Indian Journal of Electronics and Electrical Engineering (IJEEE)
Vol.2.No.1 2014pp 26-32.
available at: www.goniv.com
Paper Received :05-03-2014
Paper Published:28-03-2014
Paper Reviewed by: 1. John Arhter 2. Hendry Goyal
Editor : Prof. P.Muthukumar

DESIGN AND IMPLEMENTATION OF PMSG CONVERSION SYSTEM USING STATCOM MODEL

K.MadhuBala. D.Saravanan
ShriAndalAlagar College Of Engineering,
madhu2ece@gmail.com

ABSTRACT

Power quality is one of the major concerns in the present era. It has become one important, especially, with the introduction of sophisticated devices whose performance is very sensitive to the quality of the power supply. Recent progress as regards technology of the power electronics brings a capacity of reactive power compensation and voltage quality is improved then the voltage sag is completely eliminated by the STATCOM This is composed of a hybrid control scheme for *EnergyStorage System (ESS) and Braking Choppers (BC)* for fault - ride through capability and a suppression of the output power fluctuation and the elimination of voltage sag is proposed for*Permanent- Magnet Synchronous Generator (PMSG*) wind turbine systems. During grid faults, the dc -link voltage is controlled by the ESS instead of the *Line- SideConverter(LSC)*,where as*the LSC is exploited as a STATCOM* to inject reactive current into the grid for assisting in the grid voltage recovery. *Interleaved boost converter DC-DC Boost converter* is used to improve the voltage quality.The validity of the proposed system is verified by experimental results for a reduced-scale wind turbine simulator as well as simulation results for a 2-MW PMSG wind turbine system.

Index Terms—Braking chopper (BC), dc-link voltage control,energy storage system (ESS), permanent-magnet synchronousgenerator (PMSG), ride-through, STATCOM, wind turbine,Interleaved boost converter DC-DC Boost.

1. INTRODUCTION

A.*Overview*

Power quality plays an important role in present day.The voltage sag and reactive power compensation produced by the non linear loads have become major problems in many countries. As **WINDPOWER** penetration has increased, the power quality from wind generation has been paid much attention. One of the serious issues for the operation of wind turbine systems is **Low-Voltage Ride-Through (LVRT) capability**, through which the wind turbines are expected to comply with the requirements of grid codes. With this,wind turbine systems are required to stay connected to the grid during grid faults with consideration of the voltage drop level and voltage-time profile. As an example, the Spanish grid code for an **LVRT** requirement.

In addition, the amount of the reactive current required to support the grid during the voltage sag and restoration periods. One concern of wind turbine operation in the steady state is the output power fluctuation. The fluctuation may incur an imbalance between the supply and demand of power. The grid frequency may deviate from its rated value. Hence, it is essential to mitigate the output power fluctuation of the wind turbine systems.

B. *Objective*

To Simulate Analysis and Control of Reactive power with STATCOM model and line model with voltage sag in controlled PMSG system. The improvement of power quality is done by using MATLAB and Implement it using PIC16F844A.

C. Statcom Model

The STATCOM is a shunt connected reactive – power compensation device that is capable of generating and absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system. It is in general a solid state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed from an energy source or energy storage device at itsinput terminals .

A STATCOM can improve power system performance in such areas such as:

- The dynamic voltage control in transmission and Distribution.
- The power- oscillation damping in power transmissionSystem
- The transient stability.
- The voltage flicker control.
- The control of not only reactive power but also activePower inthe connectedline requiring a dc source

D. *PICMicrocontroller*

The advantages of the PIC- microcontroller "PIC 16F844A" is that the instruction set of this controller are fewer than the usual microcontroller. Unlike Conventional processors, which are generally complex, instruction set computer (CISC) type, PIC microcontroller is a RISC processor. The advantages of RISC processor against CISC processor are: RISC instructions are simpler and consequently operate faster. A RISC processor takes a single cycle for each instruction, while CISC processor requires multiple clocks per instruction (typically, at least three cycles of throughput execution time for the simplest instruction and 12 to 24 clock cycles for more complex instruction), which makes decoding a tough task .The control unit in a CISC is always implemented by a micro-code, which is much slower than the hardware implemented in RISC

E. *Direct driven PMSG wind turbine system*

Several techniques are used to convert the wind energy. The most popular and largely used is based on the Induction Generator(IG) this system is relatively simple and don't scope with relatively newgrid codes. However Doubly Fed Induction Generator (DFIG) is more complicated and offer more advantages for the exchange of the active and reactive power with the grid and the fulfillment of the grid codes. Permanent magnet machines are today rated up to the power of 6 MW. They are more efficient when compared to other conventional machines and simpler because of exciter is needed. In order to convert wind energy to the grid many technologies of converters are investigated the simplest is the small size permanent magnet generators associated with diode rectifiers[2].Many types of inverters can be used in variable speed wind turbine generator system. They can be characterized as network commutated or self commutated. Self commutated inverters are either current source or voltage source inverters.The rated power is considered in the range of 100KW to 1MW.

2. SYSTEM CONFIGURATION

The configuration of a direct-driven PMSG wind turbine system. The energy storage system (ESS) consists of an EDLC [1] and a bidirectional dc-dc converter, which is connected at the dc-link of the back-to-back converters. ABC is connected in parallel with the dc-link. The BC will be activated to dissipate the excessive power beyond the capacity of the ESS in cases of deep voltage sags or high wind speed variations.In normal conditions, the LSC controls the dc-link voltage of the back-to-back converters, and the ESS is able to smoothen the power ripples. In grid fault conditions, on the other hand, the LSC functions as a STATCOM, and the ESS controls the dc-link voltage.

A. ***PMSG Wind Turbine Systems Using STATCOM Model***

This chapter deals with the operation principle of Advanced Fault Ride-Through Technique for PMSG Wind Turbine Systems Using Line-Side Converter as STATCOM[19] is proposed for a hybrid control scheme for energy storage systems (ESS) and braking choppers for fault ride-through capability and a suppression of the output power fluctuation is proposed for permanent-magnet synchronous generator (PMSG) wind turbine systems. During grid faults, the dc-link voltage is controlled by the ESS instead of the line-side converter (LSC), whereas the LSC is exploited as a STATCOM to inject reactive current into the grid for assisting in the grid voltage recovery.

B. ***PMSG wind turbine system with the ESS and the BC***

In ESS or flywheel systems are required to mitigate the output power fluctuation. Using the external devices increases the cost of the whole system. With the ESS added to wind generation systems, not only the power smoothening but also fault ride- through (FRT) can be achieved effectively. However, the cost of the ESS is too high to solve this problem practically. One of the simplest methods for an LVRT [19] is to apply a braking chopper (BC). However, it is impossible to improve the output power quality of the wind turbine systems since the BC just dissipates the power and cannot return it to the grid.

Another method using a hybrid system of the ESS and the BC has been presented, where the ESS consisting of electric double-layer capacitors (EDLC) and the BC are connected to the dc-link side of the back-to-back converters in a permanent magnet synchronous generator (PMSG) wind turbine system. This scheme cannot only offer ride-through capability but also suppress the output power fluctuation of the wind turbine systems with relatively low cost. In this method, the ESS is used to control the power which is absorbed from the system or released to the grid for both normal and fault conditions. Meanwhile, the line-side converter (LSC) is used to control the dc-link voltage under both normal conditions and grid sags. However, with deep unbalanced voltage sags, excessively high grid current references, which depend on the grid voltages, are required to control the dc-link voltage.

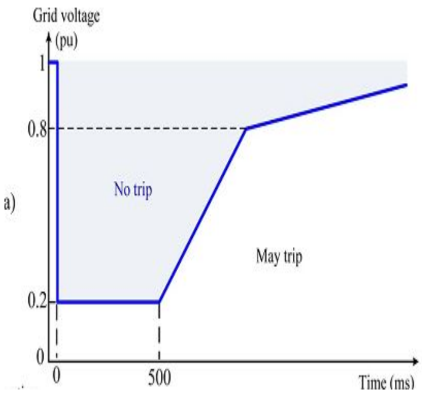


Figure.1 Spanish grid codes Low voltage ride through requirement

Hence, the amount of the reactive power provided to the grid by the LSC does not satisfy the grid code requirements due to a limited current capability of the LSC. Another control scheme for LVRT compliance of the wind power systems in grid voltage disturbances was presented in which the dc-link voltage was controlled by the generator-side converter (GSC), and the power mismatched between the turbine and grid sides are stored in the system inertia by increasing the generator speed. However, the amount of energy stored in the turbine inertia is not so large, particularly when the generator operates near the rated speed before gridsag.

Thus, the additional device such as a BC or an ESS is required to absorb the surplus power. In this project, an FRT technique of the PMSG wind turbine system is proposed during the grid fault. By switching the control mode, the ESS is operated to control the dc-link voltageofthe back-to-back converters during the grid voltage sag.Mean while, the LSC is utilized to supply the reactive current to the grid for satisfying the reactive current requirements of the grid code. By this, the grid voltage can be recovered rapidly without an external STATCOM after fault clearance. Also, the generator active power can be absorbed fully by the ESS and the BC during the voltage sags.

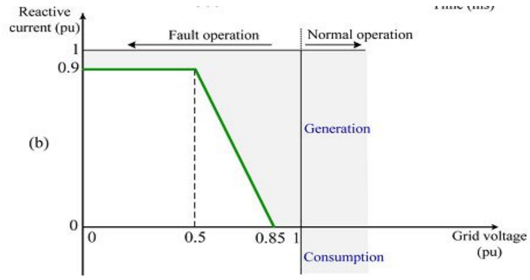


Figure.2Reactive current requirements.

In addition, the output power fluctuation of wind turbine systems operating in steady state is smoothened by the ESS. With this control scheme, the system can still operate well even though the grid voltage is fully interrupted. The validity of the proposed control algorithm is verified by simulation and experimentalresults.

2. CONTROLOF BACK-TO-BACK CONVERTERS

A.*Control of LSC*

The LSC controls the dc-link voltage, *V*dc, to be constant under normal conditions. Cascaded control structure with an inner current control loop and the outer dc-link voltage control loop is applied. During grid voltage sags, however, the dc-link voltage is controlled by the ESS.

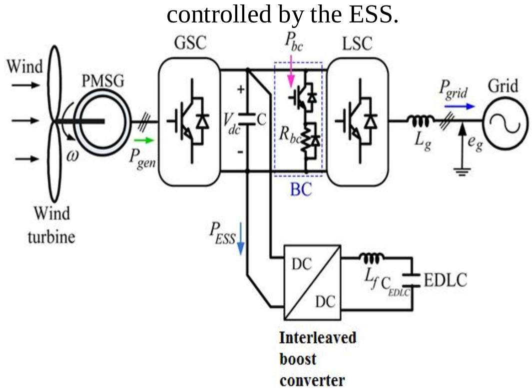


Figure.3Configuration of PMSG wind turbine system with the ESS and the BC.

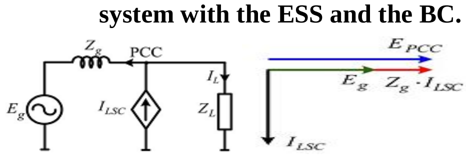


Figure.4 Operation of the line-side converter Single-phase equivalent circuit&Phasor diagram of the LSC operating as an STATCOM.

For this, the control strategy of the LSC is a voltage-controlled current source[3], in which the LSC is operated as a current source.Fig.4 shows a single-phase equivalent circuit of the LSC, and Fig. 4shows a phasor diagram of the LSC operating as a STATCOM. Assuming the grid impedance (*Zg*) as purely inductive and the load impedance as *Z*= ∞, the voltage of the point of common coupling (PCC), E_{PCC}, is expressed as

$E_{PCC} = E_{g} + Z_{g} I_{LSC}$............(1)

Where I_{LSC} is the current compensated by the LSC, in which the maximum compensation current depends on the capacity of the LSC. For the full-scale back-to-back converters, the LSC can inject reactive current up to 1 p. u. With this current, the grid voltage can be recovered within 0.6 s after the fault clearance

In the case of unbalanced grid sags, the dual-current controllers for positive- and negative-sequence components are adopted for the LSC. The control block diagram of the

LSCis shown in Fig. 5 In normal operation, the current references for positive- and negative-sequence current controllers are calculated from the output of the dc-link voltage controller as shown in Fig. 5 During grid sags, dc-link voltage control by the LSC is deactivated, and the LSC injects there active current component. Hence, the reference of the active current component, I_{pq*e}, is set to zero.

$I_{qe}^{p*}=0$…… (2)

$I_{de}^{p*} = 0.9$ p.u if $0 \leq E_{qe}^{p} \leq 0.5$ (p.u)

$I_{de}^{p*} = 2.186 - 2.571.\ E_{qe}^{p}$ if $0.5 \leq E_{qe}^{p} \leq 0.85$ (p.u) ……(3)

$I_{de}^{p*} = 0$, if $E_{qe}^{p} \geq 0.85$ (p.u)

Where I_{p*de} is the *d*-axis current reference of positive-sequence component in p.u., and E_{pqe} is the *q*-axis grid voltage of positive-sequence component.

The ***d q***-axis current references, I_{n*dqe}, of negative-sequence components are set to zero to eliminate the unbalanced current components flowing into the grid, which are expressed as

$I_{qe}^{n*} = 0$ & $I_{de}^{n*} = 0$ ……….. (4)

A proportional-integral (PI) controller is usually used for dc-link voltage control. Hence, an error accumulation in the integral regulator should be considered for fast transition when the dc-link voltage controller is reactivated after fault clearance. The PI controller is implemented in a discrete time domain. The actual dc-link voltage is able to track its reference by ESS control during the sag. Hence, an initial accumulated error, Δ*V*dc _I_ int, of the integral regulator is set to zero as

ΔV_{dc}_I_int = 0 ……… (5)

B. *Control of GSC*

The GSC is used to perform a vector control of PMSG, in which a cascaded control structure with an inner current control loopand an outer speed control loop is employed. In order to obtain the maximum torque at the minimum current, the *d*-axis current reference is set to zero, and then the *q*-axis current is proportional to the active power, which is determined by the speed controller. The control block diagram of the PMSG wind turbine is shown in Fig.5

A maximum power point tracking (MPPT) control method is applied in normal conditions. However, the MPPT control is suspended during grid voltage sags, and the speed reference of the turbine system is set higher than that in the case of pre sag. The speed reference is renewed by multiplying the previous value at the last sampling period by a *k* factor, in which the factor *k* depends on the response of the system (the system inertia constant, *H*[*s*]) and the sampling period of the speed controller (*Ts*−speed). The new generator speed reference *ω* ∗new can be expressed as

$\omega^{*}_{new}(i) = k.\ \omega^{*}_{new}(i)$, i =1, 2, 3,…….., n

$(\omega^{*}_{new}(0) = \omega_{int\_ft}$…….(6)where *ω*init_ft is the initial value of the generator speed at the

instance of grid fault, *i*is*i*th sampling time, and *n* is the number of speed samples during the fault duration Δ*T*, which is calculated by

$n = \Delta T/T_{S\text{-}Speed}$ …........(7)

Then, an increase of the generator speed is expressed as

$\Delta\omega(\%)=\Delta T/H.100$ …….. (8)

From (2.6) and (2.8), the factor *k* is calculated as

$k = \sqrt{\omega^{*}_{new}(n)}/\sqrt{\omega_{init\_ft}} = \sqrt{1 \quad \Delta\omega/100}$……….(9)

From (9), the *k* is obtained as 1.0005 from the parameters of Δ*T* = 0.5 s, *Ts*−speed = 2 ms, and *H* = 4 s

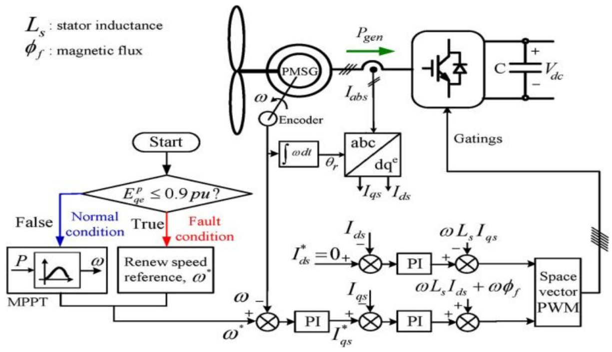


Figure.5 Control block diagram of the PMSG.

By increasing the generator speed, the generator output power delivering to the grid is reduced due to the following reasons. First, the turbine output power is also reduced since the tip-speed ratio is not optimal. Next, some portion of the turbine power can be stored in the system inertia during the increase of the system speed.

4. CONTROL OF ESS AND BC

The ESS and the BC [1] are used to suppress the generator output power fluctuation in normal conditions by absorbing or releasing the pulsated power component from or to the grid, in which the power command, *P*∗ESS, is obtained through a high-pass filter to the generator power. The ESS power is regulated by an outer PI regulator, whereas the EDLC current is controlled by an inner PI regulator.

A.***DC-Link Voltage Control***

During grid sags, the dc-link voltage of the back-to-back converters is controlled by the ESS instead of the LSC. Hence, an outer PI voltage controller is employed, which produces a current reference for an inner PI current controller.shows the overview control block diagram of the ESS and the BC in both normal and grid sag conditions.Neglecting the power losses of the converters and considering the active power negligible flowing into the grid, the dynamic equation of the dc-link voltage is expressed asP_{gen}–P_{BC}− P_{ESS}= 1/2 C dV^2/d ………. (10)

where *C* is the dc-link capacitance, *P* gen is the generator power, *P*BC is the power dissipated by the BC, and *P*ESS is the power of the ESS computed from the ESS voltage, V_{ESS}, and the EDLC current, I_{ESS} ,as

P_{ES}=V_{ESS}. I_{ESS} ………(11)

From (10), in order to keep the dc-link voltage constant, the ESS and the BC should be able to absorb the generator powerfully.

From the control block diagram shown in Fig. 5 the output of the dc-link voltage controller, *I*∗ESS, is given as

I^*_{ESS} = K_{P2} (V^*_{dc} − V_{dc}) K_{I2}/S (V^*_{dc} − V_{dc}) P_{gen} − P_{BC} / V_{ES} ……………..(12)

Where K_{P2} and K_{I2} are PI controller gains of the dc-link voltage control. In Fig. 5.8, I_{ESS} _max represents the maximum current of the ESS. To reduce the total system cost, the rating of the ESS is chosen as 30% of the full power rating of the system.

By expanding a Taylor series of the dc-link voltage at operating point *V*dc0, the following can be obtained:

V^2_{dc} V^2_{dc0} 2 V_{dc0} (V_{dc} − V_{dc0}) …….. (13)

From (5.10) – (5.13), the dc-link voltage equation can be re written in the “s” domain as

$CV_{dc0}sV_{dc}$ − $V_{ESS}K_{P2}$ (V^*_{dc} − V_{dc}) − V_{ESS} K_{I2}/s (V^*_{dc} − V_{dc}) . ….….. (14)

The transfer function of the voltage controller is derived as

$V_{dc}(s)/ V^*_{dc}(s)$ = $V_{ESS}K_{P2}s + V_{ESS}K_{I2}/s^2+2\xi\omega_n s+\omega^2_n$..(15)

Where *ξ* is the damping ratio and *ω*nis the natural frequency.

A. ***EDLC Current Control***

To establish the current control law for the dc/dc converter, a voltage across the inductance, V_{Lf}, is investigated. The dynamic equation of the inductance voltage is expressed as

V_{Lf}= $L_f dI_{ESS}$ /dt = D_{ESS} V_{dc}− V_{ESS} ……… (16)

Where *Lf* is the boost inductance, and D_{ESS} is the duty cycle. As shown in Fig.6 the output of the current controller, *V* ∗*Lf* ,is given as

V^*_{Lf} = K_{PC} (I^*_{ESS} −I_{ESS}) K_{Ic}/s (I^*_{ESS} −I_{ESS}) .... (17)

Where *K p c* and *K I c*are PI controller gains of the current control. In this project, the PI controller gains are chosen as

D_{ESS} = V_{ESS} +V^*_{Lf} /V_{dc}……...(18)

Then, the gating signals for switches S_1 and S_2 are generated by comparing the duty cycle with the carrier wave of 2 kHz

B. ***BC Control***

During the grid disturbance, the ESS may not absorb the full generator power, and then the BC will be activated to dissipate the rest of power, *P*BC as

P_{BC} = P_{gen}− P_{ESS}………. (20)

The BC is controlled by the switch *S*3 shown in Fig. 5.The

duty ratio D_{S3} for the switch depends on P_{BC}, which is expressed as

D_{S3}=R_{bc}/$V^2_{dc}P_{BC}$ ………(21)

Where R_{bc} is the braking resistance.

5. INTERLEAVED DC-DC BOOST CONVERTER

The schematic of the dual interleaved boost dc-dc converter. The interleaved boost dc-dc converter consists of two parallel connected boost converter units, which are controlled by a phase-shifted switching function (interleaved operation). To illustrate interleaving operation, Fig.7 shows the timing diagram of control signals to the switches. Since this converter has two parallel units, the duty cycle for each unit is equal to (Vout-Vin)/Vout, and it is same for each unit due to parallel configuration. A phase shift should be implemented between the timing signals of the first and the second switch.

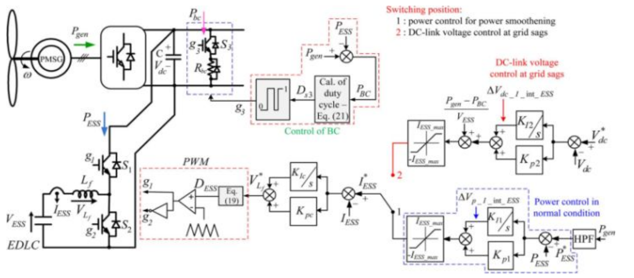


Figure.6 Control block diagram of the ESS and BC

Since there are two units parallel in this converter, the phase shift value is 180 degree. It is used to improve the voltage quality.

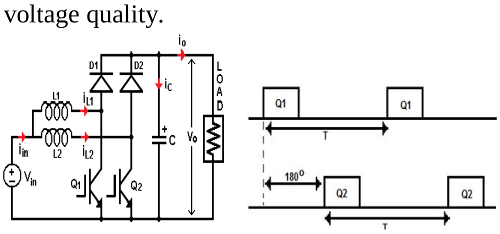


Figure .7 Interleaved Boost DC –DC ConverterTiming Diagram of control signals

6 .HARDWARE AND SOFTWARE

A.*HARDWARE*

- Wind pitch
- PMSG
- Power converters
- InterleavedBoost converters
- Pulse amplifier

B.*SOFTWARE*

- Operating System : Windows7
- Tools : MATLAB7
- Language : C++

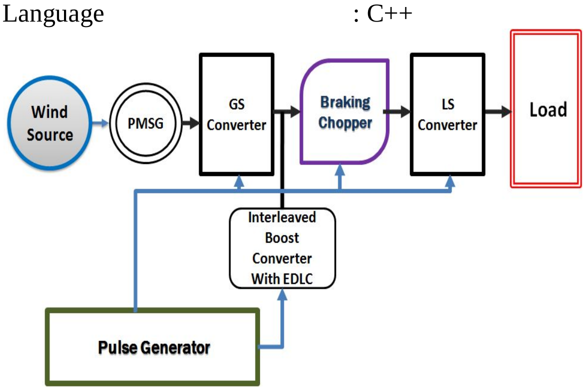


Figure.8 SimulationblockdiagramofSTATCOM Model

7. SIMULATION CIRCUIT AND RESULTS

The simulation circuit of conventional method and proposed system and the waveforms are given below as:

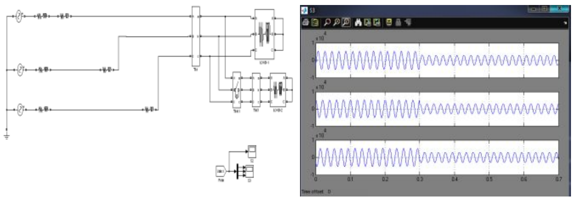


Figure.9simulation circuit without STATCOM Model & Line model with load voltage

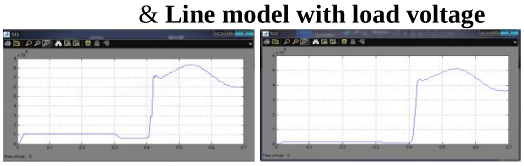


Figure. 10 Real power&Reactive power

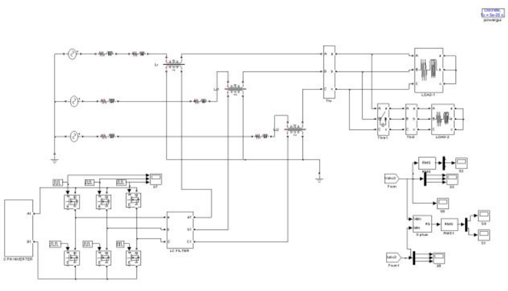


Figure .11 simulationcircuit with STATCOM model

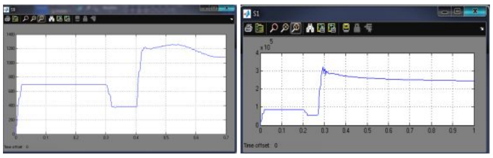


Figure .12 RMS Voltage&Real power

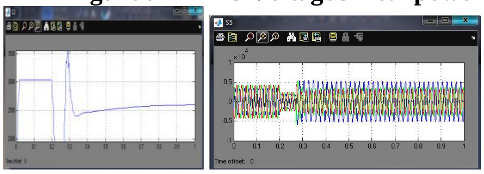


Figure .13 Reactive power&Grid output voltage with STATCOM Model

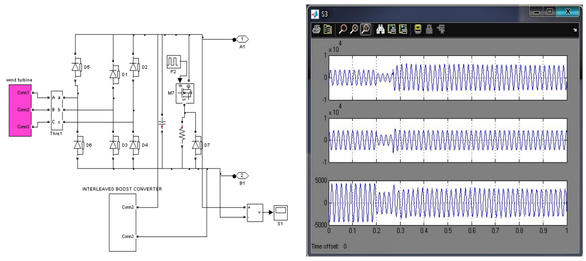
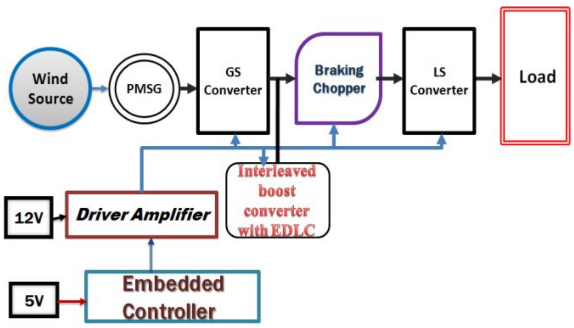


Figure.14 InterleavedboostconverterwithSTATCOMModel & Grid output voltage

8. HARDWARE IMPLEMENTATION DIAGRAM



This project has presented a hardware prototype Advanced Fault Ride-Through Technique for PMSG Wind Turbine Systems Using Line-Side Converter as STATCOM. These are verified with the experimental results.

9. CONCLUSION

This work has presented the procedures for the design and implementation for PMSG Wind Turbine Systems Using Line-Side Converter as STATCOM model. This project has proposed a cost-effective solution which combines the ESS and the BC for the LVRT in PMSG wind turbine systems. Controlling the dc-link voltage by the ESS, the LSC is able to comply with the reactive current requirements of the grid code. By this, the grid voltage can be recovered rapidly without an external STATCOM after fault clearance. Also, the output power fluctuation of the wind turbine system operating in steady state is smoothened by the ESS. This control scheme offers an FRT capability for the wind turbines even though the grid voltage is fully interrupted. The voltage quality is improved .The validity of the proposed control algorithm is verified by simulation and experimental results. The Simulation results coincide with the theoretical results.

REFERENCES

[1] C. Abbey and G. Joos, "Supercapacitor energy storage for wind energyapplications," *IEEE Trans. Ind. Appl.*, vol. 43, no. 3, pp. 769–776,May/Jun. 2007.

[2] W. Li, C. Abbey, and G. Joos, "Control and performance of wind turbinegenerators based on permanent magnet synchronous machines feeding adiode rectifier," in *Proc. IEEE PESC*, Jun. 2006, pp. 1–6.

[3] S. Alepuz, A. Calle, S. B. Monge, J. Bordonau, S. Kouro, and B. Wu,"Control scheme for low voltage ride-through compliance in back-to-back NPC converter based wind power systems," in *Proc. IEEE ISIE*, Jul. 2010,pp. 2357–2362.

[4] R. Cardenas, G. Asher, R. Pena, and J. Clare, "Power smoothingcontrol using sensorless flywheel drive in wind-diesel generationsystem," in *Proc. 28thAnnu. IEEE IECON*, Seville, Spain, 2002,pp. 3303–3308.

[5] J. F. Conroy and R. Watson, "Low-voltage ride-through of a full converterwind turbine with permanent magnet generator," *IET Renew.Power.Gener.*, vol. 1, no. 3, pp. 182–189, Sep. 2007.

[6]R. Data and V. T. Ranganathan, "A method of tracking the peak powerpoints for a variable speed wind energy conversion system," *IEEE Trans.Energy Convers.*, vol. 18, no. 1, pp. 163–168, Mar. 2003.

[7]J. P. Da Costa, H. Pinheiro, T. Degner, and G. Arnold, "Robust controllerfor DFIGs of grid-connected wind turbines," *IEEE Trans. Ind. Electron.*,vol. 58, no. 9, pp. 4023–4038, Sep. 2011.

[8]A. Garces and M. Molinas, "A study of efficiency in a reduced matrixconverter for offshore wind farms," *IEEE Trans. Ind. Electron.*, vol. 59,no. 1, pp. 184–193, Jan. 2012.

[9] H. Geng and G. Yang, "Output power control for variable-speed variablepitchwind generation systems," *IEEE Trans. Energy Convers.*, vol. 25,no. 2, pp. 494–503, Jun. 2010.

[10] J.-I. Jang and D.-C.Lee, "High performance control of three-phase PWMconverters under nonideal source voltage," in *Proc. IEEE ICIT*, Dec.2006, pp. 2791–2796.

[11] P. K. Keung, P. Li, H. Banakar, and B. T. Ooi, "Kinetic energy of windturbinegenerators for system frequency support," *IEEE Trans. PowerSyst.*, vol. 24, no. 1, pp. 279–287, Feb. 2009.

[12] K. H. Kim, Y. C. Jeung, D. C. Lee, and H. G. Kim, "LVRT scheme ofPMSG wind power systems based on feedback linearization," *IEEETrans. Power Electron.*, vol. 27, no. 5, pp. 2376–2384, May 2012.

[13] K. Li, J. Liu, Z. Wang, and B. Wei, "Strategies and operating pointoptimization of STATCOM control for voltage unbalanced mitigation in three-phase three-wire systems," *IEEE Trans. Power Del.*, vol. 22, no.s1,pp. 413–422, Jan. 2007.