Enhanced Grid Synchronization of a DG system based on Positive Sequence Estimation and Current Control

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Abstract—Distributed Generation (DG) System is a small scale electric power generation which encompasses a wide range of technologies such as wind energy, fuel cell, solar power, micro turbines etc. Grid synchronization has been identified as the most significant barrier to the control of inverters connected to the grid. A Wind turbine based on direct drive permanent magnet synchronous generator (PMSG) is connected to the grid. The proper operation of grid connected inverter system is determined by grid voltage conditions such as phase, amplitude and frequency. A phase-locked loop (PLL) is used to track the phase angle in order to improve the synchronization systems response in adverse grid conditions. Using the enhanced synchronization structure the fundamental positive-sequence component of grid voltages in asymmetric and distorted three-phase systems is estimated. The α-β stationary frame is used to obtain the pulsation for grid inverter using a space vector pulse width modulation (SVPWM) technique. The performance of the proposed structure is verified through simulations using a grid set of ideal and non-ideal grid conditions (three-phase voltage unbalance, variation in frequency, variation in amplitude and phase shift).The simulation results demonstrates that the proposed method is very effective in digital structure synchronization .

Keywords—Distributed Generation (DG), permanent magnet synchronous generator (PMSG), discrete phase-locked loop (PLL), synchronization systems, positive-sequence component, SVPWM, non-ideal grid conditions.

I. INTRODUCTION

The Distributed Generation (DG) systems are highly sporadic power generation system and their power output depends heavily on the natural conditions. Wind power generation based on direct drive permanent magnet synchronous generator has received much attention due to its self excitation capability and high efficiency operation [1]. Various grid code requirements must be met to connect the DG systems with the utility grid. To ensure safe and reliable operation of power system based on DG system [2], usually power plant operators should satisfy the grid code requirements such as fault ride through, power quality improvement, grid synchronization, grid stability and power control etc.

The grid synchronization techniques can be adversely affected by the application of a disturbing influence (influence quantity) on the electrical input signals. Due to the increase in number of Distributed Generation (DG) Systems has lead to complexity in control while integrating into grid. As a result requirements of grid connected inverters have become stricter to meet very high power quality standards.

Grid voltage conditions such as phase, amplitude and frequency determine the proper operation of a grid connected system. In such applications, a fast and accurate detection of the phase angle, frequency and amplitude of the grid voltage is essential. These factors, together with the implementation simplicity and the cost are all important when examining the credibility of a synchronization scheme. Therefore an ideal phase-detection scheme must be used to promptly and smoothly track the grid phase through various short-term disturbances [3] [4] and long term disturbances to set the energy transfer between the grid and the power converter.

One of the earliest methods used for tracking the phase angle is Zero Crossing Detector (ZCD) method [5], but the performance of ZCD is badly affected by power quality phenomena [6]. The Linear PLL is mainly used to detect phase for single phase supply. Use of voltage controlled oscillators (VCOs) resulted in more rigid controllers such as the Phase Locked Oscillator systems and the Charge-Pump PLLs. However with the development of discrete devices such as microcontrollers, various high performance synchronization methods have been introduced.

The most recently proposed technique that can be used for grid synchronization is the phase-locked loop (PLL); it is a control system that generates an output signal whose phase is related to the phase of an input "reference" signal [7].Some significant applications are active power filters [8] [9], uninterruptible power supplies [10], power-factor control [11], [12], distributed power generation [13] and flexible ac transmission systems [14]. Synchronous reference frame–phase-locked loops (SRF-s) are the most widely used systems for synchronizing signals [15].

A fast and accurate estimation of fundamental positive-sequence component [16] of grid voltage is essential for different applications involving FACTS, power devices and grid connected power converters. It is essential to estimate for both monitoring and control in order to satisfy grid codes, and to obtain high performance response.

This paper proposes an enhanced synchronization structure based on PLL and fundamental positive-sequence components which is used to synchronize the component of grid voltages in three-phase systems that can include distorted and asymmetric voltage terms. Finally, the performances of the digital synchronization structure are investigated in the presence of both ideal and non-ideal grid conditions such as amplitude variation, frequency variation, phase jump and improper phase shift. The analysis is carried out in MATLAB/SIMULINK environment and the obtained results are discussed for effectiveness of the study.

II. Overview of Proposed System

A. Wind Turbine based DG

The PMSG-based wind turbine is fed to an ac-dc-ac converter so as to maintain the ac output voltage at specified frequency and amplitude. One of the main challenges is to provide inverter control to present the customers with balanced supply voltage. The wind speed is maintained constant so as to keep the modulation index 1 in the load side inverter.

B. Synchronous reference frame based PLL

A phase-locked loop is a control system that generates an output signal whose phase is related to the phase of an input "reference" signal [6]. Frequency is the time derivative of phase. Keeping both the input and output phase in lock step implies keeping the input and output frequencies in lock step. Consequently it can track an input frequency or it can generate a frequency that is a multiple of the input frequency.

At present Synchronous Reference Frame PLL (SRF-PLL) is the one of the most employed PLL topology. If the single-phase voltage input Vα, is an internally generated signal that is a 90 degrees shifted version of Vβ .The transformation blocks changes the reference frame, bringing the voltages system from an α-β stationary reference frame to a d-q rotating synchronous reference frame.

The feedback loop controls the angular position of this d-q reference frame. In particular the utility voltage vector is totally lined up to the q-axis. In this way it coincides with all its q-component; consequently the d-component is made equal to zero. The q-component describes the voltage vector amplitude course.

After studying the various Phase Locked Loop schemes used today in modern power system, we observe that the Synchronous Reference Frame PLL method provides a simple yet effective way to measure the phase angle. In case of a single phase system we obtain the quadrature signal by delaying the available sinusoid or adopting some other similar structure, however in 3 phase system this problem is greatly reduced due to the availability of three phase shifted signals. Hence by using arithmetic manipulation we obtain the required orthogonal signal necessary for SRF-PLL implementation.

C. Current control with PI Regulator:

The PI controller is a linear controller and one of the most common controllers used in control system. It is based on the principal of control loop feedback. The error of the measured and reference output signal is the function of the control response which will produce an output until it matches the value of reference. There are two actions to be performed namely proportional and integral action in the controller. The proportional term control action is to simply proportional to the control error. The proportional term output is given by multiplying the error by a constant Kp(0.08) which is called the proportional gain constant. The integral term objective in PI controller is to eliminate control error in steady state. It calculates and accumulates a continuous sum of the error signal. The accumulated error is then multiplied by constant Ki(200) which is called the integral gain constant and gives the integral control output.

D. Space vector pulse width modulation:

It is used for the control of pulse width modulation. To implement space vector modulation a reference signal is sampled with fundamental frequency. The reference signal needed is generated from the Clarke transformation from three phase voltage source.

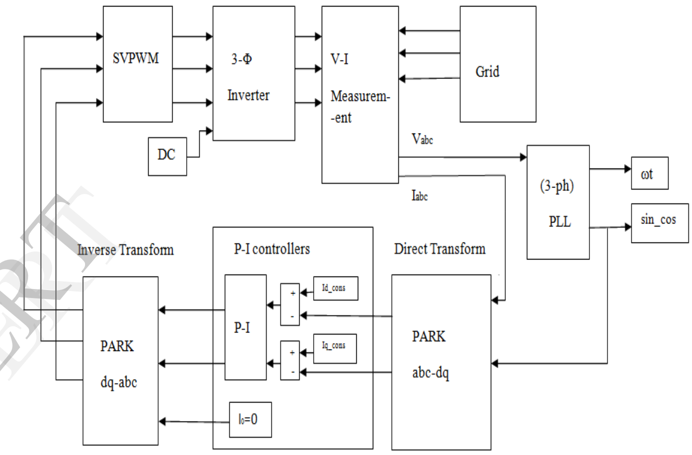

Fig. 1. Synchronization sytem structure

III. PROBLEM FORMULATION

The operation of the proposed synchronized structure is implemented by considering three phase supply voltage source Va, Vb and Vc. In order to track the phase angle a discrete three phase PLL is used. It controls the internal voltage source. The output consists of estimated phase synchronous angle θ and (sin θ, cos θ) for the dq transformation blocks. In steady state sin θ will be in phase with the fundamental positive sequence of the α-component. The PLL also measures the frequency and generates a signal ωt locked on the variable frequency of system voltage. The sin θ, cos θ values estimated using the PLL are used to obtain d, q and zero components using Park transformation.

$$I_d = 2/3(I_a \sin \omega t + I_b \sin(\omega t - 2\pi/3) + I_c \sin(\omega t + 2\pi/3)) \quad (1)$$

$$Iq = 2/3(I_a \cos \omega t + I_b \cos(\omega t - 2\pi/3) + I_c \cos(\omega t + 2\pi/3)) \quad (2)$$

$$I_0 = 1/3(I_a + I_b + I_c) \quad (3)$$

The current control is usually performed in a d-q synchronous reference frame. A distortion free, balanced, constant magnitude three-phase voltage has d components only, while the 'q' and '0' components will be zero. Hence a reference current for Iq is set zero. The controller gains calculated for the PI regulator are Kp=0.08 and Ki=200. The output obtained is again converted into Iabc using Park transformation. The dq0_to_abc Transformation is commonly used in three-phase electric machine models. It transforms three quantities such as direct axis, quadratic axis and zero-sequence components. It is also expressed in a two-axis reference frame back to phase quantities. The following transformation is used:

$$I_a = I_d \sin(\omega t) + I_q \cos(\omega t) + I_0 \quad (4)$$

$$I_b = I_d \sin(\omega t - \frac{2\pi}{3}) + I_q \cos(\omega t - \frac{2\pi}{3}) + I_0 \quad (5)$$

$$I_c = I_d \sin(\omega t + \frac{2\pi}{3}) + I_q \cos(\omega t + \frac{2\pi}{3}) + I_0 \quad (6)$$

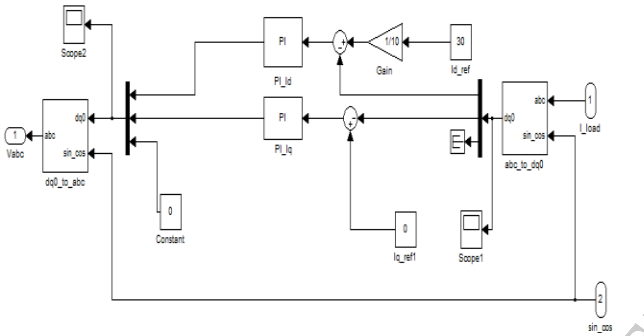

Fig. 2. Simulation model for positive sequence estimation and current control.

A SVPWM is used to obtain the pulsation for the DC-AC inverter with Uα and Uβ as the reference signal obtained by using Clark transformation.

$$U\alpha = 2/3*(Va - 0.5Vb - 0.5Vc) \quad (7)$$

$$U\beta = 2/3*(\sqrt{3}/2*Vb - \sqrt{3}/2*Vc) \quad (8)$$

IV. RESULT AND DISCUSSION

To verify the effectiveness of the proposed synchronization system structure, some significant cases have been simulated are performed using Matlab-Simulink software.

The main objective is to estimate the fundamental positive-sequence component from the three phase supply voltages which contains distortion asymmetries. The fundamental grid frequency is 50 Hz and the sampling frequency used is 5 kHz.

1) Case test-1: The proposed structure is initially tested with ideal condition without considering any distortion. The grid positive sequence amplitude is set as 380V.

2) Case test-2: A three-phase voltage unbalance is applied with a voltage reduction of 50V in each phase.

3) Case test-3: A three-phase frequency unbalance is produced by a variation of 5Hz from the fundamental grid frequency of 50Hz.

4) Case test-4: The amplitude is varied by 50V in phase-A of the grid supply voltage.

Case test-5: Improper phase-shift is produced by having constant frequency but not the proper phase shift of 120° relative to each other. A phase shift of 5° variation is applied to the balanced three phase voltage. If you have an odd number of affiliations, the final affiliation will be centered on the page; all previous will be in two columns.

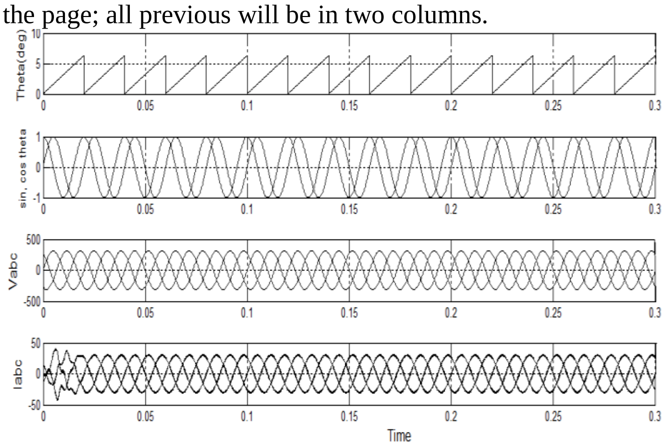

Fig. 3. Simulated results for PLL output, grid voltage and current.

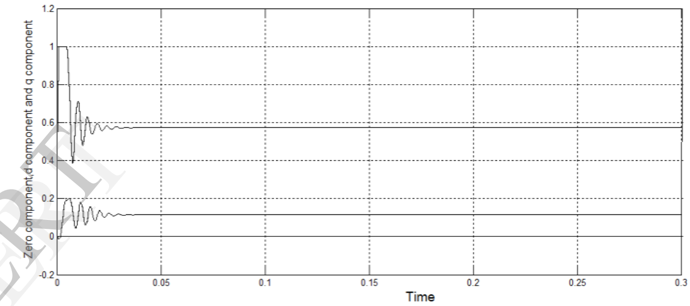

Fig. 4. Simulated results for current control.

Waveforms presented in Figs. 5-9 show the simulated output for the cases described. All of the cases first include (top plot) the Vα and Vβ that corresponds to the grid voltages in the α-β frame. The central plots show the fundamental positive sequence grid voltages Vα+ and Vβ+ in the α-β frame. The bottom plots show the phase angle of the fundamental positive sequence of grid voltages.

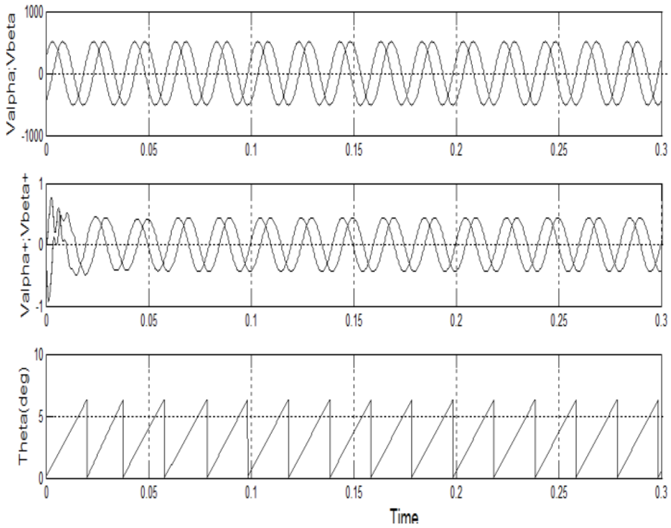

Fig. 5. Simulated result for case 1 (ideal condition).

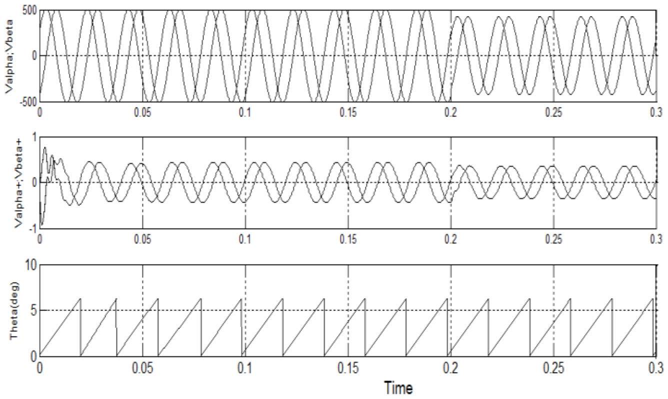

Fig. 6. Simulated results for case 2 (Three phase voltage unbalance).

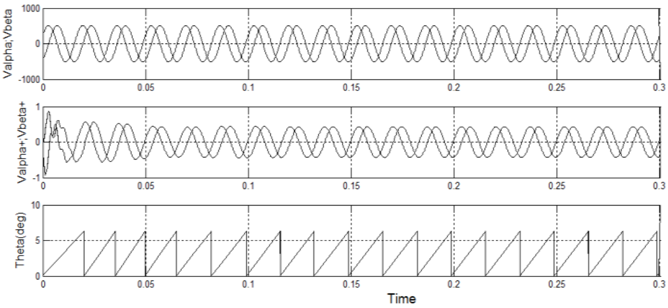

Fig. 7. Simulated results for case 3 (Three phase frequency unbalance).

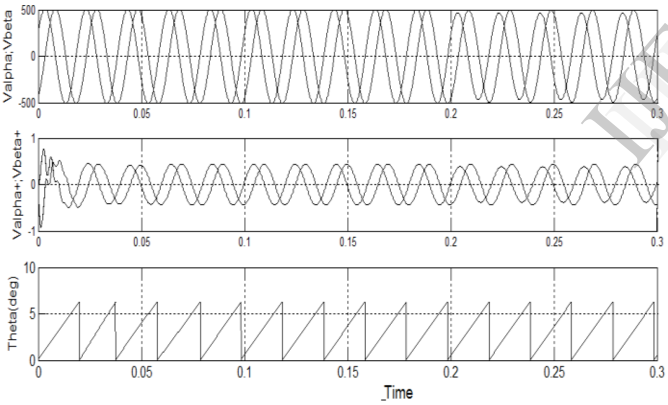

Fig. 8. Simulated results for case 4(voltage unbalance).

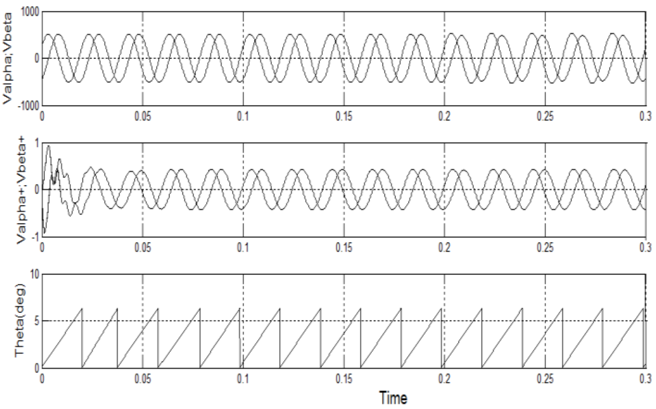

Fig. 9. Simulated results for case 5(Improper phase shift).

Different non-ideal conditions were simulated and most were handled well by the system. Unbalances in the three phase input signals were overall handled well by the system. The estimation of fundamental positive sequence component and phase angle tracking was performed well by the system. Although the system could handle the non-ideal cases fairly well it was sometimes slow.

V. CONCLUSION

A PLL can be used to obtain magnitude, frequency and phase information for estimation of fundamental positive-sequence component of grid voltage. Accurate and fast estimation of these quantities can be used for control and protection of the system. Overall the wind turbine integrated grid synchronization system based on positive-sequence estimation is able to handle non-ideal conditions well. The positive-sequence phase angle is tracked within acceptable margins and therefore the PLL system as given with the positive sequence estimation could indeed operate in a real life application.

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REFERENCES

[1] C.N. Bhende, S.Mishra and Siva Ganesh Malla, "Permanent magnet synchronous generator-based standalone wind energy supply system," IEEE Transactions on Sustainable Energy, vol. 2, no. 4, October 2011.

[2] F. Blaabjerg, R. Teodorescu, M. Liserre, and A. V. Timbus, "Overview of control and grid synchronization for distributed power generation systems," IEEE Trans. Ind. Electron., vol. 53,no. 5, pp. 1398-1409,Oct. 2006.

[3] J. Svensson, "Synchronisation methods for grid-connected voltage source converters," Proc. Inst. Elect. Eng., vol. 148, no.3, pp.229-235,May 2001.

[4] M. Karimi-Ghartemani and M. Iravani, "A method for synchronization of power electronic converters in polluted and variable-frequency environments,"IEEE Trans. Power syst., vol.19, no. 3,pp. 1263-1270, Aug.2004.

[5] F. M. Gardner, Phase Lock Techniques. New York:Wiley, 1979.

[6] Francisco D. Freijedo, Jesus Doval-Gandoy, Oscar Lopez, Carlos Martinez-Penalver, Alejandro G. Yepes, Pablo Fernandez-Comesana, Andres Nogueiras, JanoMalvar, Nogueiras, Jorge Marcos and Alfonso Lago, "Grid-synchronization methods for power converters," Proc. Of IEEE 35th Annual Conference on Industrial Electronics, IECON 2009, pp. 522-529.

[7] FANG Xiong, WANG Yue, LI Ming, WANG Ke and LEI Wanjun,"A novel PLL for grid synchronization of power electronic converters in unbalanced and variable-frequency environment," Proc. of IEEE International Symposium on Power Electronics for Distributed Generation Systems: pp. 466-471, 2010.

[8] C. Lascu, L. Asiminoaei, I. Boldea, and F. Blaabjerg, "High performance current controller for selective harmonic compensation in active power filters," IEEE Trans. Power Electron., vol. 22,no. 5,pp. 1826-1835,Sep. 2007.

[9] M. Routimo, M. Salo, and H. Tuusa, "Comparison of voltage-source and current-source shunt active power filters," IEEE Trans. Power Electron.,vol. 22, no. 2,pp. 636-643, March 2007.

[10] J. M. Guerrero, L. Hang, and J. Uceda, "Control of dis tributed uninterruptible power supply systems," IEEE Trans. Ind. Electron., vol. 55, no. 8,pp. 2845-2859, Aug. 2008.

[11] A. I. Maswood and F. Liu, "A unity-power-factor converter using the synchronous-reference-frame-based hysteresis current control," IEEE Trans. Ind. Appl., vol. 43,no. 2, pp. 593-599, Mar./Apr. 2007.

[12] B.Wang, G. Venkataramanan, and A. Bendre, "Unity power factor control for three-phase three-level rectifiers without current sensors," IEEE Trans. Ind. Appl., vol. 43, no. 5,pp.1341-1348, Sep./Oct.2007.

[13] T. Ahmed, K. Nishida, and M. Nakaoka, "A novel stand-alone induction generator system for AC and DC power applications," IEEE Trans. Ind Appl., vol. 43, no. 6, pp. 1465-1474, Nov./Dec.2007.

[14] H. Awad, J. Svensson, and M. J. Bollen, "Tuning software phase-locked loop for series-connected converters," IEEE Trans. Power Del., vol. 20, no. 1,pp. 300-308, Jan.2005.

[15] A. Timbus, M. Liserre, R. Teodorescu, P. Rodriguez, and F. Blaabjerg, "Evaluation of current controllers for distributed power generation systems," IEEE Trans. Power Electron., vol. 24,no. 3,pp. 654-664,Mar. 2009.

[16] Pedro Roncero-Sanchez, Xavie del Toro Garcia, Alfonso Parreno Torres, and Vinvente Feliu, "Fundamental positive-and negative-sequence estimator for grid synchronization under highly disturbed operating coditions," IEEE Trans. Power Electronics., vol. 28, no.8, August. 2013.