Performance Analysis of interline Power Flow Controllers for IEEE-30 Bus with NR Method

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ABSTRACT

One of the latest generation flexible AC transmission system (FACTS) controllers is Interline power flow controllers (IPFC). In general it is connected in multiple power transmission line of a power system networks. In this paper presents power injection model (PIM) of IPFC. This model is incorporated in Newton-Raphson (NR) Power flow algorithm to study the effect of IPFC parameters I n power flow analysis. A program in a MATLAB has been written in order to extend conventional NR algorithm based on this model.

Keywords : Interline Power Flow of Controllers (IPFC), Flexible AC Transmission System (FACTS).

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1 INTRODUCTION

THe main aim of power system is to satisfy continuously the electrical power contracted by all consumers. This is a problem of great engineering complexity where the following operational policies must be observed:

1. Nodal voltage magnitude and system frequency must be kept within narrow boundries.
2. The alternating current (AC), voltage and current waveform must remains boundries.
3. Transmission line must be operated well below thear thermal and stability limits.
4. Even short-term interruption must keep to minimum.

Moreover because of very competitive nature of electricity supply business in area of deregulation and open acess, transmission costs must be kept low as possible. One of the most common computational procedures used in power systems analysis is the load flow calculation.

2 APPLICATION AREAS OF LOAD FLOW

In general one can obtain a possibility distribution of the state and output variables (voltages, angles, line flows, losses) for a given range of input varIebles individual or simultaneous uncertain in the voltage depend loads and the parameters can also be handled. Load flow is however, extremely useful if only one or a few fuzzy variables calculations, e.g. real, reactive power loss, flows on few specific lines, voltages at some buses are of interest. Load flow studies are used encompasses two system areas:-

2.1 System planning

System Planning has the objective of designing a system capable of reliable bulk electrical power supply. There are some common tasks of the system planning as follower:-

(1) Transmission planning:- It involves design, analysis, sizing of conductor, transformers, reactors, shunt capacitor, and future planning of transmission circuit.
(2) Generation adequacy studies and generation planning.
(3) Cost to benefit analysis of sytem additions.

1.1.2System Operatiuon and Control

(1) Economic dispatch of the generating stations.
(2) Contingency Analusis.
(3) Studies that ensure power pool coordination.
(4) Generation dispatch and load demand control.
(5) Studies related to setting of protective gears.

3 LOAD FLOW SOLUTION METHODS AND HISTORY

The computational task of determining power flows and voltages for even a small network for a given system condition is formidable. Solution of large networks for many system conditions as required for analysis of present-day power systems requires sophisticated computational tools. The first load flow solution device was a special purpose analog computer called the ac network analyzer developed in the late 1920s. Power system networks under study were represented by an equivalent, scaled-down network. The device allowed the analysis of a variety of operating conditions and expansion plans. However, setup time was long. Digital computers began to emerge in the late 1920s as computational tools. By the mid–1950 large-scale digital computers of sufficient speed and size to handle the requirements of a power system network calculation were available. Parallel to the hardware development, algorithms to efficiently solve the network equations were developed. There are some methods for solving the load flow problem which are as follows:-

- Gauss - Seidel (G - S) iterative method.
- Newton – Raphson (N – R) method.
- Fast Decoupled Power – flow Method.
- Linearized(DC) Power – Flow Method

4 INTRODUCTION TO NEWTON-RAPHSON METHOD

The application of Newton's method to load flow problem is essentially the n-dimensional generalization of the well known Newton-Raphson method [6,20] for the solution of a nonlinear equation in one variable. Taylor's series expansion for a function of two or more variables is the basis for the Newton-Raphson method of solving the load flow problem . Let the following represent n nonlinear equations in n unknowns

$$f_1(x_1; x_2; \ldots\ldots\ldots\ldots.\ x_n) = b_1$$

$$f_2(x_1; x_2; \ldots\ldots\ldots\ldots..\ x_n) = b_2$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..$$

$$f_n(x_1; x_2; \ldots\ldots\ldots\ldots; x_n) = b_n \qquad (2.1)$$

If the iterations start with an initial estimate of x_{01}; x_{02}; .... x0n for n unknowns and if $\Delta x_1;\Delta x_2$; ……………….. ;Δx_n are the corrections necessary to the estimates so that the equations are exactly satisfied, we have

$$f_1(x_{01}+ \Delta x_1; x_{02}+ \Delta x_2; \ldots\ldots\ldots\ldots\ldots\ x_{0n} + \Delta x_n) = b_1$$

$$f_2(x_{01}+ \Delta x_1; x_{02}+ \Delta x_2; \ldots\ldots\ldots\ldots\ldots\ x_0 n + \Delta x_n) = b_2$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$f_n(x_{01}+ \Delta x_1;\ x_{02}+ \Delta x_2;\ \ldots\ldots\ldots.;\ x_{0n} + \Delta x_n) = b_n (2.2)$$

Each of the above equations can be expanded using Taylor's theorem. The expanded form of the ith equation is

$$f_i(x_{01}+\Delta x_1\ldots\ldots\ldots.,x_{0n}+\Delta x_n) = \left\{ \begin{array}{l} f_1(x_{01},x_{02}\ldots\ldots..x_{0n}) + (\dfrac{\partial f_i}{\partial x_1})\Delta x_1 \\ +\ldots.+((\dfrac{\partial f_i}{\partial x_n})\Delta xn + terms \\ higherpower\,\Delta x_1\ldots\ldots\ldots\ldots.\Delta x_n \end{array} \right\} = b_i \qquad (2.3)$$

The terms of higher powers can be neglected, if our initial estimate is close to the true solution. The resulting linear set of equations in matrix form is

$$\begin{bmatrix} b_1 - f_1(x_{01},x_{02}\ldots\ldots\ldots..x_{0n}) \\ b_2 - f_1(x_{01},x_{02}\ldots\ldots\ldots..x_{0n}) \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ b_n - f_1(x_{01},x_{02}\ldots\ldots\ldots..x_{0n}) \end{bmatrix} = \begin{bmatrix} \left(\dfrac{\partial f_1}{\partial x_1}\right)_0 \left(\dfrac{\partial f_1}{\partial x2}\right)_0 \ldots\ldots \left(\dfrac{\partial f_1}{\partial x_n}\right)_0 \\ \left(\dfrac{\partial f_2}{\partial x_1}\right)_0 \left(\dfrac{\partial f_2}{\partial x_2}\right)_0 \ldots\ldots \left(\dfrac{\partial f_2}{\partial x_n}\right)_0 \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ \left(\dfrac{\partial f_n}{\partial x_1}\right)_0 \left(\dfrac{\partial f_n}{\partial x_2}\right)_0 \ldots\ldots \left(\dfrac{\partial f_n}{\partial x_n}\right)_0 \end{bmatrix} \begin{bmatrix} \Delta x_1 \\ \Delta x_n \\ \cdots \\ \Delta x_n \end{bmatrix}^0 \qquad (2.4)$$

In general

$$\Delta F = J\Delta x$$

Where J is referred to as the Jacobian. If the estimates x_{01}; …….; x_{0n} were exact, then ΔF and Δx would be zero. However, as x_{01}; ………; x_{0n} are only estimates, the errors ΔF are finite. The above equation provides a linearized relationship between the errors ΔF and the corrections Δx through the Jacobian of the simultaneous equations. A solution for Δx can be obtained by applying any suitable method for the solution of a set of linear equations. An updated value of x can be calculated as

$$x_{1i} = x_0 i + \Delta x_i$$

(2.5)

The process is repeated until the errors ΔF are lower than a specified tolerance. The Jacobian has to be recalculated at each step.

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5 BASIC PRINCIPAL OF INTERLINE POWER FLOW CONTROLLER

In its general form the interline power flow controller employs number of DC to AC inverters each providing series compensation for a different line as shown in Fig.1.IPFC is designed as a power flow controller with two or more independently controllable static synchronous series compensators (SSSC) which are solid state voltage source converters injecting an almost sinusoidal voltage at variable magnitude and are linked via a common DC capacitor. SSSC is employed to increase the transferable active power on a given line and to balance the loading of a transmission network. In addition, active power can be exchanged through these series converters via the common DC link in IPFC. It is noted that the sum of the active powers outputted from VSCs to transmission lines should be zero when the losses of the coverter circuits can be ignored. A combination of the series connected VSC can inject a voltage with controllable magnitude and phase angle at the fundamental frequency while DC link voltage can be maintained at a desired level. The common DC link is represented by a bidirectional link for active power exchange between voltage sources.

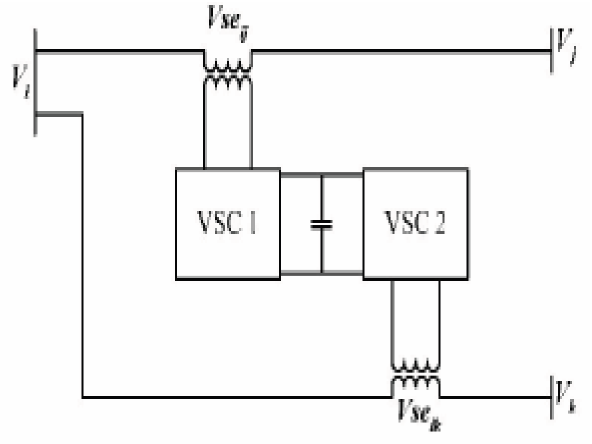

Figure 1. Basic Configuration Of Interline

The equivalent circuit of the IPFC is shown in Fig.2.

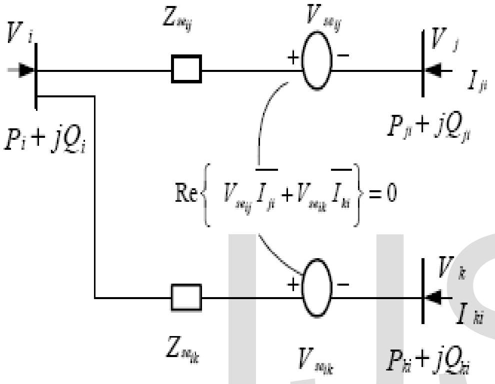

Fig.2. Equivalent circuit of IPFC

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6 STABILITY FUNDAMENTALS

6.1 Definiation of Stability

In the study of electric power systems, several different types of stability descriptions are encountered. There are three types of stability namely,

(1) Steady State Stability

It refers to the stability of a power system subject to small and gradual changes in load, and the system remains stable with conventional excitation and governor controls.

(2) Dynamic Stability

It refers to the stability of a power system subject to a relatively small and sudden disturbance, the system can be described by linear differential equations, and the system can be stabilized by a linear and continuous supplementary stability control.

(3)Transient Stability

It refers to the stability of a power system subject to a sudden and severe disturbance beyond the capability of the linear and continuous supplementary stability control, and the system may lose its stability at the first swing unless a more effective countermeasure is taken, usually of the discrete type, such as dynamic resistance braking or fast valving for the electric energy surplus area, or load shedding for the electric energy deficient area. For transient stability analysis and control design, the power system must be described by nonlinear differential equations. Transient stability concerns with the matter of maintaining synchronism among all generators when the power system is suddenly subjected to severe disturbances such as faults or circuits caused by lightning strikes, the sudden removal from the transmission system of a generator and/or a line, and any severe shock to the system due to a switching operation.

7 FLEXIBLE AC TRANSMISSION SYSTEM

Flexible transmission system is akin to high voltage dc and related thyristors developed designed to overcome the limitations of the present mechanically controlled ac power transmission system.Use of high speed power electronics controllers, gives 5 oppertunities for increased efficiency.

(1) Greater control of power so that it flows in the prescribed transmission routes.
(2) Secure loading (but not overloading) of transmission lines to levels nearer their required limits.
(3) Greater ability to transfer power between controlled areas, so that the generator reserve margin- typically 18 % may be reduced to 15 % or less.
(4) Prevention of cascading outages by limiting the effects of faults and equipment failure.
(5) Damping of power system oscillations,which could damage equipment and or limit usable transmission capacity.

Flexible system requires tighter transmission control and efficient management of inter-related parameters that constrains today's system including –

(1) Series impedance- phase angle.
(2) Shunt impedance- occurrence of oscillations at various frequencies below rated frequency.

This results in transmission line to operate near its thermal rating. Eg- a 1000kv line may have loading limit 3000-4000Mw .but the thermal limit may be 5000Mw.

8 BUS CLASSIFICATION

A bus is a node at which one or many lines, one or many loads and generators are connected. In a power system each node or bus is associated with 4 quantities, such as magnitude of voltage, phage angle of voltage, active or true power and reactive power in load flow problem two out of these 4 quantities are specified and remaining 2 are required to be determined through the solution of equation. Depending on the quantities that have been specified, the buses are classified into 3 categories.

7.1 Variables and Bus Classification

Buses are classified according to which two out of the four variables are specified

(1)Load Bus: No generator is connected to the bus. At this bus the real and reactive power are specified.it is desired to find out the volatage magnitude and phase angle through load flow solutions.It is required to specify only Pd and Qd at such bus as at a load bus voltage can be allowed to vary within the permissible values.

(2)Generator Bus or Voltage Controlled Bus: Here the voltage magnitude corresponding to the generator voltage and real power Pg corresponds to its rating are specified.It is required to find out the reactive power generation Qg and phase angle of the bus voltage.

(3)Slack (Swing) Bus: For the Slack Bus, it is assumed that the voltage magnitude $|V|$ and voltage phase Θ are known,whereas real and reactive powers Pg and Qg are obtained through the load flow solution.

9 MATLAB PROGRAMMING BASED RESULTS

Table A-3.1: Bus data

Bus No	Status	V	P_G	Q_G	P_L	Q_L
1	1	1.060	0.000	0.000	0.000	0.000
2	2	1.045	0.400	0.000	0.217	0.127
3	3	1.000	0.000	0.000	0.024	0.012
4	3	1.000	0.000	0.000	0.076	0.016
5	2	1.010	0.000	0.000	0.942	0.190
6	3	1.000	0.000	0.000	0.000	0.000
7	3	1.000	0.000	0.000	0.228	0.109
8	2	1.010	0.000	0.000	0.300	0.300
9	3	1.000	0.000	0.000	0.000	0.000
10	3	1.000	0.000	0.000	0.058	0.020
11	2	1.082	0.000	0.000	0.000	0.000
12	3	1.000	0.000	0.000	0.112	0.075
13	2	1.071	0.000	0.000	0.000	0.000
14	3	1.000	0.000	0.000	0.062	0.016
15	3	1.000	0.000	0.000	0.082	0.025
16	3	1.000	0.000	0.000	0.035	0.018
17	3	1.000	0.000	0.000	0.090	0.058
18	3	1.000	0.000	0.000	0.032	0.009
19	3	1.000	0.000	0.000	0.095	0.034
20	3	1.000	0.000	0.000	0.022	0.007
21	3	1.000	0.000	0.000	0.175	0.112
22	3	1.000	0.000	0.000	0.000	0.000
23	3	1.000	0.000	0.000	0.032	0.016
24	3	1.000	0.000	0.000	0.087	0.067
25	3	1.000	0.000	0.000	0.000	0.000
26	3	1.000	0.000	0.000	0.035	0.023
27	3	1.000	0.000	0.000	0.000	0.000
28	3	1.000	0.000	0.000	0.000	0.000
29	3	1.000	0.000	0.000	0.024	0.009
30	3	1.000	0.000	0.000	0.106	0.019

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Table A-3.2: Line Data

Line No.	From bus	To bus	R	X	Line Charging	Tap
1	1	2	0.0192	0.0575	0.0264	1.0
2	1	3	0.0452	0.1852	0.0204	1.0
3	2	4	0.0570	0.1737	0.0184	1.0
4	3	4	0.0132	0.0379	0.0042	1.0
5	2	5	0.0472	0.1983	0.0209	1.0
6	2	6	0.0581	0.1763	0.0187	1.0
7	4	6	0.0119	0.0414	0.0045	1.0
8	5	7	0.0460	0.1160	0.0102	1.0
9	6	7	0.0267	0.0820	0.0085	1.0
10	6	8	0.0120	0.0420	0.0045	1.0
11	6	9	0.0000	0.2080	0.0000	0.978
12	6	10	0.0000	0.5560	0.0000	0.969
13	9	11	0.0000	0.2080	0.0000	1.0
14	9	10	0.0000	0.1100	0.0000	1.0
15	4	12	0.0000	0.2560	0.0000	0.932
16	12	13	0.0000	0.1400	0.0000	1.0
17	12	14	0.1231	0.2559	0.0000	1.0
18	12	15	0.0662	0.1304	0.0000	1.0
19	12	16	0.0945	0.1987	0.0000	1.0
20	14	15	0.2210	0.1997	0.0000	1.0
21	16	17	0.0824	0.1923	0.0000	1.0
22	15	18	0.1070	0.2185	0.0000	1.0
23	18	19	0.0639	0.1292	0.0000	1.0
24	19	20	0.0340	0.0680	0.0000	1.0
25	10	20	0.0936	0.2090	0.0000	1.0
26	10	17	0.0324	0.0845	0.0000	1.0
27	10	21	0.0348	0.0749	0.0000	1.0
28	10	22	0.0727	0.1499	0.0000	1.0
29	21	22	0.0116	0.0236	0.0000	1.0
30	15	23	0.1000	0.2020	0.0000	1.0
31	22	24	0.1150	0.1790	0.0000	1.0
32	23	24	0.1320	0.2700	0.0000	1.0
33	24	25	0.1885	0.3292	0.0000	1.0
34	25	26	0.2544	0.3800	0.0000	1.0
35	25	27	0.1093	0.2087	0.0000	1.0
36	28	27	0.0000	0.3960	0.0000	0.968
37	27	29	0.2198	0.4153	0.0000	1.0
38	27	30	0.3202	0.6027	0.0000	1.0
39	29	30	0.2399	0.4533	0.0000	1.0
40	8	28	0.0636	0.2000	0.0214	1.0
41	6	28	0.0169	0.0599	0.0065	1.0

Table A-3.3: Reactive power limits

Bus No.	Q_{Gmax} p.u.	Q_{Gmin} p.u.
2	0.50	-0.40
5	0.40	-0.40
8	0.40	-0.10
11	0.24	-0.06
13	0.24	-0.06

Table A-3.4: Bus Status

Type of Bus	Status
Slack Bus	1
PV Bus	2
PQ Bus	3

CONCLUSION

In this paper work, firstly basic load flow algorithm is presented from which only crisp data can be obtained. Newton – Raphson method is used in crisp load flow algorithm. Optimal Placement of FACTS Controllers in Power System has been carried out to find optimal location of IPFC and to improve the losses and voltage profile of the system

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