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ac — Small power dc hybrid transmission for improving power system stability

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Abstract

The paper presents a novel FACTS concept to improve the dynamic stability of an ac power system. The concept of parallel ac/dc transmission between two ac systems has been exploited in the scheme presented, using one ac line for both the ac and the dc transmission. A small unit of power is extracted from the system, converted to dc and injected into the ac line through the transformer, neutrals at the two ends to enhance the dynamic stability. The objective of the paper is to introduce the new concept and prove its feasibility. To demonstrate the validity of the proposed method, computer simulated dynamic responses of an ac power system, with and without the controlled dc injection are presented. It has been shown that by using about 2% of ac power transfer, as modulated dc power, substantial system of damping could be achieved.

Keywords: Power system dynamic stability; FACTS device; ac/dc Transmission

1. Introduction

The majority of the generating units in power systems are equipped with automatic voltage regulators. These could have an adverse effect on the dynamic stability as oscillations of small magnitude and low frequency (0.2–2.5 Hz), can occur. These oscillations often persist for long period of time and can sometimes limit the power transfer capability [1]. Power system stabilisers (PSS) were thus developed to damp these oscillations, through modulation of the generator excitation [2,3]. To cause damping, PSS must provide an electrical torque on the rotor proportional to the speed variations. Sub-synchronous resonance (SSR) can also occur in series capacitor compensated transmission lines when the complement of the natural frequency of the L–C network corresponds to one of the torsional frequencies (15–45 Hz) of the turbine-generator shaft system. The consequences of subsynchronous resonance can be dangerous [4,5]. However, PSS cannot be used to overcome this problem.

Additional damping is required under conditions of weak transmission and heavy load; for example, when attempting to transmit power over long transmission lines from remote generating plants or over relatively weak ties between systems. Contingencies such as line outages, often precipitate such conditions. Hence, systems, which normally have adequate damping, can often benefit from stabilisers during such abnormal conditions. It is important to realise that the stabiliser is intended to provide damping for small excursions about a steady-state operating point, and not to enhance transient stability. In fact, the stabiliser will often have an adverse effect on transient stability by attempting to pull the generator field out of limits too early in response to a fault. The stabiliser output is generally limited to prevent serious impact on transient stability, but stabiliser tuning also has a significant impact upon system performance following a large disturbance [1].

The capability of an HVDC link to rapidly modulate the power flow, in response to control signals has been utilised for some time to improve the dynamic stability of ac/dc systems [6,7]. Studies [8–10] have also shown that modulation signals such as frequency deviation and rate of change of ac power transmitted provide additional damping.

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Due to the high cost of converters, HVDC transmission has been typically used for interconnecting asynchronous ac systems and for economic transmission of bulk power usually over long distances. However, due to the availability of low-cost low-power converters at low voltage, these may now be used to improve the dynamic stability of the existing ac systems.

The use of a low-power low-voltage dc link in parallel with a high-voltage high-power ac line is found to be a means of ensuring the improved dynamic stability of the ac line. A new approach is proposed where the dc power would be transmitted not over a separate dc line but superposed on the ac line by injecting into the transformer neutrals at the two ends. A simple control strategy was utilised and fine tuning has not been attempted at this stage.

Advantages seen from this method of stabilisation are that it does not adversely interfere with the nominal function of the generators excitation system and that the generator will not be subjected to pulsating shaft torques during disturbances.

The proposed controller will have a high bandwidth compared with PSS and therefore could also be used to damping of higher frequency oscillations such as SSR (with dc bypass inductors across the compensating capacitors).

Modelling and simulation of the system and controllers were done with the electromagnetic transient program EMTDC/PSCAD.

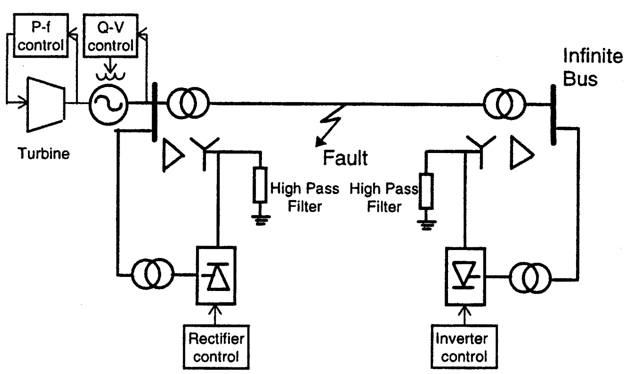

Fig. 1. Single line diagram of ac/dc system studied.

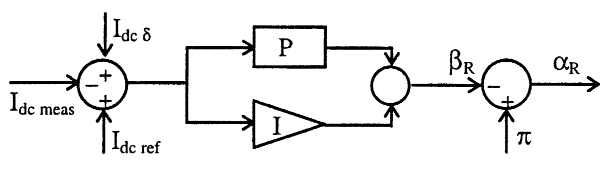

Fig. 2. Rectifier control.

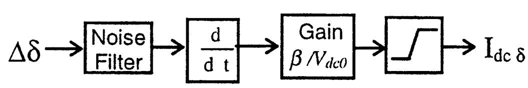

Fig. 3. Proposed modulation controller.

2. Control strategy

The proposed method improves the dynamic stability of the ac system by transmitting a suitably modulated dc power in the ac transmission line by injection into the transformer neutrals at either end.

Fig. 1 shows the ac transmission line together with the dc circuit.

The proposed modulation ($I_{dc\ \delta}$) has been incorporated in the rectifier control (Fig. 2).

The generator-ac system behaviour (linearised for small signals) is governed by the swing Eq. (1).

$$\Delta P_m - \Delta P_{ac} - \Delta P_{dc} = \frac{2H}{\omega_0}\frac{d^2\Delta\delta}{dt^2} \quad (1)$$

The active power transfer can be written as in Eq. (2).

$$\Delta P_{ac} \cong \frac{V_1 V_2}{X}\cos\delta_0\Delta\delta = K_s\Delta\delta \quad (2)$$

If the dc power is controlled proportional to the rate of change of the variation of the transmission angle δ, and the mechanical power input assumed constant during the dynamic condition, we obtain the condition, as given in Eqs. (3) and (4).

$$\Delta P_{dc} = \beta\frac{d\Delta\delta}{dt} \quad (3)$$

$$\Delta P_m \cong 0 \quad (4)$$

Thus, the governing equation for small changes may be written as in Eq. (5).

$$\frac{2H}{\omega_0}\frac{d^2\Delta\delta}{dt^2} + \beta\frac{d\Delta\delta}{dt} + K_s\Delta\delta = 0 \quad (5)$$

3. Controller design

The controller to obtain the necessary damping of the ac system is designed considering the critical damping condition. Thus we have β given by Eq. (6).

$$\beta = \sqrt{\frac{8K_sH}{\omega_0}} \quad (6)$$

Eq. (3) can be re-written in terms of the controlled change in dc current as in Eq. (7).

$$I_{dc\ \delta} = \Delta I_{dc} = \frac{\Delta P_{dc}}{V_{dc0}} = \frac{\beta}{V_{dc0}}\frac{d\Delta\delta}{dt} \quad (7)$$

This control is implemented as shown in Fig. 3.

In the modified controller for the rectifier, the signal fed to the $P-I$ controller has, in addition to the error of the dc current signal, a signal proportional to the derivative of the angle to improve the dynamic stability.