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Reactive power control in decentralized hybrid power system with STATCOM using GA, ANN and ANFIS methods

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ABSTRACT

In this paper, STATCOM performance for voltage–reactive power control is investigated by comparing different tuning methods, used to evaluate gain parameters of STATCOM controller in presence of high probabilistic uncertainty in input wind power and reactive power load demand. To control voltage transient response in least time, reactive power demand is managed by STATCOM. The conventional methods for tuning gain parameters of STATCOM controller do not satisfactorily operate in case of random disturbances and therefore, advanced controllers such as Genetic Algorithm (GA), Artificial Neural Network (ANN) and Adaptive Neuro Fuzzy Inference System (ANFIS) are required. The main contribution of the paper is: (i) Investigation of STATCOM performance in presence of high probabilistic uncertainty with step changes in input wind power and reactive power load demand, (ii) system studies during dynamic conditions with composite load model in lieu of static load model in the system, (iii) comparison of voltage control and STATCOM reactive power using various tuning methods. Results comparison through all tuning methods show that advanced tuning methods are able to preserve optimal performances over wide range of disturbances using Integral of Square of Errors (ISE) criterion.

Introduction

Up to now almost half of the India population those living in India's rural areas, still had no access to electricity [1] and nearly 1.3 billion people have no access to electricity in the world [2]. Geographical diversity, concentrated availability of natural resources, dispersed power demand in India is a real challenge for Government to provide electricity using traditional centralized generation units. Because of the remoteness of much of India's un-electrified population, renewable energy can offer an economically viable means of providing connections to these groups. Government of India is also promoting use of decentralized distributed generating units through various schemes [3]. In recent years, production of clean energy (renewable ones) by private investors is encouraged [4]. To provide continuous and reliable power in such far located areas, renewable energy based generators along with conventional fuel based generators are used without grid connection. Such system is called wind–diesel based decentralized hybrid power system. Researchers have presented a model for wind diesel based power system in which induction generator and synchronous generator are used for fetching power through wind and diesel respectively [5,6]. Self excited induction generator is a popular option for wind driven system but demands reactive power for its operation [7]. The reactive power is also required in system for stabilizing the voltage response at the instant of disturbances in load and input power demand. The transient response becomes more dominating in presence of random behaviors of load and/or input power change. Therefore, fast acting dynamic compensation is required so that the system may attain its steady state in least time. SVC mitigate these transient response but STATCOM operate fast to stabilize voltage of the system [8]. STATCOM operates to release/absorb reactive power as system requirement by controlling firing angle in STATCOM. This is achieved by controlling proportional and integral controller constants of STATCOM [9].

The probabilistic load model (PLM) considers the effect of uncertainties in load and/or input power for reactive power compensation using STATCOM. An analytical approach analyzes a system and its inputs using the exact mathematical expressions of random variables e.g. PDFs and obtains its results in terms of mathematical expressions. Several random variables have been used to model disturbances in load and/or input power behavior, for instance: uniform PDF, Weibull PDF, normal PDF, lognormal PDF and beta PDF [10–12]. In presence of high amplitude disturbances, tuning methods for STATCOM becomes more important [13]. The

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basic tuning methods, available in literature, in which tuning of PI controller is achieved by minimizing performance index, does not give satisfactory result with uncertain dynamics, time delays and non-linearity. However, improper PI parameters tuning could lead to cyclic and slow recovery, poor robustness and the worst case scenario would be the collapse of system operation [14]. These outputs carry high overshoots high oscillations and longer settling time for a high order system. Hence it is necessary to automatically tune the PI parameters for obtaining satisfactory response. Therefore, researchers are continuously trying to explore the best method in searching optimum PI parameters through intelligent controllers [15]. In many papers including [16–23], Genetic Algorithm (GA), Artificial Neural Networks (ANNs) and Adaptive Neuro Fuzzy Inference Systems (ANFISs) based approaches are discussed as soft computing techniques for stabilizing theirs output responses by tuning PID controllers.

Reactive power compensation methods for various model of wind–diesel based decentralized hybrid power system have been discussed by many authors. In [24], neural network based controller is applied to design an integrated non-linear controller for controlling excitation and governor systems input at the same time. In [25], the dynamic responses of the hybrid power systems with an optimum gain setting of SVC are presented. In [26], feedback linearized technique and control of nonlinear differential and algebraic systems is used as the coordinated controllers of excitation and SVC of power systems with nonlinear loads to improve voltage behavior. In [27], the dynamic responses of the hybrid power systems with an optimum gain setting of SVC are presented. In [28], an Artificial Neural Network (ANN) based approach is given to tune the parameters of the SVC reactive power controller over a wide range of exponential load model parameters. In [29], a fuzzy logic based supervisor is proposed in order to minimize variations of the generated power and stator voltage in presence of SVC with fixed capacitor. In [30], the dynamic responses of the hybrid power systems with an optimum gain setting of STATCOM are presented. In [31], this paper proposes a robust control using SVC and AVR. The genetic algorithm is applied to solve an optimization problem and to achieve PI control parameters of SVC and AVR simultaneously. In [32], a controller design and simulations of a wind–diesel generation plant based on LQG approach is presented for controlling AVR and static exciter. In [33], a new multilevel control strategy is proposed for adjusting controller based on past system and environmental data. In [34], modified AVR is implemented for reactive power compensation and voltage stability. In [9], proportional and integral (PI) gains of the STATCOM and VSC controllers are optimized using integral square error criterion (ISE). In [35], performance analysis of a Seeker optimization algorithm-Takagi–Sugeno fuzzy logic (SOA-TSFL) based controller for isolated hybrid power system model is carried out which tracks the degree of reactive power compensation for any sort of input perturbation in real time. In [36], self tuned fuzzy logic based PI controller is developed into regulate the reactive power of a decentralized wind–diesel hybrid power system.

In most of the studies, SVC and AVR is used for voltage regulation using different advanced techniques for very small 1% step disturbances in load and input power. Studies with individual tuning methods are available in literature while comparison among tuning methods are not presented by any author for voltage stability of decentralized hybrid power system by reactive power compensators. Previous papers suggest that STATCOM gives rapid and better response for regulating voltage especially in presence of high percentage changes including probabilistic pattern in load demand and input power. In this paper, STATCOM performance for voltage stability is investigated comparing tuning methods in presence of high probabilistic uncertainty with 10% step change in input wind power and reactive power load demand. Results with 1% and 5% step changes are also compared in this paper.

This paper is organized as follows; in Section 'Modeling for voltage–reactive power balance equation', STATCOM modeling is explained along with reactive power balance equation for wind diesel based decentralized hybrid power system. In Section 'Load modeling', composite load model transfer function for reactive power change with voltage and then probabilistic load pattern is developed.

In Section 'Estimation of gain constants using GA, ANN and ANFIS', steps for estimating STATCOM gain constants using GA, ANN and ANFIS is discussed in detail.

In Section 'Analysis of system performances', results are elaborated for the system and performances are compared. In Section ' Conclusion', objective of the paper are concluded.

Modeling for voltage–reactive power balance equation

In this paper, a decentralized hybrid power system is developed for this simulation based study which includes; wind operated self excited induction generator, diesel operated synchronous generator, composite load (combination of both static and dynamic load) and STATCOM as reactive power compensator. The rating of induction generator and synchronous generator is taken as 150 kW and 100 kW respectively. Base values of power and voltages are considered 250 kW and 400 V respectively. The sudden change in load demand and/or input power causes a voltage deviation, to stabilize these changes synchronous generator and STATCOM has to release extra reactive power. The reactive power equations for all components and power balance equations evolved in decentralized hybrid power systems are well established and documented in [20,25,27,28,30–32]. A MATLAB simulink model using linearized transfer functions of each component is developed for a system as shown in Fig. 1. A detail description has been presented for obtaining the transfer functions by the authors in Ref. [37].

The reactive power balance equation derived for the decentralised hybrid power system is;

$$\Delta V(s) = \frac{1}{D_v + s\frac{V}{\omega X_m}}[\Delta Q_{SG}(s) + \Delta Q_{ST}(s) - \Delta Q_{IG}(s) - \Delta Q_L(s)] \quad (1)$$

To regulate the system voltage at the instant of load and/or input disturbances, reactive power is generated by synchronous generator and STATCOM while induction generator and load

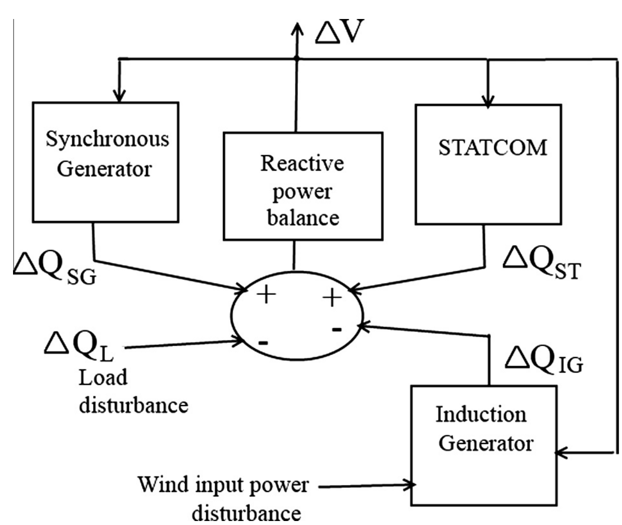

Fig. 1. Reactive power balance diagram using STATCOM compensation.