iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL
FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 Issue: VII Month of publication: July 2022

DOI: https://doi.org/10.22214/ijraset.2022.45608

www.ijraset.com

Call: 08813907089 | E-mail ID: ijraset@gmail.com

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue VII July 2022- Available at www.ijraset.com

HVDC Interconnections with SMES Device for PV and Wind Hybrid Power Transmission System

Negma Iqbal[1], Aswathy Vidyasagar[2], Dr. John Chembukavu[3]
[1, 2, 3]Electrical and Electronics Engineering, Kerala Technological University

Abstract: The consumption of power shows a steeply increasing behavior in the present scenario which demands the integration of various novel techniques to the existing grid. With the penetration of PV and wind energy units into the grid, the evolution from a generator dominated grid to an inverter dominated grid arises in the near future. The paper discusses the characterization of HVDC convertors with the behavior of SG emulating virtual inertia for frequency stabilization and proper power oscillation damping during transmission of renewable energy based power. The conventional control of HVDC converters is integrated with synchronous power controller with second order characteristics inside power control loop for proper damping essentialities. The functioning of HVDC link is enhanced by means of SMES coil based energy storage operation. The proposed formulation is applied to a four area model in IEEE 14 bus system incorporated with PV, wind and HVDC links. The dynamic behavioral improvements are tested by means of MATLAB simulation.
Keywords: Virtual Inertia, Grid connected converters, PV and Wind Energy Systems, Synchronous Power Controller(SPC), HVDC Transmission, Superconducrting Magnetic Energy Storage(SMES).

I. INTRODUCTION

The development and swift expansion of AC systems into a scenario of multi-area interconnected power systems demands the rise in the presence of high power converter applications in future power grid which follow up with a very difficult issue which will affect various parts of the power grid and particularly the frequency stabilization and power oscillation issues in AC/DC systems [1]. Automatic generation control facilitates various responsibilities like frequency restoration, optimal power dispatch and scheduled tie-line power flow in a multi-area power system [2].

Multi-area system may constitute AC or DC transmission lines in between various authority areas which perform scheduled tie-line power flow and appropriate support during abnormalities or contingencies [3]. Even though AC transmission is very much implemented in the grid at present, HVDC links have gained a lot of attention in recent times for long distance transmission [4]. HVDC has various beneficial advantages like frequency stability, maintain fast and bidirectional controllability, power oscillation damping (POD), better reliability and prevents global blackouts acting against cascaded disturbances [5]-[7]. Renewable energy resources based power generation has been a great contribution in the recent years. Integration of large off-shore wind farms, solar energy, pit head steam and hydroelectric power plants demand HVDC transmission as they are at a faraway place from the major power demand zone. The main reason for the latter is the economic feasibility of HVDC links in long distance transmission. Hence, the trend for HVDC connections and hybrid connections has gained an increasing attention as a preferred solution [8].

Conventional generators have the droop capability for providing inertia and respond against frequency fluctuations. The incorporation of renewable based energy systems, and HVDC links evolutes a convertor dominated grid from a generator dominated grid. A convertor based grid will lack sufficient inertia for stable power system operation [9]-[10]. The major issues include variation in scheduled tie-line power flow, oscillating power, complexity in frequency regulation. So, it is obvious that the present requirement is to model a system which emulates appropriate virtual inertia and implement the behavior of synchronous generators to inverters used in HVDC and RES based systems.

Efficient load frequency control (LFC) is a major concern for the stable operation of power system. There are various methods adopted for LFC in the modern systems with implementation of more functionality to conventional methods [11]-[12]. Coordination of HVDC transmissions and FACTS devices are very much useful for long-term dynamics control of modern systems [13]-[16]. There are various topologies for the virtual inertia emulation with diverse control methodologies [17]-[19]. Virtual inertia is emulated by highly innovated control strategy of power converters embedding the behaviors of synchronous machines to control part of converter systems to some extent [20]-[23].

Emulation of inertia based on synthetic inertia method [24], frequency derivative criterion for HVDC systems [26]-[28] and Virtual Synchronous Generator (VSG) method [25] are some of the commonly discussed methods.

Corresponding signal for convertor controllers is the derivative of grid frequency in one of the methods which is a highly efficient criterion [26]. The criteria based on frequency derivative for emulation of inertia are sensitive to the noise especially during measurement of frequency. Phase Locked Loop (PLL) is essentially used for proper assessment of the signals in most cases [29]. Thus, any case of frequency deviation may give rise to amplification of noise signals. This may cause lose of locked condition of PLL which adversely affects the inverter operation.

The inertial response usually depends on the physical nature of various components, while in this paper enhanced method of emulating alternative inertia without this constraint is discussed. Synchronous Power Controller (SPC) is integrated with the usual control strategy of HVDC convertors for better operation. The control strategy proposes a novel technique in power converter control to behave itself similar to a SG with the capacity to emulate inertia without the limitations of a conventional generator. During the integration of the renewable energy sources into the power system, various instability issues are caused which can be power oscillations due to unstable generation from RES units. Damping of power oscillations is a major concern for the stable operation of the power grid. The HVDC convertor control is thus to be modeled so as to solve these instability concerns. The widespread use of renewable energy in the system necessitates the use an energy storage device (ESS) for reliable power system. Instantaneous and independent exchange of the active and reactive power in renewable energy based HVDC system is possible with energy storage devices [30]. These energy storage devices help to mitigate the power quality issues arising due to the integration of renewable sources [31]. Super-conducting magnetic energy storage (SMES) is a type of ESS which has a very high efficiency of more than 90%. SMES is a direct current device which can store energy of magnetic field in a superconducting coil [32].

The paper discusses a Virtual Synchronous Power (VSP) based control method for HVDC convertors of the multi-area interconnected power system incorporated with various renewable energy resources; namely solar and wind for power generation. The VSP based concept adopted in the paper was patented in the year of 2012 [18]. The HVDC convertor control of the same system with conventional method of control and VSP based control is to be compared. The behavior of the system with VSP control after incorporating RES units is to be studied from simulation results. The performance of HVDC system with and without SMES coil as an energy storage device has been studied under fault conditions.

The main purpose of this paper is to suggest a novel move towards of power oscillation damping and frequency stability analysis in multi-area system, implementing the concepts of VSP and SMES based ESS in HVDC links. The significance of the VSP theory to provide additional capabilities like emulating the inertia and damping for frequency and power control improvements is another desire through the study in this paper. In case of higher order control designing of HVDC stations, the real time experimentation is really hard and thus this method proposes a very efficient pre-evaluation strategy for studying the dynamic behavior of the system [33]. The significance of energy storage devices for HVDC links transmitting renewable energy based power is high in the current scenario. Hence a very efficient methodology for the same using SMES coil may be very helpful to cope up with the major power quality issues.

II. SYCHRONOUS POWER CONTROLLER

A. *Electrical Princle of Operation*

The interlinking of a synchronous generator to the grid can be represented using the circuit shown in fig. 1, where v represents the grid voltage, e is the internal induced emf of generator.

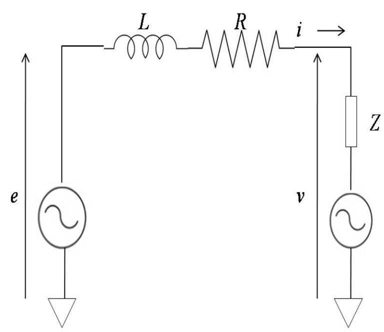


Fig. 1. Connection of SG to a grid

The Laplace transform domain based expression of the about circuit can be written as,

$$v(s) = e(s) - i(s)\,(R+Ls) \qquad (1)$$

By programming the above equation in a digital controller, emulation of the electrical behavior of SG is possible. While, the implementation of the above equation straightforward will bring about issues due to the derivative term of measured current. This is due to presence of high frequency ripples, which will bring out issues during calculation of reference signals for the control of power converter. Hence, rearranging equation (1), results to generate equation below,

$$i(s) = \frac{1}{R + sL} (e(s) - v(s)) \qquad (2)$$

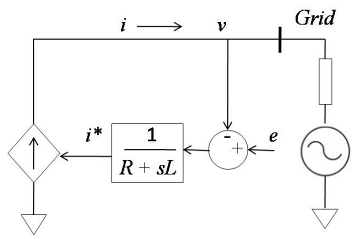


Fig. 2. Virtual admittance model for virtual generator

This alternative for equation (1) will be more realistic for physical modeling and performs stable, smoother and sensitivity to distortions is less. Thus, it represents the admittance model of the virtual generator shown in fig.2. The cost for extra filtering can be avoided using this model. There is an interior control loop for current in the model which helps to control power converters used in power generation applications. The model is based on the virtual admittance concept.

B. Electromechanical Princle of Operation

The electromechanical behavior of a synchronous machine is defined with the help of Swing equation. The difference between electrical and mechanical power is the reason for the rotor swing, which leads to inertial response. The immediate response during a frequency event due to rotor swing is by the inertial response by trying to mitigate the imbalance between the electrical supply and demand. This property of inertial response is due to the large rotating mass of the synchronous generators present in the power grid. The high penetration of renewable energy resources lead to a low inertia power grid. The paper discusses a novel method to implement the inertial response characteristics of a synchronous generator to the control scheme of an inverter, thus to compensate the absence of synchronous generator. While digitalizing the behavior of synchronous generator, it can also overcome drawbacks of conventional SG's inherent oscillatory response. The values of inertia and damping are responsible for the inertial response in a synchronous generator which is due to its physical very large rotational mass. This limitation doesn't occur in case of digitalized control system as the values of damping and inertia can be varied dynamically during perturbations. Swing equation may be mathematically expressed as,

$$M \frac{d\Delta\omega}{dt} = P_m - P_e - D\,\Delta\omega \qquad (3)$$

Applying Laplace transform,

$$sM\Delta\omega = \Delta P - D\Delta\omega \qquad (4)$$

where P_m and P_e *are* mechanical input power and electrical output power of a generator. D and M are the damping power constant and inertia constant. ΔP represents any variation among power delivered. Rearranging equation (4) and substituting M in terms of moment of inertia (J) and the synchronous frequency ω_s.

$$\Delta P = \Delta\omega\,[sJ\omega_s + D] \qquad (5)$$

$$\Delta\omega = \frac{\Delta P}{J\omega_s} \div \left(s + \frac{D}{J\omega_s}\right) \qquad (6)$$

$$\Delta\omega = \left(\frac{\Delta P}{J\omega_s} \quad \frac{P_{max}}{P_{max}}\right) \div \left(s + \frac{D}{J\omega_s} \quad \frac{2\sqrt{P_{max}}}{2\sqrt{P_{max}}}\right) \quad (7)$$

$$EV/X \quad (8)$$

where P_{max} is the maximum value of active power that can be delivered. *V, E* and *X* represent the grid voltage, internal *emf* voltage and overall impedance respectively. From the above modeling, the required parameters for the implementation of synchronous power controller can be defined as follows,

$$\omega_n = \sqrt{(P_{max}/(J.\omega_s))} \quad (9)$$

$$\xi = \frac{k}{2\sqrt{(P_{max}\, J.\omega_s)}} \quad (10)$$

where k and D denotes the damping coefficient. Substituting the values of ω_n and ξ in the equation (7), $\Delta\omega$ can be expressed as,

$$\Delta\omega = \Delta P \, \frac{\omega_n^{\,2} / P_{max}}{s + 2\xi\omega_n} \quad (11)$$

C. Control Scheme for the HVDC converter

Virtual synchronous power control based strategy is incorporated in to the control of a convertor by implementing the loop of active power synchronization; equation (10) and virtual admittance block; equation (2) with proper designing.

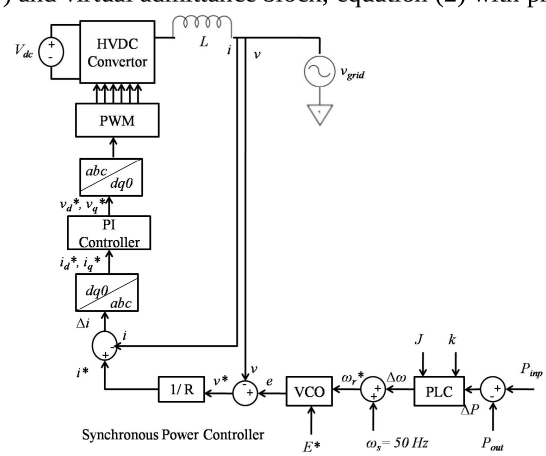


Fig. 3. Control Strategy using Synchronous Power Controller

As shown in fig. 3, any variation in the input power P_{inp}, product of v_{dc} and i_{dc} and the power delivered by the converter P_{out}, product of *v* and *i*, is denoted as ΔP, which is the input to the Power Loop Controller (PLC). The PLC will generate a relative value of frequency $\Delta\omega$ using equation (8) and (11). The values of ω_n and ξ are generated executing the equations (9) and (10). The virtual inertia, *J* and the damping coefficient, *k* for the system are selected properly in order to emulate required amount of virtual inertia and damping. The value of rotating frequency of virtual rotor (ω_r) is generated by adding up the values of relative frequency generated by PLC and synchronous frequency. The Voltage Controlled Oscillator (VCO) which acts as a simple oscillator is fed with the voltage and frequency signals to generate a three-phase virtual *emf* denoted as *e*. VCO implementation can be represented as below,

$$e = \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} = VCO\,(E,\,\omega) = \sqrt{(2E)} \begin{pmatrix} \cos(\omega_r t) \\ \cos\,(\omega_r t - 2/3\,\pi) \\ \cos\,(\omega_r t + 2/3\,\pi) \end{pmatrix} \quad (12)$$

The generated emf voltage *e* and the grid voltage *v* is compared to generate the error *v** which is fed to the virtual admittance block, where at the output generates current reference, *i**. This is compared with the grid current *i* and this if fed to the standard current controller where PWM signals are generated fot the gate control of converter switches. The dynamic relationship between the input and output powers may be represented as,

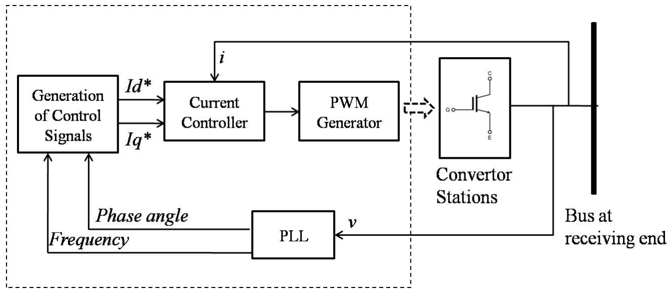


Fig. 4. Standard Current Controller

The block diagram standard current controller of the HVDC convertor is represented in the fig. 4. The voltage and current of the receiving end bus or grid is monitored and is fed to generate control signals. The phase locked loop fed with the grid voltage will generate the required phase angle and frequency for control signal generation. The generation process is undergone with dq0-abc transformation and vice-versa where the phase angle is required. After the generation of I_d* and I_q*, i.e. the d and q components of the reference signal, the required voltage signal to be fed to PWM generator is processed.

III. SUPERCONDUCTING ENERGY STORAGE DEVICE (SMES)

Superconducting energy storage device is made use of to store energy in the form of magnetic field. The electrical energy is being converted to magnetic energy, where excess of the DC current will circulate through the coil without any decay. This phenomenon is explained with the property of zero resistance to current flow of superconductors when the temperature goes below critical temperature.

The main benefits of using SMES compared to any other energy storage devices are high energy storage density, long application life time, high energy storage efficiency and little environmental pollution. The specification of SMES coil is expressed in rated power (W). The energy stored in the SMES coil may be expressed in terms of coil inductance, L_{SMES} and DC current flowing through the coil I_{SMES} as follows,

$$E = ½ (L_{SMES} I^2_{SMES}) \qquad (13)$$

A. Interfacing AC Grid to the SMES coil

In order attain the operation as a superconducting material; the coil has to be maintained at proper temperature which is attained by means of cryogenic system with refrigerator.

The superconducting coil has three modes of operation while it acts a storage device, maximum charging mode, storage/standby mode and discharging mode. Power Conditioning System (PCS) is required to attain this various modes, which is usually an inverter followed by a DC-DC chopper to attain variable DC supply according to the requirement of the AC grid. During this mode, the voltage that acts across the coil should be 0. DC voltage across the coil can be expressed as,

$$E_d = 2\, V_d \cos\alpha - 2 I_d\, R_c \qquad (14)$$

where E_d, I_d, V_d, R_c and α represent the DC voltage applied across the coil, current flowing through the coil, maximum voltage that can be applied across the coil, equivalent value of commutating resistance and the firing angle respectively.

B. Operation of SMES Device

The load change in the system is accompanied by frequency deviation in the system which can cause power quality issue like voltage sag or voltage swell. The variation of the load and frequency has an inversely proportional relationship. The change in frequency is considered as the control signal for the operation of the SMES device. The SMES coil will be initially charged to a particular residual value.

When there is a negative change in the frequency, SMES supplies power to the system and it get discharged. While the positive change in frequency will make SMES coil to absorb power and get charged. When there is no change in the system frequency, the SMES remains at its standby mode of operation. The various modes of charging and discharging can be attained by means of the DC-DC chopper which will vary the DC voltage that comes across the SMES coil. Chopper has to maintain a duty cycle of 50% in order to attain a mode of standby operation. As shown in fig. 5, the control signal for the mode selection of SMES device is the Δf signal. K_{SMES} is the gain of control loop, ΔI_d represent the deviation in inductor current, and T_{dc} is the time delay. The net deviation in the power, either absorbing or supplying power of SMES coil is ΔP_{SMES}.

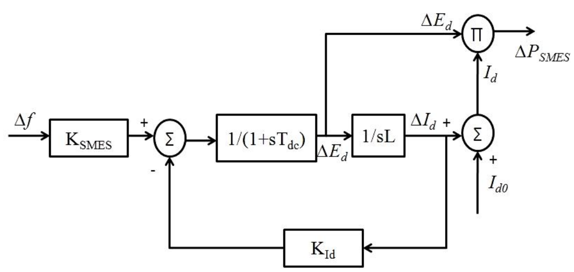


Fig.5. Control block of SMES device

IV. SYSTEM MODEL

The multi-area power system for the study is modeled in IEEE 14 bus test system [34]. The IEEE 14 bus system is modeled in MATLAB using the bus datas and line datas available. The whole bus system is divided into four areas as shown in fig. 6. The Area 4 is assumed to be at a distant place from other areas while the power requirement in this area is high. Thus in order to attain a better transfer of power over long distance, a HVDC line is installed in between Area 3 and Area 4. The HVDC convertor control using conventional method is compared with that of synchronous power controller based strategy.

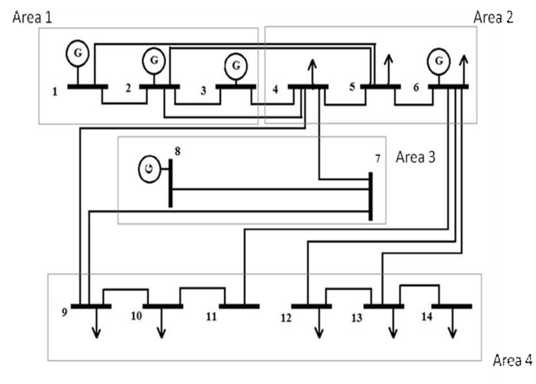


Fig. 6. Four-area power system

The Area 3 has high potential for the generation of power from solar energy and wind energy. HVDC being a good option for the transmission of wind generated power over long distance, there will be better performance. The synchronous generator in Area 3 is replaced and the power requirement is met with RES system comprising of wind and solar. The performance of the synchronous power controller based strategy is applied to the HVDC convertors for RES power transmission. The incorporation of the RES unit can lead to various power quality issues like voltage sag and voltage swell. To overcome the issues of power quality, SMES coil is integrated to the HVDC link. SMES coil has the ability to act according to fault conditions happening in the system by proper sharing of power with grid, choosing its exact operating mode. The schematic of the whole system is represented in figure 7.

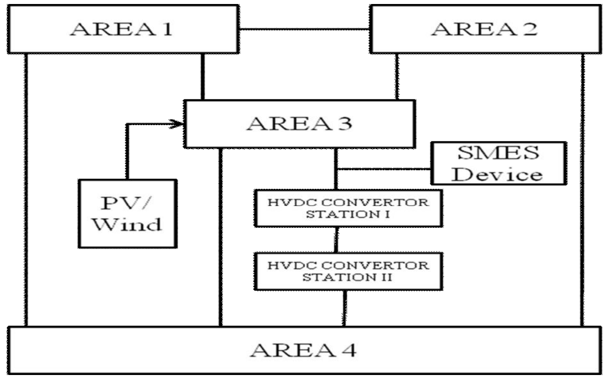


Fig. 7. Schematic of the system

TABLE I

Parameter	Value	Unit
Rated real power of SG	100	MW
Rated AC Voltage of SG	69	kV
Rated frequency of the system	50	Hz
Transformer Ratio	69/13.8	kV
Transformer Rating	100	MVA
Rated AC Voltage of load	13.8	kV
HVDC link Voltage	1300	V
HVDC line rating	13.8,100	kV,MVA
Cable Length	300	km
Virtual admittance of SPC	0.47	Ω
Natural frequency , ω_n	100	Hz
Damping Factor, ξ	0.27	
SMES coil capacity	100	KW
SMES coil inductance	10	H

V. SIMULATION RESULTS

The various ideas that were discussed in the previous sections have been simulated using MATLAB software. IEEE 14 bus system is modeled and simulated to obtain the stable result to ensure the test system credibility. The HVDC link is to be installed in between 8th and 14th bus of Area 3 and Area 4 respectively. The bus voltage and current of 8th and 14th bus in stable IEEE 14 bus system is shown in fig. 8. The various parameters of the system used to generate simulation results are given in Table 1.

The HVDC link is installed into the system and the convertor is being controlled by means of conventional control strategy. Then, the synchronous power control based method is incorporated with the conventional controller. The variations of the system based on both the methods can be studied by close analysis of the frequency deviation and power deviations curves plotted using simulink. The proper designing of firing angle is to be achieved.

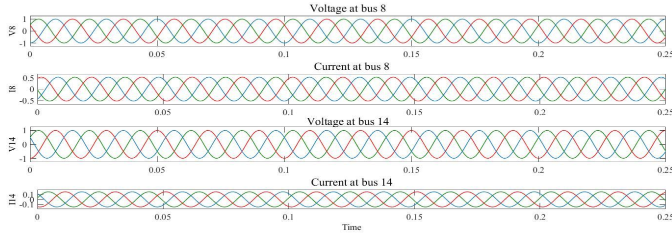


Fig. 8. Bus voltage and current

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue VII July 2022- Available at www.ijraset.com

The analysis of the frequency deviation and power oscillations are studied from the simulation results. The results of the both control strategies can be compared to understand the advantages of the latter. Fig. 9 and fig. 10 shows the variation of the power and frequency of the system when the convertors are being applied with conventional current control.

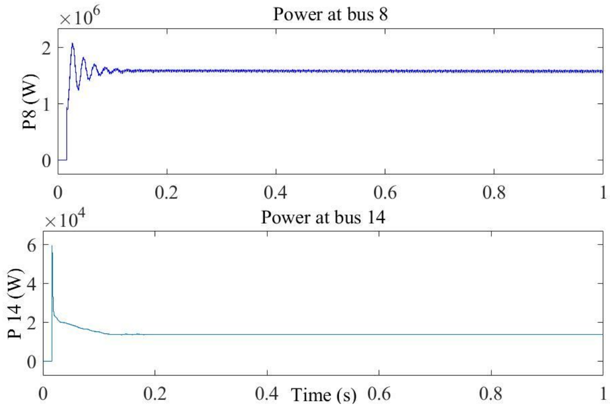


Fig. 9. Power deviation in conventional controlled system

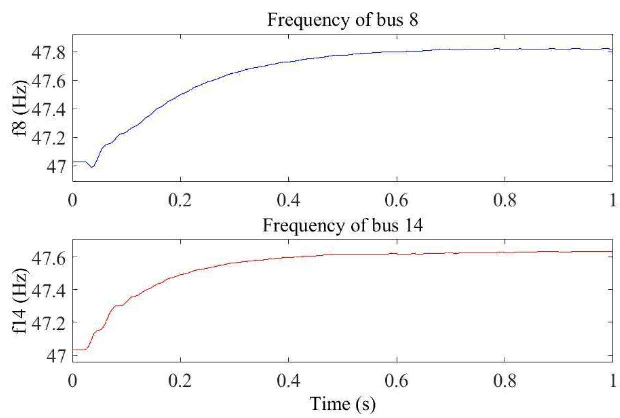


Fig. 10. Frequency deviation in conventional controlled system

The better working of the synchronous power converter can be easily depicted from results shown in fig. 11 and fig.12. The frequency doesn't reaches to the rated value in the first case, while in latter case; frequency is maintained at system frequency. In case of power deviations, the power oscillations are easily damped in the latter case. The better operation of this strategy based on proper feed backing of the frequency, power, current and voltage can make overall improvement in the operation of grid. The study of the graphs reveals requires inference.

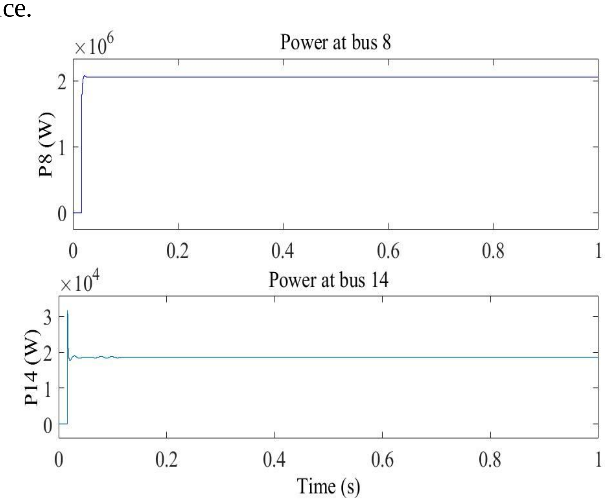


Fig. 11. Power deviation in SPC based strategy

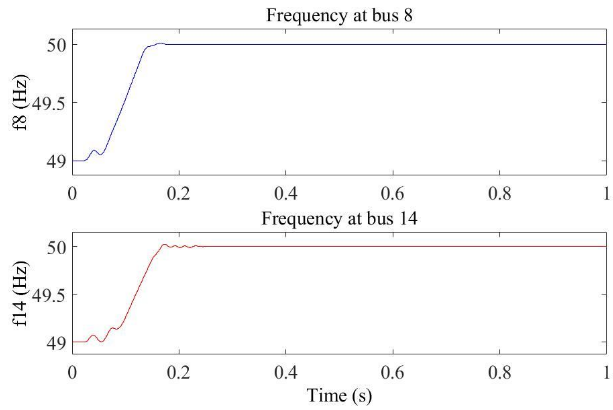


Fig. 12. Frequency deviation in SPC based strategy

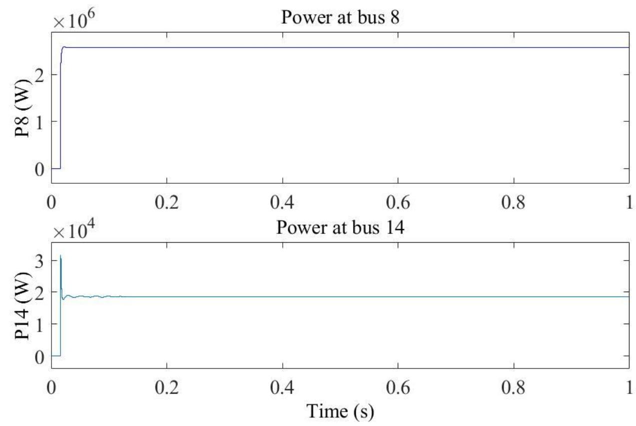


Fig. 13. Power deviation curve with RES incorporated

The SPC strategy is best suitable for the case with AC grid incorporated with RES units. Hence, in order to analyze the performance of the system with RES, the synchronous generator in the bus 8 is incorporated with wind and solar generation. PV panels and wind together generates a power of 1MW. The variation in frequency and power deviations seems to be satisfactory in figures 13 and 14.

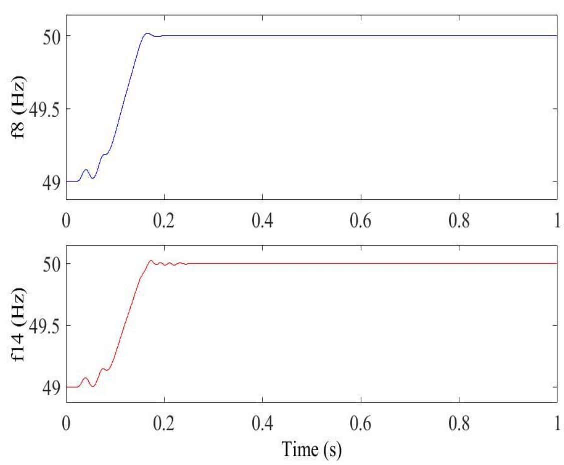
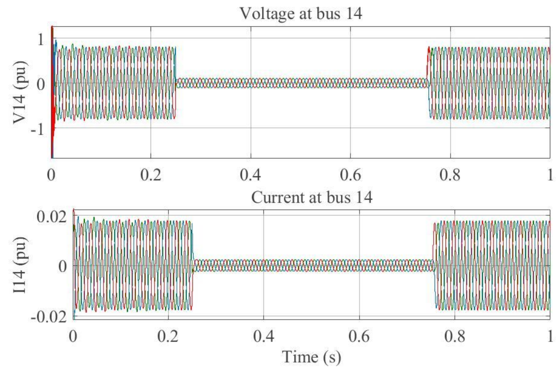
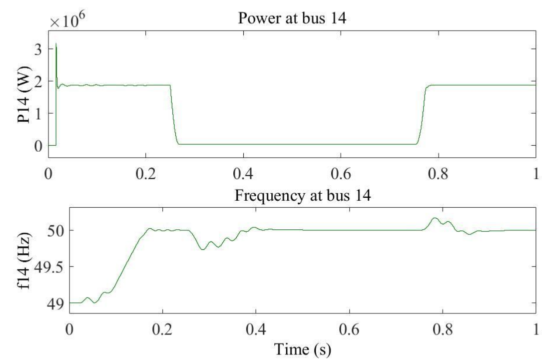


Fig. 14. Frequency deviation curve with RES incorporated

The wind, PV or any other renewable energy resource generates power in a varying nature. This is due to frequent variations in the driving source which is dependent on various environmental factors like temperature, pressure and other climatic variations. In case of such deviating power sources, it is very much necessary to incorporate very efficient control strategies for the coupling devices which connect them to the main grid. Hence VSP based control strategy can give better results.



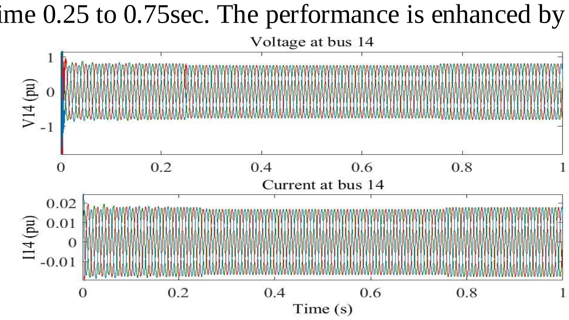
(a)



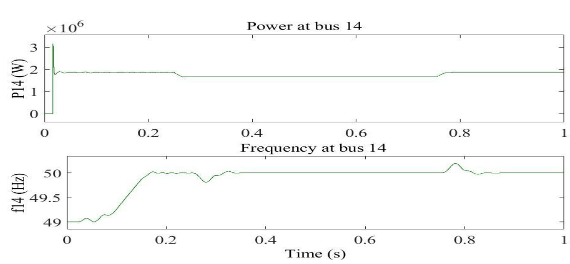
(b)

Fig. 15. Characteristics of system with fault (a) Voltage and current at bus 14 (b) Power & Frequency at bus 14

The wind or PV or any other renewable energy resources has a frequently varying behavior throughout its operation period due to their dependence on natural factors. Thus we opt for the integration of a energy storage device to the system. The SMES coil is used as an energy storage device. To analyze the performance of SMES device, a fault is being applied to the transmission line connecting 8th and 14th bus at sample time 0.25 to 0.75sec. The performance is enhanced by proper control of SMES device.



(a)



(b)

Fig. 16. Characteristics of system with SMES (a) Voltage and current at bus 14 (b) Power & Frequency at bus 14

The analysis of the result during the fault with and without the SMES device is depicted in figures 15 and 16. The SMES coil shifts to discharging mode during the fault and compensates the system power and maintains stable operation.

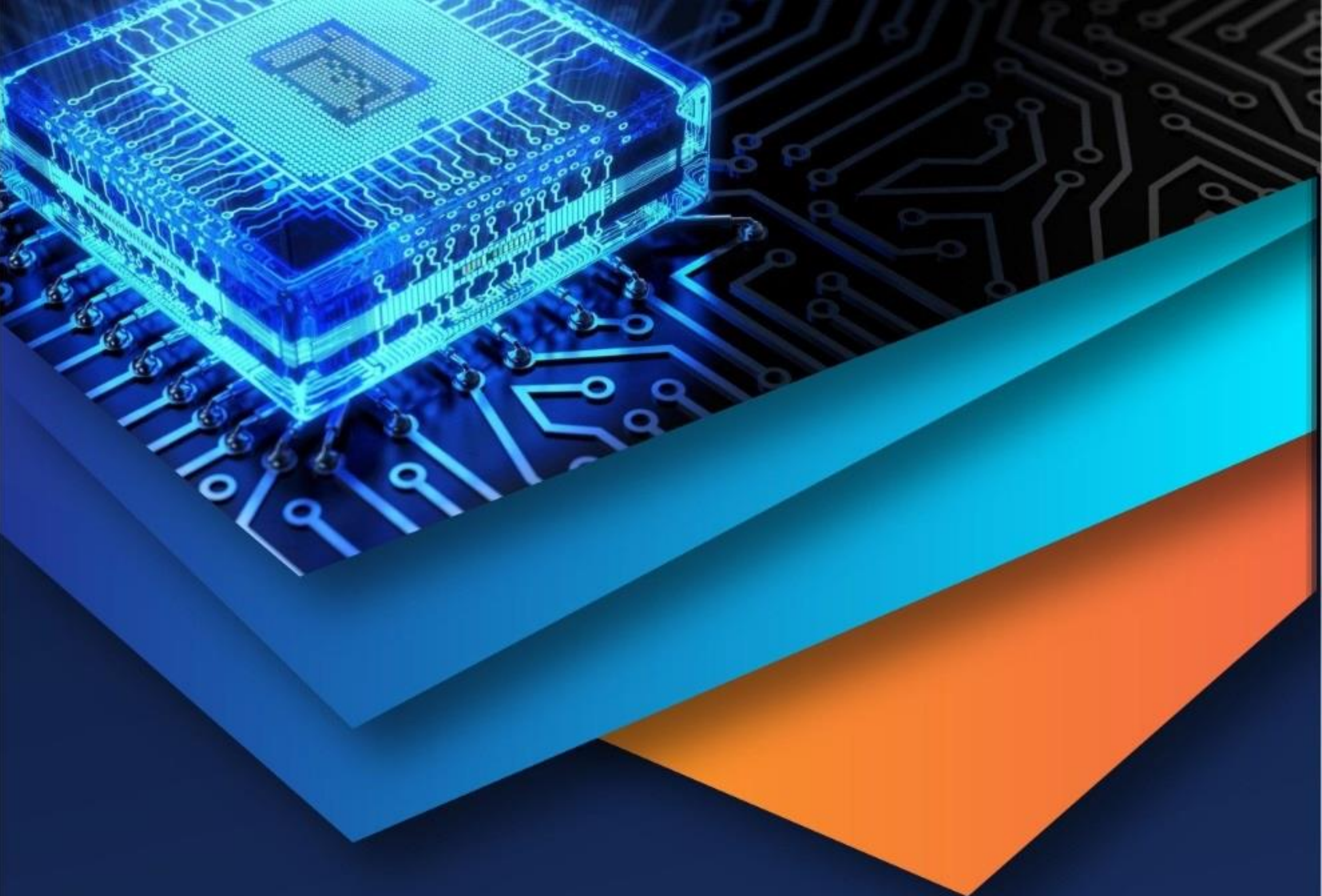
VI. CONCLUSION

A novel advanced method to implement the emulation of virtual inertia based power in HVDC links in multi-area interconnected power systems is proposed. The performance of the system is analyzed by studying the characteristics of a four area system modeled in Matlab. The significance of the method in maintains the stability of a power system is shown with appropriate simulation diagrams, which depicts the performance of the system. The power deviations and frequency deviations of different cases are simulated and inferred the results. The variation of frequency beyond the allowable limits may make the system act even so worse with high penetration of solar and wind energy resources based energy into the power grid. SPC based AC/DC systems can be better during any kind of contingencies in the power system. The incorporation of SMES gives better results in case of any load change in the system. The fault situations are well dealt with proper selection mode of operation of SMES. The power quality issues are solved by proper sharing of power among SMES device and power grid. All together the system can be very much useful in future grids with high penetration of renewable energy resources which can solve the issue of low inertia. The practical implementation of the system requires proper and in depth designing which will be very complex.

REFERENCES

[1] S. Koohi-Kamali, V.V. Tyagi, N.A. Rahim, N.L. Panwar, H. Mokhlis, “Emergence of energy storage technologies as the solution for reliable operation of smart power systems: A review,” Renewable and Sustainable Energy Reviews, vol. 25, pp. 135-165, Sept. 2013.
[2] P. Kunder, Power System Stability and Control, McGraw-Hill; 1994
[3] Z. E. Al-Haiki, and A. N. Shaikh-Nasser, “Power Transmission to Distant Offshore Facilities,” IEEE Transactions on Industry Applications, vol. 47, no. 3, 2011.
[4] E. Rakhshani, P. Rodriguez, “Active Power and Frequency Control Considering Large Scale RES”, in Large Scale Renewable Power Generation: Advances in Technologies for Generation, Transmission and Storage, Springer-Verlag: Berlin Heidelberg, November 2013.
[5] O.A. Giddani, A. Y.M. Abbas, G. P. Adam, O. Anaya-Lara, K.L. Lo, “Multi-task control for VSC–HVDC power and frequency control,” Electrical Power and Energy Systems, vol. 53, pp. 684-690, 2013.
[6] Lingling Fan, Zhixin Miao, and Dale Osborn,” Wind farms with HVDC delivery in Load Frequency Control,” IEEE Transactions on Power Systems, vol. 24, no. 4, 2009.
[7] Du Cuiqing, E. Agneholm, G. Olsson, “Use of VSC-HVDC for industrial systems having onsite generation with frequency control,” IEEE Trans. on Power Delivery, vol. 23, no. 4, pp. 2233–2240, 2008.
[8] Wolff G, Supergrid costs and Benefits, DESERTEC-UK, 2010, available online: http://www.trecuk. org.uk/resources/supergrid_costs1.pdf
[9] H. Bevrani, Robust Power System Frequency Control, 2nd edition, Springer, 2014.
[10] M. H.Variani, and K. Tomsovic, “Distributed Automatic Generation Control Using Flatness-Based Approach for High Penetration of Wind Generation,”IEEE Trans. on Power Systems, vol. 28, no. 3, 2013.
[11] M. Datta, T.Senjyu, A. Yona, T. Funabashi, K. Chul-Hwan, “A Frequency-Control Approach by Photovoltaic Generator in a PV–Diesel Hybrid Power System,” IEEE Transactions on Energy Conversion, vol. 26, pp. 559-571, 2011.
[12] S. Ali Pourmousavi, and M. HashemNehrir, “Introducing Dynamic Demand Response in the LFC Model,” IEEE Transactions on Power Systems, 2014.
[13] Du ZB, Zhang Y, Liu L, Guan XH, Ni YX, Wu FF, “Structure-preserved power-frequency slow dynamics simulation of interconnected ac/dc power systems with AGC consideration.” IET Gener. Transm. Distrib., vol. 1, no. 6, pp. 920–927, 2007.
[14] Ganapathy S, Velusami S, “MOEA based design of decentralized controllers for LFC of interconnected power systems with nonlinearities, AC–DC parallel tie-lines and SMES units,” Energy Conversion and Management, vol. 51, pp. 873–880, 2010.
[15] Du Z, Zhang y, Chen Z, Li P, Ni Y, Shi L, “Integrated emergency frequency control method for interconnected AC/DC power systems using centre of inertia signals,” IET Gener. Transm. Distrib., vol. 6, no. 6, pp. 584–592, 2012.
[16] Silva, B.; Moreira, C.L.; Seca, L.; Phulpin, Y.; Peas Lopes, J.A., “Provision of Inertial and Primary Frequency Control Services Using Offshore Multiterminal HVDC Networks,” IEEE Transactions on Sustainable Energy, vol. 3, no. 4, pp. 800-808, 2012.
[17] Qing-Chang Zhong, and G. Weiss, “Synchronverters: Inverters That Mimic Synchronous Generators,” IEEE Transactions on Industrial Electronics, vol. 58, no. 4, April 2011.
[18] P. Rodriguez, “Synchronous power controller of a generation system based on static power converters,” Patent Number: WO 2012/117131, Priority date: 28 Feb. 2011.
[19] P. Rodriguez, J. Ignacio Candela and A. Luna, “Control of PV Generation Systems using a Synchronous Power Controller,” IEEE Energy Conversion Congress and Exposition, ECCE, USA, 2013.
[20] Luis M. Castro, and Enrique Acha, “On the Provision of Frequency Regulation in Low Inertia AC Grids Using HVDC Systems,” IEEE Transactions on smart Grid, 2016.
[21] M. Guan, W. Pan, J. Zhang, Q. Hao, J. Cheng, and X. Zheng, “Synchronous Generator Emulation Control Strategy for Voltage Source Converter (VSC) Stations,” IEEE Transactions on Power Systems, vol. 30, no. 6, 2015.
[22] J. Alipoor, Y. Miura, and T. Ise, “Power System Stabilization Using Virtual Synchronous Generator With Alternating Moment of Inertia,” IEEE Journal of emerging and Selected Topics in Power Electronics, vol. 03, no. 2, 2015.

[23] M. Ashabani and Y. Abdel-Rady I. Mohamed, “Novel Comprehensive Control Framework for Incorporating VSCs to Smart Power Grids Using Bidirectional Synchronous-VSC,” IEEE Transactions on Power Systems, vol. 29, no. 2, March 2014.
[24] Gonzalez-Longatt, F.M.: 'Effects of the synthetic inertia from wind power on the total system inertia: simulation study', Int. Symposium on Environment Friendly Energies and Applications (EFEA), pp. 389-395, 2012.
[25] Driesen, J., Visscher, K., “Virtual synchronous generators,” IEEE Proceeding on Power and Energy Society - General Meeting, 2008.
[26] J. Zhu, C. D. Booth, G. P. Adam, A. J. Roscoe and C. G. Bright, “inertia Emulation Control Strategy for VSC-HVDC Transmission Systems,” IEEE Transactions on Power Systems, vol. 28, no. 2, May 2013.
[27] Jiebei Zhu, Josep M. Guerrero, “Generic inertia emulation controller for multi-terminal voltage-source-converter high voltage direct current systems,” IET Renewable Power Generation, vol. 8, issue7, 2014.
[28] E. Rakhshani, D. Remon, A. Mir Cantarellas, and P. Rodriguez, “Analysis of Derivative Control Based Virtual Inertia in multi-area highvoltage direct current interconnected Power Systems,”IET Generation Transmission & Distribution, vol. 10, issue. 6, 2016.
[29] H. Bevrani, T. Ise, Y. Miura, “Virtual synchronous generators: A survey and new perspectives,” Electrical Power and Energy Systems, vol. 54, pp. 244–254, 2014.
[30] N. Rampersadh, Innocent E. Davidson, “Grid Energy Storage Devices,” 2017 IEEE PES-IAS PowerAfrica.
[31] Mohamed I. Daoud, Ahmed M. Massoud, Ayman Samy Abdel-Khalik, Ahmed Elserougi, Shehab Ahmed, “A Flywheel Energy Storage System for Fault Ride Through Support of Grid-Connected VSC HVDC-Based Offshore Wind Farms” IEEE Transactions on Power Systems.
[32] Ali, Mohd.H.; Tamura, J.; Bin Wu, "SMES strategy to minimize frequency fluctuations of wind generator system," Industrial Electronics, 2008. IECON 2008. 34th Annual Conference of IEEE , vol., no., pp.3382,3387, 10-13 Nov. 2008.
[33] E. Rakhshani, D. Remon, A. Mir. Cantarellas, J. M. Garcia, and P. Rodriguez, “Virtual Synchronous Power Strategy for Multiple HVDC interconnections of Multi-area AGC Power Systems”, IEEE Transactions on Power Systems.
[34] IEEE standard 14 bus test system line data and bus data as per standers.



10.22214/IJRASET

INDEX COPERNICUS

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Call : 08813907089 (24*7 Support on Whatsapp)