Modeling, Simulation and Stability Analysis of Multilevel Inverter Control for Grid Connected Distributed Generation

1A. Gowrishankar, 2R. Revathi, 3B. Lalitha, 4D. Sathish kumar and 5R. Sampath Kumar

1,2,3,4,5 Department of EEE
1,2,3,4,5 KPR Institute of Engineering and Technology, Coimbatore
1a.gowrishankar@kpriet.ac.in, 2r.revathi@kpriet.ac.in, 3lalitha.b@kpriet.ac.in, 4d.sathishkumar@kpriet.ac.in, 5sampathkumar.r@kpriet.ac.in

Abstract - This paper deals with the stability issues of grid integrated distributed generations through voltage source inverter (VSI). Distributed generation is now increased day by day due to demand of power so power production from nonconventional sources is connected to the grid via VSI with traditional PI controller for controlling of grid currents. Due to grid impedance variations, the PI controller’s bandwidth and their low frequency gain has to be reduced to maintain the system stability, thus degrading the tracking routines and capability of rejecting disturbance of system tends to unstable. In this proposed methodology, the VSI is controlled by the way of novel controller long with stability is analyzed. This proposed technique determines the grid stability which relies upon the impedance of VSI and the impedance of grid network. It expresses that the electrical grid the grid stability which relies upon the impedance of VSI and the impedance of grid network. It expresses that the electrical grid network stays stable if the proportion of inverter impedance to grid network impedance fulfills the Nyquist stability criterion. The simulation of the novel controller scheme and the traditional PI regulator with VSI are given and analyzed, which approves the exhibition of the methodology.

Keywords - Voltage Source Inverter (VSI), Nyquist stability criterion, grid impedances, Distributed Generation (DG).

1. Introduction

Most of the Distributed Generations are connected to the electrical utility grid by means of three phase multilevel voltage source inverter (VSI). Distributed Generations such as wind, solar, tidal, etc. helps to limit the greenhouse gas emission in the atmosphere and also improves the systems overall reliability. Today fossil fuels form the majority source for power production in the world. But these sources cause environment problems such as emission of greenhouse gases, pollution, etc. The day-by-day increasing power demand makes the mankind to find substitute source of energy since fossil fuels are going to extinct. In grid-connected systems, either three-phase or single-phase Voltage-source inverters (VSI) are frequently used for integrating the intermediate DG to the electrical utility grid [1]. Here two types of strategies are generally utilized for controlling utility grid integrated inverters are stationary frame and synchronously reference frame. In grid integrated system, the VSI is voltage controlled current source which injects current to the main grid. Traditional Proportional Integrator controllers are mostly realized for current control since its uncomplicated structure and easy realization. The αβ-control reference frame Proportional Integrator controllers are suffers large tracking steady-state error and this might not be satisfactory. Even though, this steady-state error would reduce it may show the way to system instability. The nil steady-state error could be accomplished in single phase grid integrated inverter using dq-control frame PI. But the above mentioned strategies need transformation [2]. During the transformation of all parameters, errors may be created which does not produce desired performance.

The VSI output is injected to the electrical utility grid through either by pure inductor L filter or LCL π-filters. The LCL π – filter is more preferred than L filter because L filter cannot attenuate high frequency harmonics. L filter be able to function in both grid-connected and standalone mode. The impendence of the utility grid is very large when weigh against grid-side inductor so this value can neglected, only as LC filter values are accounted and also LCL filter is of order three which has high peak resonant value. In the VSI current (Iinv) is given as feedback as an alternative to (Ig) utility grid currents in the quasi-resonant-proportional controller with admittance compensator. The major weakness in this technique is parallel resonant LC circuit is created between the grid’s inductor and capacitor. And also a latest control approach is projected in which grid currents as well as filter capacitor current can be taken as feedback [3-6]. In this method the VSI control scheme can be framed to 1st order and also grid current cannot be controlled directly which can be distress by capacitor current.

Furthermore, great variations impedances of utility grid critically have a consequence on the output of the system and also affect the grid connected system stability [7]. By suitable choice of filter capacitance and inductance values, the stability can be attained which consist of grid line impedance, transformer leakage inductance. To respond the stability issues a novel controller is incorporated in the grid inter-connected scheme and it is evaluated by appropriately choosing the weighting functions, the anticipated novel controller exhibits vigorous control scheme on all conditions. Figure 1 represents the arrangement of grid-integrated Voltage-Source Inverter (VSI). The DC-DC...
converter is introduced between the DG and inverter to achieve better voltage profile which is produced from distributed energy sources to meet the grid requirements. The large variation in impedance of utility grid leads to instability in VSI alike to the filter converter as found in other modern systems [8]. A well-established methodology to examine such DG interconnected systems stability is through the impedance-based condition. The proportion between source and the load impedances fulfills the Nyquist criterion to model the stable source interconnected load system. The above-mentioned methodology is widely incorporated in the realization of highly efficient SMPS (switched mode power supplies) circuits with EMI filters and other complicated distributed DC power systems.

The inverter detailed control schemes and their inner loop stability are important for the realization of every grid-connected inverter. At the point when the goal is grid stability, performance of a VSI is of further concentration than its inner loop stability and is similarly less confounded to secure [9]. In such instances, the impedance-based technique is greater fine and effective because it does not require remodeling of the VSI and replicate its loop stability evaluation whilst the change in grid impedance, or whilst further inverters are interconnected to the same utility grid. There is no need of complete design parameters of each inverter, which is frequently not accessible to those performing grid system stability analyses.

2. Design of Proposed Novel Controller for Grid Integrated Inverter

A novel robust controller is projected to deal with stability issues resulted by the variation of grid impedance. The main objective of the novel controller is to minimize THD level of output parameters and steady-state error. In order to attain this state, weighing functions are calculated equivalent to the condition of the system while the utility grid is affected by large variation of impedance values. The dynamic grid-impedance assessment technique is utilized to measure the whole impedance in Figure 1, below \( Z_g = r_g + j\omega L_g \) which consists of line impedance and the inner grid impedance.

![Image](image_url)

**Fig. 1:** Simulation diagram of Multilevel Inverter Control for Grid Connected DC Power Source

The grid side inductor filter is neglected since it is very small when compared to grid inductor which shows that LC filter used in this approach [10-14]. The selecting procedure for the weighing function is explained below in Equation (1). The weighing function must show high gain value.

\[
H(s) = \frac{k\omega^2}{s^2 + 2\delta\omega s + s^2}
\]  

(1)

Here \( \omega \) is the natural line frequency of oscillation. The \( \omega \) value is utilize for regulating the tracking error over range of frequency and damping ratio is put as 0.002. When damping ratio value is zero, it proceeds as ideal proportional resonant controller [15-17]. The weighing function for healthy performance is given by the following Equation (2)

\[
G(s) = \frac{1}{L_g C s^2 + C r_0 s + 1}
\]  

(2)

3. Impedance-Based Stability Analysis

For analyzing stability issues, ratio of impedances of the grid to output impedance of the VSI is formed. This stability criterion method is applicable for both current source inverter (CSI) and voltage source inverter (VSI). But stability condition is reversible for another case. The system represented in Thevenin’s equivalent model consists of load impedance in series connection with the independent voltage source. Since the entire power electronic components are nonlinear, consider only small signal representation [18]. With this assumption current flow in the circuit is given by Equation (3).

\[
I(s) = \frac{V(s)}{Z(s) + Z(s)}
\]  

(3)

The Equation (3) also can be written in the subsequent form as shown in Equation (4):

\[
I(s) = V(S) \frac{1}{Z(s) + Z(s)/Z(s)}
\]  

(4)

For stability analysis of the system, during unloaded condition, source voltage of the system is to be stable, whereas load current is also stable while it is fed from ideal power source [19-20]. In that case, if the voltage (V) and grid impedance \( (1/ Z_g(s)) \) terms are stable, and then the current I(s) is stable for the system.
When relate the method represented on top, it is significant to distinguish for stable voltage source when it is unloaded [21]. It is considered to remain that the majority of the practical sources are stable voltage sources. Moreover, grid-tie inverters are operated in controlled current mode and it does not act as a voltage supply [22]. Hence existing impedance-based technique cannot be investigated for stability.

From Equation (4) we can write in the subsequent form:

\[
F(s) = \frac{1}{1 + \frac{Zi(s)}{Zg(s)}}
\]  

(5)

The criteria of stability based on the above Equation (5) in which it forms closed loop gain where unity forward gain is achieved and negative feedback of \(\frac{Zi(s)}{Zg(s)}\) which assure the Nyquist stability condition, i.e., ratio of output impedances of the VSI to the impedances of utility grid. The condition of stability states that the grid impedances must be high value in turn to be in stable operation. The impedance based method does not need detailed inverter model since the stability is analyzed using impedance method.

4. Results and Discussion

The simulation is done using MATLAB / Simulink model. In \(H^\infty\) controller the grid is controlled by taking grid current as feedback element and the error signal is given to system controllers which control the whole system. The impedance method is carried out for analyzing the system stability. The Figure 4 (a) shows the three-phase inverter output line voltage \(V_{ab}\).

The Figure 4 (b) shows the three-phase inverter output line voltage \(V_{bc}\).

The Figure 4 (c) shows the three-phase inverter output line voltage \(V_{ca}\).

The Figure 5 (a) shows the waveform of grid currents after implementing \(H^\infty\) controller.
controller, which is a control scheme based on novel impedance conditions, then the system remains in stable condition.

References

[1]. Abilash Thakallapelli, Sukumar Kamalasadan, Kashem M. Muttaqi and Mehrdad T. Hagh, “A Synchronization Control Technique for Soft Connection of Doubly Fed Induction Generator based Wind Turbines to the Power Grids”, IEEE Transactions on Industry Applications, vol. 55, no. 5, pp. 5277 – 5288, 2019.

[2]. Qi Zhang, Jiangjiang Li, Rongwu Liu, Fujin Deng, Xiangdong Sun, Shaoliang Ann and Marco Liserre, “Output Impedance Modeling and High-Frequency ImpedanceShaping Method for Distributed Bidirectional DC–DC Converters in DC Microgrids”, IEEE Transactions on Power Electronics, vol. 35, no. 7, pp. 7001 – 7014, 2020.

[3]. Adrian Timbus, Marco Liserre, Remus Teodorescu, Pedro Rodriguez and Frede Blaabjerg, “Evaluation of Current Controllers for Distributed Power Generation Systems”, IEEE Transactions on Power Electronics, vol. 24, no. 3, pp. 654 – 664, 2009.

[4]. Abdeldjabar Benrabah, Farid Khoucha, Khoudir Marouani, Abdelaziz Kheloui, Ali Raza and Dianguo Xu, “Improved Grid-Side Current Control of LCL-Filtered Grid-Tied Inverters under Weak Grid Conditions”, 2019 Algerian Large Electrical Network Conference (CAGRE), IEEE Xplore, 2019.

[5]. Rachid Erroussi; Saeed Alkhaddieim, “Output Feedback Control of Three-Phase Grid-Tied Inverter with LCL Filter with Enhanced Transient Response”, 2020 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM), IEEE Xplore, 2020.

[6]. Weimin Wu; Jiahao Liu; Yun Li; Frede Blaabjerg, “Individual Channel Design-Based Precise Analysis and Design for Three-Phase Grid-Tied Inverter with LCL-Filter under Unbalanced Grid Impedance”, IEEE Transactions on Power Electronics, vol. 35, no. 5, pp. 5381 – 5396, 2020.

[7]. Lei Xing; Jian Sun, “Optimal Damping of Multistage EMI Filters”, IEEE Transactions on Power Electronics, vol. 27, no. 3, pp. 1220 – 1227, 2012.

[8]. F. Blaabjerg, R. Teodorescu, and M. Liserre, “Overview of Control and Grid Synchronization for Distributed Power Generation Systems”, IEEE Trans. Ind. Electron., vol. 53, no. 5, pp. 1398–1409, 2006.

[9]. X. Feng, J. Liu, and F. C. Lee, “Impedance Specification for Stable DC Distributed Power Systems”, IEEE Transactions on Power Electronics, vol. 17, no. 2, pp. 157-162, 2002.

[10]. E. Twining and D. G. Holmes, “Grid Current Regulation of a Three-Phase Voltage Source Inverter with an LCL Input Filter”, IEEE Trans. Power Electron., vol. 18, no. 3, pp. 888–895, 2003.

[11]. L. Xing, F. Feng, and J. Sun, “Optimal Damping of EMI Filter Input Impedance”, in Proceedings of 2009 IEEE Energy Conversion Congress and Exposition (ECCE 2009), pp. 1685-1692, 2009.

[12]. M. Liserre, R. Teodorescu and F. Blaabjerg, “Stability of Photovoltaic and Wind Turbine Grid-Connected Inverters for a Large Set of Grid Impedance Values”, IEEE Transactions on Power Electronics, vol. 21, No. 1, pp. 263-272, 2006.

[13]. R. Revathi, N. Senthilnathan, V. Kumar Chinnaian, and J. Sevugan Rajesh, “A Review of Demand Response Opportunities and Challenges for Residential Applications in Smart Grid”, International Journal of Future Generation Communication and Networking (IJCFCN), vol. 13, no. 4, pp. 1920 – 1927, 2020.

[14]. J. M. Carrasco, L. G. Franquelo, J. T. Bialasiewicz, E. Galvan, R. C. P. Guinea, M. A. M. Prats, J. I. Leon, and N. Moreno-Alfonso, “Power-Electronics Systems for the Grid Integration of Renewable Energy Source: A Survey”, IEEE Trans. Ind. Electron., vol. 53, no. 4, pp. 1002–1016, 2006.

[15]. D. N. Zmood and D. G. Holmes, “Stationary Frame Current Regulation of PWM Inverters with Zero Steady-State Error”, IEEE Trans. Power Electron., vol. 18, no. 3, pp. 814–822, 2003.

[16]. M. Liserre, F. Blaabjerg, and S. Hansen, “Design and Control of an LCL-Filter based Active Rectifier”, IEEE Trans. Ind. Appl., vol. 41, no.5, pp. 1281–1291, 2005.

[17]. R. Revathi, N. Senthilnathan, V. Kumar Chinnaian, and J. Sevugan Rajesh, “Automatic Shedding of Non-Prioritized Loads for Reduced Energy Consumption in Smart Grid System using Solar PV and Electric Vehicles”, IOP Conference Proceedings: Journal of Physics: Conference Series, 2020.

[18]. J. Sevugan Rajesh, R. Karthikeyan, R. Revathi, “Hybrid DPSO based MPPT Control of High Static Gain Converter in Photovoltaic System for DC Microgrid Applications”, IOP Conference Series: Materials Science and Engineering, vol. 1, no. 937, 2020.

[19]. P. Loh, M. Newman, D. L. M. D. Zmood, and D. Holmes, “A Comparative Analysis of Multiloop Voltage Regulation Strategies for Single and Three-Phase UPS Systems”, IEEE Trans. Power Electron., vol. 18, no. 5, pp. 1176–1185, Sep. 2003.

[20]. E. Coelho, P. Cortizo, and P. Garcia, “Small-Signal Stability for Parallel Connected Inverters in Stand-Alone AC Supply Systems”, IEEE Trans. Ind. Appl., vol. 38, no. 2, pp. 533–542, 2002.

[21]. J. Sevugan Rajesh and R. Revathi, “Modeling and Simulation of Modified Bridgeless Converter and a Single Phase Seven Level Inverter for a Solar Power Generation System”, ARPN Journal of Engineering and Applied Sciences, vol. 11, no. 2, pp. 1177 – 1183, 2016.
[22]. M. Lavanya, R. Revathi, J. Sevugan Rajesh and S.I. Manjur Basha, “Efficiency Enhancement of PV Panel using Soft Computing Based on Seeker Optimization Algorithm and Seven Level Inverter Configuration”, 12th IEEE conference on Intelligent Systems Design and Applications (ISDA 2012) Cochin University of Science and Technology, Cochin, India, November 2012.