Application of SMES in Wind Generator Controlled by 12 Pulse Converter

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Abstract- Superconducting magnetic energy storage systems are getting increasing interest in applications of power flow stabilization and control in the transmission network level. This trend is mainly supported by the rising integration of large scale wind energy power plants into the high-power utility system and by major features of SMES units. Due to arbitrary variations of wind speed, Load fluctuation is occurred. So minimization of fluctuation is essential for power system security. This paper represent SMES strategy to reduce load fluctuation in wind generation system. 12 pulse converter is the core of a SMES system. 12 pulse converter has the certain freedom in choosing active & Reactive power. By utilizing the reactive power modulation capacity of the converter, the inductor-converter unit of function as a static VAR controller using a switched capacitor bank, while acting as a load frequency stabilizer at the same time.The converter is a voltage source converter with a controller. Superconducting magnetic energy storage (SMES) technology is one of the most active research areas of applied superconductivity in the recent years especially after the high temperature superconducting (HTS) materials were discovered.

Keywords- 12 pulse, SMES, firing angle, Active power, reactive power.

1. Introduction

In Recent years mainly due to the technology innovation, cost reduction and for government policies there is a rapid growth in the exploration of the renewable energies. Today there exist a large scale wind-plants and Photovoltaic (PV) solar power plants all over the world. This situation can lead a severe problem in power system security, particularly in a weak power system i.e. system frequency oscillations due to insufficient damping or violations of transmission capability margin due to severe fluctuations of tie-line power flow among other [1][2].It is not possible to control the power output from a wind-park or the output from a wave energy power-plant to hydropower. The output power can also have relatively large variations with a short of time span. Even more because majority of these renewable power- plant with high installed capacity are connected to the power system, their impacts are more widespread. In addition as presently deregulated market are taking place, generation and transmission facilities are being utilized at higher efficiency rate. Leading to a tighter control of a space capacity [3]. To overcome this problem Superconducting magnetic Energy Storage can be placed as a effective device in a ac power system. The most important advantage of SMES is the high power energy and energy density with outstanding conversion efficiency and fast independent power resource in four-quadrants.Fig.1.shows the some of the different concepts and their characteristics with regards to power output and output duration. The different storage type can principally be divided into two groups. There are devices which can store large amount of energy. But do not react fast. Pumped Hydro storage is one energy storage solution of this type. In the other end there are fast acting devices which store smaller amount of energy.SMES placed in this group. The SMES is a coil which is in a superconducting state at cryogenic temperature. This means that the ohmic loss during the operation is close to zero. An energy storage system of this type can charge & discharge very fast or

absorb or deliver high quality of power. Another positive element is about its life cycle.A coil of this type can withstand tens of thousands of charging power. This corresponds to several decades of operation and compared to battery storage systems the lifetime is much longer[4].To reach the Superconducting state the coil has to be cooled to less than 9.8K[5].This is achieved using liquid helium which brings the temperature down to 4.2K.The need for cooling is an aspect which lowers the efficiency but the power needed for cooling is far less than the output power of the SMES[6].combined with ohmic losses in the non superconducting devices the efficiency can exceed 90%[7]. In a SMES system the power conditioning system (PCS) is the interface that allows the effective connection to the power system. The dynamics of the PCS directly influences the validity of the SMES in the dynamic control of the power system. With the appropriate topology of the PCS and its control system design the SMES unit is capable of simultaneously performing both active & Reactive power flow control.[8]-[11].When deciding which converter topology to use to connect the SMES to grid, aspects as harmonic distortion usage of reactive power and on-state loss should be considered. Among the self-commutated converters there are mainly to different from to choose from: current source converter(CSC),Voltage source converter (VSC),Thyristor Source Converter(TSC).A VSC is chosen here because of better topology than CSC.
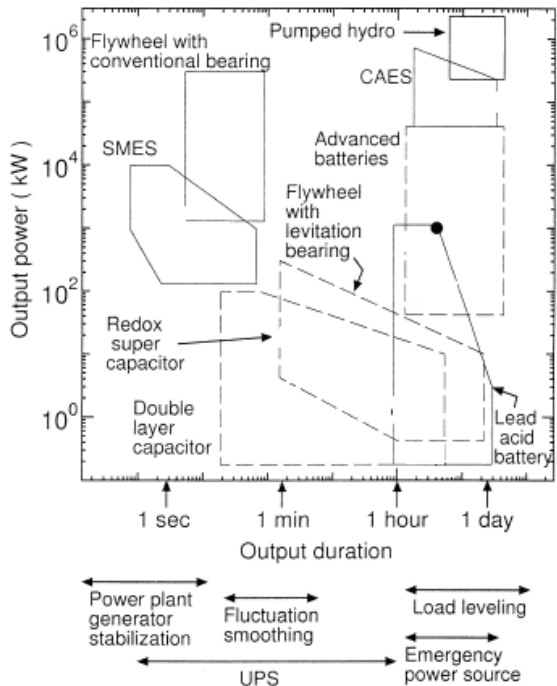

Fig. 1. Different Energy Storage Concepts,and their range of power output and output duration[4].

2. SMES Unit

An SMES device is a dc current device that stores energy in magnetic field. The dc current flowing through a superconducting wire in a large magnet creates the magnetic field. Since energy is stored as a circulating current. Energy

can be drawn from an SMES unit with almost instantaneous response with energy stored or delivered over periods ranging from a fraction of a second to several hours. An SMES unit consists of a large superconducting coil at the cryogenic temperature. This temperature is maintained by a cryostat or dewar that contains helium or nitrogen liquid vessels. A bypass switch is used to reduce energy losses when the coil is on standby. And it also serves other purposes such as bypassing dc coil current if utility tie is lost, removing converter from service, or protecting the coil if cooling is lost [13]. Fig.2. shows the main configuration of the SMES unit. The unit consists of a superconducting inductor which is considered as the heart of the system. two series connected six-pulse converter connected to a ac power system via $Y - \Delta / Y - Y$ step down transformer. Consequently the ac voltages applied to each six-pulse valve group that make up the 12 pulse valve group have a phase shift difference of 30^0 which is utilized to cancel fifth and seventh harmonic and dc sides sixth harmonic voltage. Thus resulting in a significant saving in harmonic filter [12].
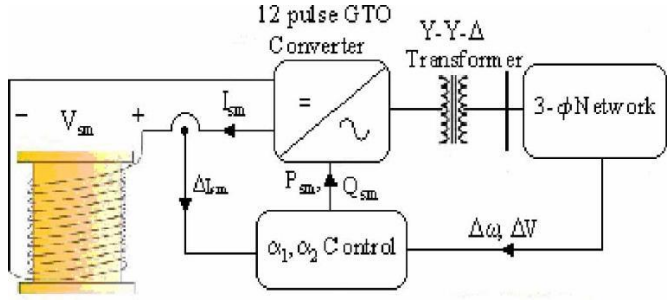

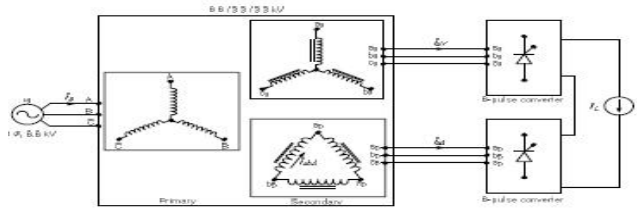**Fig. 2.** Schematic Diagram of a SMES system

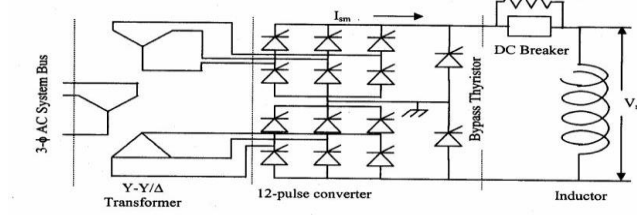**Fig. 3.** Series Connected 12 pulse converter.

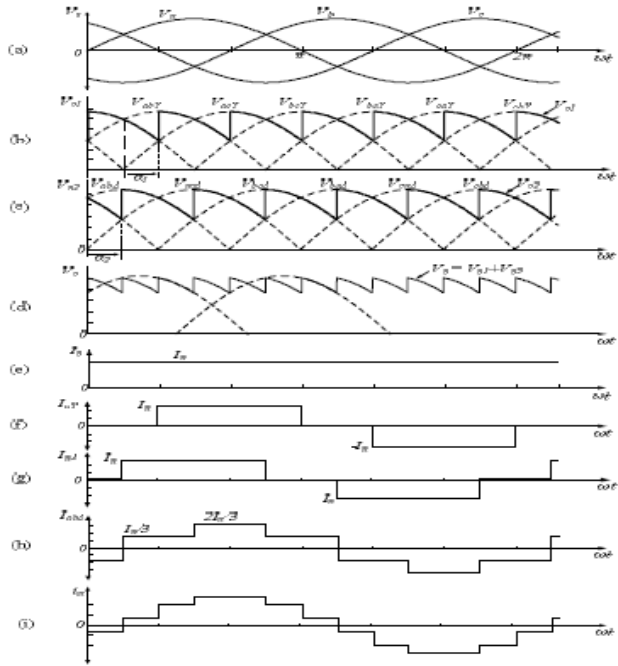
Fig. 4. Block Diagram of SMES unit

Fig. 5. Series connected 12 pulse converters (a) phase voltage (b) upper converter output voltage (c) lower converter output voltage (d) output voltage) (e) Load current (f and g) Transformer output current (h) supply current.

3. SMES Unit Controller

In accordance with converter theory the voltage V_{sm}

on the dc side of the bridge is expressed by

$$V_{sm} = V_{sm0}(\cos\alpha_1 + \cos\alpha_2) \qquad (1)$$

Where V_{sm0} is the ideal no load maximum dc voltage of the six-pulse bridges. The current and voltage of the superconducting inductor relationship

$$I_{sm} = \frac{1}{L_{sm}}\int_{t_0}^{t} V_{sm}\,d\tau + I_{sm0} \qquad (2)$$

Where I_{sm0} is the initial current of the inductor .The real power absorbed or delivered by the SMES unit is

$$W_{sm} = W_{sm0} + \int_{t_0}^{t} P_{sm}\,d\tau \qquad (3)$$

Where $W_{sm0} = \frac{1}{2}L_{sm}I_{sm}^2$ is the initial energy of the inductor. Equation (3) shows that the stored energy depends on the inductance and the current of the coil. The current can never reverse its direction, so it can only have positive values. At any time, the active and reactive power delivered or absorbed by an SMES unit is given by

$$P_{sm} = V_{sm0}I_{sm}(\cos\alpha_1 + \cos\alpha_2) \qquad (4)$$

$$Q_{sm} = V_{sm0}I_{sm}(\sin\alpha_1 + \sin\alpha_2) \qquad (5)$$

The value of V_{sm} can be varied in wide range of positive and negative values by controlling the α_1 and α_2. Equations (4) and (5) are show that there are three modes of operation in the SMES unit. : 1) The standby mode when firing angles are equal to 90 , the voltage across the SMES coil is equal to zero, and the SMES coil current is at its rated value; consequently, there will be no energy transferred between the SMES unit and the ac system. 2) Charging mode at firing angles of less than 90, where power will be transferred from the ac system to the SMES unit. 3) Discharging mode at firing angles greater than 90, where power will be injected from the SMES unit into the ac system. Adjusting the values of the firing angles can control the rates of charging and discharging. Using (5) and (6), the firing angles of the converter under four-quadrant operation can be calculated as

$$\alpha_1 = \cos^{-1}(\frac{P_{sm}}{P_{sm}^2 + Q_{sm}^2}) + \cos^{-1}(\frac{P_{sm}^2 + Q_{sm}^2}{2V_{sm0}I_{sm}}) \qquad (6)$$

$$\alpha_2 = \cos^{-1}(\frac{P_{sm}}{P_{sm}^2 + Q_{sm}^2}) - \cos^{-1}(\frac{P_{sm}^2 + Q_{sm}^2}{2V_{sm0}I_{sm}}) \qquad (7)$$

4. Simultaneous Control of Active & Reactive Power

The output voltage of the series connected 12 pulse converter is the sum of two output voltage of six-pulse converter.

$$\begin{aligned} V_0 &= V_{0Y} + V_{0\Delta} \\ &= \frac{3V_{m,L-L}}{\pi}\cos\alpha + \frac{3V_{m,L-L}}{\pi}\cos\alpha \\ &= \frac{6V_{m,L-L}}{\pi}\cos\alpha \end{aligned} \qquad (8)$$

V_{max} is the maximum voltage supplied to the converter and α is the firing angle of the two-six pulse converter. Recalling the equation (4) and (5)

$$P_{sm} = V_{sm0}I_{sm}(\cos\alpha_1 + \cos\alpha_2)$$

$$Q_{sm} = V_{sm0}I_{sm}(\sin\alpha_1 + \sin\alpha_2)$$

The variation of P_{sm} and Q_{sm} with simultaneous variations of α_1 and α_2 is shown in fig 6 and 7. A MATLAB/SIMULINK model is to use for this simulation respectively. If $\alpha_1 = \alpha_2$ is selected then many problem will arise and the SMES UNIT will be less effective. Additional PID controller is suggest for that. However if unequal α mode is selected then all problems associated with the equal α - mode can be eliminated. The necessity of incorporating an extra PID controller is also eliminated. These figures also illustrate that a constant active power operation can be achieved through a different combinations of firing angles α_1 and α_2 .and the converter absorbs or delivers different kinds of which in consequent affects the input power factor.This means for the different conditions of $\alpha_1, \alpha_2, P_{sm}$,

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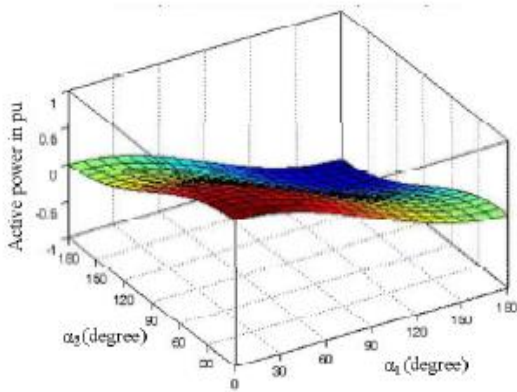Q_{sm} can be evaluated and produce a certain power locus which affects the converter performance.
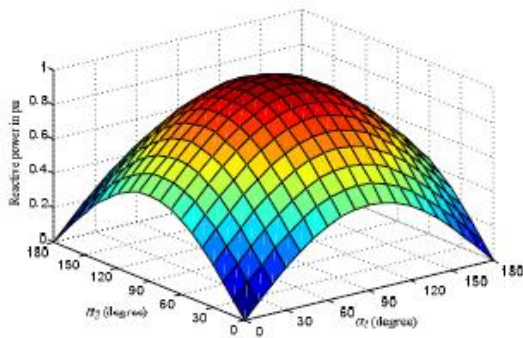

Fig. 6. Active power variations with α_1 and α_2.

Fig. 7. Reactive power variations with α_1 and α_2

5. Combined Operation with Wind Turbine

The performance of the micro grid in interconnected operation and with high penetration is analyzed through

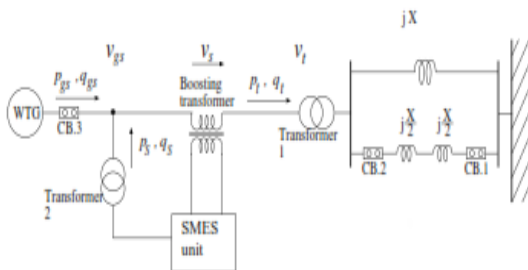MATLAB/SIMULINK and shown the simulation result in Fig.8.

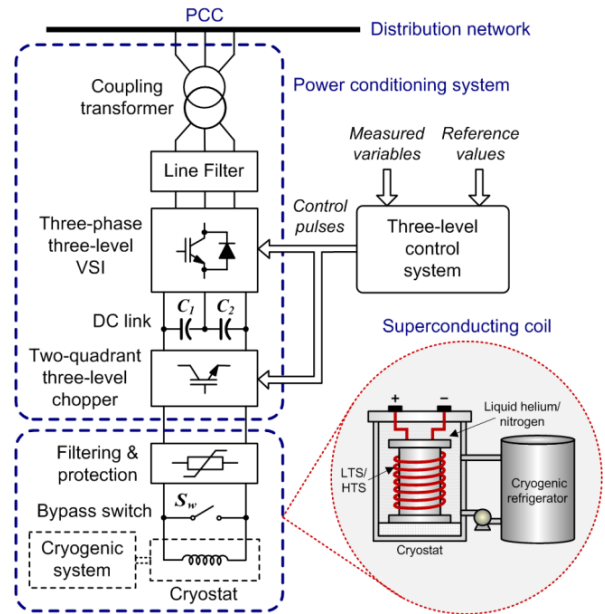**Fig. 8.** Block Diagram of SMES unit with Wind Turbine

Fig. 9. SMES unit with terminal bus of a wind turbine

Under standard condition the wind generator produces fluctuating active power. The consequence of including the proposed SMES system can be verified through the simulation results shown in Fig.10. with blue solid lines and the black line shows base line(without SMES). The SMES effectively stabilize the tie-line power flow, absorbing surplus energy from the system and releasing energy at the appropriate time
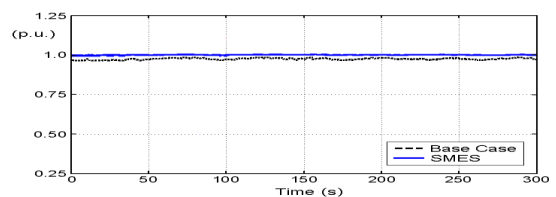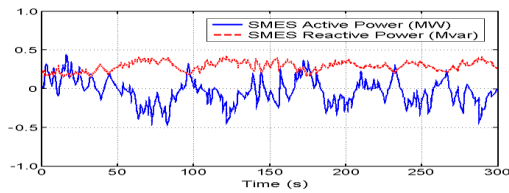
6. Simulation result

(a)

(b)

(c)

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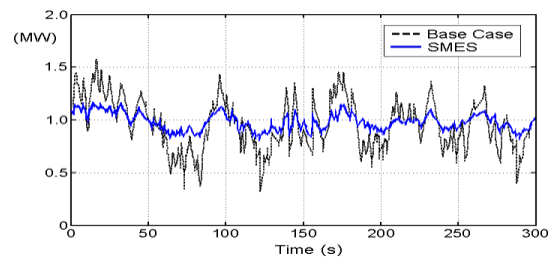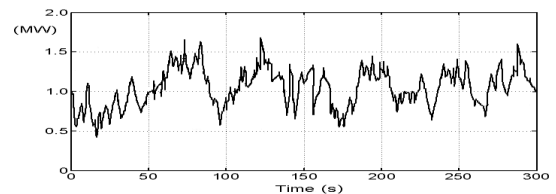
(d)

Fig. 10. Dynamic response of power flow stabilization and control mode (a) tie-line power flow (b) wind generator active power.(c) Point of common coupling terminal voltage. (d) SMES active and Reactive power

7. Conclusion

This paper provides an effective SMES controller for the stabilization for the power flow of a wind generation. It's also describes the symmetrical & asymmetrical operation of 12 pulse converter. Because of the use of SMES system the system frequency fluctuates can be minimized and well smooth the transmission line power.

References

[1] [1] Marcelo Gustavo Molina, Pedro Enrique Mercedo, Edison Hirozaku watanbe "Improved Super Conducting Magnetic Energy Storage (SMES) Controller for HighPower Utility applications.

[2] P.Pourbeik,P.S.Kundur and C.W. Taylor "The anatomy of a power grid black out -Root causes and dynamics of recent major Blackouts.",IEEE power energy Mag.,vol 4,no.5,pp 22-29,sep/oct 2006.

[3] P.Pourbeik,M.Bahrman, and E.John "Modern Counters Measures to blackouts",IEEE power energy mag.,vol4,no.5,pp 36-45,sep/oct 2006.

[4] Knut Erik Nielson,Marta Molians "Superconducting Magnetic Energy Storage (SMES) in Power Systems with Renewable Energy Sources",pp 2487-2492,Jul 2010.

[5] J.Brag 'Superconductors in applications;Some practical aspects.", IEEE Transactions on Applied Superconductivity, Vol 19,pp 2533-2539,June 2009.

[6] T.Katagiri,H.Nakabayashi,Y.nijo,T.Tanda,T.Noda,T.naga ta,S.nagaya,M.Yamane,Y.Ishii and T.Nitta. "Field test result of 10mva/20MJ SMES for load fluctuation

compensation".,IEEE Transactions on Applied Superconductivity,Vol 19,pp1993-1998.,June 2009.

[7] P.Tinador "Superconducting magnetic energy storage; status and Perspective", IEEE/CSC&ESAS European Superconductivity news forum, January 2008.

[8] R.H.Lasseter and S.G.Lalali, "Power conditioning systems for superconductive Ma gnetic Energy Storage",IEEE Trans.Energy Convers.,vol.6,no.3,pp 381-387,sep 1991.

[9] I.D. Hasan,R.M.Bucci and K.T.Swe, "400-MW SMES power conditioning system development and simulation"IEEE Trans.Power Electron.Vol.8.,no.3,pp 237-249,Jul 1993.

[10] M.G.Molina,P.E.Mercado and E.H.Watanabe "Dynamic Performance of a static synchronous compensator with superconducting magnetic energy storage",In proc. IEEE Power Electron. Spec. conf. Jun.2005,pp 224-230.

[11] L.chen, Y.liu, A.B.Arsoy, P.F.Ribeiro, M.Sturer and M.R.Irvani, "Detailed Modeling of Superconducting magnetic energy storage (SMES) system".IEEE Trans.power del.,vol 21,no.2,pp 699 -710.June 2006.

[12] Abu-saida,syed Islam "Application of SMES unit in improving the the performance of an AC/DC Power System"IEEE Transactions on sustainable energy,vol2, no.2,April 2010.

[13] Mohd.Hasan Ali,Bin Wu,Roger A.Dougal "An overview of SMES Applications in Power and Energy systems" IEEE Transactions of sustainable energy,Vol 1,no.1,April 2010.

[14] M.G.Rabbani,J.B.X.Devotta and S.Elangovan, "Application of simultaneous active and reactive power modulation of SMES unit under unequal α-mode for power system stabilization",IEEE trans.power syst.vol.14no.2,pp 547-552,May 1999.

[15] A.Abu-saida, "Application of Superconducting Magnetic Energy Storage Units to Improve Power System Perfomance",Ph.D.Thesis Curtin University of Technology ,Perth,Australia 2004.

[16] Mohd.Hasan Ali,Junji Tanura and Bin Wu "SMES Strategy to Minimize Frequency Flactuations of Wind Generator system pp 3383-3387.