COORDINATION OF PSS AND FACTS DEVICES FOR POWER SYSTEM STABILITY ENHANCEMENT: A REVIEW OF THE STATE-OF-THE-ART

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ABSTRACT

Power systems stability has been a concern and it will continue to be the major concern in power system operations due to power system oscillations caused by complex interconnections. Efforts have been attracted towards damping the power system oscillations for enhancing stability in power systems. The instability that has been affected by the complex interconnections is the small signal stability. Power system stabilizers (PSS) are promising in damping small signal stability. Although, PSS are confronted with some drawbacks of serious variation in the voltage profiles and it may also results in leading power factor operations which may cause reduction of system stability under heavy disturbances. In large multi-machine power systems, the application of only conventional PSS may cease to provide adequate damping for inter-area oscillations and effect of variation in voltage profile. However, power electronic device known as Flexible Alternating Current Transmission System (FACTS) devices are effective in damping the inter-area oscillations and capable of handling the variations in voltage profile. Therefore this paper presents a comprehensive review and evaluation of PSS and FACTS power oscillation damping (POD) controllers in mitigating low frequency oscillations based on computational intelligence methods. Technical paper publications on design, optimal location and optimal parameter tuning associated with PSS and FACTS based controllers are highlighted. Finally the potential future research directions for novel PSS and FACTS devices is proposed as a reference for interested researchers.

Keywords: power system stabilizers, flexible AC transmission system, low frequency oscillation, SVC, TCSC, SSSC, STATCOM, UPFC.

1. INTRODUCTION

The major characteristic of the modern power systems is the complexity in the interconnections with increasing dependence on controllers for optimum operation of existing resources. In interconnected power systems, particularly in the deregulated setup, the problems of instability are mainly as a result of low frequency oscillations. These oscillations though small in magnitude, but often remained for a long period. In some cases, they continue to rise which have adverse effect and limitations on the power-transfer capabilities and even cause system separation if adequate damping device is not provided (Shayeghi, 2010). In order to provide fast acting damping device, thereby enhancing the dynamic performance, a supplementary control signal in the excitation system and/or the governor system of a generating unit can be used (Eslami M., 2012). To boost the dynamic stability of power systems, conventional power system stabilizers (PSS) popularly known as the fixed parameter lead/lag PSS has been broadly used in the past two decades as the most powerful damping controller for low frequency oscillations. Generators are equipped with PSSs by power system utilities the world over as the first measure to enhance damping and help in preserving consistent performance of the power system stability by providing supplementary feedback stabilizing signal in the excitation systems.

Though, PSSs have been effective in providing damping for low frequency oscillations in power systems, yet, it suffers a drawback of being liable in the variation of voltage profile which may have effect in leading power factor, and may not be able to suppress oscillations resulting from rigorous disturbances, particularly those three-phase faults which may happen at the generator terminals and inter-area oscillations (L. Cong, 2004). Consequently, the recent advances in power electronic have led to the development of the FACTS damping controllers. FACTS damping controllers are coordinated with PSS for damping enhancement in power systems. The introduction of FACTS devices is now the most recent alternative for enhancing damping in power systems (Voci and Mascioli, 2009). Addition of FACTS devices is one of the most recent concepts to ease the aforementioned drawbacks by controlling the power flow along the transmission lines and improving power oscillations damping. Application of FACTS damping controllers increases the flexibility of the operation by exploring more solutions for the power system operators. Generally, FACTS devices are designed to overcome the limitations of the existing controllers in power systems and improve power system stability by using reliable and high-speed power electronic devices. They are also placed in the system to provide fast continuous control of power flow in the transmission system by controlling voltages at critical buses.

This paper provides a broad review and assessment of the performance of PSS and FACTS based controllers is presented. In the literature, the rising interest in this area of damping low frequency oscillations for the past two decades is provided, where the improvement on power system stability by means of PSS and FACTS based damping controllers for damping low frequency oscillations has been extensively investigated. Widespread investigations on the research and enhancements in the area of power system stability development using PSS and FACTS controllers are provided. Paper publications relating the installation of PSS and FACTS installations have been highlighted. PSS and FACTS based controller performance comparison of different optimization technique has also been investigated. An investigation of the literatures from quality web resources and the largest citation databases (web of science including Scopus) is presented in this work.

2. PSS AND FACTS DAMPING CONTROLLER DESIGN

2.1. Mathematical (Algorithmic) methods

Over the years, many design methodologies have been effectively examined to design a high performance damping controllers based on PSS and SVC for damping low frequency oscillations in power systems (Sugihara, Yokoyama *et al*., 2006; Nguyen and Gianto, 2007; Sugihara, Yokoyama *et al*., 2007). In recent years, power systems are largely interconnected and complex nonlinear system (Rabih A. Jabr, 2010), the application of mathematical (algorithmic) methods to the solution of large scale power systems is not simple, even though they have been applied for planning (Rahmat Allah Hooshmand, 2010), operation and control problems (Swasti R. Khuntia, 2011) in power systems for the past few decades. This is because in the real world problems, mathematical formulations are derived under certain assumptions and even with these assumptions it is not easy to obtain optimum solutions. Most recently, deregulation of power system utilities has hosted new problems in addition to the existing problems. It is desirable that solution of power system problems should be optimum globally (Abdel-Magid, 1999; Afzalian, 2000; Abido, 2000; Do Bomfim, Taranto *et al*., 2000). For the purpose of this article the most recently used Computational Intelligence methods (Engelbrecht, 2007) are investigated due to the increasing interest by researchers which may be considered as the most effective in damping low frequency oscillations.

2.2. Computational intelligence techniques

The main point of an argument in algorithmic advancement is the design of algorithmic models to resolve the increasingly complex problems (Panda, 2011). Huge successes have been recorded over the modelling of biological and natural intelligence, resulting in so-called ‘intelligent systems’.

In this paper, five main hypotheses of Computation Intelligence (CI) related to damping low frequency oscillations are considered, namely artificial neural networks (ANN), evolutionary computation (EC), swarm intelligence (SI), artificial immune systems (AIS), and fuzzy systems (FS). Figure-1 summarizes the objectives of the CI. Probabilistic techniques are most often used together with CI techniques (Wang, Chung *et al*., 2001; Lee and Chen 2007; Wang, Chung *et al*., 2009; Bian 2011; Eslami 2011; Ke 2011) far damping low frequency oscillations, which are also shown in the Figure. The arrow heads indicate that each and every technique from different hypotheses can be joined together to form hybrid systems.

Each and every member family in CI paradigms has its origins to simulate in biological schemes (R. C. Eberhart, 1996; Engelbrecht, 2007). EC mimics the natural evolutions, genetic and social evolution is not left out, and SI also mimics the social and interactive behavior of organisms living in swarms or colonies, ANN simulates the biological neural systems, FS originated from studies of how organisms interact with their surroundings and finally AIS models the human immune system.

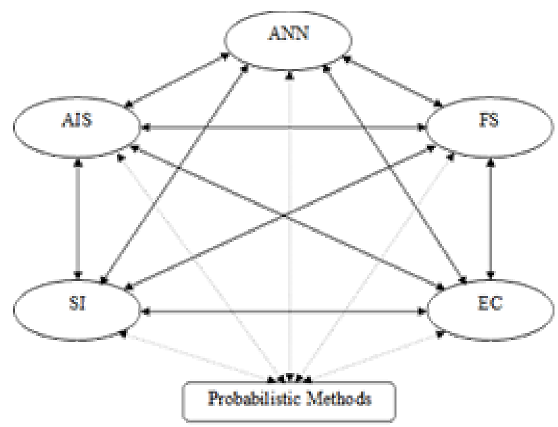

Figure-1. Computational intelligence (CI) paradigms.

2.2.1. Artificial neural networks (ANN)

The ability to learn, memorize and still generalize, prompted research in algorithmic modeling of biological neural systems is known as artificial neural networks (ANN). Many research problems have been reported using artificial neural network (Dash, Mishra *et al*., 2000; Kim and Lee, 2005). An adaptive power system stabilizer based on recurrent neural networks is presented in (He, 1997). The architecture of this proposed adaptive PSS has two recurrent neural networks, one function as a tracker to learn the dynamic characteristics of the power system and the other one function as a controller to damp the oscillations caused by the disturbances. Power system stabilizer design using an online adaptive neuro-fuzzy controller with adaptive input link weights was investigated by (Ramirez-Gonzalez and Malik, 2008) to damp the low-frequency oscillations in power systems by employing neuro-identifier to track the dynamic behavior of the plant. Abido (Abido, 2011) suggested a power system stabilizer tuning study of east central power system in Saudi Arabia for damping low frequency oscillation. A self-tuning power system stabilizer based on artificial neural network has been reported in (Segal, 2004). Adaptive neural network based power system stabilizer design has been investigated by (Liu, 2003). Coordination control of ULTC transformer and STATCOM based on an artificial neural network was put forward by Kim (Kim and Lee, 2005) to reduce the level of tap changes of the transformer as well as STATCOM output while keeping the voltage magnitude at the substation bus at acceptable level. The coordination controller is designed in such a way that a classical ULTC mechanism can be replaced so that the active and reactive powers can utilize tap position and STATCOM output. Tuning of power system stabilizers using an artificial neural network (Hsu and Chen, 1991; Zhang, 1993; Shamsollahi and Malik, 1997; Liu, 2003) are mostly a past ideas. Investigations shows that most of the artificial Neural Network based Power System Stabilizer design appears to be inefficient in its performance and not recently been employed by authors which is not a wise idea to abandoned instead of making an improvement.

Most of the literatures related to using artificial neural networks are in the late nineties, this may be due to the fact that it is associated problems with a single objective can be solved quite easily with moderate sized ANN as constrained by the capabilities of modern computing power and storage space. Despite it have some limitations of working on single objective function; efforts should have been made by researchers to improve on it so that it can accommodate a multi-objective function.

2.2.2. Artificial immune systems (AIS)

An artificial immune system (AIS) models the natural immune system's ability to detect cells foreign to the body (Hunjan, Venayagamoorthy *et al*., 2006). The outcome is a new computational prototype with strong pattern of recognition abilities, mainly applied to anomaly detection (Ridhuan, 2007). It is clear to understand that on the event of discussing artificial immune system, natural immune system has to be discussed even in brief. "Different views on how the natural immune system (NIS) functions have been developed which result to heated argument among immunologists. These models include the classical view of lymphocytes that are used to distinguish between self and non-self, the clonal selection theory where stimulated B-Cells produce mutated clones, danger theory, which postulates that the NIS has the ability to distinguish between dangerous and non-dangerous foreign cells, and lastly, the network theory where it is assumed that B-Cells form a network of detectors." (Engelbrecht, 2007).

AIS was recently used by Ridhuan (Ridhuan, 2007) in designing PSS to damping low frequency oscillations so that stability in power systems can be enhanced. This technique employs the artificial immune controller known as the enhanced Varela immune network stabilizer. This technique can keep memory of the controller parameters to be used online, but then the must have been tune properly and accurately maintained so that it can avoid been keeping track of uncoordinated outcome. SVC scheduling by the use of artificial immune system for loss minimization and voltage improvement is investigated in (Ishak, 2004). Basically, SVC application in improving voltage variation has been known. The power loss minimization is achieved by the artificial immune system to optimize the parameters of the SVC. Artificial immune network theory has been suggested in the Coordination control of multiple damping controllers in (Jin, 2007). Despite immune systems primarily serves in keeping the health of human bodies based on its capability to recognize and react to the interruption of antigens, a method of coordination control established on immune network theory is suggested to handle the multiple damping controllers concurrently in order to maintain a healthy level of power system damping to enhance stability in the system.

2.2.3 Fuzzy systems (FS)

The well-known theories of two-valued or Boolean logic are established theories. Boolean logic found its importance in dealing with the computations where the knowledge of the problems that needed to be solved is encoded in binary forms. It is also important in the development of the original artificial intelligence (AI) reasoning systems particularly the inference engine of expert systems (Ahmad, 2001). unlike Boolean logic, two-valued set theory allowed the development of precise reasoning systems, which introduces a set membership function to be precise (i.e., whether the element belongs to a set or not) (Mokhtari, 2012). Though, these theories have recorded some successes in so many occasions, but it is impossible to use them to solve the other problems using the two-valued logic and sets since they solely depends on mapping the domain into two-valued variables. Majority of the real-world problems are categorized by the ability of a representation language (or logic) to modulate incomplete or uncertain information. Since they are incapable of handling such uncertain information, fuzzy logic sets are capable to handle uncertainties (Fang, 2004).

Generally, fuzzy logic theory has many advantages over other conventional techniques such as the concept is easy to understand since it is based on natural languages, it has the ability to handle ambiguity of expressed in diagnostic processes and tolerance to a data that are precise. Another more advantages of fuzzy systems is that, it can develop a control process between the information about the initial conditions of the system to be controlled (Bansal, 2003).

Survey papers have been suggested by many authors such as Momoh *et al*. (Momoh, 1995) in 1995, which presented the basics principles of fuzzy theory and set of detailed references on various areas of study in power systems using fuzzy applications. Another author presented a comprehensive set of literatures on the application of fuzzy set theory from 1994-2001 and some part of 2002 bibliographies (Bansal, 2003). A quite reasonable number of research papers have also been published in the area of damping low frequency oscillations using fuzzy set theory. Few among the most recent ones are (Abdelazim, 2005; Obulesu, 2011; Raja, 2011; Rohani, 2011; Hassan, 2012; Khazaie, 2012; Lu 2012; Murali, 2012; Nechadi, 2012).

2.2.4 Evolutionary computation (EC)

Evolution is generally a process of optimization that is aimed at improving the ability of living organisms to live in dynamic form around a competitive environment (Falehi, 2012; Farah, Guesmi *et al*., 2012; Alkhatib and Duveau, 2013). The ideas of evolution have posed a lot of argument in that and is still continued to be an area of debate. Evolution can be viewed in a variety of perspective, e.g. chemical, planetary, artificial, organic or cosmic forms of evolution. But for the purpose of this study, focus will be attracted toward biological form of evolution. In trying to define this form of evolution, Darwinian Theory has been summarized in (Engelbrecht, 2007) as each individual is competing with one another in struggling to survive due to limited availability of resources and unstable population rates.

EC is a system of solving problem using computer which employs computational models of evolutionary process. These include survival of the fittest, natural selection and reproduction as the basic concepts. Evolutionary algorithms (EA) components are implemented in different forms as follows (Engelbrecht, 2007). Genetic Algorithm (GA) (Swain, 2011), Differential Evolution (DE) (Tripathi and Panda, 2011), Genetic Programming (GP), Evolutionary Programming (EP) (Joorabian, 2011), Evolution Strategies (ES) (Abido, 2010), Cultural Evolution (CE) and Co-Evolution (CoE). In the study of damping low frequency oscillations in power systems, lot of research papers has been published using evolutionary computations. The most recent among them are; (Mondal, 2011; Vakula, 2012; Wang, 2012) to investigate the damping of low frequency oscillations in power systems so as to improve the stability in power systems.

2.2.5. Swarm intelligence (SI)

Computational Swarm intelligence can be broadly defined as the study of animals and social insects that interact with one another by exchanging locally available information through acting on their local environment to achieve a global goal (Mondal D., 2012). The objective of SI models is to model the simple attitude of individual and their local interactions with their environment and neighboring individuals so as to obtain more complex behaviors which can be employed to solve complex problems like the optimization problems (Banaei, Abbasi *et al*., 2012). Advance methods have been successfully applied to damp low frequency oscillations in power systems. The most popular and most commonly used is the swarm intelligence methods which may be believed due to their robustness and flexibility in allowing modifications to yield a better outcomes. SI refers to all the families of optimizations techniques carried out using the followings but are not limited to Bee Algorithms (BA), Artificial Bee Colony (ABC), Ant Algorithm (AA), Particle Swarm Optimization (PSO), Bacteria Foraging (BF), Ant Colony (AC), Bee Colony, and many more.

Research interests are more concentrated on the SI methods among researchers. The reason may be due to their ability to produce accurate results within a reasonable amount of time and the flexibility of the techniques to accommodate modifications (Morris, 2012). Many research papers have been published in the field of power system oscillation damping using swarm intelligence based techniques (Mondal D., 2012; Mostafa, 2012; Abd-Elazim, 2013). Figure-2 shows a bar chart representation of the publications in the area of low frequency oscillations damping to enhance power system stability using various computational intelligence methods. These reports are based on the literatures from quality web resources and the largest citation databases (web of science including Scopus).

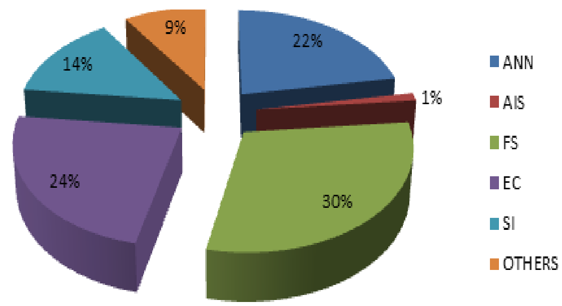

Figure-2. Paper Publications for damping low frequency oscillations using different computational intelligence techniques.

3. HYBRID SYSTEMS

Power System problems especially low frequency oscillations are dynamic and increasingly becoming more and more complex due to increasing complexity of power system interconnections (Alkhatib and Duveau, 2013). Most of the problems may not be solved using the assumptions of a single computational intelligence technique or by the use of the capability and strength of single technique. An alternative to such real world power oscillation problems that cannot be solved using the single technique can be achieved by combining the strength of two or more computational intelligence methods to overcome such optimization problems. The process of combining or integrating two or more techniques in order to achieve the desired set objectives is referred to as hybrid systems. Due to the benefit offered by the hybridization, the use of hybrid techniques to general power systems problems is rapidly growing (Peric, 2012; Vakula, 2012).

4. CONCLUSIONS

The benefits of mathematical methods or algorithmic methods in power system oscillation problems have been presented. They are promising in their solutions but yet are not very fast and reliable in power oscillation problems. The importance and limitations of computational intelligence have been discussed, once the problem is well defined, computational intelligence technique are sufficient in determining the optimal solution. Some of them suffer from the knowledge of the problems as such they are not capable to learn or adapt to the new solutions like the AIS. Fuzzy systems are realistic in describing the power system oscillation problems. ANN is promising in adaptive training process and is generally suggested for further studies of power system analysis. The evolutionary computation in comparison to other techniques has the deep knowledge of the system problem with well-defined models. Swarm intelligence appears to have more potential in power system analysis and they are also the most recent in the field of computational intelligence techniques. Finally hybrid systems have been gaining popularity among power system engineers and it is the novel techniques that provide fast and reliable future trend in power system oscillation problems.

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REFERENCES

A. Afzalian D. A. L. 2000. Training of neurofuzzy power system stabilisers using genetic algorithms. Electrical Power and Energy Systems. 22: 93-102.

Abd-Elazim E. S. A. a. S. M. 2013. Bacteria Foraging: A New Technique for Optimal Design of FACTS Controller to Enhance Power System Stability. WSEAS TRANSACTIONS on SYSTEMS. 12(1): 42-52.

Abdel-Magid Y., Abido MA., Al-Baiyat S. and Mantawy AH. 1999. Simultaneous stabilization of multimachine power systems via genetic algorithms. Power Systems, IEEE Transactions on. 14(4): 1428-1439.

Abdelazim T. a. M., O. P. 2005. Power system stabilizer based on model reference adaptive fuzzy control. Electric Power Components and Systems. 33(9): 985-998.

Abido M. A. 2000. Simulated annealing based approach to PSS and FACTS based stabilizer tuning. International Journal of Electrical Power and Energy System. 22(4): 247-258.

Abido M. A. 2010. Robust design of power system stabilizers for multimachine power systems using differential evolution. B. K. Panigrahi. 302: 1-18.

Abido M. A. 2011. Power system stabilizer tuning study of east central power system in Saudi Arabia, Paris.

Ahmad R. 2001. Expert Systems: Principles and Programming. Scalable Computing: Practice and Experience. 7(4).

Alkhatib H. and J. Duveau 2013. Dynamic genetic algorithms for robust design of multimachine power system stabilizers. International Journal of Electrical Power and Energy Systems. 45(1): 242-251.

Banaei M. R. and S. Abbasi, *et al*. 2012. Stabilization of Multi-Machine Power Systems Using Craziness Based Particle Swarm Optimization and Harmony Search Algorithms. International Review of Electrical Engineering-Iree. 7(1): 3495-3504.

Bansal R. C. 2003. Bibliography on the fuzzy set theory applications in power systems (1994-2001). Power Systems, IEEE Transactions on. 18(4): 1291-1299.

Bian X., Tse CT, Zhang JF and Wang KW. 2011. Coordinated design of probabilistic PSS and SVC damping controllers. International Journal of Electrical Power and Energy Systems. 33(3): 445-452.

Dash P. and S. Mishra, *et al*. 2000. A radial basis function neural network controller for UPFC. Power Systems, IEEE Transactions on. 15(4): 1293-1299.

Do Bomfim A. L. B. and G. N. Taranto, *et al*. 2000. Simultaneous tuning of power system damping controllers using genetic algorithms. Power Systems, IEEE Transactions on. 15(1): 163-169.

Eberhart R. C., Simpson P. and Dobbins R. 1996. Computational Intelligence Pc Tools [Books in Brief]. IEEE Transactions on Neural Networks. 8(3): 817-817.

Engelbrecht A. P. 2007. Computational Intelligence: An Introduction. The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England, John Wiley and Sons, Ltd.

Eslami M., Shareef H., Mohamed A. and Khajehzadeh M. 2011. Particle swarm optimization for simultaneous tuning of static var compensator and power system stabilizer. PRZEGLĄD ELEKTROTECHNICZNY. 87(9 A): 343-347.

Eslami M., S. H., Mohamed A. and Khajehzadeh M. 2012. A Survey on Flexible AC Transmission Systems (FACTS). Electrical Review (PrzeglÄ… d Elektrotechniczny).

Falehi A. D., Rostami M., Doroudi A. and Ashrafian A. 2012. Optimization and coordination of SVC-based supplementary controllers and PSSs to improve power system stability using a genetic algorithm. Turkish Journal of Electrical Engineering and Computer Sciences. 20(5): 639-654.

Fang D. Z., Xiaodong Y., Chung T. S. and Wong K. P. 2004. Adaptive fuzzy-logic SVC damping controller using strategy of oscillation energy descent. IEEE Transactions on Power Systems. 19(3): 1414-1421.

Farah A. and T. Guesmi, *et al*. 2012. Optimal design of multimachine power system stabilizers using evolutionary algorithms, Nabeul.

Hassan L. H., Moghavvemi M., Almurib H. A. F., Muttaqi K. M. and Du H. 2012. Damping of low-frequency oscillations and improving power system stability via auto-tuned PI stabilizer using Takagi-Sugeno fuzzy logic. International Journal of Electrical Power and Energy Systems. 38(1): 72-83.

He J. M., O. P. 1997. An adaptive power system stabilizer based on recurrent neural networks. IEEE Transactions on Energy Conversion. 12(4): 413-418.

Hsu Y. Y. and C. R. Chen. 1991. Tuning of power system stabilizers using an artificial neural network. Energy Conversion, IEEE Transactions on. 6(4): 612-619.

Hunjan M. and G. K. Venayagamoorthy, *et al*. 2006. Adaptive power system stabilizers using artificial immune system.

Ishak S., Abidin AF and Rahman TKA. 2004. Static Var compensator planning using artificial immune system for loss minimization and voltage improvement. Power and Energy Conference, 2004. PECon 2004. Proceedings. National, IEEE.

Jin X., Zhao J., Wang H. F. and Du Z. 2007. Coordinated control of multiple damping controllers using artificial immune network theory, Chongqing.

Joorabian M., Noshad B., Mohammadi B. and Javadi M. S. 2011. Inter-area oscillation damping by optimal and coordinated design of PSS and SVC using an improved differential evolution algorithm. International Review of Electrical Engineering. 6(4): 1811-1821.

Ke D. P., Chung C. Y. and Xue Y. 2011. An eigenstructure-based performance index and its application to control design for damping inter-area oscillations in power systems. IEEE Transactions on Power Systems. 26(4): 2371-2380.

Khazaie J., Mokhtari M., Khalilyan M. and Nazarpour D. 2012. Sub-Synchronous Resonance damping using Distributed Static Series Compensator (DSSC) enhanced with fuzzy logic controller. International Journal of Electrical Power and Energy Systems. 43(1): 80-89.

Kim G. W. and K. Y. Lee. 2005. Coordination control of ULTC transformer and STATCOM based on an artificial neural network. Power Systems, IEEE Transactions on. 20(2): 580-586.

L. Cong Y. W. and D.J. Hill. 2004. Coordinated control design of generator excitation and SVC for transient stability and voltage regulation enhancement of multi-machine power systems. International Journal of Robust and Nonlinear Control. 14(9-10): 789-805.

Lee T. Y. and C. L. Chen. 2007. Unit commitment with probabilistic reserve: An IPSO approach. Energy Conversion and Management. 48(2): 486-493.

Liu W., Venayagamoorthy G.K. and Wunsch D.C. 2003. Adaptive neural network based power system stabilizer design. Neural Networks, 2003. Proceedings of the International Joint Conference on, IEEE.

Liu W., Venayagamoorthy G.K. and Wunsch D.C. 2003. Design of an adaptive neural network based power system stabilizer. Neural networks. 16(5): 891-898.

Lu C. F., Hsu C. H. and Juang C. F. 2012. Coordinated Control of Flexible AC Transmission System Devices Using an Evolutionary Fuzzy Lead-Lag Controller With Advanced Continuous Ant Colony Optimization. IEEE Transactions on Power Systems.

Mokhtari M. A., F., Nazarpour D. and Golshannavaz S. 2012. Wide-Area Power Oscillation Damping With a Fuzzy Controller Compensating the Continuous Communication Delays. IEEE Transactions on Power Systems.

Momoh J., Ma XW and Tomsovic K. 1995. Overview and literature survey of fuzzy set theory in power systems. IEEE Transactions on Power Systems,. 10(3): 1676-1690.

Mondal D., Chakrabarti A. and Sengupta A. 2011. Small signal stability assessment employing PSO based TCSC controller with comparison to GA based design. World Academy of Science, Engineering and Technology. 56: 1594-1601.

Mondal D. and A. C. a. A. S. 2012. Investigation of Small Signal Stability Performance of a Multimachine Power System Employing PSO Based TCSC Controller. Journal of Electrical Systems. 8-1: 23-34.

Morris S., Ezra M. A. G. and Lim Y. S. 2012. Multi-machine power transmission system stabilization using MPSO based neuro-fuzzy hybrid controller for STATCOM/BESS. International Review of Electrical Engineering. 7(2): 4123-4133.

Mostafa H. E., El-Sharkawy Metwally A., Emary Adel A. and Yassin Kamel. 2012. Design and allocation of power system stabilizers using the particle swarm optimization technique for an interconnected power system. International Journal of Electrical Power and Energy Systems. 34(1): 57-65.

Murali D. a. R., M. 2012. Neuro-fuzzy based power system stabilizers for damping oscillations in multi-machine power systems. Journal of Electrical Engineering. 12(2): 31-38.

Nechadi E., Harmas M. N., Hamzaoui A. and Essounbouli N. 2012. A new robust adaptive fuzzy sliding mode power system stabilizer. International Journal of Electrical Power and Energy Systems. 42(1): 1-7.

Nguyen T. T. and R. Gianto. 2007. Optimisation-based control coordination of PSSs and FACTS devices for optimal oscillations damping in multi-machine power system. Generation, Transmission and Distribution, IET. 1(4): 564-573.

Obulesu D., Kodad S. F. and Sanker Ram B. V. 2011. Design and development of a fuzzy coordinated control strategy for faults occurring at different buses in an interconnected power system. International Journal of Computer Applications in Technology. 42(1-2): 32-48.

Panda S. 2011. Multi-objective PID controller tuning for a FACTS-based damping stabilizer using Non-dominated Sorting Genetic Algorithm-II. Electrical Power and Energy Systems. 33: 1296-1308.

Peric V. S., Saric Andrija T. and Grabez Dejan I. 2012. Coordinated tuning of power system stabilizers based on Fourier Transform and neural networks. Electric Power Systems Research. 88: 78-88.

Rabih A. Jabr, B. C. P. and Nelson Martins. 2010. A Sequential Conic Programming Approach for the Coordinated and Robust Design of Power System Stabilizers. IEEE Transactions On Power Systems. 25(3).

Rahmat Allah Hooshmand, a. M. E. P. 2010. Corrective action planning considering FACTS allocation and optimal load shedding using bacterial foraging oriented by particle swarm optimization algorithm. Turk J. Elec Eng and Comp Sci. 18(4).

Raja A. J. a. C. A. R. and B. C. 2011. Fuzzy controlled SMES unit for damping power system oscillations in a combined cycle gas turbine. Journal of electrical engineering. 11(1): 36.

Ramirez-Gonzalez M. and O. P. Malik. 2008. Power system stabilizer design using an online adaptive neurofuzzy controller with adaptive input link weights. IEEE Transactions on Energy Conversion. 23(3): 914-922.

Ridhuan F. P. a. O. and Mohd Fauzi. 2007. Application of artificial immune system to design power systems stabilizer. 2007 5th Student Conference on Research and Development: 35-40.

Rohani A., Tirtashi M. R. S. and Noroozian R. 2011. Combined design of PSS and STATCOM controllers for power system stability enhancement. Journal of Power Electronics. 11(5): 734-742.

Segal R., Sharma A. and Kothari ML. 2004. A self-tuning power system stabilizer based on artificial neural network. International Journal of Electrical Power and Energy Systems. 26(6): 423-430.

Shamsollahi P. and O. Malik. 1997. An adaptive power system stabilizer using on-line trained neural networks. Energy Conversion, IEEE Transactions on. 12(4): 382-387.

Shayeghi H., Shayanfar H. A., Safari A. and Aghmasheh R. 2010. A robust PSSs design using PSO in a multi-machine environment. Energy Conversion and Management. 51(4): 696-702.

Sugihara T. and A. Yokoyama, *et al*. 2007. Selective on-line parameter tuning of adaptive PSS by trinomial tree method in wide-area power system. IEEJ Transactions on Power and Energy. 127(11): 1119-1126, 1111.

Sugihara T., Yokoyama A. and Izena A. 2006. Online parameter design method of adaptive PSS based on low-order linear model in multi-area power system. IEEJ Transactions on Power and Energy. 126(12): 1215-1222, 1214.

Swain S. C., Balirsingh A. K., Mahapatra S. and Panda S. 2011. Design of static synchronous series compensator based damping controller employing real coded genetic algorithm. World Academy of Science, Engineering and Technology. 51: 1319-1327.

Swasti R. Khuntia, a. S. P. 2011. A Novel Approach for Automatic Generation Control of a Multi-Area Power System. IEEE CCECE.

Tripathi S. S. and S. Panda. 2011. Tuning of power system stabilizer employing differential evolution optimization algorithm. Visakhapatnam, Andhra Pradesh. 7076 LNCS: 59-67.

Vakula V. S. and Sudha K. R. 2012. Design of differential evolution algorithm-based robust fuzzy logic power system stabiliser using minimum rule base. Iet Generation Transmission and Distribution. 6(2): 121-132.

Voci F. and F. M. F. Mascioli. 2009. Sugeno model based control for semi active vehicle suspension. 193: 12-21.

Wang K. W., Chung C. Y., Tse C. T. and Tsang K. M. 2001. Probabilistic eigenvalue sensitivity indices for robust PSS site selection. Generation, Transmission and Distribution, IEE Proceedings. 148(6): 603-609.

Wang S. K. 2012. A Novel Objective Function and Algorithm for Optimal PSS Parameter Design in a Multi-Machine Power System. IEEE Transactions on Power Systems. (99): 1-1.

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Wang Z., Chung C. Y. and Wong K. P. 2009. Systematic approach to consider system contingencies in PSS design. Electric Power Systems Research. 79(12): 1678-1688.

Zhang Y., Chen G.P., Malik OP and Hope G.S. 1993. An artificial neural network based adaptive power system stabilizer. Energy Conversion, IEEE Transactions on. 8(1): 71-77.