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A Novel Approach for Designing a Subsynchronous Damping Controller

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Abstract—**In this paper a simple and novel additional subsynchronous damping controller (SSDC) is proposed for STATic synchronous COMpensator (STATCOM) to damp out subsynchronous oscillations in a series compensated transmission line power system. The subsynchronous damping controller (SSDC) which uses remotely located generator rotor speed deviation signal as the stabilizing input signal to damp subsynchronous oscillations has been designed. Transient simulations of detailed nonlinear system and FFT analysis are considered to investigate the performance of the controller. This paper deals with 48-pulse GTO based Voltage Source Converter. The IEEE Second Benchmark system is considered for the analysis of subsynchronous resonance (SSR) and the transient simulations of the entire system with STATCOM are performed in the MATLAB/Simulink environment.**

Index Terms— **FFT Analysis, Rotor Speed Deviation, SSDC (SubSynchronous Damping Controller), SSR (SubSynchronous Resonance), STATCOM, and Voltage Source Converter.**

I. INTRODUCTION

Increased power flow on transmission lines can be achieved by the use of: 1. Series compensation to partly compensate the transmission line reactance using series capacitors. 2. Shunt compensation to maintain voltage at appropriate buses in the power system network by reactive power compensators. Since 1950 series capacitors have been extensively used as an effective means of increasing the power transfer capability of a power system which has very long transmission lines (240 kms or more). In addition of being a perfect means of VAR and voltage control series capacitors notably increase transient and steady state stability limits. Till 1971 it was believed that up to 70% series compensation can be used in any transmission lines. However, in 1970 and in 1971, in southern Nevada, a 750 MW cross compound Mohave turbine-generator experienced shaft damage. It was learnt that series capacitors can create unpropitious interaction in between the series compensated electrical system and the spring mass mechanical system of the turbine-generator. This phenomenon is known as subsynchronous resonance (SSR). It is due to a resonant condition, having a natural frequency less than the fundamental frequency of the power system [1, 2]. This has led to the research in finding remedies and countermeasures for the subsynchronous resonance phenomenon.

Many of the counter measures to mitigate subsynchronous resonance problem have been reported by the authors in different papers [3-5]. In general most of the methods for SSR mitigation falls into the following categories (a)

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using Flexible AC Transmission Systems (FACTS) and (b) using generator controls viz. Excitation system and Power System Stabilizer (PSS).Power System Stabilizer has been one of the traditional devices used to damp out the low frequency oscillations in a power system. But during certain operating conditions, PSS may not mitigate the oscillations effectively. Hence the other effective alternatives are required in addition to PSS. On the other hand, the advent of FACTS devices has led to a new and more versatile approach to control the power system in a desired way.

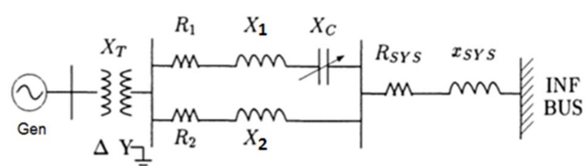
FACTS controllers are power electronic based controllers which can impact transmission system voltages, currents, impedances and/or phase angle promptly. So, such controllers can improve the security of a power system by enhancing its transient and steady state stability or by damping the subsynchronous resonance oscillations. Damping can be improved by using any one of the FACTS devices, which offer a means to mitigate power system oscillations [6, 7].

Among all the FACTS devices, STATCOM has been used effectively by different authors to damp out SSR oscillations [8-13]. STATCOM alone is not sufficient to damp out the oscillations effectively, an additional auxiliary control is needed for the STATCOM. Different authors have used different types of controllers in order to mitigate SSR oscillations. A proper signal should be selected as an input to the controller and it should be fed back either to the current regulator or voltage regulator of STATCOM circuitry.

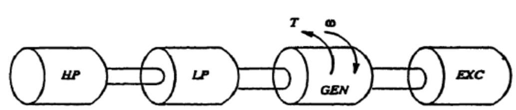
In this paper, IEEE Second Benchmark System is considered for studying the SSR phenomenon and damping performance of STATCOM is compared for the cases with (a) STATCOM without SSDC (SubSynchronous Damping Controller) (b) STATCOM with SSDC. In this paper a novel simple controller is proposed which is able to damp SSR oscillations. The SSDC here takes generator rotor speed deviation signal as the input signal. The performance of the SSDC controller is shown with transient simulations and validated with FFT analysis.

II. Model Power System

The IEEE Second Benchmark System-1 model is considered for the study of SSR [14]. The single line diagram of the system is shown in Fig. 1(a) and Fig. 1(b) shows the mechanical system. It consists of a Turbine-Generator (T-G) unit connected through a transformer and two parallel transmission lines to a very large network represented by an infinite bus. One of the transmission lines is compensated by series capacitor (line 1). The rotating mechanical system of the T-G set comprises of two turbine sections, the generator rotor and a rotating exciter. The generator is modelled in detail using the d and q axis reactance and time constants. The mechanical system is constituted by multi-mass spring damper system comprising of four masses: Mass 1- Generator; Mass 2 – Low Pressure (LP) Turbine; Mass 3 – High Pressure (HP) Turbine and Mass 4 – Exciter as shown in Fig. 1(b). An IEEE Report 1992 has described the modelling of hydraulic turbine and control model of turbine for dynamic studies [15]. Excitation system and Power System Stabilizer (PSS) are included to make the system closer to practical excitation systems. The parameters of the system are described in [1].



(a)



(b)

Fig.1 (a) IEEE Second Bench Mark System (b) Mechanical System

The analysis is carried out at a compensation level provided by the series capacitor at 55% of the reactance X_{L1} of line 1. The magnitude of the generator terminal voltage and infinite bus voltages are set at 1.0 pu respectively. The rating of the STATCOM is considered to be +/- 100 MVAR and is connected at the middle point of the second transmission line (line2). The perturbation considered is a three phase fault applied at t=0.02 sec and removed after 0.017 sec.

III. STATCOM MODEL

The STATCOM is a shunt compensation device of FACTS family. It regulates the voltage by generation or absorption of reactive power. The converter used in STATCOM is a harmonic neutralized 48 pulse Gate Turn-Off (GTO) thyristor based Voltage Source Converter (VSC) [16]. The 48 pulse VSC comprises of four identical 12 pulse GTO converters interlinked by four 12 pulse zigzag transformers with phase shifted windings [17]. The dc bus voltage V_{dc} of 48 pulse VSC is connected to four three phase inverters. The four voltages of he inverters are applied to the secondaries of the transformers which are connected either in Wye (Y) or in Delta (Δ). The four transformer primaries are connected in series fashion and the converter pulse patterns are phase shifted so that the four fundamental voltage components sums up in phase on the primary side.

IV. CONTROL SYSTEM OF STATCOM

The control system of the STATCOM with SSDC which was implemented in the study is shown in Fig. 2. The control system consists of a (1) phase locked loop (PLL) which is used to synchronize the positive sequence component of the three phase primary voltage V_1. The output of the PLL ($\theta=\omega t$) is used to compute the direct-axis and quadrature-axis components of the AC three phase voltages and currents (labelled as Vd, V_q, or I_d, I_q in the Fig. 2. (2) Measurement systems measuring the d and q components of AC positive sequence voltages and currents to be controlled as well as the dc voltage V_{dc}. (3) An outer regulation loop consisting of an AC voltage regulator and (4) a DC voltage regulator. The output of the AC voltage regulator is the reference current I_{qref} for the (5) current regulator (I_q= current in quadrature with the voltage which controls the reactive power flow). The output of the DC voltage regulator is the angle D_{alpha} which is given as one of the input to the Firing pulse generator block. The current regulator generates the angle α which is given to the firing pulse generator. The AC voltage regulator consists of a PI controller which takes input as voltage measured from the ac system and generates I_{qref} value. STATCOM output current is composed of two factors: reactive current (I_q) and active current (I_d). Reactive current is compared with the reference reactive current I_{qref} in the current regulator block. The resulting error between the two signals is given to the PI controller and after an appropriate amplification results in angle α. This angle defines the necessary phase shift between the output voltage of the converter and the ac system voltage needed for charging (or discharging) the storage capacitor to the dc voltage level required. So, the angle α is added to θ to form the α+θ angle which represents the desired synchronizing signal for the converter to satisfy the reactive current reference.

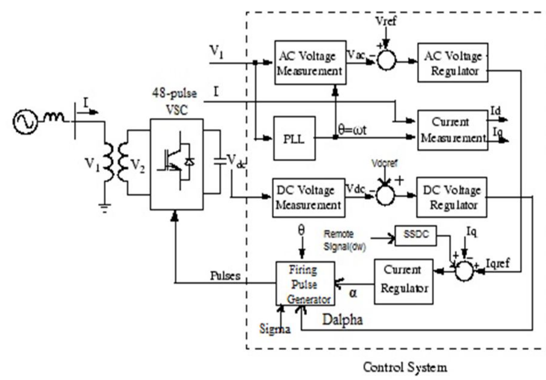


Fig.2 STATCOM and Its Control System’s Block Diagram

The K_p, K_i gains of the PI controller of the both AC voltage regulator and Current regulator should be properly tuned for the effective performance of the STATCOM controller. The DC voltage regulator is used to detect if there is any sudden variation in the DC capacitor voltage. The main aim is to correct the phase angle of the STATCOM voltage with respect to positive or negative sign of the dc voltage variation. Apart from the above mentioned blocks, the STATCOM used in the present study consists of an additional controller block SSDC controller for which the input is given as the rotor speed deviation signal (dω) obtained from the generator (remote location). The output of the SSDC is fed as one of the input to the current regulator block.

V. SSDC (SUBSYNCHRONOUS DAMPING CONTROLLER) DESIGN

The block diagram of SSDC is shown in fig 3. It consists of zero-order hold block, wash-out block and D-controller (Derivative) block. The zero- order hold receives input as rotor speed deviation signal (dω) from the synchronous generator and converts that continuous signal into discrete signal and gives it as an input to the wash-out block. The wash-out block is a high pass filter which is given by the transfer function as shown in fig 3. The value of the time constant T_w should be selected properly such that the SSR oscillations are damped out successfully. The signal from the wash-out block goes to the D-controller. The value of K i.e., gain of the D-controller is selected accordingly for successful damping of SSR oscillations. The rate limiter is used to limit the output from the D-controller. The signal from the SSDC controller goes to the current regulator input as shown in fig 2 and combines with the error signal generated from the current regulator.

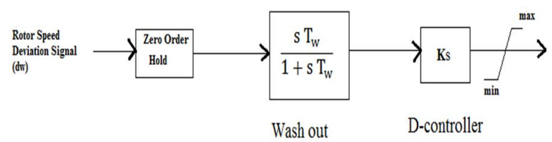


Fig.3 Block Diagram of SSDC (SubSynchronous Damping Controller)

Thus the STATCOM control system along with SSDC not only regulates reactive power but also is used to damp out SSR phenomenon.

VI. SIMULATION RESULTS

The simulation of the power system under study i.e., the IEEE Second Benchmark System with the STATCOM which is considered for studying SSR is shown in fig 4. The second transmission line is divided into two halves and the STATCOM is connected at the middle of the line (line 2). The stimulus i.e., three phase fault is considered in the first half of line 2. The simulation is carried out in MATLAB/SIMULINK environment for compensation ratio of 55%. Fig 5 shows the speed deviation of the generator (dω). It is observed that there is sustained growth in torsional mode of oscillations. It is clear from this that the system is unstable as the oscillations are growing with time. Thus there is a need to damp out these oscillations, otherwise failure of the system takes place and in worst cases shaft may break.

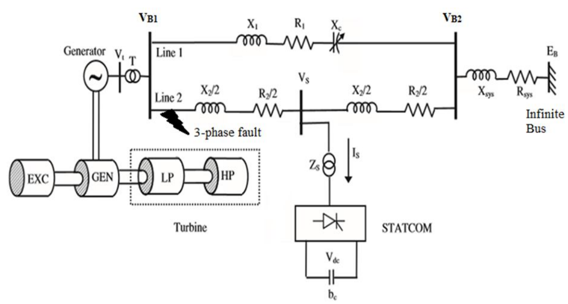


Fig.4 IEEE SBM system-1model with STATCOM

The speed deviation signal when STATCOM is applied without SSDC is shown in fig 6. Even in the presence of STATCOM the SSR oscillations are not damped out completely. So an additional control called SSDC (SubSynchronous Damping Controller) is adapted in the control system of STATCOM to successfully damp out these oscillations. After applying SSDC the oscillations are effectively damped out. This is clear from the fig 7 which shows the speed deviation signal when STATCOM with SSDC is applied. With increasing time the oscillations in the speed deviation die down completely which shows the effectiveness of SSDC in damping out SSR. The transient simulation results are validated using FFT analysis. The analysis is carried for 2-4 s with the fundamental frequency of 60 Hz. The FFT analysis of speed deviation signal is shown in fig 8 before applying STATCOM. After application of STATCOM there is some reduction in amplitude of mechanical modes of oscillations as shown in fig 9. Fig 10 shows the FFT analysis of STATCOM with SSDC which shows that the system is stabilized as there is reduction in the amplitude of oscillations.

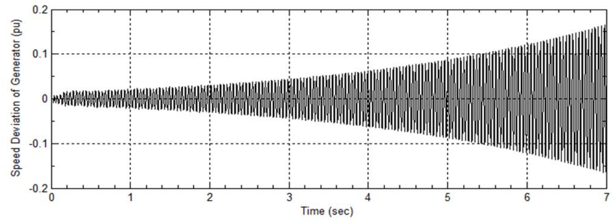


Fig. 5 Speed Deviation signal without STATCOM

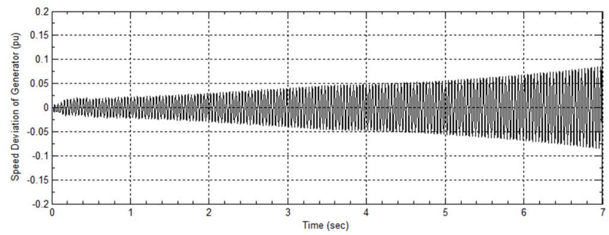


Fig.6 Speed Deviation signal with STATCOM without SSDC

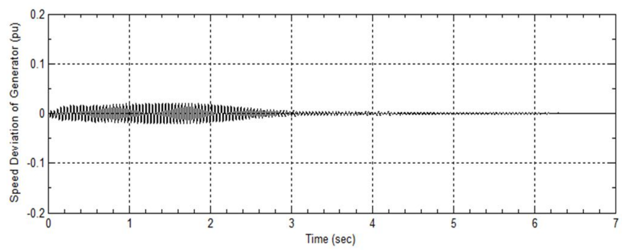


Fig.7 Speed Deviation signal with STATCOM and SSDC

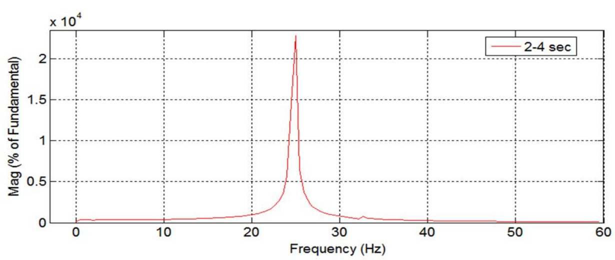


Fig.8 FFT analysis of speed deviation signal without STATCOM

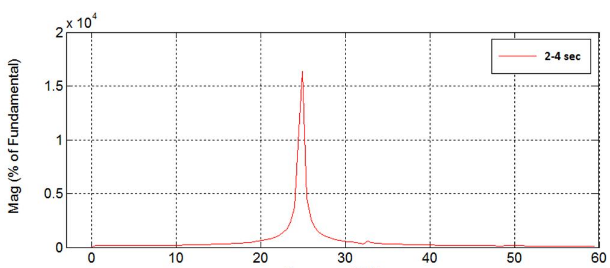


Fig.9 FFT analysis of speed deviation signal with STATCOM without SSDC

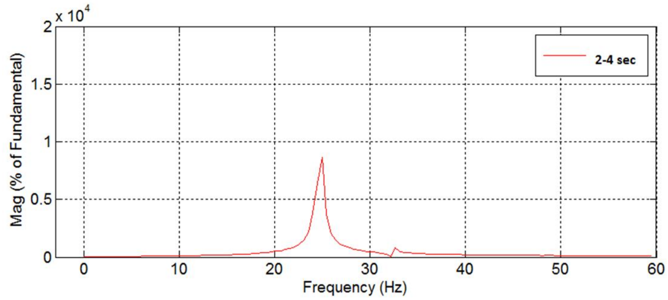


Fig.10 FFT analysis of speed deviation signal with STATCOM and SSDC

VII. CONCLUSIONS

A novel and simple controller SSDC for SSR oscillations damping is studied. The presence of STATCOM with voltage control showed only a marginal damping of the torsional oscillations. A STATCOM with SSDC using rotor speed deviation signal (dω) as an input from the generator is designed. The study results showed that such a controller is capable of delivering optimum performance. Unlike, other FACTS devices such as SVC, TCSC and TSSC, the implementation of STATCOM for SSR damping is simpler and flexible as it eliminates bulky passive components (capacitor and reactor). The excellent performance of the controller makes it ideal to be implemented in real time because of its simplicity and practicality.

REFERENCES

[1] P. M. Anderson, B. L. Agrawal, J. E. Van Ness, "Subsynchronous Resonance In Power Systems", *Newyork: IEEE Press*; 1990.

[2] Farmer RG, Schwalb Al, Katz E. Navajo project report on subsynchronous analysis and solution. IEEE Trans 1977; PAS-96: 1226-32.

[3] RajendraBhombe, AkhileshNimje, "Sub-Synchronous Resonance Control Using Thyristor Controlled Series Capacitor", *International Journal of Application or Innovation in Engineering & Management (IJAIEM)*, ISSN 2319-4847, 2013.

[4] Sujatha Subhash, B. N. Sarkar, K. R. Padiyar, "A novel control strategy for TCSC to damp subsynchronous oscillations", *IEEE Seventh International Conference on ACDC Power Transmission*, London, November 2001, (Conf. Publ. No. 485)..

[5] K. R. Padiyar, NageshPrabhu. "Design and Performance Evaluation of Subsynchronous Damping Controller With STATCOM", *IEEE Trans Power Deliv* July 2006;21(3):1398-405.

[6] Hingorani ANG, Gyugyi L, "Understanding FACTS concepts and technology of flexible AC transmission systems", *Newyork: IEEE Press*; 2000.

[7] K.R.Padiyar, "FACTS Controllers in Power Transmission and Distribution", *New Age International (P) Limited, Publishers,* ISBN (13): 978-81-224-2541-3, 2007.

[8] Keshavan B.K., Prabhu.N., "Damping Of Subsynchronous Oscillations Using Statcom-A Facts Device", *Power System Technology-* POWERCON;2004.p.12-6.

[9] Majid Al-Dabbagh, Nadia Yousif, "Subsynchronous Resonance Damping in Interconnected Power Systems", *AUPEC (*Australasian Universities Power Engineering Conference),2002.

[10] Daye Yang, Liangeng Ban, Yanlong Sun, Yizhen Wang, "Application Of STATCOM For Damping Subsynchronous Resonance In A Multi-Machine System", *Scientific Research Journal, Engineering,* 2013, 5, 180-184.

[11] Ghorbani. A, Pormohammad. S, "A novel excitation controller to Damp Subsynchronous Oscillations, Electrical Power Energy Systems, 2011; 33:411-9.

[12] Chow JH, Ren Haoxing, Sanchez-Gasca Juan J, Wang Shaopeng, " Power System Damping Controller Design Using Multiple Input Signals", *IEEE Control Sys Mag,* 2000:82-90.

[13] Amir Ghorbani, Babak Mozaffari, A.M. Ranjbar, "Application of subsynchronous damping controller (SSDC) to STATCOM", *Elsevier, Electrical Power and Energy Systems,* 43 (2012) 481-426. IEEE Subsynchronous Resonance Working Group of the Dynamic System Performance Subcommittee Power System Engineering Committee, "Second Benchmark Model For Computer Simulation Of Subsynchronous Resonance", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-104, No. 5, May 1985.

[14] IEEE Subsynchronous Resonance Working Group of the Dynamic System Performance Subcommittee Power System Engineering Committee, "Second Benchmark Model For Computer Simulation Of Subsynchronous Resonance", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-104, No. 5, May 1985.

[15] IEEE committee report, "Dynamic Models For Steam and Hydro Turbines In Power System Studies", IEEE transactions on power apparatus and systems, vol, PAS-92, no 6;1973.p.1904-15.

[16] El- Moursi MS, Sharaf AM, “Novel controllers for the 48-pulse VSC STATCOM and SSSC for voltage regulation and reactive power compensation”, *IEEE Transactions on Power Systems*, November 2005;20(4):1985-97.
[17] A. Salemnia, M. Khederzadeh, A. Ghorbani, “Mitigation of Subsynchronous Oscillations by 48-Pulse VSC STATCOM Using Remote Signal”, IEEE Bucharest Power Tech Conference,Romania,2009.
[18] Mathur RM, Varma RK. Thyristor-based FACTS controllers for electrical transmission systems. NewYork (USA): IEEE Press and Wiley Interscience; 2002.