Robust Controllers for Grid-Interactive Inverters with Renewable Power Injection and Power Quality Improvement

A. Naveen Kumar, I Jacob Raglend

Abstract: This paper presents versatile control strategy with robust controllers to get multiple benefits from Grid-interactive inverters (GII), when incorporated in Utility Grid. This Multipurpose Grid-interactive inverters is used to i) Inject power generated from Renewable energy resources to the grid in synchronization with three phase grid voltages. ii) This Grid-interactive inverter (GII) also used to reduce harmonics in the grid generated by the non-linear load connected to the grid. This Multifunctional control strategy utilizes the Robustness of Fractional order Proportional-Integral (FOPi), Sliding mode Controllers (SMC) and simple structure of PI controller to surpass the dynamic response of GII during disturbances. A comparative analysis is carried out on different controllers of GII which include PI, FOPi and SMC controllers observing the overshoot, settling time and THD during distractions. The controller’s Performance is calibrated with conditions change in RES power generation, change in loads. This versatile controller is designed and simulated with dynamic time domain analysis using GUI environment in MATLAB/Simulink.

Keywords: RES Renewable Energy Source, Grid-interactive inverters (GII), PI(Proportional and Integral), FOPi(Fractional Order Proportional and Intergraph), SMC(Sliding mode Controller), GUI(Graphical User Interface), THD(Total Harmonic Distortion),

I. INTRODUCTION

In the near future micro grids will play an important role in eco-friendly power generation reducing our dependency on carbon-based power generation. Use of more renewable energy sources paid a major role in development of new technology like micro grid [1] [2], [3]. Due to the rapid rise in consumption and demand of electrical energy, power systems engineering is witnessing rapid growth as well, in the recent years. For this reason, the power is being generated from renewable energy sources (RES) using with the distribution networks and distributed generation (DG). The renewable sources such as tidal, wind, Photovoltaic (PV), and fossil fuels are utilized by DGs and grids, which raise the electrical energy production throughout the world [4][5]. However, with ever-rising population, the RES are not adequate to meet the daily demands of energy. To enhance the power generation hybrid systems are being designed and integrated with distributed generation systems [6][7][8].

The Vital element that plays a major role in the micro grid operation is storage of energy. It is very important for one to study different energy storage systems for the microgrids, for example super capacitors and batteries. Currently Photovoltaic cells are known as PV Cells, tidal and wind are the rapidly growing technologies with the growing craze for their intermittent nature; but certain issues like stability, low power factor, regulation of voltage, low quality factor etc [9]–[11] needs to kept in mind before designing a model. Some of the mentioned issues are resolved effectively with exceptional advancement in the digital signal processors and power electronics.

The PV module exhibits low-voltage characteristics[12]. For delivering the electrical power to grid, the PV module is stepped up to high voltage (DC)[13], for which a high gain dc-dc converter is needed. Using this converter results in some cons-

- It is highly sensitive to duty ratios forcing the converter to operate in unstable region.
- Recovery issues at high duty ratio.
- The cascaded connection of these converters results in wider conversion ratios [12], [13].

Apart from disadvantages, it also has a major advantage is a high-gain and low-current ripple. Due to which the total efficiency is reduced results in the power loss and heat dissipation from switches [14]. To reduce these effects a new converter called High-Gain boost converter is introduced and effectively used for PV applications.

The current controlled voltage and current source techniques are used on microgrid side as converters to interface renewable sources for the utility[14]-[17]. The control algorithm used to monitor the operation of PV cell and also to immediately attend the quality issues[18]-[20]. The response is very slow, hence to prevent this we use static Dc capacitors.

This paper mainly focuses on the DQ based control strategy. This theory has following advantages- it has fast dynamic response; it eliminates instantaneous reactive powers and complex transformations.

Due to the usage of intermittent renewable energy and connecting to grid may result in certain problems like Issues of synchronisation, Power quality issues, Voltage quality issues, Power complexity issues, Additional boost circuit is required

However most of the time the GII cannot be utilized at its recommended rating levels due to intermittent nature of RES and price fluctuations of power.

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market. This limitation of GII usage due to uncertainties can be compensated by using it for additional services like reducing harmonics in the grid caused by the non-linear loads, imbalances in grid voltage and load current.

Distinct from prior publications on this subject, in this paper, robust controllers like FOPI, SMC are introduced to overcome the drawbacks of PI, PR and hysteresis controllers like sluggish dynamic performance, managing lower order harmonics, bandwidth of the system, high ripples and switching losses. Additionally, Multi-utilitarian control strategy provides few more features like 1) Injecting load active and reactive power requirement 2) Reducing current harmonics.

II. SYSTEM DESCRIPTION

This envisaged system consists of RES connected to decoupling DC link capacitors of GII. The DC power generated by RES is converted to three phase AC using pulse width modulated GII and is interconnected to grid through LCL filter. The LCL filter reduced the harmonic caused by the GII. The voltage form the PVA is variable with respect to solar irradiation (1 kW/hours) and ambient temperature (T°C). This variable voltage source cannot be connected directly to the GII. In order to stabilize the voltage output of the PV, a DC-DC converter needs to be connected in between PVA source and GII. The constant DC voltage is converted to constant three phase AC voltage with amplitude, frequency and phase similar to grid three phase voltages. A damping resistor, Rd is connected in series with the filter capacitor, Cf to provide passive damping and to damp out resonances. The non-linear loads are unbalanced loads which consume unbalanced currents from the source, causing harmonics in the source current load. A simple grid interconnected PVA RES can be seen above in Fig.1.

III. GENERATION OF COMMAND CURRENTS

Good SRF control is also called dq control the structure is shown in Fig.3. To inject active power from DG to grid the controlled current id* must be in phase with the grid voltages. To synchronize DG system with grid, phased locked loop (PLL) is used to extract phase angle of grid voltages. The main objective of this control strategy is to control the active power injection to the grid. To achieve this the dc-link voltage error is regulated, so that output current of RES is idg is controlled. The amount current to be injected by RES will be obtained from id*.

Another important aspect of GII is to compensate for harmonics. The content of harmonic current will be obtained from the transformed load current.

\[
\text{Id}^* = \text{id}_g + \text{id}
\]

(1)

\[
\text{id} = \text{id}_d + \text{id}_q
\]

(2)

After transformation the load current fundamental component appears like dc values where as harmonics appear like ripples. The ripple content is separated by using LPF and the resultant signal obtained from proposed controller. SRF theory to identify harmonic content is shown in fig.2. Line currents of three- phases were sensed and given to Clarke’s transformation block to transform three-phase components to d-q terms. PLL is used to obtain information regarding phase angle. For this purpose, sine and cosine signals were sent to transformation block.

IV. CONTROL USING PI CONTROLLER

One of the traditional controllers used to control the parameters in a control system is PI controller. The PI controller has a fixed Kp (Proportional gain) and Ki (Integral gain) which cannot be change during the operation of model or test system. The values of Kp nd Ki fixed by trial and error method or by bode plots with characteristic equations. A simple PI controller can be seen below in Fig.2.
The error from the comparison of reference and measured value component is fed so $K_p$ and $K_i$ gains which generate desired controller output, which can be changed by changing the values of $K_p$ and $K_i$. The output from the PI controller is generated at a constant reaction rate where the output value generated has more disturbances and peak generation. This affects the final result of the controller, inducing the same disturbance and peak generation in the applied test system. The controller matrix is given in (3),

$$G_{PI}^{(s)}(s) = \begin{bmatrix} K_p + \frac{K_i}{s} & 0 \\ 0 & K_p + \frac{K_i}{s} \end{bmatrix}$$

The FOPI controller is adaptable and give chance to change the dynamic response of the system. To damp out the oscillations in active power response with reduced settling time and improvement in THD, the PI Controller is replaced with FOPI gain controller. The FOPI controller uses internal model control log modules to tune the values of $K_i$ (integral gain). The function for turning the integral gain is given as $K_i$, $L$ is the time delay is processing time constant. The $K_i$ is tuned with the fractional order derivative value and is fed to low pass filter, this reduced the disturbance in the signal. The internal modeling of POPI can be seen below in Fig.4. The mathematical representation is given in (5)

$$G(s) = \frac{K_i e^{-Lt}}{tx+1}$$

$$U_{FOPI}(s) = k_p + \frac{k_i}{s^\lambda}$$

Where $\lambda=$ Tuning parameter

![Fig.2 Structure of PI controller.](image)

![Fig.3 Command current generation for GII](image)

![Fig.4 Structure of FOPI controller.](image)
V. CONTROL USING SMC CONTROL

However in the FOPI controller the integral gain is controlled but the proportional gain is not. The disturbance and oscillations in the controlled parameter is reduced but the peak value generation is not mitigated. The SMC Controller is a class of non-linear control designated by being robust against disturbances and variations in the framework of the system. Its main principle is to move the trajectory of the condition of the system towards a established surface called as sliding surface and safe guard that the states operate in the proximity of it through a control law. The sliding surface is elucidated based on control goals of the system. However control goals for the system deliberated are coupled to the error between the measured value and the desired, since the control plan aims to minimize the error to zero. The sliding surface is established through the voltage error (ev) and the current error (ei). The SMC voltage and current controller is shown in Fig. 5, Fig. 6.

\[ e_v = U_{dc} - U_{dc}^* \]  
\[ e_i = i_{ref} - I \]  

In order to increase the dynamic performance of the controller to the errors established in equations and their derivatives are summed to get the matrix of sliding surface.

\[ S = \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} = \begin{bmatrix} e_v + k_v \frac{de_v}{dt} \\ e_i + k_i \frac{de_i}{dt} \end{bmatrix} \]  

(8)

\[ k_v \text{ and } k_i \text{ are based the desired dynamics. Now the control laws for voltage controller and current controller written } k_{pv}, k_{iv}, \text{ and } k_{ic}, k_{pc} \text{ are PI gains.} \]

\[ i_{ref} = \left( k_{pv} + \frac{k_{iv}}{s} \right) \text{eval}(s_1) \]  

(9)

\[ d = \left( k_{pc} + \frac{k_{ic}}{s} \right) \text{eval}(s_2) \]  

(10)

VI. RESULTS AND DISCUSSION

In order to verify the effectiveness of proposed controllers, substantial simulation studies are conducted using MATLAB/Simulink. The simulation is carried out with two different cases. In case-1 Based on simulation time for t=0.1-0.32s The solar irradiation form 0 to 2100 Watts/m² with a load of 1200W. And in case-2 t=0.32-0.7s the irradiance changed to 1000 Watts/m² simultaneously at t=0.5s load increased to 2.5KW. In this duration inverter supplies the 1100W and grid supports the remaining 1400W to the load.

The power output from the RES and grid are compared and also the currents, of RES grid and load are shown. A reduction in harmonic distortion of the source current may be observed.

Fig. 7 shows grid voltage, Fig. 8-Fig. 10 shows grid current for PI, FOPI and SMC. From these waveforms it can be noted that grid currents are seems to be completely sinusoidal with THD 2.77% for PI, 2.59% for FOPI and 2.25 for SMC, so in this mode the GII performs as three phase shunt APF to filter grid current harmonics by injecting currents opposite to harmonic currents.
Fig. 11 – Fig. 13 shows THD with three different types of controllers from that we can observe that with SMC controller the grid current THD is very less when compared with remaining controllers.

Case-1) The solar irradiation form 0 to 2100 Watts/m² with a load of 1200W(t=0.1-0.32s).
In this case load is maintained at 1kW with solar irradiance varies from 0 to 2001 watts/m². The grid interactive inverter supplies 1000W where as
200W supplied by grid and in this aspect when the settling time compared for three controllers the SMC controller gives fast settling time.

The active and reactive current tracking performance of the SMC is superior when compared to remaining controllers shown in Fig. 19 – Fig. 20.

With the above results comparison, the values are noted and compared in tabular form given below in terms of peak overshoots, settling time, and THD of the source currents for all three controllers

<table>
<thead>
<tr>
<th>Controller</th>
<th>Settling time</th>
<th>% Peak Over Shoot</th>
<th>% THD</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI</td>
<td>0.35</td>
<td>40</td>
<td>3.8</td>
</tr>
<tr>
<td>FOPI</td>
<td>0.25</td>
<td>33</td>
<td>1.5</td>
</tr>
<tr>
<td>SMC</td>
<td>0.2</td>
<td>27</td>
<td>1.1</td>
</tr>
</tbody>
</table>

To check the effectiveness of controllers the values of THD and power factor are compared with variation in $K_p$ and $K_i$ values for PI.

<table>
<thead>
<tr>
<th>Controller</th>
<th>Power Factor</th>
<th>THD%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMC</td>
<td>0.99</td>
<td>2.25</td>
</tr>
<tr>
<td>FOPI</td>
<td>0.99</td>
<td>2.59</td>
</tr>
<tr>
<td>$K_p = 10$, $K_i = 15$</td>
<td>0.95</td>
<td>2.77</td>
</tr>
<tr>
<td>$K_p = 10$, $K_i = 20$</td>
<td>0.96</td>
<td>2.5</td>
</tr>
<tr>
<td>$K_p = 10$, $K_i = 30$</td>
<td>0.96</td>
<td>3.5</td>
</tr>
<tr>
<td>$K_p = 15$, $K_i = 15$</td>
<td>0.92</td>
<td>2.1</td>
</tr>
</tbody>
</table>
VII. CONCLUSION

This paper proposed versatile control strategy for Grid-interactive inverters (GII) with robust controllers to get multiple benefits, when incorporated in Utility Grid. With the simulation and comparative analysis of all the three controllers for multi objective control structure, it is observed that the settling time, peak overshoot and THD for the given changes in the system is less in SMC controller as compared to conventional PI and FOPI controllers. The variation in RES power and variation in load cases has less transient effects with SMC controlled GII. The DC voltage stabilization with variation in these values is also observed to be more robust in SMC controller as compared so PI and FOPI controllers.

REFERENCES


AUTHORS PROFILE

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