The 3rd International CUA Graduate Students Symposium

سومین سمپوزیوم بین‌المللی دانشجویان تحصیلات تکمیلی دانشگاه‌های عضو اتحادیهٔ قفقاز

University of Mohaghegh Ardabili

دانشگاه محقق اردبیلی

June 5-6, 2016

16–17 خردادماه

Power Flow Solution in a Larg Scale Power System Including IPFC

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Abstract

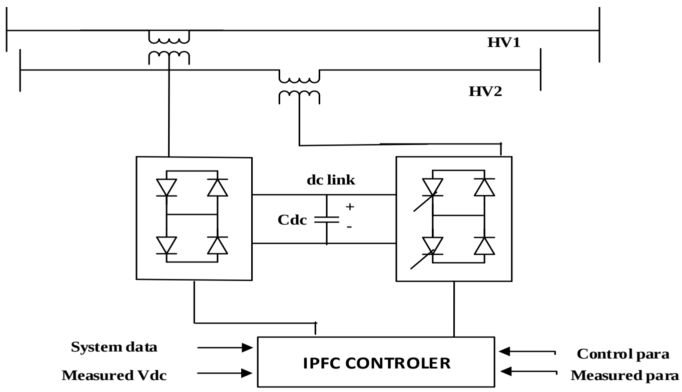
Abstract: In this paper a power injection model (PIM) of interline power flow controller (IPFC) by applying the Newton-Raphson method is discussed. This model is incorporated into Newton-Raphson power flow to study the effects of IPFC parameters in the power flow study. The IPFC has much more flexible topologies, consists of at least two converters, and can be used to control power flows of a group of lines. It can be anticipated that the IPFC may be used to solve the complex transmission network congestion management problems that transmission companies are now facing in the transmission open-access environment. The Newton-Raphson power flow solution method with IPFC model is a useful tool for operation and control of power systems.

Keywords: Interline power flow controller (IPFC), Newton-Raphson power flow, Power injection model (PIM), Loss minimization

1. Introduction

Flexible AC Transmission System (FACTS) is a technology based concept that can provide a full dynamic control over active and reactive power flow on transmission systems based on the key control variables such as transmission line impedance, phase angle and terminal voltages [1]. The latest generation of FACTS controllers are unified power flow controller (UPFC) and interline power flow controller (IPFC). It is found that, in the past, much effort has been made in the modeling of the

UPFC for power flow analysis [2]-[4]. The IPFC is conceived for the compensation and power flow management of multi-line transmission system. Like the STATCOM, SSSC and UPFC, the IPFC also employs the voltage sourced converter as a basic building block [5]. A simple model of IPFC with optimal power flow control method to solve overload problem and the power flow balance for the minimum cost has been proposed [6]. This paper investigates the performance of IPFC in a power system network. A detailed mathematical model of IPFC which will be referred as IPFC power injection model has been presented. This model is helpful in understanding the impact of IPFC on power system. Further, the IPFC injection model can easily be incorporated in the steady state power flow model. The proposed model is used to demonstrate the features of IPFC. This paper shows that the IPFC has the capability of regulating bus voltages, active power flow, reactive power flow and minimizing the power losses simultaneously [7].



2. INTERLINE POWER FLOW CONTROLLER

A. Operation Principles of IPFC

In its general form, the IPFC employs a number of dc to ac converters, each providing series compensation for a different line. The converters are linked together at their dc terminals and connected to the ac systems through their series coupling transformers [8]. The simplest IPFC consists of two back-to-back dc-to-ac converters, which are connected in series with two transmission lines through series coupling transformers and the dc terminals of the converters are connected together via a common dc link. With this IPFC, in addition to providing series reactive compensation, any converter can be controlled to supply real power to the common dc link from its own transmission line [9].

B. Mathematical Model of IPFC

In this section, a mathematical model for IPFC which will be referred to as power injection model is derived. This model is useful to study the impact of the IPFC on the power system network and can easily be incorporated in the power flow algorithm [7]. Usually, in the steady state analysis of power systems, the VSC may be represented as a synchronous voltage source injecting an almost sinusoidal voltage with controllable magnitude and angle. Based on this, the equivalent circuit of IPFC is shown in Fig.2. In this circuit, is the complex $V_{se_n} = V_{se_n} \angle \theta_{se_n}$ (n=j, k) controllable series injected voltage. $Z_{se_n} = R_{se_n} + jX_{se_n}$ (n=j, k) is the series transformer impedance [10]. V_i, V_j and V_k are the complex bus voltages at the buses i, j and k respectively, defined as $V_m = V_m \angle \theta_m$ (m= i, j and k). Therefore, the current source can be expressed as

$$I_{se_n} = -jb_{se_n} V_{se_n} \tag{1}$$

Now, the current source (I_{se_n}) can be modeled as injection powers at the buses i, j and k. The complex power injected at i^{th} bus is

$$S_{inj,i} = \sum_{n=j,k} V_i (-I_{se_n})^*$$

(2)

Subtitle (1) in (2)

$$S_{inj,i} = \sum_{n=j,k} V_i (jb_{se_n} V_{se_n})^* \tag{3}$$

After simplification, the active power and reactive power injection at i^{th} bus are

$$P_{inj,i} = RE(S_{inj,i}) = \sum_{n=j,k} (V_i V_{se_{in}} b_{se_{in}} \sin(\theta_i - \theta se_{in})) \tag{4}$$

$$Q_{inj,i} = IM(S_{inj,i}) = \sum_{n=j,k} (V_i V_{se_{in}} b_{se_{in}} \cos(\theta_i - \theta se_{in})) \tag{5}$$

The complex power injected at n^{th} bus (n=j,k) is

$$S_{inj,n} = V_n (I_{se_n})^* \tag{6}$$

Substitute (1) in (6)

$$s_{inj,n} = V_n(-jb_{se_{in}} V_{se_{in}})^* \tag{7}$$

After simplification, the active power and reactive power injections at n^{th} bus are

$$P_{inj,i} = RE(S_{inj,n}) = -V_{se_{in}} b_{se_{in}} \sin(\theta_n - \theta se_{in}) \tag{8}$$

$$Q_{inj,i} = IM(S_{inj,n}) = V_n V_{se_{in}} b_{se_{in}} \cos(\theta_n - \theta se_{in}) \tag{9}$$

Based on (4), (5), (8), and (9), power injection model of IPFC can be seen as three dependent power injections at buses i, j and k.

As IPFC neither absorbs nor injects active power with respect to the ac system, the active power exchange between the converters via the dc link is zero, i.e.

$$\mathrm{Re}(\mathrm{Vse}_{ij} \mathrm{I}_{ji}^* + \mathrm{Vse}_{ik} \mathrm{I}_{ki}^*) = 0 \tag{10}$$

Where the superscript * denotes the conjugate of a complex number. If the resistances of series transformers are neglected, (10) can be written as

$$\sum_{m=i,j,k} P_{inj,m} = 0 \tag{11}$$

3. IMPLEMENTATION OF IPFC MODEL IN NR METHOD

A. Power Balance Equations with IPFC

The IPFC power injection model can be incorporated into NR power flow algorithm by addition of power injections to the corresponding power mismatch equations. The power balance equations can be expressed as:

$$\Delta P_i = \Delta P_i^0 + P_{inj,i}$$

$$\Delta Q_i = \Delta Q_i^0 + Q_{inj,i}$$

$$\Delta P_n = \Delta P_n^0 + P_{inj,n}$$

$$\Delta Q_n = \Delta Q_n^0 + Q_{inj,n}$$

Where the superscript ‘0’ denotes the power mismatch without IPFC and n=j, k.

4. Results and Analysis

In this section, numerical results are carried out on IEEE 57-bus system [19] to show the robust performance and capabilities of IPFC model. In the test system, bus 1 is considered as slack bus, while bus 2, 3, 6, 8, 9 and 12 as generator buses and other buses as load buses. For all the cases, the convergence tolerance is 1e-7 p.u. System base MVA is 100. The inductive reactance of the coupling transformers are taken to be 0.01 p.u.

Beginning, the power flow solution i.e. bus voltages, line flows and line losses of 57-bus system are calculated using Newton-Raphson method without IPFC. Next, for the same system the power flow solution is obtained using NR method with IPFC. The one converter of IPFC is embedded in a line between the buses 13-14 which is considered as 1st line and the other converter of IPFC is placed in a line between the buses13-15 which is considered as 2nd line and bus 13 is selected as common bus for two converters. The bus voltages, line flows and line losses of test system without and with IPFC (parameters Vse= 0.3 p.u and θse=- 120) are shown in Table I, II and III respectively

$$. -180 < \theta_{se} < 180$$

$$V_{se} = 0.3$$

Table 1

LINE FLOWS WITHOUT AND WITH IPFC

From-To	Active power flow (MW)		Reactive power flow (MVAR)	
	Without IPFC	With IPFC	Without IPFC	With IPFC
13-14	-0.089	-0.534	0.259	0.268
13-15	-0.485	-0.595	0.127	0.170

Table 2

Line Losses without and with IPFC

Total active power losses (P.U)		Total reactive power losses (P.U)	
without IPFC	with IPFC	without IPFC	with IPFC
0.240	0.212	1.167	1.016

5. Conclusion

In this paper, a power injection model of IPFC has been presented. This model is incorporated in NR power flow solution method to study the effects of IPFC parameters in power flow studies.It is shown that there is a possibility of regulating bus voltage, active and reactive power flow and minimizing the power loss with proper IPFC parameters.. The strong multi line control capability of IPFC plays an important role in power systems. The NR power flow solution method with IPFC model is a useful tool for planning, operation and control of power systems.

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