IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 7, Issue 6, June 2019

The Impact of Grid Impedance in Operation of Voltage Source Converter Integrated to Weak Grid

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Abstract: Voltage source converter is the bonding part between renewable energy source and power grid to transfer electricity. When a renewable power source is connected to the far end of distribution system, the grid will become non ideal and possess the considerable amount of impedance. In this paper the effect of grid side impedance on operation of Voltage Source Converter (VSC) is presented. It is shown that for weaker grid, stable power transfer ability of VSC reduces as grid impedance increases. To demonstrate grid impedance effect on operation of VSC, Matlab simulation results are presented.

Keywords: Grid impedance, weak grid, grid connected converter etc

I. INTRODUCTION

Day by day use of renewable energy is increasing as it gives pollution free electricity and also do not use any fossil fuel to produce electricity. To utilize the power generated by renewable energy sources it is necessary to integrate this energy in to the power grid. The voltage source converter is employed widely in grid integration application of renewable sources [1], because of its simple circuit and control structure. In such application, VSC connected to grid is controlled by current loop to control the current supplied by VSC to grid [2].

Dynamic behavior of grid connected converter is massively affected by condition of grid at point of common coupling (PCC). The VSC control working satisfactorily with stronger grid may not work in weaker grid. The grid can be defined stronger or weaker based on SCR (short circuit ratio) at PCC. The grid at PCC can be said to be stronger if SCR>3 and is considered weak grid if SCR<3 [3] according to IEEE standards 1204-1997. The SCR can be directly related with grid impedance parameter. Larger the grid impedance weaker is the grid and a vice versa.

Usually VSC is integrated at the far end of distribution system for feeding power in to the grid. This will increases effective grid impedance which leads to represent weaker grid. This leads to have increasing attention for analyzing operation of grid connected converter with high impedance grid. So in this paper important issue of grid connected converter operation with non ideal condition effect of grid impedance is addressed. The operation of VSC is simulated to test its stable power transfer capacity with different grid impedance.

Remaining paper is organized in different section as: In Section 2 three phase grid connected inverter with LC filter and grid impedance is presented and in section 3 impedance based stability model is discussed. Section 4 is used to present matlab simulation of three phase grid connected inverter with different grid side impedance value and summary will be given in section 5.

II. GRID CONNECTED INVERTER

Three phase VSC used in the study of effect of grid impedance on its operation is shown in fig.1. It is having components like two level voltage source converter, LC filter, and Grid, PLL and control algorithm. In circuit arrangement VSC is integrated to grid at point of common coupling formed at midpoint of grid impedance and LC filter. For this study DC supply of converter is assumed to be constant.

In schematic of grid connected converter, it can be seen that VSC is connected to grid at PCC through LC filter. In this schematic, at PCC local load is also connected to observe effect of load switching on converter operation. Voltage at PCC and converter current is sensed using voltage and current sensor respectively and given to control mechanism. SRF PLL is used to detect grid voltage phase and frequency for synchronizing the VSC at PCC with grid. In control algorithm a linear current controller is used to generate voltage reference for PWM generation block which will generate the required gate signals for power semiconductor switches of 2 level voltage source converter.

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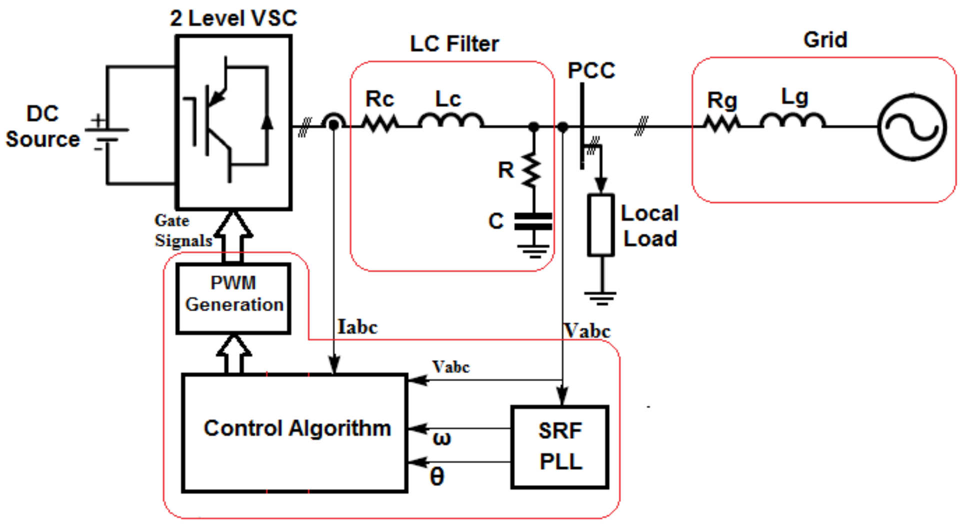

Fig.1. Schematic diagram of Grid Connected converter

III. IMPEDANCE BASED MODEL

Grid connected converter is usually controlled with constant current to feed in to the grid, so it can be represented as constant current source in small signal model used for understanding the power flow behavior of converter. On the other side power grid can be considered as constant voltage source in series with line impedance of grid [4-5]. Impedance based small signal model is shown in fig.2.

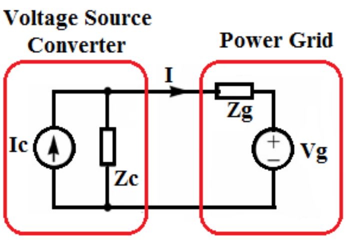

Fig.2. Small Signal Equivalent Grid-Inverter System

From the equivalent circuit we can have VSC output current as below [5],

$$I = \frac{I_C Z_C}{Z_C + Z_g} - \frac{V_g}{Z_C + Z_g} \tag{1}$$

By rearranging the terms in equation we can write the converter as,

$$I = \left[Ic - \frac{V_g}{Z_C}\right] \frac{1}{1 + {Z_g}/{Z_C}} \tag{2}$$

From the formula (2) above, we can see that for a stable grid voltage Vg, stability of converter current feed in to the grid is depends on second terms of the equation (2). According to [5-6] grid connected VSC can stably supply the current to grid when ratio of grid impedance and converter output impedance satisfy Nyquist criterion of stability. This can satisfy the stability criterion when grid impedance is low. But for weak grid condition as the PCC is at very far end of Vg, grid impedance will be of a considerable high value. So in weak grid case power transfer from converter to grid is affected due to high grid impedance. In next section a Matlab simulation is presented to verify effect of grid impedance on stable current transfer or power transfer capacity of VSC.

IV. SIMULATION & RESULTS

The aim of this section is to discuss the simulation model used for verification of instability phenomenon in converter operation during high impedance value of grid in weak grid condition. Fig. 3 shows the MATLAB Simulink model of three phase VSC integrated to grid through a LC filter at point of common coupling (PCC).

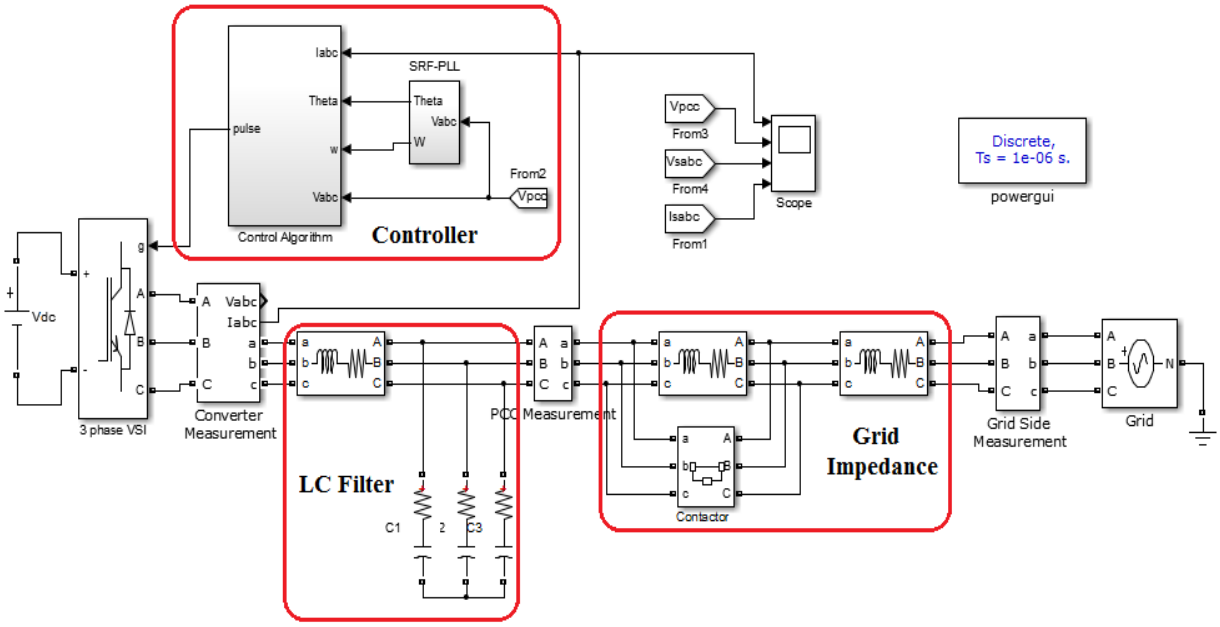

Fig.3 Three phase VSC connected to grid as a model

In Simulation model closed loop power control in Synchronous Reference Frame (SRF) is used to generate Id* reference for inner closed loop current control. For current control and power control loop PI controller is used to minimize the error and to provide required closed loop control. The closed loop control applied is shown in fig.4 as control algorithm. A SRF-phase locked loop is used to detect the grid voltage phase at PCC. Grid voltage is sensed at PCC and current is sensed from converter output in presented model. The parameter used for simulation is listed in table 1. The Kp and Ki gain of PI controller is set by auto tuning feature of Matlab and then varying it to achieve better performance.

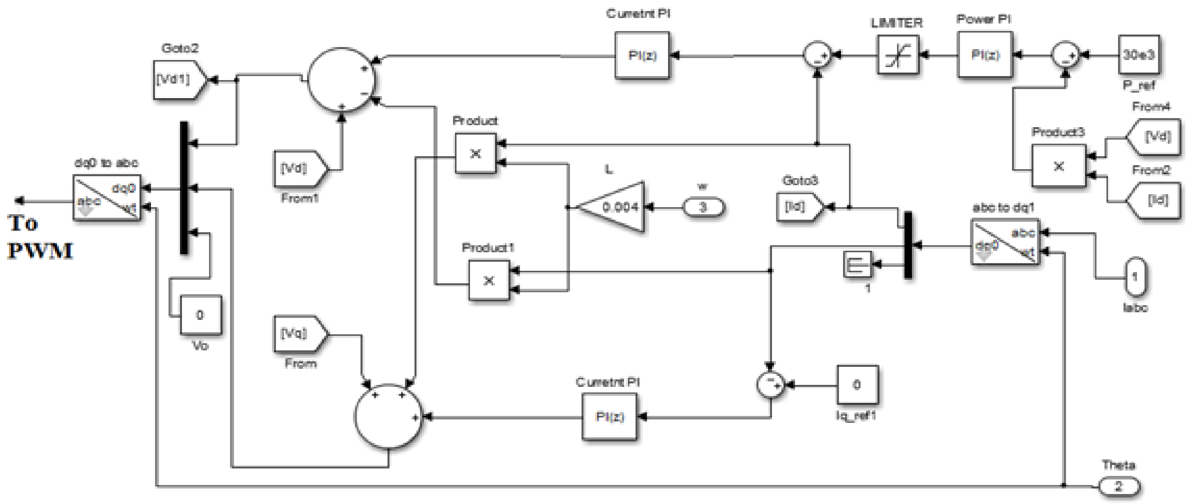

Fig.4 Detailed Simulink connection for Control Algorithm

For testing the performance of VSC connected to grid in weak grid condition, in simulation it is used to apply step change in grid impedance from 2mH to 4mH at t=0.2 sec. The current reference Id* is generated by power control loop and Iq* is set to zero in simulation. Fig. 5 shows the converter current, voltage at PCC, Grid voltage and current measured at grid side measurement. This result shows that before increment in grid impedance VSC is working in stable mode and giving required amount of active power flow converter to grid. But when change in grid impedance is applied VSC becomes unstable and large amount distortion and magnitude change occurs in converter power as well as current. This makes it necessary to disconnect the converter from grid to keep it safe. Fig. 6 shows the set references and actual plot for active power and Id current. The converter power and current reference both are getting violated

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from its set reference after increment of grid impedance. This both results verify that when VSC is connected to weak grid having large impedance its performance gets deteriorated and not able to remain stable.

Table 1: Setting Of Simulation Parameter

Parameter	Value
Grid Phase Voltage (Normal Condition)	325 V peak
Frequency	50 Hz
Kp (SRF & DSRF)	0.9
Ti (SRF & DSRF)	4
Kp (Current & Power Loop)	10
Ti (Current & Power Loop)	200
Filter Inductance	4mH
Filter Capacitance	25 µF

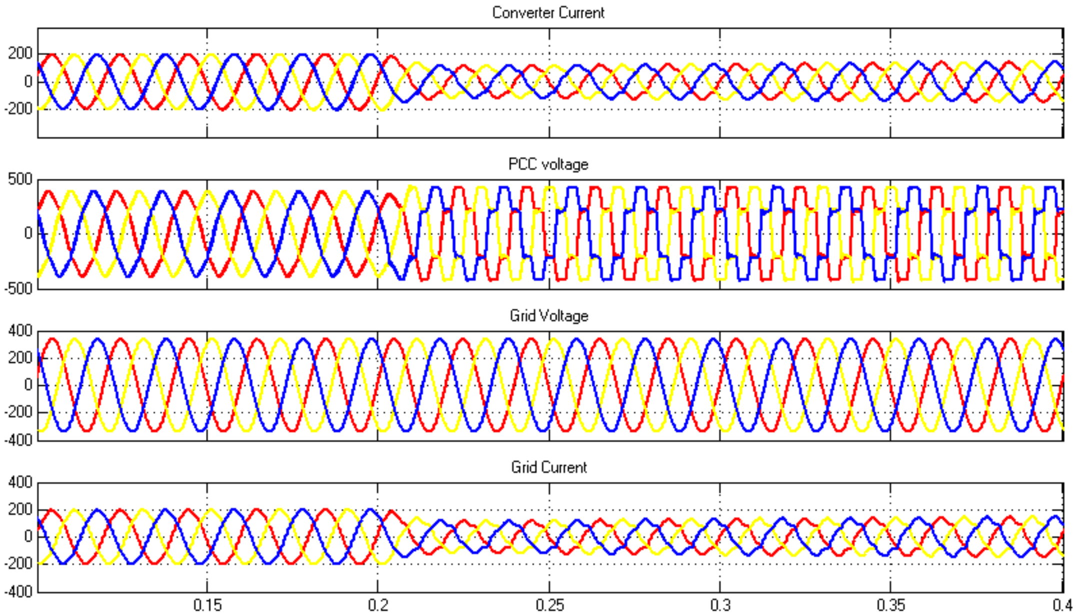

Fig.5 Converter current, PCC voltage, Grid Voltage and grid current with change in Zg from 2mH to 4mH

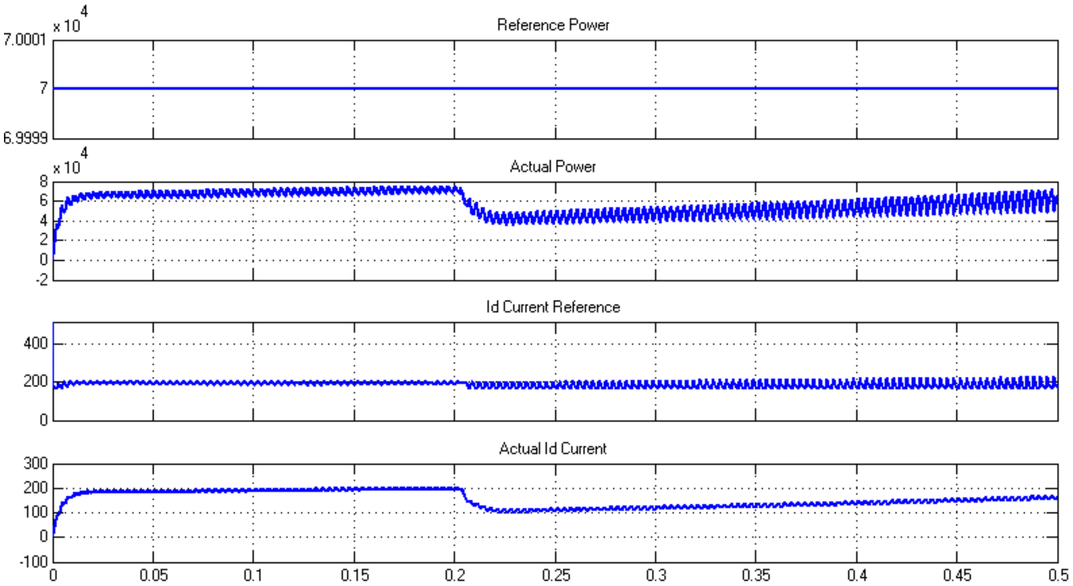

Fig.6 Power Reference, Actual Power, Id* and Actual Id with change in Zg from 2mH to 4mH

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DOI 10.17148/IJIREEICE.2019.7609

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V. CONCLUSION

This paper presented a detail discussion and simulation results to investigate the issues of grid impedance on performance of VSC under weak grid condition. The VSC integration with stronger grid with less value of grid side impedance makes it suitable for giving better performance and it is able to transfer more active power from converter to grid, whereas in case of weak grid due to large value of grid impedance VSC performance gets deteriorated and not able to transfer the required power to grid. Also from the small signal study of stability it can be understood that inverter should be designed with high output impedance to satisfy the Nyquist criteria and make it suitable for operating in large value of grid impedance.

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