three phase voltage and current. Fig. 9 shows the three phase voltage waveform.

Fig 10: Three phase voltage waveform

It can be seen that the voltage drops when a voltage sag happens in the system at 0.1 sec until 0.15 sec. Fig. 10 shows three phase current waveform. It is clear that the current has increased when the sudden voltage occurs at 0.1 sec in order to balance the active power transfer from the PV source. Fig. 13 shows the stationary reference frame (alpha) current waveform and Fig. 14 shows the stationary reference frame (beta) current waveform for conventional PR controller. They show significant deviation when variation in the current waveform.

Fig 11: Simulation Waveform for unbalanced grid condition: three phase voltage waveform

Fig 12: Simulation Waveform for unbalanced grid condition: three phase current waveform

Fig. 13 and Fig. 14 show the stationary reference frame alpha and beta current waveform respectively. The measured current following the reference current which they point out that the fuzzy controller works effectively when there is change in the grid conditions. However, in the case of unbalanced voltage sag the fuzzy controller
achieves better dynamic response. Fig.11 and 12 shows the three phase voltage and current waveform respectively; note the reduction in the overshoot characteristics and the recovery time to achieve steady state. It is clear that the adaptive controller can better compensate the unbalanced current. It can be shown that this is due to the adaptive and fuzzy controllers improved ability to regulate the positive and negative sequence components.

FIG 13: Simulation Waveforms for Conventional PR controller i-alpha and i-beta.

FIG 14: Simulation Waveforms for Adaptive PR controller i-alpha and i-beta

FIG15: Total Harmonic Distortion

CONCLUSION

This thesis has considered the impact of an adaptive PR current controller and fuzzy controller scheme of a three phase grid connected inverter. In particular, this work has shown the performance of the adaptive PR controller compared with the conventional PR controller which is popular in grid connected inverters. Simulation studies confirm that the adaptive PR controller demonstrates better performance under normal and abnormal operating conditions. There is no steady state error output, and the harmonic content of the current waveform is very low. A Fuzzy controller is also implemented in this project in order to reduce the total harmonic distortion. In addition, the fuzzy and adaptive PR controller offers superior output power regulation, and improved power quality performance. Overall, it can
be concluded that the adaptive PR and fuzzy controllers are better suited in the event of grid faults, or operation in weak grid environments, compared to fix gain controllers.

REFERENCES:


