Power System and Strategy for Damping of Synchronous Modes of Oscillations

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ABSTRACT

This paper introduces a new method for dampening torsional oscillations due to subsynchronous resonance (SSR) of a condenser-compensated power device by regulating the Superconducting Magnetic Energy Storage (SMES) unit's firing angles. Depending on the operational conditions and the form of disruption, the benefit from the SMES controller is produced on-line. The proposed SMES unit control approach for stabilization of the power system was evaluated on the first IEEE benchmark model for subsynchronous resonance studies. Using the non-linear device model, complex simulations are carried out. The SMES device has been found to be very successful in reducing the slowly rising transients that originate from unstable modes.

Keywords: SSR, Energy Storage, SMES.

1. INTRODUCTION

1.1 NATURE OF POWER SYSTEM OSCILLATIONS

Synchronous generators should spin at the same pace in an integrated power grid and power flows across tie-lines should stay steady under standard operating conditions. However, when a disruption is added to the power system, low frequency electromechanical oscillations can occur. In most control device variables, such as bus voltage, line current, generator speed and power, these oscillations may be observed. Oscillations of the power grid were first detected as soon as synchronous generators became interconnected to provide the power system with more generating energy and more stability. Originally, at frequencies of about 1-2 Hz, the very tightly coupled generators were found to swing toward each other. To prevent the amplitude of oscillations from rising, damper windings on the generator's rotor were used. Since the implementation of fast excitation systems to avoid the generators from loosening synchronism following a device breakdown, it was noted that this form of excitation method often appears to decrease the damping of oscillations of the machine. Power System Stabilizers (PSS) were therefore commonly used to apply damping torque and improve the damping of these oscillations, which are the damping regulators dependent on the excitation system. In the 1950s and 1960s, along a very long transmission line, power companies began linking to other companies to gain more stability and economy. However, as a consequence of this interconnection, very low frequency oscillations (0.1-1Hz) were found where the generators in one field shifted very slowly towards those in the adjacent regions. In certain instances, these low frequency rising oscillations prevented the preservation of the interconnection and induced custom loads to lose power supply (Graham Rogers 2002). Oscillations of the control grid are a part of the mechanism and they are unavoidable. From an operational point of view, though, as long as they decay, oscillations are appropriate. Oscillations of the power grid are caused by regular minor shifts in machine loads, and after a major interruption, they get far worse. The power movement of the large transmission line for the failure of the integrated western US / Canada grid in August 1996 is seen in Figure .1 (Graham Rogers 2002). The initial fault (occurred in Figure.1 at approximately 400 seconds) induces a system oscillation at approximately 0.26 Hz; the cascading disruptions (faults and defensive relaying operation) caused the oscillation to increase in amplitude and caused the final breakdown of the entire device by this increasing oscillation. As a consequence, the grid was divided into isolated regions and the electricity sources were lost to a large number of consumers. On August 14, 2003, a similar outage occurred.

For the system's safe activity, the damping of power system oscillations within interconnected areas is quite necessary. Some of the findings published in (Klein et al 1991, Momoh and Hawary 1999, Graham Rogers 2002, Guoping Liu et al 2004, Bikash Pal and BalarkoChaudhuri 2005) showed that in several power systems worldwide, electromechanical oscillations triggered by the contact between the electrical transmission device and the generator mechanical system were observed. The oscillations may be localized (localized oscillations) to a single generator or generator plant or may include a variety of geographically widely dispersed generators (inter-area oscillations). When a rapid exciter is used on the generator, local oscillations frequently occur and power system stabilizers have been designed to control these oscillations. As the device loading is increased over the poor transmission links in the scheme that characterizes these oscillations, inter-area oscillations can occur. Generator angle or line angle oscillations are commonly synonymous with disruptions in the transmission grid and may occur due to load shifts in stages, abrupt generator voltage adjustments, transmission line switching, and short circuits. Dampening these oscillations as soon as possible is necessary because they can cause mechanical wear in power plants and many issues with power quality. If more problems arise, the device is still susceptible. These oscillations may trigger absolute or partial power interruption if not regulated (Noroozian and Andersson 1995, Graham Rogers 2002). The rapid development of power electronics has made FACTS controllers very significant in terms of sensor implementations in power systems in recent years. Noroozian et al (1997) also published a number of research work addressing oscillation damping change by the use of VSC-based series and shunt FACTS controllers. The STATCOM and the SSSC are used here for providing or extracting reactive electricity. The suppression of power system oscillations may be done by adjusting the speed Z (and hence the unit angle G) of the generator, thus monitoring its output capacity. Here, in the presence of FACTS instruments, the transient energy function (TEF) approach proposed by Haque (2006) is used to test the damping of a power source. There are two components to the transient energy feature, Kinetic Energy (KE) and Potential Energy (PE). The electrical output power of the unit declines significantly over the fault cycle, whereas the input power to the prime mover stays unchanged and thus gains some surplus energy from the overall operation. This extra energy speeds up the devices, thereby allowing the kinetic energy and the potential energy components of the energy mechanism to rise. When the fault is cleared, the mechanism of energy transfer takes place (from kinetic energy to potential energy and vice versa). The devices initially oscillate and eventually stabilize at the Stable Equilibrium Point (SEP) where the transient energy is negligible for a stable condition. The transient energy obtained in the fault cycle is therefore dissipated in the post-fault phase during the energy transfer process before the device hits the SEP. The more rapidly the energy dissipates, the quicker the SEP is hit by the device. In the Matlab / simulink setting, a single generator linked to an infinite bus system equipped with VSC-based STATCOM and SSSC devices is simulated.

Series capacitor mitigation is a widely employed strategy to improve the power transfer capacity to commercially reasonable levels of a power system's high voltage long transmission lines. It often has the additional bonus of retaining the control of the line within tolerable margins. One big downside to such capacitor relief, though, is that SubsynchronousResonance(SSR) is vulnerable to such schemes. This happens because the subsynchronous frequency of the electrical components (such as transmission lines, condensers in series, transformers and generators) is similar to the normal torsional frequency of the turbogenerator mechanical components. Transient currents of subharmonic frequency are excited at some device interruption, such as line flipping or load shift, and this inevitably contributes to broad electromechanical oscillations that frequently result in generator tripping, circuit divergence and, in certain situations, mechanical collapse of the process shafts. Except in situations when no mechanical loss happens, the extreme stresses triggered by extremely high frequency torques inevitably decrease the shaft life due to mechanical fatigue[1]. The subsynchronous resonance issue has gained a lot of attention since the two shaft failures at the Mojave generating station in 1970 and 1971, and the IEEE (SSR) working group has suggested countermeasures such as static and dynamic filters and specific excitation device dampers to avoid or mitigate the problems caused by SSR[2-4]. In view of the fact that the torsional oscillations are triggered by the unfavorable portion of the energy exchange between the electromechanical turbogenerator mechanism and the electrodynamic control system, energy storage systems are good candidates to solve this issue. The usage of massive superconducting electromagnets as a competitive alternative medium for storing electrical energy, similar to that of power batteries, fly wheels and fuel cells, has culminated in recent advances in superconductive technology. These devices may also be used for power system stabilization in addition to load leveling. The usage of the SMES device for the removal of SSR has created a lot of interest in recent years after the active commissioning of a SMES device of considerable scale in 1985. Superconducting storage devices for magnetic energy have the capacity to retain energy in their low resistance coils. Depending on the device specifications, the energy may be moved to or / from the machine. It is possible to monitor the sum of energy supplied or obtained by it by adjusting the firing angles of the converters in the SMES array. The usage of the SMES device for transient power system stabilization, dynamic stability, load frequency regulation and stabilizing transmission lines[5,6] has been documented in a variety of papers. SMES damp SSR implementations have recently been documented in the first and second IEEE benchmark models[7-9]. A new method of regulating the compensating force of the SMES to damp subsynchronous oscillation in the power system is described in this article. Based on the form of disruption and the ranking of the SMES unit, the revenue from the SMES controller is determined on-line. The SMES voltage needed is obtained from the power and the corresponding firing angles of the converters can be measured using the sensed SMES current until the SMES voltage is defined. In controlling the unregulated subsynchronous modes, direct generation of the compensating power from the SMES unit allows the control strategy quite effective.

1.2 LITERATURE REVIEW

Numerous studies on the damping of low frequency oscillations of the power system have been performed and written. Any of the reported work in this field will be discussed in this portion.

Demello and Concordia (2016) were the first to describe the oscillation phenomenon through the principles of synchronous and damping torques and claimed that the cause of oscillation or instability is the absence of sufficient damping torque. To study the existence of low frequency electromechanical oscillations in power systems, they used a single-machine infinite-bus (SMIB) device and developed a linearized model of an asynchronous generator and its excitation device attached to an infinite bus in the form of a block diagram. The authors came up with expressions of torques on the basis of this block diagram and thus showed the influence of the excitation mechanism on stability; usually, AVR acts raise the synchronizing torque and unintentionally decrease the damping torque. Based on this interpretation, to compensate for this negative effect on damping torque induced by the excitation mechanism, the authors used frequency domain methods to build a speed-dependent PSS and demonstrated efficiency by analog simulation.

The theoretical work and systematic process to evaluate PSS parameters for broad power production in a realistic control system was given by Kundur et al (2018). In this article, the basic PSS concept idea is based on the stabilizer suggested by Demello and Concordia (1969). However, instead of a single process model, the step characteristics were obtained using a multi-machine eigenvalue software. This review stressed enhancing the overall reliability of the device, and the authors considered simultaneous damping of inter-area and local modes and examined the efficiency of the PSS under various system conditions. The authors have evaluated the transient stability efficiency of the PSS and the output during device islanding, in addition to poor signal stability performance. The authors also showed the significance of adequate choice of constant washout period, limits of stabilizer performance and other parameters of excitation device power. The authors concluded that it was reasonably safe to use the frequency response approach used to adjust for the gap between the excitation feedback and the electric torque.

Hsu and Cheng (1990) suggested a PSS focused on the principle of fuzzy sets. As the input signals to the blurry stabilizer, speed deviation ('Z) and acceleration (x' Z) were selected. In order to construct a mapping relationship from inputs to control output, a classical Mamdani style fuzzy framework was used. A seven-by-seven rule table was used, and all the membership functions were calculated based on the knowledge of the authors and no optimization was contemplated in their paper on these membership functions. The proposed PSS was evaluated on a nine-bus device with two computers, including an infinite-bus. As opposed to a traditional lead-lag PSS, the findings recorded showed better damping.

Some papers have been published (Hiyama 1990, Hiyama 1994) on implementing rule-based fuzzy logic controllers to balance power systems. As two inputs, the author exploited speed deviation and acceleration and created a phase plane. The step plane has been split into many sectors covering numerous control regions and involving various control acts. The plurality of parameters used in this controller is described and sequentially optimized in a linguistic type. On a SMIB system and a 3-machine 9-bus system, simulations were conducted. The findings demonstrated enhancement of damping over synthetic stabilizers. Hiyama et al (1994) implemented a PID (Proportional + Integral + Derivative) style fuzzy logic control system stabilizer; the speed deviation integration data was often used as one input and, depending on the integral signal, the center of the phase plane was shifted left or right. To prove the feasibility of the adjustment, both simulations and experiments were conducted. In his sequence of research works, Hiyama's heuristic dependent method demonstrated some progress. In his thesis, though, the fuzzy PSS parameters were not globally configured since he stated that the parameters were fairly responsive to external conditions. In fact, in the cases considered in his design, this method was only considered robust.

Barton (2014) proposed a powerful PSS (ANFPSS) dependent artificially intelligent Adaptive Neuro-Fuzzy Inference System (ANFIS) architecture to dampen electromechanical oscillation modes and improve synchronous synchronization of the power system. An entire power device was split down into different subsystems; one unit consisting of each subsystem. With each subsystem, the local ANFPSS was connected. Only knowledge unique to their subsystem was based on the local input controllers. The velocity, power angle and actual power production were the input signals. The ruggedness of the ANFPSS was demonstrated through nonlinear simulations.

A very fascinating control technique for SVC and TCSC was suggested by Noroozian et al (2001). In an energy method, the writers integrated the concept of SVC and TCSC and then extracted the control rule by taking the energy function derivative and rendering this derivative negative. The authors have stated that each system

would lead to the damping of power swings by using this approach without synchronization with other damping devices for power oscillation. Ghandhari et al (2001) applied the role principle of Lyapunov to develop a controller for devices in a controllable sequence. By having the derivative of the energy function negative, the authors extracted the control technique. The model used in the creation of the control rules, however, had a particular shape. For obtaining a Lyapunov function, it was rendered easy, but it did not explain real actions of the power mechanism accurately. In the shape of a Hamiltonian device, Ramirez Arredondo (2000) described the power system and developed a passivity-based nonlinear controller for a TCSC to improve the reliability of the power system. Only on the SMIB framework was this control method checked. Del Rosso et al (2003) suggested a hierarchical management method for both complex and steady state equilibrium enhancement. Also proposed were management mechanisms to minimize detrimental relations between the hierarchical controls of the TCSC. In this article, using the equal area criterion, the authors qualitatively evaluated and contrasted distinct locally observable input signals. However, the authors centered only on comparing the usage of active power and line current asinput signals due to the restriction of the system, and did not make any attempt to examine the probability of using bus voltage and bus frequency as internal signals to the damping controller.
Wang (2019) developed a linearized Phillips-Heffron power system model mounted with a STATCOM and demonstrated the model's implementation in the study of the STATCOM's damping effect. Both SMIB and multimachine power device incidents were examined. The work was then enlarged to explore the detrimental experiences between the regulation of STATCOM AC and DC (Wang and Li 2000, Wang 2003). For the unified regulation of STATCOM AC and DC voltages, a technique to build a decoupled multivariable sampled regulator for multi-input multi-output systems was implemented to address the recorded negative interaction.

1.3OBJECTIVES OF THE STUDY

1. To help the damping of power system oscillations, and there are also many different control methods for the damping controller design.
2. To analyses the strategy for damping of synchronous modes of oscillations

1.4SYSTEM MODELLING

The device examined in this paper is the first IEEE benchmark model[3], which consists of a turbogenerator linked to the infinite bus by a transmission line compensated by a capacitor, as seen in Fig.1. To maximize the damping of the SSR modes, the superconducting magnetic energy storage device is situated at the generator bus terminal. The generator 's dynamic activity is represented by the non-linear maximum current model [1,2]. A set of 27 order non-linear differential equations for the system without SMES can be obtained by combining the mass-spring system, armature and field windings, excitation system, governor system, and capacitor compensated transmission line. The mass-spring mechanism consists of six bodies, such as the high-pressure turbine (HP), the medium-pressure turbine (IP), the two low-pressure turbines (LPA and LPB), the generator (GEN) and the exciter (EXC), all of which are attached to the same shaft. Fig. Fig. 2 displays the SMES unit setup. It consists of a superconducting inductor of dc, an AC / DC converter of 12-pulse cascaded bridge form and a Y-D / Y-Y-Y-Y converter

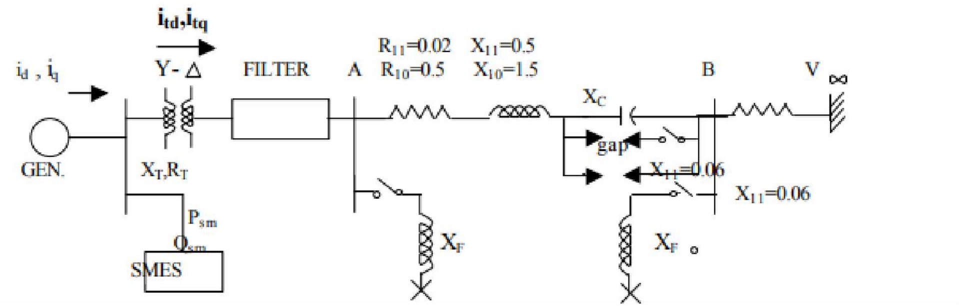

Fig. 1 IEEE First Benchmark Model for SSR

Transformer Move Back. Converter firing angle regulation causes a broad variety of positive and negative values to be constantly varies by the dc voltage V_{sm}running around the inductor. Gate Switch OffThyristors (GTO) helps one to develop converters of this nature. The unidirectional converter output current Ism, the regulation for the orientation of the inductor power flow P_{sm}, is obtained by continuously controlling the angle of firing a. Based on the required charging time, the bridge voltage V_{sm} is kept constant at an acceptable positive value for initial charging of the SMES array. The Ism inductor current grows exponentially and$W_{sm}$is retained in the inductor for magnetic capacity. It is sustained by lowering the voltage around the inductor to zero when the inductor current exceeds its maximum value of $I_{sm}0$. The SMES device is then able for torsional oscillation stabilization to be combined with the power grid. The pace of the generator fluctuates due to abrupt application or load denial. The speed decreases at the first moment as the device load grows, but due to the governor's operation, the speed oscillates around the reference point. The converter acts as an inverter (90 ° <a < a and the P_{sm}strength is positive[6]. The superconducting inductor current and voltage are linked as

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

where I_{sm0} is the initial current of the inductor. The real power absorbed or delivered by the SMES unit is
$P_{sm} = V_{sm} I_{sm}$

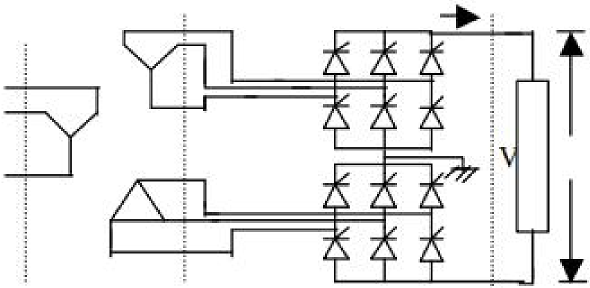

Fig. 2 SMES configuration

If Vsm is positive, power is transferred from power system to the SMES unit. Whereas, if Vsm is negative, power is released from the SMES unit. The energy stored in the superconducting inductor is

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

Where $W_{sm0} = \frac{1}{2} L_{sm} I_{sm}^2$ is the initial energy in the inductor. Because of the constraint of hardware implementation, the current of the inductor has upper and lower limits. As the converter operates in continuous mode, the upper limit of the inductor is 1.38Ism0 , and the lower limit is 0.3Ism0 . The limits of the terminal voltage are ± 0.2532(p.u.) [7].

1.5THE PROPOSED CONTROL SCHEME FOR THE SMES UNIT

The basic framework used in this analysis of the proposed SMES controller as seen in Fig. 2. Generator speed variance (Dώ) is known as the input signal to the SMES controller, utilizing the information acquired from practice. The SMES power P_{sm} needed can be calculated as

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$$P_{sm} = \frac{K_{sm}}{1 + sT_{dc}} \Delta\omega$$

1. Night. Night. From$P_{sm}$and the sensed current Ism, the SMES voltage V_{sm} is then measured. If the magnitude of V_{sm} in the rectifier mode or in the inverter mode reaches V_{sm}, the real V_{sm} is set to match the corresponding limit factor. The V_{sm} settling signal along with this sensed Ism signal gives the active power needed to flow through the converter in such a situation. The following measures are carried out to assess the controller 's income.
2. 1. By simulating it with a considerably broad disruption, taking the observed control structure to the edge of chaos. In the presence of a SMES device, evaluate the maximum deviation Dώmax and maximum derivative ώmax D &. Get the proportion b max max K = Dώ / Dώ&. The value of the constant Kb is observed in the present study to be 0.034 and must be calculated until off-line.
3. From the first few samples of Δώ, calculate the derivative Δώ& on-line for a particular operating condition. and then update the value of Dώ& , if and only if $|\Delta\dot{\omega}| > \Delta\dot{\omega}_{max}$. & . It is necessary because the system's free responses to a transient stimulus will converge via mixed modes of activity to a steady state , i.e. damped and. Unhumidified. Until the device reaches a damped state that is reliable, ώ& remains set.
4. Determine the gain of the SMES controller as follows:

$$K_{sm} = \frac{V_{sm,max}\, I_{sm,\,max}}{K_b \Delta\dot{\omega}_{max}}$$

whereV_{sm},max and I_{sm},max are the maximum limits of converter dc voltage and inductor current for a particular SMES unit. The value of K_{sm} is not fixed but is adapted depending on the operating condition and disturbance.

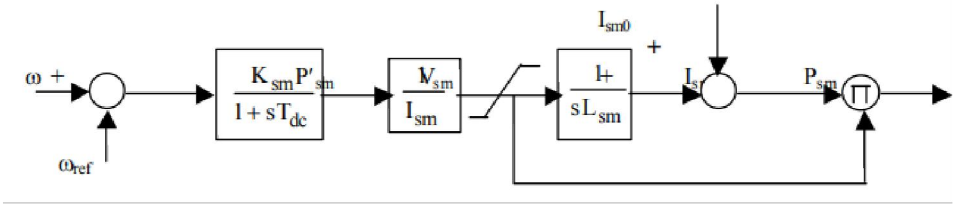
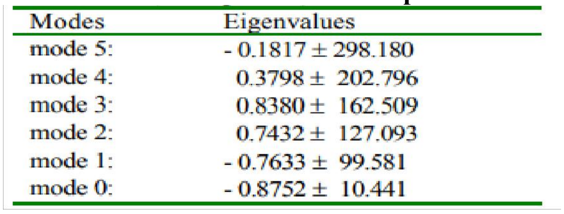


Fig. 3 SMES Controller

1.6 COMPUTER SIMULATION AND PERFORM - ANCE EVALUATION

In order to demonstrate the damping impact of the SMES device with the proposed controller, digital simulations on the non-linear dynamic model of the device are conducted inside the MATLAB setting. Many nonlinearities are often listed, such as the exciter voltage limit and the superconducting inductor's current level. To demonstrate the SMES unit 's output at 100 ms, 0.15 p.u. Shift of torque phase with initial working state, P0 = 1.0 p.u. The disruption is known to be XC / XL = 0.5. The individual values of the different torsional oscillation modes without the SMES device are mentioned in Table 1. It can be found that positive actual sections of the eigenvalues occur in mode 3 and mode 4 that pose a danger to the reliability of the device without the SMES array. From the detailed study of the method, this argument can be further confirmed. Fig. Fig. 4 clearly shows that, as planned, the device without the SMES unit is unstable. The addition of the SMES machine has, however, changed the condition. It is worth noting that the SMES device damps out subsynchronous oscillations with the suggested trigger.

Eigen values of different modes of torsional oscillations P0 =1.0 p.u. XC /XL = 0.5



Modes	Eigenvalues
mode 5:	- 0.1817 ± 298.180
mode 4:	0.3798 ± 202.796
mode 3:	0.8380 ± 162.509
mode 2:	0.7432 ± 127.093
mode 1:	- 0.7633 ± 99.581
mode 0:	- 0.8752 ± 10.441

Fig. 4 shows the system performance with and without the SMES unit following the disturbance. The system oscillations are growing up and after 5 secs., the system

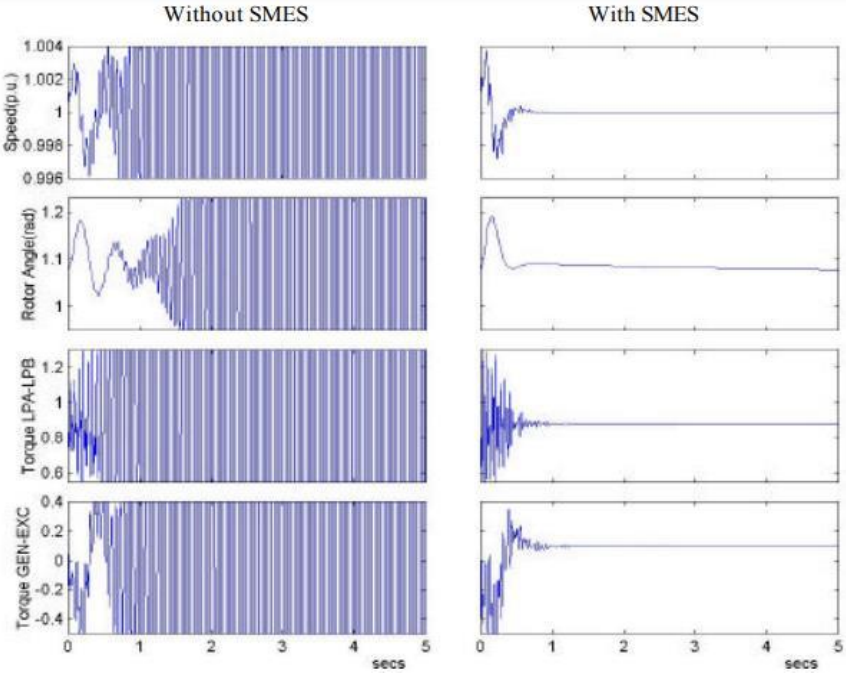


Fig. 4 System performances with and without SMES unit

It's becoming unpredictable. This increasing oscillations can contribute to the failure of the series shaft. These issues can be easily countered by a well managed SMES device. It is noted in the figure that all such oscillations are suppressed by the SMES device and the machine stabilizes within 0.6sec. It therefore reduces the overall variability of the speed and rotor angles. The figure also indicates that the third peak has almost decreased with the inclusion of the SMES device. The figure also indicates that the third peak has almost decreased with the inclusion of the SMES device. These intensified reactions are done for the following reasons:
1. The compensating power is absorbed immediately, allowing the system more vulnerable to interruption.
2. The gain of the controller is balanced based on the degree of the interruption. In this article, reactive power modulation is not included, which is an added stabilization gain. This is under review at present.

2.0 CONCLUSIONS

It presents a method of regulating the unstable modes resulting from the subsynchronous resonance phenomena by regulating the SMES unit 's strength. The control strategy is extracted from the basic premise that, according to the degree of disruption, the SMES device should obtain or transmit electricity. Therefore, the benefit of the controller is modified to make the controller more effective. As is demonstrated in the findings, the unstable synchronous modes owing to series capacitor compensation are canceled by the required transition of compensating strength. Equally efficient at some degree of disruption is the suggested controller for the SMES device. Transient responses indicate that in less than one second, the sub synchronous oscillations are eliminated. This means that, if fitted with appropriate SMES control circuitry, long transmission links with series capacitor compensation can be efficiently controlled.

3.0 REFERENCES

1. Y. N. Yu, “Electric Power System dynamics”,
2. IEEE SSR Working Group, “Third Supplement to a Biography for the Study of Subsynchronous Resonance between the Rotating Machines and Power Systems”, IEEE Trans. on Power Systems, Vol. PWRS-6 pp. 830-834, 1991.
3. IEEE committee, “ First Benchmark Model for Computer Simulation of SubsynchronousResonance” IEEE Trans. on Power Apparatus and Systems, Vol. PAS-96, pp. 1565-1572, 1977.
4. Li Wang and Y. Hsu, “ Damping of Subsynchronous Oscillations Using Excitation Controllers and Static Var Compensators”, IEEE Trans. on Energy conversion, Vol. 3, pp. 6-13, 1988.
5. C. J. Wu and Y. S. Lee, “ Application of Superconducting Magnetic Energy Storage Unit to improve damping of Synchronous Generator”, IEEETrans. on Energy Conversion, Vol. 6, pp. 573-578, 1991.
6. S. Banerjee, J. K. Chatterjee and S.C. Tripathy, “ Application of Magnetic energy Storage Unit as Load Frequency Stabilizer”, IEEE Trans. on Energy Conversion, Vol. 5, pp. 46-51, 1990.
7. Y. S. Lee and C. J. Wu, “Application of Superconducting Magnetic Energy Storage Unit on Damping of TurbogeneratorSubsynchronous Oscillation”, IEE Proceedings-C, Vol. 138, pp. 419- 426, 1991.
8. L. Wang, S. Lee and C. Huang, “Damping Subsynchronous Resonance Using Superconducting Magnetic Energy storage Unit”, IEEE Trans on Energy Conversion, Vol. 9, pp. 770-777, 1994.
9. A. H. Rahim, A.M. Mohammad and M. R. Khan, “Control of Subsynchronous Resonant Modes in a Series Compensated System Through Superconducting Magnetic Energy Storage Units”, IEEE Trans. on Energy Conversion, Vol. 11, pp. 175-180, March 1996.