

Alternative Control Strategy Approach of Generator Side Two-level Voltage Source Converter Using Plecs toolbox on Matlab/Simulink

Molla Biweta, Dr. Mengesha Mamo

Abstract— This paper presents an alternative closed-loop control strategy approach of generator side two-level voltage source converter to regulate the dc link voltage. Both rotor speed of the Permanent Magnet Synchronous Generator (PMSG) side and the DC-link voltage of load side are controlled by a PI controller. Modeling and simulation of the control structure has been carried out using PLECS software on Matlab/Simulink environment. PLECS is a software package for modeling and simulating dynamic systems. It is preferable for high-speed simulations of circuit-oriented electric and electronic systems. The validity and performance of the proposed control scheme has been verified by simulation results and is in agreement with what is expected. The simulation results demonstrate that the controller is capable of maintaining constant dc-link voltage under dynamic and steady-state performance of the system.

Keywords — DC-link voltage, Matlab/Simulink, Modeling and Simulation, Permanent Magnet Synchronous Generator (PMSG), PLECS software, Voltage Source Converter (VSC)

1 INTRODUCTION

Recently, renewable energy systems are undergoing an important development and booming all over the world. Among them wind energy stands out for its installed capacity, power generation and steady growth. In particular, Permanent magnet synchronous generator based variable speed wind energy conversion systems (WECS) integrated with power electronic interfaces is becoming popular due to its capability of extracting optimal energy capture [1].

In connection to renewable energy systems, power generation and distribution characteristics of a given nature have to be adapted to electrical load characteristics of different nature. This requires some form of energy flow controlling between source and load, and introduces the concept of the processing of power in its electrical form. In the modern technology, the electronic processing of power is the alternative that offers the benefits of low losses, long equipment life, low maintenance and maximum adaptability and controllability [3]. These lead to the concern of power electronics with converters operating in the switching mode, with the associated problems of devices having two stable states (conducting and non-conducting). Moreover, converters have to switch stably at low loss from one state to the other as well as with the associated problems of control by devices and subsystems.

The generator side three-phase converter keeps the DC-link

voltage constant, feeds generated energy into the load and adjusts the amount of the active and reactive powers delivered to the load [5]. The generator side three phase converter, which uses a vector control strategy, works as a driver controlling the generator operating at optimum rotor speed to obtain maximum energy from the source. Both rotor speed of the machine side and the DC-link voltage of load side are controlled by a PI controller.

In this paper, investigation and simulation of two-level voltage source converter has been carried out using PLECS software on Matlab/Simulink. PLECS is a software package for modeling and simulating dynamic systems. It is preferable for high-speed simulations of circuit-oriented electric and electronic systems. In this case, graphic modeling (block diagram) method that is commonly used in control engineering has been implemented due to the fact that block diagrams are very convenient to model control structures where it is clear what the input and output of a block should be.

The blocks are interconnected with directed lines to form a larger system. The direction of the connections determines the order in which the equations of the individual blocks must be evaluated.

2 SYSTEM CONFIGURATION AND TOPOLOGY

The system configuration under investigation is shown in Fig1. The main electrical circuit model consists of a three-phase voltage source with line inductance and resistance is connected to the AC-side of a 2-level IGBT converter. The DC-side of the converter is connected to a load, modeled as an ideal current source, via a DC-link capacitor.

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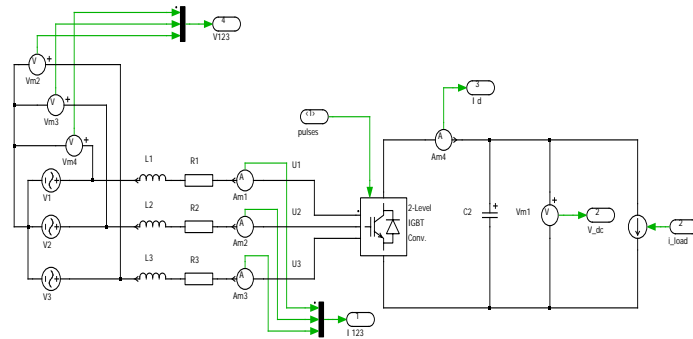


Fig.1 System configuration with generator side converter

Two-level three-phase voltage source converter (VSC) is the most commonly used topology in today's motor drives and other loads. In case of single switching per cycle, six-step modulations, the control of the circuit is accomplished by varying the turn on time of the upper and lower switches of each inverter leg, with the provision of never turning on both switches at the same time, to avoid a short circuit of the DC bus [10].

In a classical two-level low power frequency converter increasing the switching frequency and modifying the modulation techniques have been executed for a smoother output voltage [7]. Fig.2 shows the topology of two-level voltage source converter (VSC), in which the block implements a three phase, two level IGBT converter. The gate input is a vector of three signals-one per phase. The upper IGBT is turned on with a positive, the lower with a negative gate signal.

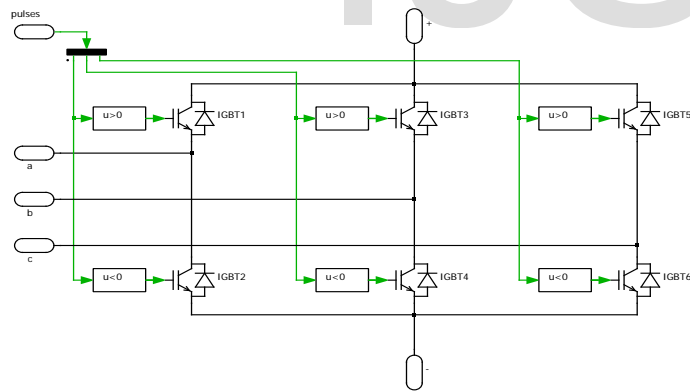


Fig.2 Topology of two-level VSC [Plecs V-3.7.5]

In the case of the high power applications the switching frequency cannot be increased, because of higher switching losses and electronic limitation of the power switches (turn on and off times are bigger with high voltage switches than with low voltage switches). One solution for this problem is a multi-level frequency converter. In the multilevel converters the voltage rating of power switches can be lower than in two-level converters. Lower voltage rating of switches, decrease the switching losses and diminish the electronic limitation of the high voltage switches [9].

3 CONTROL STRUCTURE AND STRATEGY OF THE GENERATOR-SIDE PWM CONVERTER

The structure of generator side control system for the power converter is shown in fig.3. The generator-side converter is mainly used to keep the DC-link voltage constant regardless of the magnitude of the machine power. A vector-control approach is used with a reference frame oriented along the supply voltage vector position, enabling independent control of the active and reactive power flowing to the supply. The PWM converter is current regulated, with the d-axis current used to regulate the DC-link voltage and the q-axis current component used to regulate the reactive power.

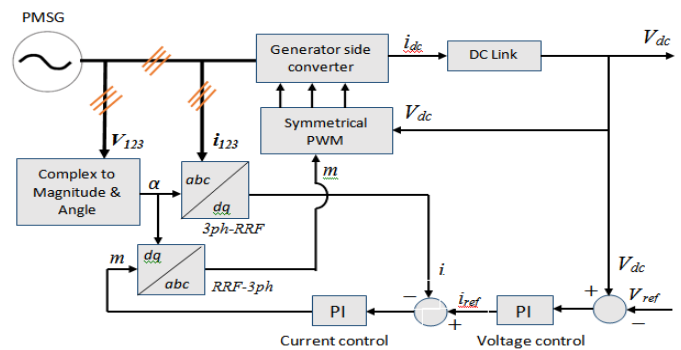


Fig.3 Schematic diagram of the control structure

The converter is controlled with an outer voltage control loop and an inner current control loop. The DC-link voltage is measured and compared against a voltage set point. The error signal is converted to a d-axis current set point via a PI regulator. The circuit is controlled to achieve unity power factor by setting the q-axis current set point to zero. The dq-current set points are then fed to a current controller.

The three-phase currents are measured and transformed to the dq-axis. A PI regulator with a feed forward term is used to convert the current error signal into a corresponding modulation signal. The modulation signal is scaled with the DC-link voltage and fed into a PWM modulator to generate the gate signals for the IGBT converter. In order to get the generator rotor position angle α from measured 3-phase terminal voltage, a subsystem (Fig. 4) has been used to realize the transformation from complex to magnitude and angle.

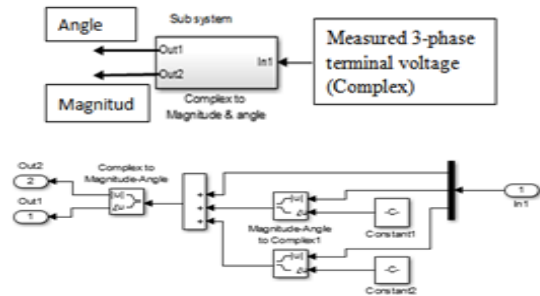


Fig.4 Subsystem to transform complex to magnitude and angle
 The three input parameters of the adder function block

(fig.4) constitute two constants (C1 and C2) to fix the phase shift of supply voltage wave form by 120°. Their values are given as follows:

$$\begin{cases} C_1 = 120^0 \times \frac{2 \times \pi}{360^0} \\ C_2 = 240^0 \times \frac{2 \times \pi}{360^0} \end{cases} \quad (1)$$

4 MODELING AND SIMULATION

Based on system configuration fig.1, the dynamic equation of the converter in the reference frame rotating synchronously with the source voltage space vector is:

$$\begin{cases} L \frac{di_d}{dt} = V_d - U_d - Ri_d + \omega Li_q \\ L \frac{di_q}{dt} = V_q - U_q - Ri_q - \omega Li_d \\ C \frac{dV_{dc}}{dt} = \frac{V_d}{V_{dc}} i_d + \frac{V_q}{V_{dc}} i_q - i_{load} \end{cases} \quad (2)$$

Where, V_d and V_q are active and reactive source voltage in the synchronous rotating frame respectively; U_d and U_q are active and reactive input voltage in the synchronous rotating frame respectively; i_d and i_q are active and reactive current respectively; L and R are the generator side inductance and resistance respectively, C the DC-link capacitor and ω is the generator speed in the synchronous rotating frame.

If the reference frame is oriented along the supply voltage, the d-axis voltage vector is equal to supply voltage, i.e. $U_d = V_d$ and $U_q = 0$. Then active and reactive power can be expressed as [12].

$$\begin{cases} P = \frac{3}{2} U_d i_d \\ Q = \frac{3}{2} U_d i_q \end{cases} \quad (3)$$

From (3), it is seen that active and reactive power control can be achieved by controlling direct and quadrature current components respectively. The controller is divided in a line-current controller and a dc-link voltage controller operating in cascade. The controller is a PI-controller that operates on vectors in (d, q) space. The outlined closed-loop control system (Fig.3) can be described with the following differential equation systems:

$$\begin{cases} \frac{dI_u}{dt} = \frac{K_{pu}}{T_{iu}} (V_{ref} - V_{dc}) \\ \frac{dI_i}{dt} = \frac{K_{pi}}{T_{ii}} (I_{ref} - i_{dc}) \end{cases} \quad (4)$$

Where I_u and I_i is the integral part of the PI controllers; K_{pu} and T_{iu} is the proportional gain and integral time of the dc-link voltage controller; K_{pi} and T_{ii} is the proportional gain and integral time of the current controller.

Modeling of nonlinear and time variant circuit components with PLECS software in the Matlab\Simulink environment can be realized directly by applying graphic modeling method. However the nonlinear electrical and electronic circuit component parameters should be defined as an element of the Simulink input vector allowing the component value to be dynamically defined by any Simulink block. Component parameters can be interactively changed during the simulation

by changing the value of the S-function parameter vector in the Simulink model. From the schematic diagram of the electrical circuit, PLECS automatically generates mdl-file which would be used as an S-function in Simulink model. It is possible to place, resize, drag and connect components rapidly. Accordingly, PLECS allows creating the desired complex electric/electronic circuit by using the sub-circuit components to assemble several basic components and other sub-circuits. The masking feature enables us to hide the contents of the new sub-circuit behind a customized interface and simplify entering parameters of the sub-circuit.

Fig. 5 shows the Simulink model used to validate the performance of the presented control scheme, the closed loop control system for a generator-side two-level voltage source converter. The model is developed using components from the PLECS tool box. This is a particularly useful add-on to Simulink that provides models for a wide range of power electronic devices and control structures. In addition to PLECS circuit other sub systems (blocks) used in the modeling are taken from the standard Simulink library.

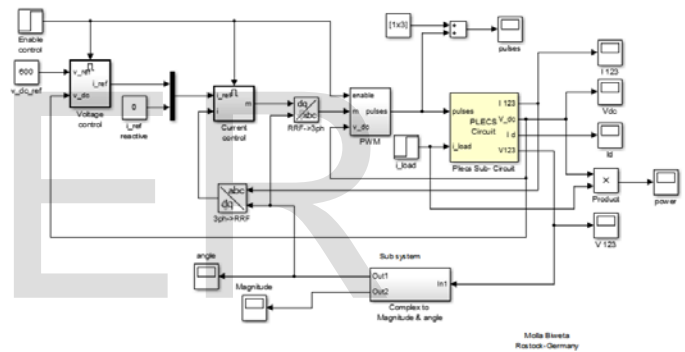


Fig.5 Simulink model for closed loop control system

TABLE 1
SYSTEM PARAMETERS

Parameter	Value
Source Voltage	325 V
Source frequency	50 Hz
Line inductors	10mH
Line resistance	0.25Ω
DC link capacitor	10mF
Nominal power	5kW

The system parameters given in table 1 and controller parameters in table 2 were used to define component parameters through the mask interface of each Simulink block model. These parameters can be interactively changed during the simulation in order to optimize the expected output signals from block models.

TABLE 2
CONTROLLER PARAMETERS

Parameter	Value
DC link voltage	600V
Load current	8.3A
Proportional gain, K_{pu}	0.2
Proportional gain, K_{pi}	10
Integral term, I_u	20
Integral term, I_i	1000
Switching frequency	1 kHz

5 RESULTS AND DISCUSSION

Fig. 6-9 shows the simulation results obtained under the parameters and conditions given in Table 1 and 2. Initially all the controls are disabled and the 2-level IGBT converter acts as a passive rectifier. The rectified three-phase voltage charges the DC-link capacitor to the rectified three-phase voltage. When the controls are enabled, after 50ms, the DC-link capacitor is actively controlled to 600 V_{dc} set-point at a time of 500ms.

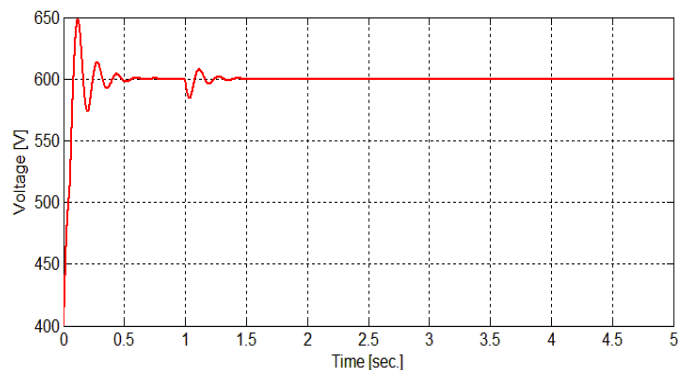


Fig.7 DC link voltage regulation

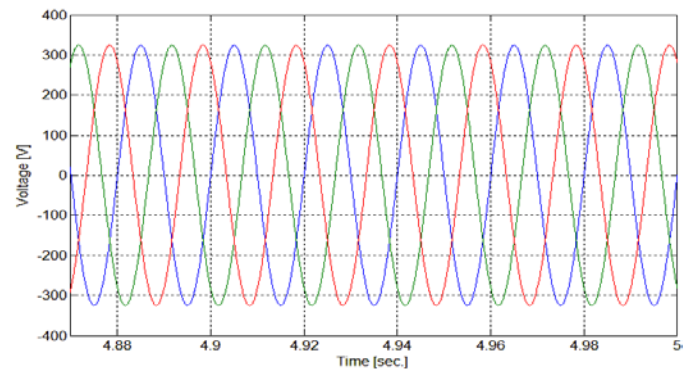
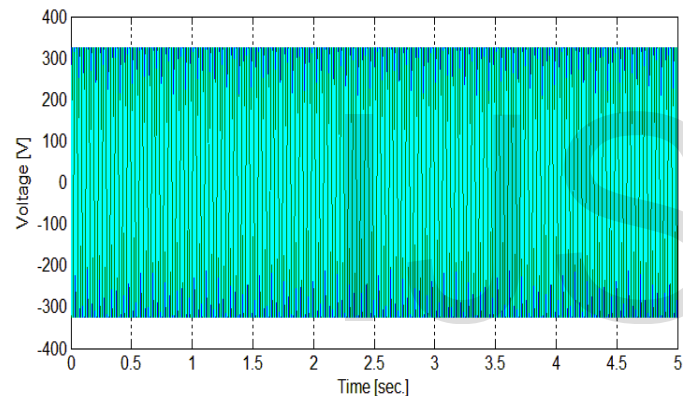


Fig.6 Generator terminal 3-phase voltage

Fig.6 shows the input, 3-phase generator terminal voltage given by full simulation time (the upper) and the later with limited simulation time so as to expand the scope signals for better observation.

As shown in fig.7, at a time of 1second the load is stepped into the circuit and starts drawing 8.3A. This causes a sag in the DC-link voltage as the capacitor is discharged by the load.

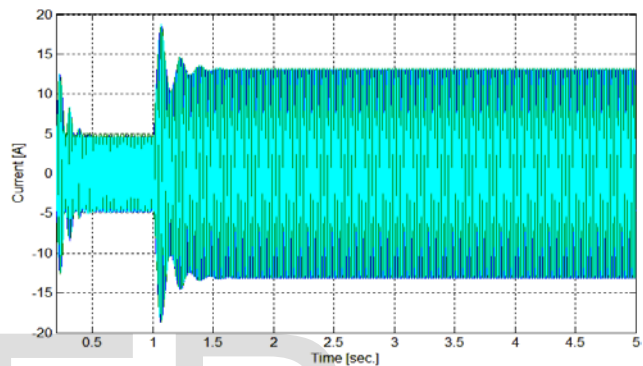


Fig.8 Generator side 3-phase current response

As the capacitor voltage sags, the voltage error increases and the voltage controller adjusts the current set point to draw additional current from the source (fig.8) in order to increase the DC-link voltage back to the desired level. This voltage sag and current overshoot is no more observed throughout the simulation as the load constantly draws power from the system.

Fig.9 shows the delivered power (5kW) after the load steps to the system at a time of 1 sec.

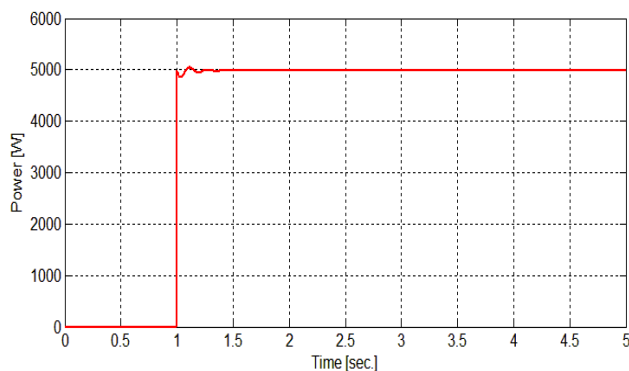


Fig.9 Power delivered to the load

6 CONCLUSION

In this paper an alternative closed loop control strategy of

generator side two-level VSC has been realized to control the DC link voltage. The DC link voltage control is regulated according to the balance of power exchanged by the converter. Accordingly, the dc link voltage exhibits considerable voltage ripple and rather serious in the input line currents when the control system is not activated. As soon as the controller is activated, the dc link voltage ripples drops and stabilized to the set value. The simulation results demonstrate that the controller works very well and shows very good dynamic and steady-state performance.

Plecs software tool box were used to model and simulate the control system which offers many advanced features which enable us to model and simulate complex power electronics including control systems conveniently. Moreover, circuit partitioning and decoupling is a powerful feature which enable us to reduce large power electronics system in to a number of sub systems which can be modeled as separate S-functions to facilitate accurate and fast simulation.

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