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Implementation of a Converter in Sequence Domain to Counter Voltage Imbalances

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Abstract—**This paper demonstrates the basic problem of the conventional d-axis and q-axis control applied to a voltage source converter (VSC) during a system imbalance. The specific imbalances studied are a balanced fault and an unbalanced fault at the terminals of the converter. The dc link voltage of the VSC is disturbed during the unbalanced fault due to negative sequence components in the system. The sequence characteristics of the system during an imbalance are further analyzed. A novel controller in the sequence domain is proposed. The positive sequence components of the control are implemented in the positive synchronous reference frame and the negative sequence components of the control are implemented in the negative synchronous reference frame. The negative sequence components are commanded to zero in the control. The approach demonstrates the stabilization of the voltage to a greater extent. The control also points out the need for a storage element when the VSC is to be used for application with that of a Doubly-Fed Induction Generators (DFIG) in wind turbines.**

Index Terms— **Doubly-fed induction generator, wind turbine, wind power, unbalanced fault**

I. INTRODUCTION

GENERAL controllers used for three phase PWM converters are generally designed on the assumption that the input voltage is balanced. They are implemented in the synchronous reference frame (SRF) as it eliminates the steady state error and the control is decoupled. These controllers do not behave as expected when the input is unbalanced like in the case of voltage sags, SLG faults, DLG faults, etc. In such instances, the current reference is distorted by a second harmonic voltage due to the presence of negative sequence. Hence a more detailed control which takes into account this imbalance needs to be investigated.

Enjeti and Choudhury [1] propose a technique which counter balances the gating signals so that the imbalance in the supply is rectified. The technique is a feed-forward approach where the sequence components of the unbalanced input supply are calculated and are used to counter-unbalance the PWM gating signals of the converter switches to cancel the generated abnormal harmonics. This method is suitable for high power GTO type PWM ac to dc converters. Rioual, et al [2] propose a cascade regulation of PWM rectifier, in the park frame, the system is distributed with unbalanced voltage; this regulation is calculated with a positive sequence network voltage as well as a negative sequence network voltage separately and obtained positive and negative sequence current commands for a constant dc link voltage and average reactive power. Kim et al [3] propose a PWM converter where decomposition of symmetrical components of input voltage is needed. The negative sequence current component is commanded to be zero. It can be observed that negative sequence is transformed into the second harmonic component on the synchronous reference frame and hence the positive sequence can be detected using band pass filter with center frequency of 120 Hz. Seok and Nam [4] propose a dual converter scheme where two reference frames are used for measuring the positive sequence in the positive SRF by eliminating the negative sequence with the 120 Hz and negative sequence in negative SRF. Separately measured currents are used for two feedback PI controllers called as the dual current controller. One regulates the positive sequence current and the other regulates the negative sequence current thus allowing the control of negative sequence in its own frame ad a dc signal. Giuseppe et al [5] propose two different controllers to deal with unbalanced conditions. The first controller (VCC) is implemented in the positive synchronous reference frame. Active and reactive currents are controlled independently of each other with a high bandwidth. The second controller (VCCF) uses a feed forward approach for the sequence separation. The DC link voltage controller used in this case is the same as that for the VCC. A third controller (DVCC) is considered similar to the one proposed in [4]; however the transient performance of the controller is not analyzed in [4]. Slavomir et al [6-7] propose FEM modeling of the magnetic field in the generator in two dimensions. This model takes in to account magnetic saturation of the stator and the rotor leakage inductances. The large difference from the conventional model is that, during an unsymmetrical fault, the FEM model represents unsymmetrical magnetic saturation better than the conventional analytical models.

In our work, a conventional control scheme based on ref [8] is implemented first in Matlab simulink® and tested for different unbalanced conditions. Predictably, the converter does not function well as will be seen later. Later, a modified control scheme is implemented in the two sequence domains

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and tested during voltage imbalance. The PWM converter under analysis for the above schemes is shown in Fig. 1.

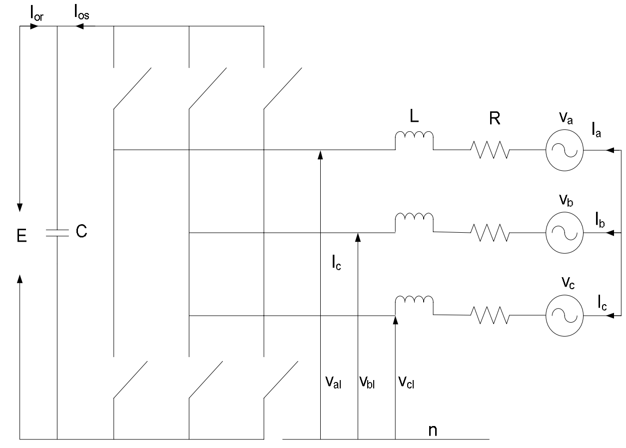

Fig. 1. PWM converter.

II. CONVENTIONAL DECOUPLED CONTROL

A conventional control scheme in the dq reference frame [8] is implemented in Matlab simulink®. The block diagram of the control scheme is shown in Fig. 2.

The simulation is run for two different disturbances - one a three phase fault, shown in Fig. 3, which is a balanced disturbance and the other - a single line to ground fault, shown in Fig. 4, which is an unbalanced disturbance. A detailed performance of the machine during disturbance using DIgSILENT® is discussed in [9].

In the single line to ground fault case, the source voltage has a negative sequence component and hence the conventional control fails to balance the dc link voltage. In the three phase fault case, as the three phases are balanced, there is no negative sequence in the input voltage; hence the disturbance does not affect the conventional control technique.

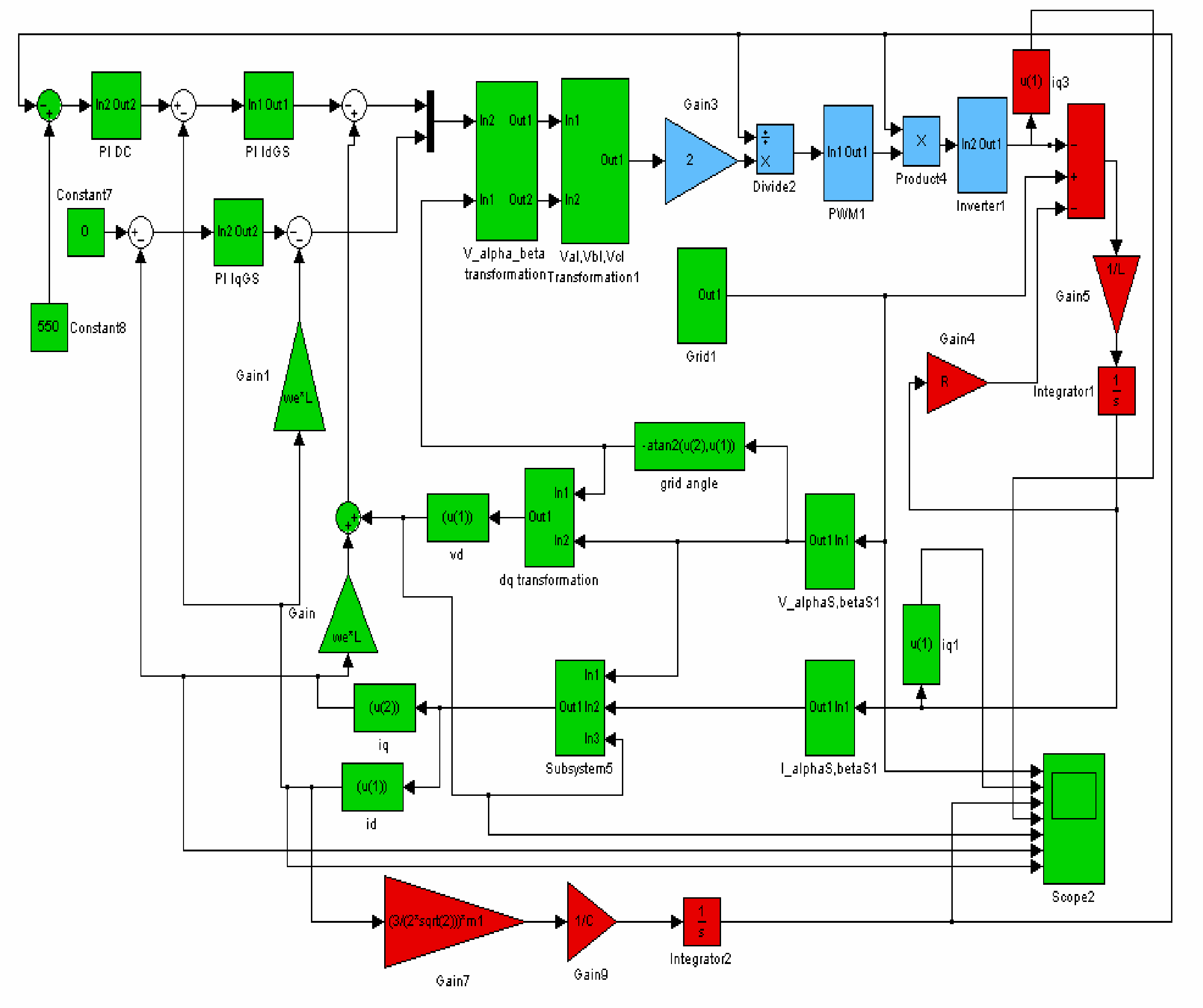

Fig. 2. Block diagram of PWM converter in Matlab simulink®.

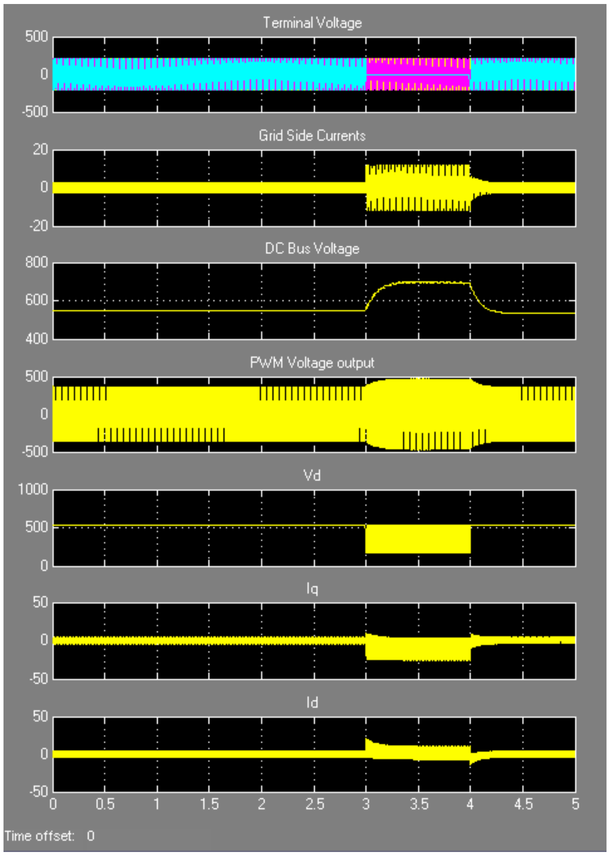

Fig. 3. Simulation of a single line to ground fault.

III. Analysis of Unbalanced Inputs

The case of imbalance in inputs is studied next using the sequence components of the input voltages. The difference in the performance of the system will be shown both in the sequence as well as in the dq domain. The block diagram for the dq and sequence components implementation is shown in Fig. 5.

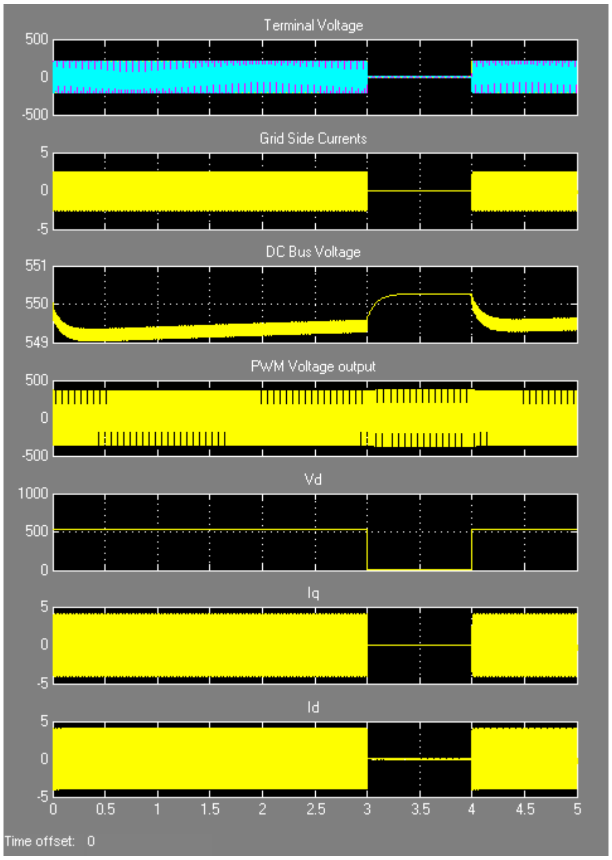

Fig. 4. Simulation of a three phase fault.

In the simulation, a line to ground fault is simulated in a balanced set of voltages after 0.5 sec. the simulation is run for 1 second. The simulation of the sequence components shows that the decoupled control during the imbalance gives rise to a negative sequence component in the output which is twice the source frequency. The simulation results are shown in Fig. 6

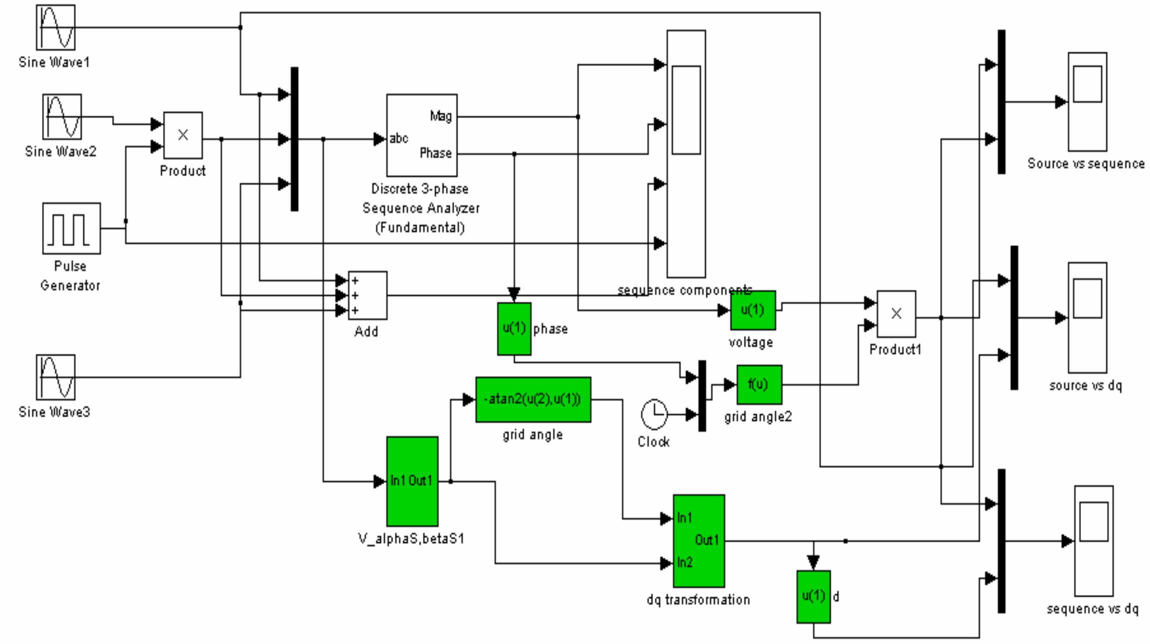

Fig. 5 Block diagram of sequence components and park’s co-ordinates during a voltage imbalance.

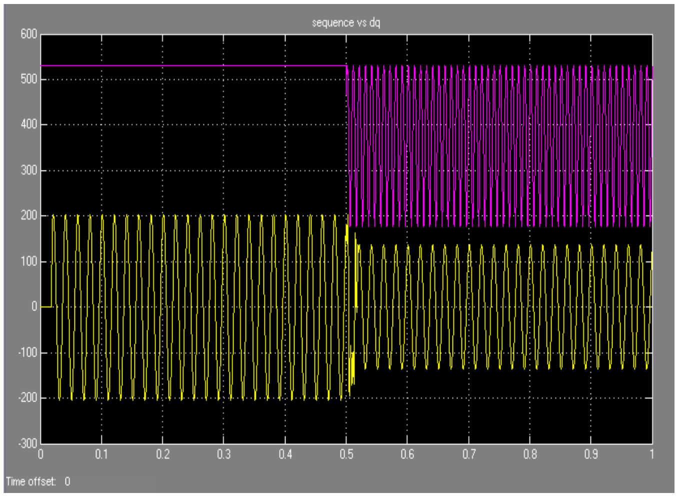

Fig. 6 Sequence components vs. dq components for a voltage disturbance

From the above analysis, the negative sequence component appears as a second harmonic component in the synchronous reference frame. A mathematical derivation of this may be found in [3]. Hence two different reference frames for the positive and negative sequences would decouple the control in respective sequence frames independently. A dual control scheme similar to that reported in ref [4] is simulated. Here, the positive sequence is simulated in the positive SRF and the negative sequence is simulated in the negative SRF. A second order notch filter of 120 Hz frequency is used to separate the components from the real values In the analysis, the negative sequence d-q components are commanded to zero whereas the positive sequence components are commanded according to the dc link voltage and the reactive power requirement. The block diagram for the controller in the sequence domain is shown in Fig. 7.

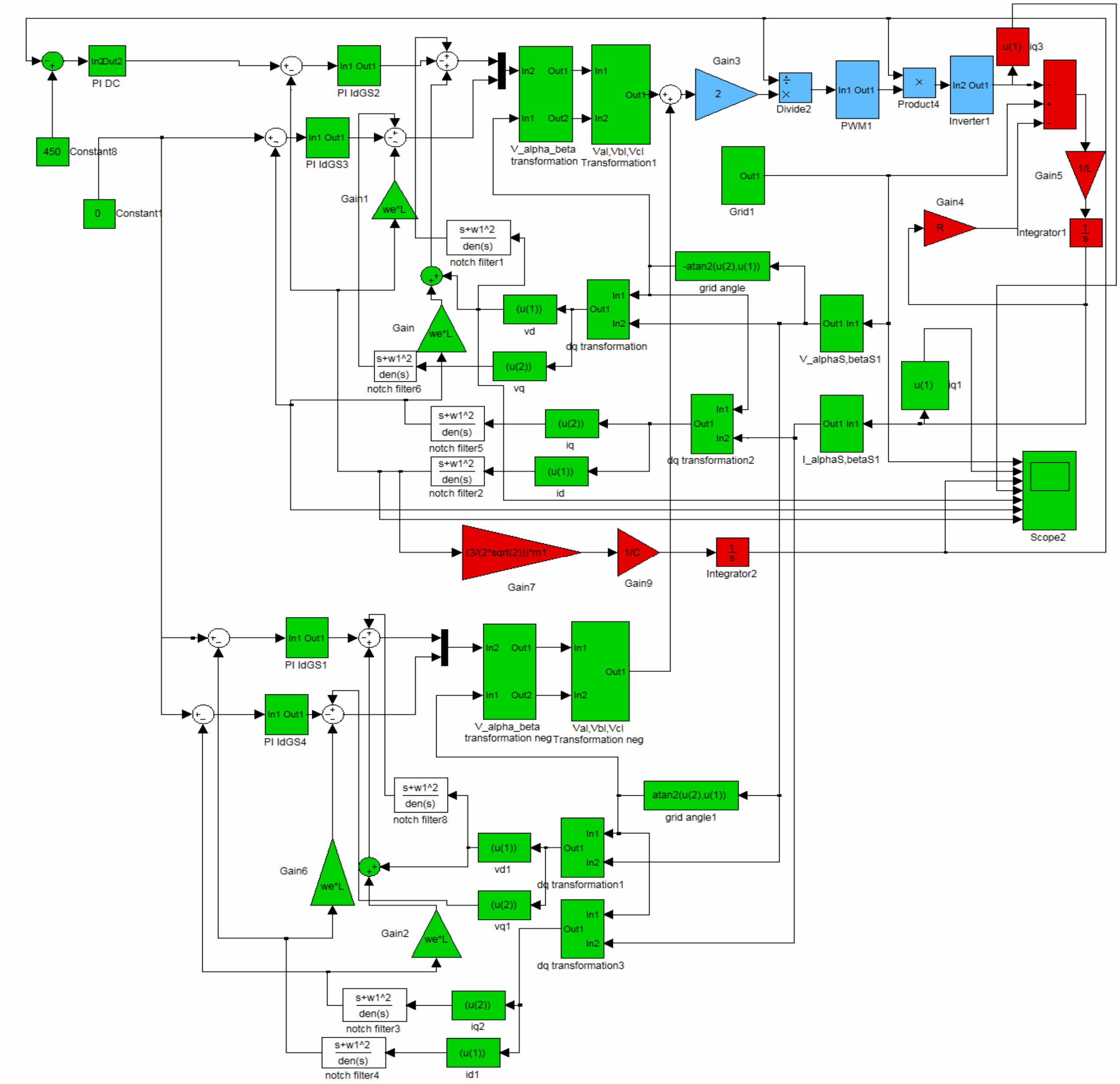

Fig. 7 Block diagram of VSC controller using different controllers in positive and negative reference frames.

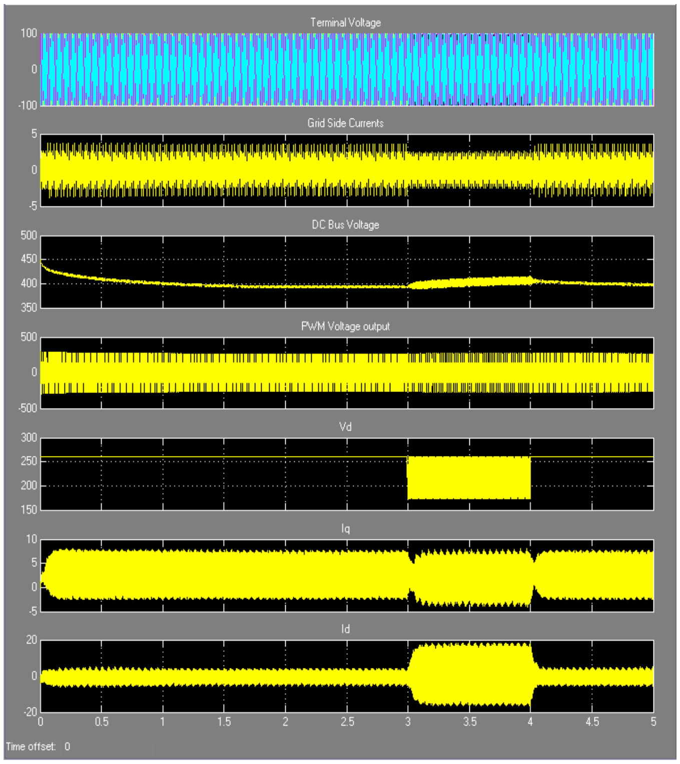

Fig. 8 Simulation results of the controller for a single line to ground fault.

Fig. 8 shows the simulation results of the sequence controllers. The fault on the system is applied between 3 and 4 seconds. It can be observed from the results that the dc link voltage due to the sequence controllers is stabilized compared to the conventional controllers. There is a little oscillation of the voltage during the fault and shows a significant improvement over the conventional controller.

This VSC will ultimately be used for control of doubly fed induction generators applied in wind turbines. Hence the dynamics of the dc link voltage would mainly depend on the stator side converter [8]. However, the rotor side converter can affect the dc link voltage as well if there are severe wind speed variations. Hence, just a control of the dc link may not be adequate to counter the affects of the stator and the turbine-side disturbances. Hence a storage device may become necessary at the dc link that would make the system more robust under a wide variety of system imbalances. The method of sequence control shown in the paper would need to be modified so that four controllers – P and Q control in both sequences could be used. This combination of sequence-based control and a storage element could help the DFIG ride-through low voltage conditions, thus allowing the wind turbines to maintain continuous operation even under intermittent or temporary faults.

IV. CONCLUSION

This poor performance of a conventional control under voltage imbalance is demonstrated here. A controller in the sequence domain is proposed to rectify this problem. The controller stabilizes the dc link voltage to a great extent. Application of a VSC to a DFIG for wind power application demands a stiff dc link voltage to ride-through temporary faults. The sequence controller is capable of providing this flexibility. A storage element along with the sequence control is suggested for further modification. A DFIG equipped with the modified VSC control can easily be adopted for low voltage ride through applications.

V. REFERENCES

[1] P.N.Enjeti, S.A. Choudhury, "A new control strategy to improve the performance of a PWM AC to DC converter under unbalanced operating conditions," *IEEE Trans. Power Electron*., vol. 8, no. 4, pp. 493-500 , Oct. 1993.

[2] P. Rioual, H. Pouliquen and J.P.Louis, "Regulation of a PWM rectifier in the unbalanced network state using a generalized model," *IEEE Trans. Power Electron*. vol. 8, no. 3, pp. 495-502, May 1996.

[3] H.S. Kim, H.S. Mok, G.H. Choe, D.S. Hyun and S.Y. Choe, "Design of current for 3-phase PWM converter with unbalanced input voltage," in *Proc. IEEE 29th Ann. Power Electron. Specialists Conf. (PESC'98)*, vol. 1, pp. 503-509.

[4] H. S. Song and K. Nam, "Dual current control scheme for PWM converter under unbalanced input voltage conditions," *IEEE Trans. Ind. Electron*., vol. 46, no. 5, pp. 953-959, Oct. 1999.

[5] G. Saccomando, J. Svensson and A. Sannino, "Improving voltage disturbance rejection for variable-speed wind turbines," *IEEE Trans. Energy Conversion*, vol. 17, no. 3, pp. 422-428, Sept. 2002.

[6] S. Seman, J. Niiranen and A. Arkkio, "Ride-through analysis of doubly fed induction wind-power generator under unsymmetrical network disturbance," *IEEE Trans. Power Syst*., vol. 21, no. 4, pp. 1782-1789, Nov. 2006.

[7] S. Seman, J. Niiranen, A. Arkkio, S. Kanerva and J. Saitz, "Performance of a doubly fed induction generator under network disturbances," *IEEE Trans. Energy Conversion*, vol. 21, no. 4, pp. 883-890, Dec. 2006.

[8] R. Pena, J.C. Clare and G.M. Asher, "Doubly fed induction generator using back-to-back PWM converters and its application to variable-speed wind-energy generation," *IEE Proc. Elect. Power Appl*., vol. 143, no. 3, pp. 231-241, May 1996.

[9] M.M. Baggu and B.H. Chowdhury, "Performance of doubly fed-induction machine wind-generators during grid and wind disturbance," *in Proc. of the38th NAPS,* Carbondale, Illinois, pp. 51-57, Sept. 2006.

VI. BIOGRAPHIES

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