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Design of sliding mode controller for UPFC to improve power oscillation damping

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ABSTRACT

In this paper, a new indirect method of sliding mode control (SMC) for series converter of unified power flow controller (UPFC) is proposed. In this method, the dynamic model of controller is obtained through special concepts of state variable transform, feedback linearization and differentially flat output. This new and simple control strategy has been developed base on the modified SMC principles which utilizes only the active and reactive output powers as the control inputs. Since these measurable control inputs are known as differentially flat outputs, they have a direct influence on the state variables of series converter to control them with the capability of power oscillation damping. The absence of discontinuous component input to UPFC controller avoids the chattering effect on state variables, especially on the dc capacitor voltage of inverters. For the validation of the proposed new controller, the obtained results were compared with results obtained from the PI controller.

1. Introduction

Due to the increasing power demand, some transmission lines may reach to stress condition and cause instability following dynamic or transient states. The construction and exploitation of new transmission lines based on economical and maintenance aspects, time of execution and other related functional problems, has pursued designers to use more practical methods to improve power transfer and the exploitation of existing lines [1].

In the traditional method, phase shifting transformer and series or shunt capacitors may increase the power transfer capability and enhance the stability of the power system [2]. In newer methods, with the use of FACTS devices such as SSSC, TCSC, SVC, STATCOM or UPFC which have a fast dynamic because of their fast switching devices, it is possible not only to increase power transfer capability, but also to improve transient, dynamic or voltage stability in a faster dynamic than traditional compensators [3–5]. Among these FACTS devices, UPFC is one of the most important and most comprehensive which has the capability of regulating power flow in transmission lines by its series converter and the input voltage by its shunt converter [6]. It can also increase the stability of the system. This stability improvement depends on applying suitable control strategies in UPFC converters [7].

Various control strategies have been used to design the controllers of UPFC that can be categorized to classical and modern controllers. In classical methods such as PI controllers, the active and reactive powers, input bus voltage and the internal variable of dc capacitor voltage are regulated to reference values without any need to UPFC dynamic equations [8,9]. Since the inputs and outputs' variables of UPFC interact with each other similar to multi-input multi-output systems, various decoupling methods have been used to reduce the interaction between these variables [10–12]. PI controller is one of the simple and practical methods but they do not have any robust about the operating point and may cause instability following large disturbances.

In modern methods, some of them such as state space base controller need to obtain a model for the system and the controllers are designed according to that model and in other methods such as fuzzy controller, there is no need to obtain a complete model of the system [13,14]. In complex systems, obtaining a complete model of the system is very difficult and therefore a dynamic that can describe the system in a suitable manner is used to design the controller. This approximation may lead to reduce the quality of the controller that is designed base on this model.

SMC is one of the modern control methods that is robust against uncertainties of dynamic model of a system and has been applied to a wide range of engineering systems [15]. Chattering effect is one of the major drawbacks of this controller that may lead to instability in many systems [16]. In UPFC, there is need for constant dc capacitor voltage of converters due to the safe operation of the converters and since applying the SMC with discontinuous input component lead to the variation of this voltage, the SMC is not applicable to control UPFC.

In this paper, after assessing some control concepts and combining them, a new control method is proposed base on the principles of sliding mode control without chattering effect to control the series converter of UPFC with the capability of power oscillation

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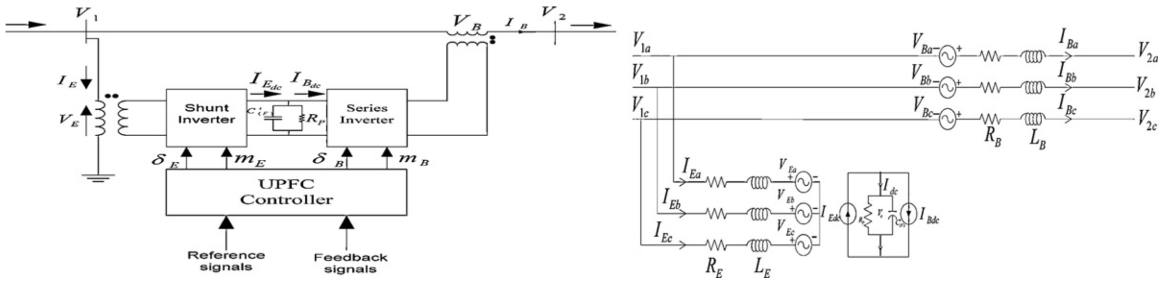

Fig. 1. Block diagram of a UPFC and equivalent circuit.

damping. This simple method uses the active and reactive powers of UPFC as the sliding surfaces and the control law is derived from phasor diagram of UPFC relation.

2. A review on the concepts of SMC, feedback linearization and differentially flat output to design the converter controller

SMC has been proven to be a useful control method for a wide rang of linear and nonlinear systems. This relatively simple controller provides robustness to disturbance, parameter variation and uncertainty of system and is based on the variable structure of control input in order to reach the variables to the reference values in finite time. In this method, a discontinuous input component with a high switching frequency, puts the system's dynamic in two different forms so that the variables lie in the hysteresis bands.

After reaching sliding surfaces, the continuous input component or equivalent input takes the variables to reference values according to the simplified dynamic of the sliding surfaces. High frequency oscillation or chattering on the system's variables due to high frequency switching of discontinuous input component may lead to system instability [17]. In order to reduce the effect of chattering due to discontinuous input component, a higher degree SMC can be used. In this case, discontinuous input component affects the derivatives of the higher levels of sliding surface which really increases the order of sliding mode and decreases chattering effect. In the '*r*' order sliding mode control, consistent derivatives until the 'r – 1' are equal to zero and the discontinuous input component influences the '*r*' derivative [18].

In complex or nonlinear systems, the equations of a system may be simplified and then SMC can be applied using feedback linearization. In the feedback linearization method, parts of the non-linear terms are considered as new variables and these new equations will be in the form of linear and linear controller or decoupling methods can be applied [18,19].

Differentially flat outputs are the new state variables that can be obtained from original state equations. In these new equations, the system is completely determined the same as primary state equations. In this paper, theses states are considered as the sliding surfaces and so the equivalent input of this system will be obtained by setting these sliding surfaces to zero. Since the differentially flat outputs are considered as the real outputs of the system which are measurable, there is no need to estimate these variables [19].

3. UPFC structure and modeling

Fig. 1 shows the block diagram and equivalent circuit of shunt and series converters of UPFC. The dc side of these converters is connected together via a dc link capacitor. The ac side of series converter is in series with the transmission line via a three phase transformer and the ac side of the shunt converter is also connected to the input bus of UPFC through a three phase transformer. Active and reactive power flow is regulated by q and d component of series converter voltage, respectively. Shunt converter regulates input bus voltage and dc capacitor voltage by regulating reactive power of input bus and balancing between input-output active pow-

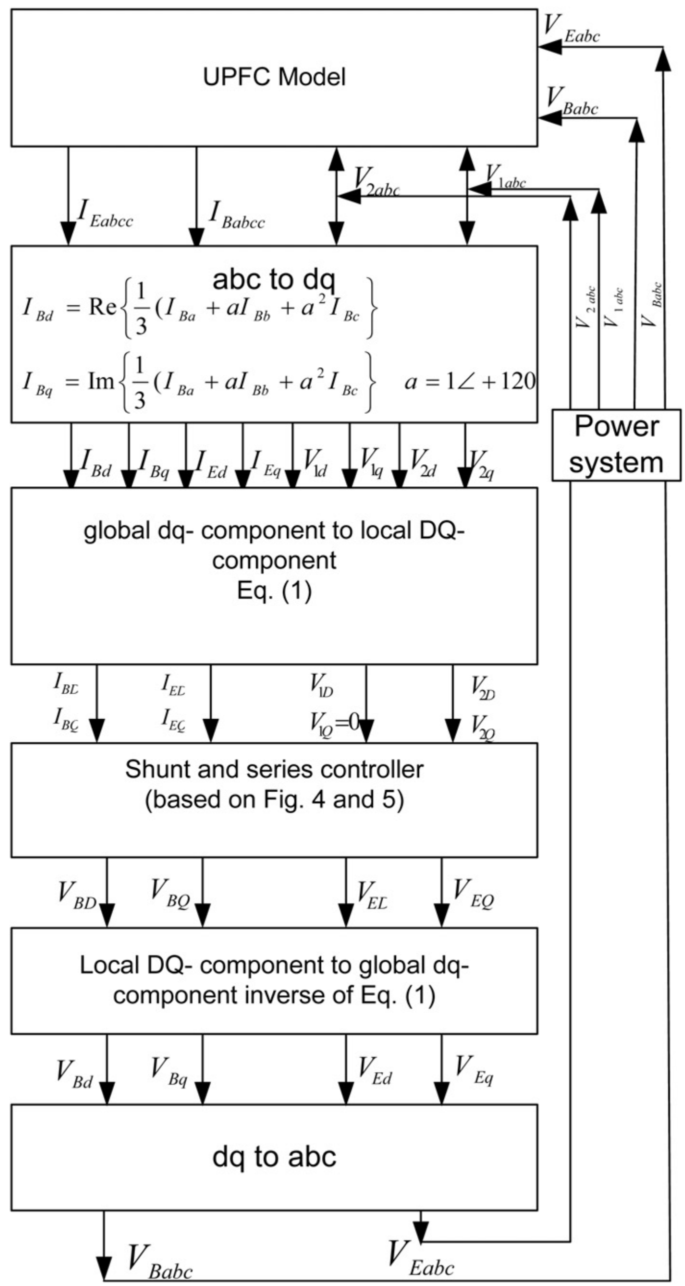

Fig. 2. UPFC modeling and simulation procedure in power system.