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Active Power Transfer Enhancement in VSC using Impedance Compensated DSRF-PLL during Weak Grid Condition

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Abstract: In last two decades the use of renewable sources has been increased tremendously. This has increased the number of inverters connected to grid for the integration of energy from renewable sources. The stability of grid tied inverter is very much important with increased number of inverters. Especially in weak grid, which leads to voltage fluctuation, stability of inverter needs more attention. For a stable operation of VSC it is very important to detect the phase of grid voltage at point of common coupling (PCC) with proper accuracy. In this paper a Double Synchronous Reference Frame PLL (DSRF-PLL) with grid impedance compensation is presented. It is shown that with grid impedance compensation in phase detection, a VSC can be virtually synchronized at a stronger point of common coupling (PCC) in grid and this will enhance the active power transfer capacity of VSC with stable operation in weak grid condition. MATLAB simulation results are presented to verify the findings.

Keywords : DSRF-PLL, Impedance compensation, Grid tied inverter etc.

I. INTRODUCTION

A voltage source converter (VSC) is the power converter topology, well suited for grid integration of renewable energy. When VSC is required to be interacting with grid at weak point of common coupling (PCC), it faces the large challenges in control mechanism. Several literatures has discussed and verified that the performance of VSC is affected by the control parameter, filter parameter as well as grid impedance in case of weak grid condition. Furthermore, grid connected VSC can become unstable if the harmonic component with frequency matching to natural frequency of filter is present in voltage at PCC [1-3].

Phase locked loop (PLL) is commonly used in all type of grid connected VSC for synchronization with AC grid [4]. It has also been reported that operation of PLL can affect the dynamic performance as well as stability of grid connected VSC. Especially in weak grid with high grid impedance, as voltage measured at PCC is affected by current supplied by VSC in to the grid, stable range of VSC operation gets affected [5-7]. The stability issue of grid-connected VSCs with non ideal grid has been discussed in many literatures. For instance, Zhou in [8] presented impact of short circuit ratio (SCR) and PLL on converter stability.

In [9] it has been reported that to maintain stability of VSC connected to weak grid having high impedance (SCR=1), the active power injection of VSC needs to reduced to 0.5 to 0.6 per unit. To overcome this potential issue of instability due to large grid impedance a virtual flux based grid voltage estimation approach has been presented in [10]. Although it has given the stable operation of VSC with increased active power transfer capacity, it requires dedicated estimation method and separate block for it. A impedance compensated synchronous reference frame PLL (SRF-PLL) has been presented in [12-13] to enhance the power transfer capacity of VSC in non ideal grid. However, this SRF-PLL phase detection gets affected by harmonic component present in voltage measured at PCC.

In this paper an impedance compensated double synchronous reference frame PLL is presented to improve stability of VSC operation in weak grid and to enhance the active power transfer capacity of VSC into the weak grid.

Remaining paper is organized in different section as: In Section 2 weak grid connected three phase voltage source inverter with LC filter and grid impedance is presented and in section 3 brief operation of double synchronous reference frame PLL is discussed. Section 4 is used to show how impedance compensation can be applied to DSRF-PLL to make it ICDSRF-PLL which can give enhanced power transfer in grid with stable operation. In section 5 MATLAB simulation of proposed method has been presented and summary will be given in section 6.

II. INCREASED ACTIVE POWER TRANSFER IN WEAK GRID

The effect of grid impedance compensation in grid synchronization for weak grid connected VSC has been investigated. The system configuration used in investigation is shown in figure 1, in which it can be seen that VSC is connected to grid at PCC through LC filter. Voltage at PCC and converter current is sensed using voltage and current sensor respectively and given to control mechanism. Phase Locked Loop (PLL) is used to detect grid voltage phase and frequency for synchronizing the VSC at PCC with grid.

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In control algorithm a predictive current controller is used to generate voltage reference for PWM generation block which will generate the required gate signal for power semiconductor switches of 2-level VSC. For this study, input DC supply of converter is assumed to be constant. During unbalanced and distorted voltage condition of grid, for VSC to operate with stable power flow, it is very much important to detect phase and frequency of grid voltage.

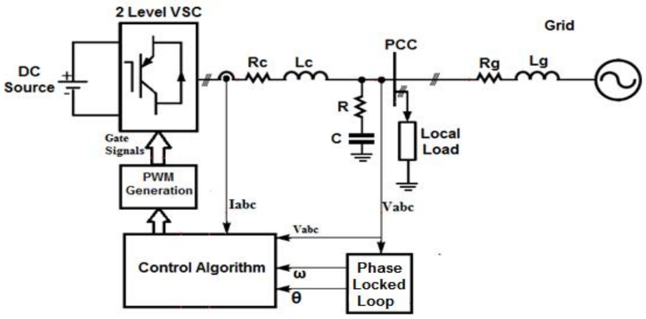

Fig.1 System of VSC integrated to weak Grid.

In proposed investigation double synchronous reference frame PLL is used to apply grid impedance compensation, which has capability to track the phase of positive sequence grid voltage component even in distorted voltage with harmonics *[4]*.

III. DOUBLE SYNCHRONOUS REFERENCE FRAME PLL

In conventional DSRF-PLL as given in [4], symmetrical component of unbalanced grid voltage is first obtained using Clarke and Park transformation in double reference frame rotating opposite to each other. Then positive sequence component is used to track the phase. The block diagram representation of DSRF-PLL is shown in fig.2. It can be divided in three part: (1) Obtain positive and negative symmetrical component of grid voltage (2) Remove the coupling between two reference frame using decoupling network and (3) obtain phase and frequency.

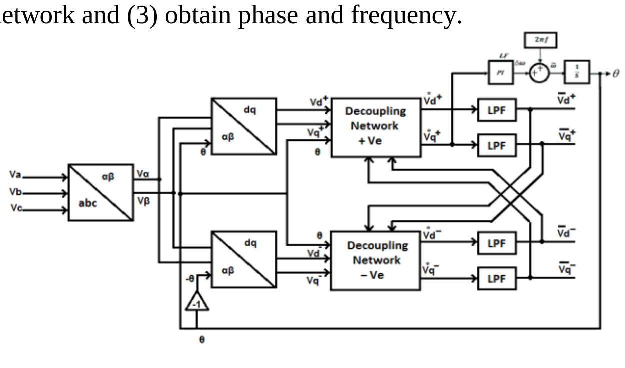

Fig.2 Block diagram of DSRF –PLL

A decoupling network is used to remove the coupling effect of double frequency component, which is cancelling the effect of cross coupling of positive and negative sequence component of unbalanced voltage.

IV. GRID IMPEDANCE COMPENSATED DSRF-PLL

In weak grid condition, voltage at PCC becomes fluctuating due to the large impedance drop in grid side impedance. As we can see in vector diagram of fig.3, voltage at PCC is the vector sum of grid voltage Vg and grid impedance drop considering power flow from inverter to grid.

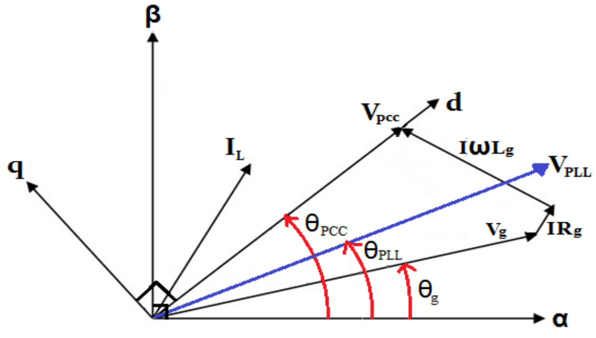

Fig.3 Vector diagram for Grid and PCC voltage

Here considering grid impedance Zg=Rg+jωLg for a line current I resistive drop IRg and reactive drop IωLg can be added as shown in vector diagram. Hence at high active power transfer from VSC to grid line current I will be large in magnitude and this will increase the grid impedance drop and it will affect the voltage at PCC. DSRF-PLL cannot synchronize VSC at stronger point due to this large impedance of weak grid. Thus to enhance power flow from VSC to grid, this grid impedance voltage drop compensation has to be applied. After grid voltage compensation voltage at PLL can be given by following relation,

$$V_{PLL} = V_{PCC} - IZ_{virtual}$$

By selecting proper value of Zvirtual according to grid impedance Zg, PLL can be synchronized at stronger point in to grid. A virtual impedance compensation inspired from [12] is developed and added between the voltage sensor signals and DSRF PLL to make it ICDSRF-PLL (Impedance compensated DSRF-PLL). From block diagram of ICDSRF-PLL shown in fig.4, it can be observed that voltage at the input of DSRF-PLL block can be compensated by virtual impedance drop and hence this will enable the PLL to synchronize at stronger point in grid. With proper selection of virtual impedance for compensation it is possible to synchronize VSC at phase θpll, which can be adjusted between grid voltage phase θg and phase at point of common coupling θpcc.

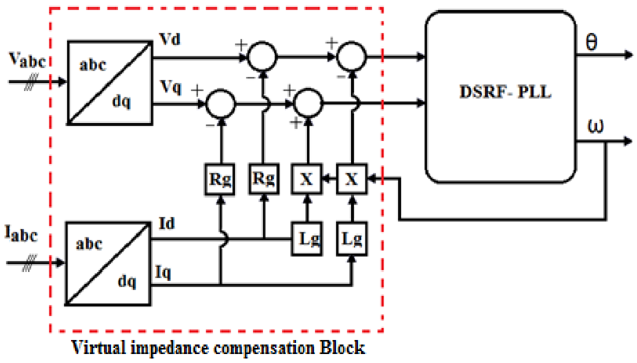

Fig.4 Block diagram of ICDSRF –PLL

However, it needs to be noted that grid impedance which required to be compensated is not a known parameter always as well as it can change with variation in grid condition by addition or removal of load and/or grid connected VSC.

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Thus it will not be possible to compensate grid impedance drop completely but instead we can do partial impedance compensation in such a magnitude that VSC can be interacted at stronger position of grid. Also with higher compensation the voltage at converter terminal needs to be increased, that can reach the voltage limit of semiconductor device used in VSC.

V. VERIFICATION WITH SIMULATION

In this section, stability of VSC for range of active power transfer is observed with the help of MATLAB simulation of grid connected system shown in fig.5. The LC filter value chosen for the setup is Lf=1 mH and Cf=25 μF. For representing weak grid, the grid side impedance is taken as Rg=0.1 Ω and Lg=3 mH. This value of grid impedance is making short circuit ratio (SCR) at PCC to be less than 3 which is the weak grid condition according to IEEE standard. The DC power source to the input of VSC is taken constant at 680 V assuming constant power is available from power generating unit. In control algorithm, to generate switching pulse for VSC, SPWM technique is used. The voltage reference for SPWM is calculated by closed loop control of VSC, implemented using PI current controller in synchronous reference frame with current reference generated by power outer loop.

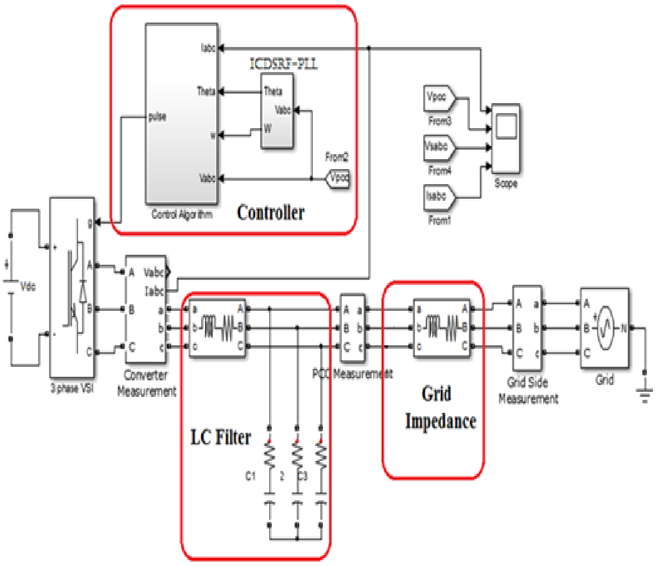

Fig.5 Simulation model of weak grid connected VSC

The impact of virtual impedance compensation is verified by simulation model of the grid connected VSC which has been described above, firstly observing performance of VSC with conventional DSRF-PLL without virtual impedance compensation and then with virtual impedance compensation. During this analysis it has been assumed that controller dynamics do not change and kept at constant Kp and Ki gain value in both cases. For this simulation, PI controller tuning for closed loop current controller is achieved with the Kp=25 and Ki=200. For observing the effect of grid impedance on active power flow from VSC to grid, reference of active power is changed from 35kW to 65 kW. From the result of active power tracking without grid impedance presented in fig.6 and Fig.7, it can be observed that VSC is capable to track the active power up to 55 kW and VSC becomes unstable after active power of 60 kW.

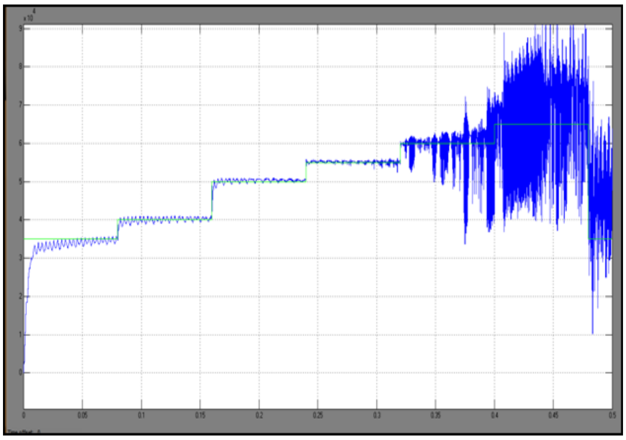

Fig.6 Active power tracking by VSC without Grid Impedance Compensation

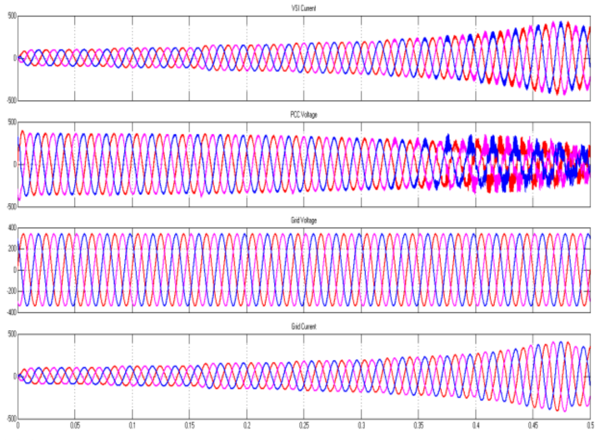

Fig.7 VSC current, PCC voltage, Grid voltage without grid Impedance compensation

For the same converter model when its performance is observed by applying virtual impedance compensated DSRF-PLL, results are presented in fig. 8 and fig. 9. It can be observed that with virtual impedance compensation VSC can remain stable with higher active power transfer from VSC to grid. With virtual impedance compensation VSC has been given stable active power tracking till 65 kW.

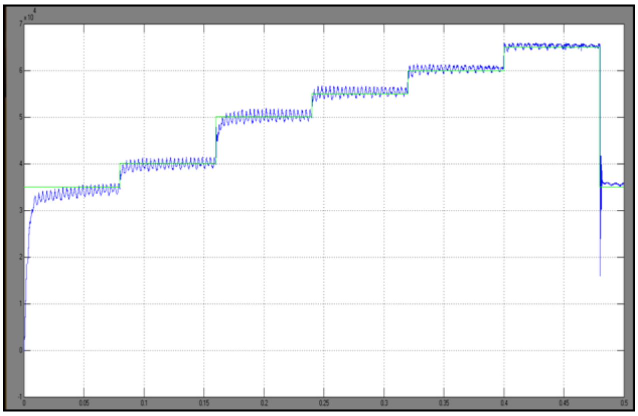

Fig.8 Active power tracking by VSC with Grid Impedance Compensation

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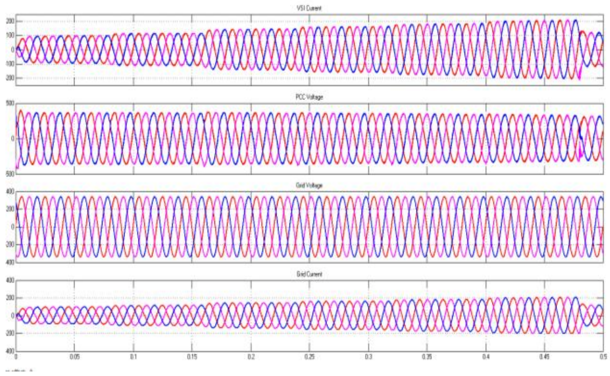

Fig.9 VSC current, PCC voltage, Grid voltage with grid Impedance compensation

From the results presented, it can be seen that the VSC with conventional DSRF-PLL becomes unstable at 55 kW active power reference while with virtual impedance compensated ICDSRF-PLL, VSC remains stable with 65 kW active power reference. Hence it can be verified that virtual impedance compensation gives effective synchronization of VSC at stronger point in weak grid.

VI. CONCLUSION

In this paper, a method of enhancing active power transfer from VSC to weak grid by adding virtual grid impedance compensation in DSRF-PLL has been presented. This virtual grid impedance compensation with DSRF-PLL enable VSC to synchronize at stronger point in grid as well as due to basic nature of DSRF-PLL to track positive sequence phase of grid voltage, it can give better phase detection in distorted voltage also. As virtual impedance compensated voltage at PLL has less effect of converter operation and grid impedance voltage drop, stable operation of VSC can be achieved for a higher active power transfer to grid. The proposed method is verified using MATLAB simulation and results are presented to verify the enhanced active power transfer to grid. Hence, in weak grid with large impedance of grid, VSC can be integrated through virtual impedance compensation to have more active power feed from converter to grid.

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