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Intelligent control of SVC using wavelet neural network to enhance transient stability

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ABSTRACT

In order to enhance transient stability in a power system, a new intelligent controller is proposed to control a Static VAR compensator (SVC) located at center of the transmission line. This controller is an online trained wavelet neural network controller (OTWNNC) with adaptive learning rates derived by the Lyapunov stability. During the online control process, the identification of system is not necessary, because of learning ability of the proposed controller. One of the proposed controller features is robustness to different operating conditions and disturbances. The test power system is a two-area two-machine system power. The simulation results show that the oscillations are satisfactorily damped out by the OTWNNC.

1. Introduction

The transient stability issue has been challenging researchers of the electrical power field for many years. The transient stability plays the main role in determining the capacity of power transfer, planning and scheduling power systems. With rapid growth of power systems in recent decades, some of areas of a large scale power system may be interconnected by weak tie-lines. So the low frequency oscillations (LFO) can be observed. If these oscillations are not restrained, the instability will occur certainly in the power systems. Accordingly, preventive measures should be performed to overcome this problem. In this regard, researchers' effort has led to many controllers so far. One of the effective methods for improving the transient stability is to use flexible AC transmission system (FACTS) devices. FACTS devices can approximately be used for any purpose in power systems. The different types of these devices and with different control techniques are employed to damp the power oscillations (Pahlavani and Mohammadpour, 2011; Padiyar and Prabhu, 2006; Alomari and Zhu, 2011; Panda, 2009; Jusan et al., 2010; Rai et al., 2010). Among these devices, the SVC is usable for power oscillation damping, improvement stability and frequency stabilization (Jusan et al., 2010). By changing its reactance characteristic from inductive to capacitive, the SVC can control the power flow and enhance the capability of power transfer in power systems. Also, an auxiliary controller can be added to the SVC for improving the transient stability (Wang, 2000).

Most of controllers proposed for controlling the FACTS devices such as PID controllers (Pahlavani and Mohammadpour, 2011), transfer function (Padiyar and Prabhu, 2006) and lag-lead compensators (Panda, 2009; Wang, 2000) are designed as a controller with constant parameters. Such controllers cannot guarantee their good performance in all operating conditions of a power system and under different disturbances, since from the perspective of control engineering, a power system is large scale system with multi-inputs multi-outputs, many control loops and time varying parameters. So, a controller with constant parameters may be unable to damp the oscillations in a wide range of operating conditions of a power system. Accordingly, to overcome this problem and to accommodate a controller in a wide range of operating conditions, parameters of controller must periodically be retuned, so the controller can always maintain its good performance. For this purpose, an intelligent controller with adaptive learning capability is required. In addition, since accurate modeling of the system in the design of an adaptive controller is not required, it can be used to control nonlinear models, while accurate modeling is an essential factor for determining parameters of fixed controllers.

Based on what mentioned above, a well-designed controller used in power systems should have the following features: learning ability, flexibility to different loading conditions, robustness to unmodelled dynamics and nonlinearity. With advantages like the abilities of adaptive, parallel, and fault tolerance, neural networks (NNs) are a good suggestion for this purpose. Recently,

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wavelet neural networks (WNNs) have attracted researchers' attention. Much research has been carried out on applications of WNNs (Wai and Chang, 2002; Oussar et al., 1998; Zhang et al., 1995; Zhang and Benveniste, 1992; Oussar and Dreyfus, 2000; Yoo et al., 2005, 2007). WNNs combine the ability of neural networks in learning from systems and the ability of wavelet decomposition for the identification of dynamical systems (Wai and Chang, 2002).

Many papers have been assigned to the application of NNs to control power systems (Shamsollahi and Malik, 2000; He and Malik, 1997; Wu et al., 1992; Sindhu Thampatty et al., 2011). However, there are two major problems in connection with using neural network controllers. The first one is to guarantee the convergence of NNs. In general, the convergence problem of NNs has not been investigated in these papers. The next problem is to use a neural network identifier to approximate the dynamic of controlled system. This method has some drawbacks such as heavy computation, time limitations of online training, hardware implementation limitations and so on. Also, this method requires an offline training which is difficult in practice.

The main contribution of this paper is the application of an online trained wavelet neural network controller to provide the necessary control signal to the SVC so that power system oscillations are quickly damped out, since the Lyapunov stability method is used to guarantee the convergence of proposed controller, the overall control system is globally stable and hence, the transient stability of power system is improved; the control error can be reduced to zero by selecting appropriate parameters and learning rates; and the proposed controller can achieve favorable controlling performance. Meanwhile, no neural network identifier is used to approximate the dynamic of controlled power system.

2. Power system under study

The power system shown in Fig. 1 contains two power generation substations and one large load center at bus 3. The generation capacity of first power generation substation (M_1) is 1000 MVA. The capacity of other one (M_2) is 5000 MVA. A large load is used to model the load center of approximately 6000 MW. Both L_1 and L_2 are 350-km long. To restrain the system after disturbances, a 400-MVAR static VAR compensator (SVC) is installed at the middle of transmission line. All the data needed to this model are provided in Appendix A.

3. Overview of SVC

The Static Var Compensator (SVC) is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids (Hingorani and Gyugyi, 2000). The SVC can control the amount of reactive power injected into or absorbed from the power system via regulating the voltage at its terminal. When system voltage is low, the SVC generates reactive power (SVC capacitive). When system voltage is high, it absorbs reactive power (SVC inductive). The change of reactive power is performed by switching three-phase capacitor banks and inductor banks connected on the secondary side of a coupling transformer. Each capacitor bank is switched on and off by three thyristor switches (Thyristor Switched Capacitor or TSC). Reactors are either switched on-off (Thyristor Switched Reactor or TSR) or phase-controlled (Thyristor Controlled Reactor or TCR).

4. Online trained wavelet neural network controller (OTWNNC)

Fig. 2 shows the intelligent system structure proposed for the control of the SVC. As seen in this figure, the intelligent control system contains an online trained wavelet neural network controller. Also, the power calculation block calculates the active power transferred via L_1. The output of the power calculation block P is then compared with a reference value P_{ref}. This reference value is equal to the active power transferred via L_1 in steady-state of power system. Eventually, this error is used as the input of the WNN. Also, the output of intelligent control system u is added to the reference voltage of SVC (V_{ref}). Meanwhile, a voltage regulator that uses the voltage error (difference between the measured voltage V_m and the reference voltage ($V_{ref}+u$)) to determine the SVC susceptance B_{eq} needed to keep the system voltage constant. Therefore, the SVC regulates its output voltage based on the summation of the reference voltage and the output of the proposed controller.

4.1. WNN

A three-layer WNN comprised of an input layer, a wavelet (the j layer) and an output layer is shown in Fig. 3. The objective is to

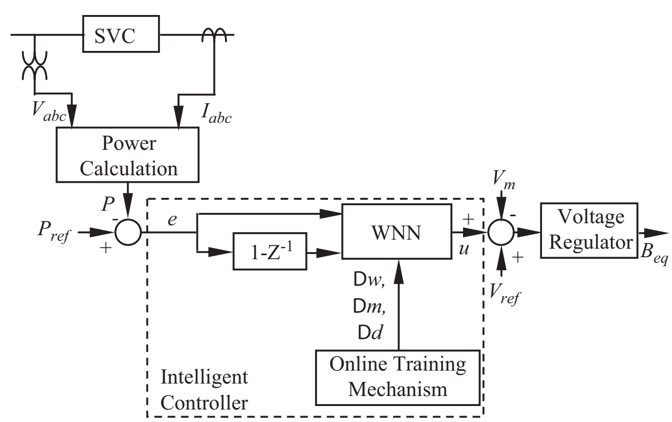

Fig. 2. Block diagram of intelligent control system.

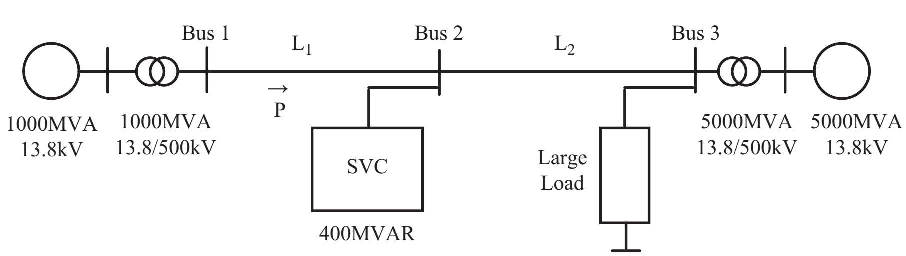

Fig. 1. Power system under study.