Location of IPFC Under Contingency Condition in Power System

B.V. Rami Reddy, P. Sujatha and Y.V. Siva Reddy

Abstract The interline power flow controller (IPFC) is the latest generation of flexible AC transmission systems (FACTS) device specifically used for the control of power flows in multi transmission system. If the load on the power system is heavily increased, then the system is at high risk because of line outages and consequent voltage instability problem. The power loss and voltage drop are reliable indicators of voltage security of power networks. Here we analyze the voltages, line apparent power flows and total power losses in the system. This paper also proposes an algorithm for optimal location of the IPFC so as to enhance voltage stability and to maintain the line flows within the limit under the over loaded line outage contingency in a power system network. The over loaded lines (outages) are ranked based on Severity Index. The effectiveness of the proposed method is tested for IEEE-30 bus system with the help of MATLab software.

Keywords FACTS devices · IPFC · Line flows · Line losses · Contingency condition · Severity index · Voltage stability improvement

1 Introduction

The introduction of the FACTS devices into the power system offered great opportunities for the power engineer in the area of operation and control of modern power systems. For example, FACTS devices are often planned for power flow regulation in the steady state thus enhancing the power transfer capability of existing transmission lines. Various types of FACTS devices and their location at

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different places have varying advantages [1, 2]. The FACTS devices like Static VAR Compensator (SVC), Thyristor Controlled Series Capacitor (TCSC), Static Synchronous Series Compensator (SSSC) and Static Synchronous Compensator (STATCOM) are the first generation FACTS devices available in the literature for control of power flow in transmission systems [3].

The introductory FACTS devices were able to regulate either the flow of active or reactive power along a single transmission line. A breakthrough was made with the introduction of the UPFC [4], which is one of the most versatile FACTS devices and also capable of simultaneously controlling the flow of both active and reactive power in the transmission line. Another newly developed FACTS device, namely IPFC, further extends the capability of independently influencing the active and reactive power flows to simultaneous compensation of multiple transmission lines. These significant functions are made possible by the combination of multiple compensators coupled via a common dc link. Thus, both the UPFC and IPFC are defined as the combined compensators [5].

The IPFC is an advanced FACTS device aimed at controlling the power flow in multiline systems in a substation [6]. IPFC employs Voltage Source Inverter (VSI) as basic building block. Generally, it composes of two VSIs which are capable of transferring real power from one line to any other line and thereby facilitating transfer of real power among the lines, and also achieving independent control of series compensation of each individual line.

IPFC is presented as a power injection model and is implemented to study the effect of IPFC parameters on bus voltages, active and reactive power flows in the lines [7]. The applications of IPFC to improve damping of the system have been reported by few researches and they have applied IPFC to improve transient stability of power system [8]. It can also be utilized to compensate against reactive voltage drops and the corresponding reactive line power and thereby increase the effectiveness of the compensating system against dynamic disturbances [9]. The minimization of generation cost, transmission losses and maximization of the loadability of the transmission system can be achieved by optimally placing IPFC. Different operating conditions of the power system must be considered while determining the optimal size and location of the power flow controller.

Contingency analysis deals with the study of the impact and performance of the system during the outage of the power system components such as transmission lines, transformers and generators. Among these contingencies referring to major disturbances like loss of a transmission line or a generator may create sudden and large changes in both the configuration and the operating state of the power system. Contingencies sometimes may also result in severe violations of the operating constraints. Consequently, to have a secure operating evaluation and planning for contingencies forms an important aspect. [10, 11].

This paper proposes an algorithm for optimal location of the IPFC to improve voltage stability under the over loaded line outage contingency in a power system network. This paper also analyses the performance of the IPFC for various combinations of voltage magnitudes and angles at best IPFC location.

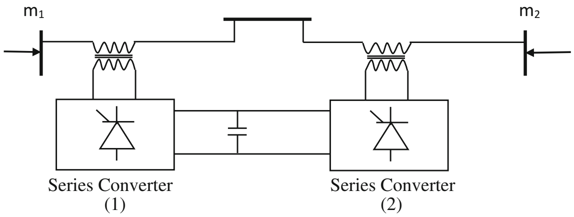


Fig. 1 Simple model of IPFC

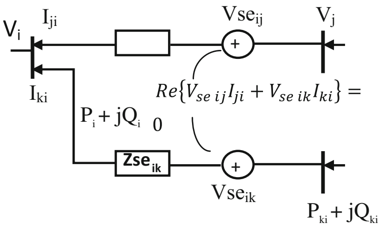


Fig. 2 Equivalent circuit of IPFC

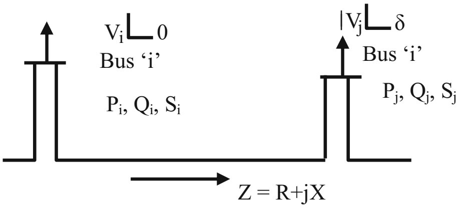
2 Interline Power Flow Controller (IPFC)

In general the IPFC utilizes a number of DC to AC converters each providing a dedicated series compensation for a given line as shown in Fig. 1 and equivalent circuit shown in Fig. 2. The series compensation is achieved by employing two or more independently controllable static synchronous series compensators (SSSC) which are solid state voltage source converters (VSC). By maintaining DC link voltage at the desired level the combination of the series connected VSC can inject a voltage at fundamental frequency with controllable magnitude and phase angle. In practice the DC link is represented as a bidirectional link for exchange of active power among the converters. SSSC is employed for increasing real power transfer on a given line by directly compensating for the voltage drop due to inductive loading of a transmission network. In addition, active power can also be exchanged through these series converters via the common DC link in IPFC. It is noted that the sum of the active powers resulting from VSCs to transmission lines should be zero when the losses in the converter circuits are ignored.

3 Modeling of IPFC

The modeling for IPFC which will be referred to as power injection model is presented here. This model is helpful in understanding the impact of the IPFC on the power system in the steady state. Furthermore, the IPFC model can easily be incorporated in the power flow model. For steady state analysis of power systems the normal practice is to represent VSC as a synchronous voltage source injecting an almost sinusoidal voltage with controllable magnitude and angle. On this basis, the equivalent circuit of IPFC has been modified and is represented as shown in Fig. 3.

Fig. 3 Equivalent circuit of IPFC



In Fig. 3, V_i, V_j and V_k are the bus voltages at the buses i, j and k respectively, $V_x = V_x∠\theta$ (x = i, j and k). In V_{se} it is the controllable voltage source injected by connecting in series, $V_{se} = V_{se}∠\theta_{se}$ (n = j, k) and in Z_{se} (n = j, k) is the transformer impedance. The complex power injected into any bus can be determined by modeling IPFC as a current source. The line and the series coupling transformer's resistances are neglected for making the calculations simpler. The injected power at buses are summarized and The Power flow equations for IPFC can written as below,

$$\begin{aligned} P_i = V_i^2 g_{ii} - \sum_{j=1, j\neq i}^{n} V_i V_j \left(g_{ij}\cos\left(\theta_j - \theta_i\right) + b_{ij}\sin\left(\theta_j - \theta_i\right)\right) \\ - \sum_{j=1, j\neq i}^{n} V_i Vse_{ij}\left(\left(g_{ij}\cos\left(\theta_i - \theta se_{ij}\right) + b_{ij}\sin\left(\theta_i - \theta se_{ij}\right)\right)\right. \end{aligned} \tag{1}$$

$$\begin{aligned} Q_i = V_i^2 b_{ii} - \sum_{j=1, j\neq i}^{n} V_i V_j (g_{ij}\sin\left(\theta_j - \theta_i\right) + b_{ij}\sin\left(\theta_j - \theta_i\right)) \\ - \sum_{j=1, j\neq i}^{n} V_i Vse_{ij}\left(g_{ij}\sin\left(\theta_i - \theta se_{ij}\right) + b_{ij}\sin\left(\theta_i - \theta se_{ij}\right)\right) \end{aligned} \tag{2}$$

where: V = Bus voltage magnitude, θ = Voltage angle, V_{se} = magnitude of injected voltage, θ_{se} = Angle of injected voltage.

4 Voltage Stability Index Formulation

In this study the Voltage Stability Index [12] abbreviated by "L_{ij}" and referred to a line is formulated as the measuring unit in predicting the voltage stability condition in the system. The mathematical formulation presented here is very simple and also achieves faster computation. By using the second order linear voltage equation at the receiving bus on a two bus system the Lij is obtained (Figs. 4, 5 and 6).

From Fig. 3, the voltage quadratic equation at the receiving bus is written as

$$\lfloor V_j^2 - \left(\frac{R}{X}\sin\delta + \cos\delta\right)V_i V_j + \left(X + \frac{R^2}{X}\right)Q_j = 0\rfloor \tag{3}$$

Setting the discriminate of the equation to be greater than or equal to zero:

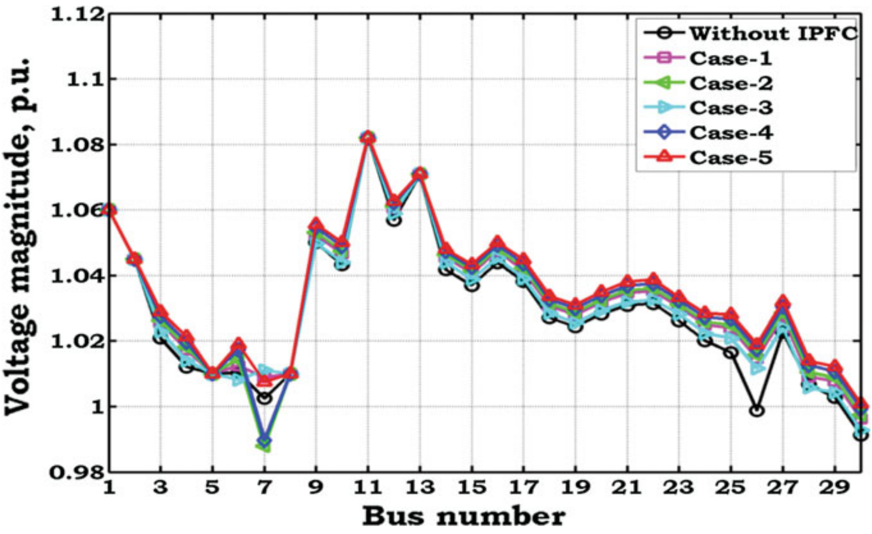


Fig. 4 Plot between bus number and voltage mangitude witout IPFC and with IPFC during various conditions

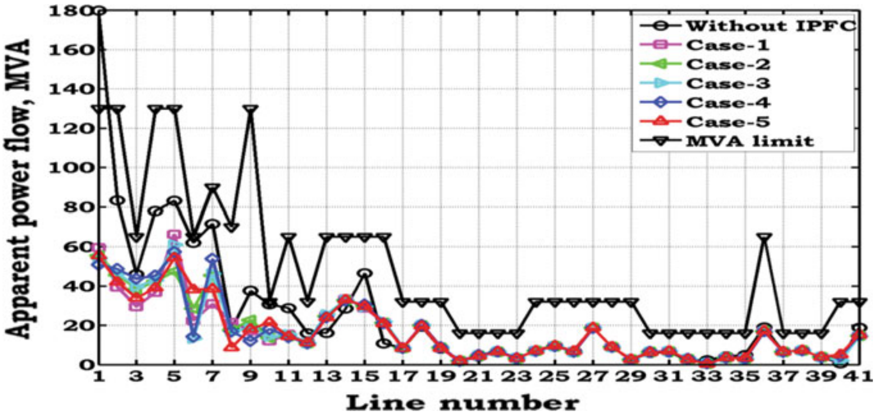
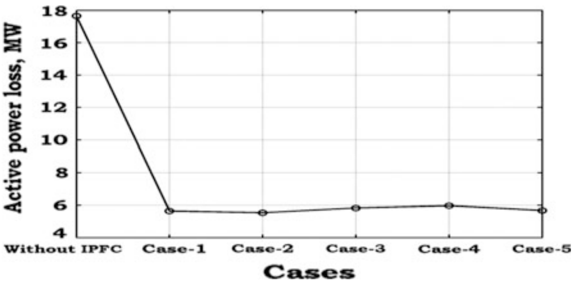


Fig. 5 Plot between line number and apparent power witout IPFC and with IPFC during various conditions

Fig. 6 Plot of power losses witout IPFC and with IPFC during various conditions



$$\lfloor \left(\frac{R}{X}\sin\delta + \cos\delta\right) V_i^2 \rfloor - 4\left(X + \frac{R^2}{X}\right) Q_j \geq 0 \tag{4}$$

Rearranging above equation, Voltage Stability Index "L_{ij}" is

$$L_{ij} = \frac{4Z^2 Q_j X}{V_i^2 (R\sin\delta + X\cos\delta)^2} \tag{5}$$

where: Z and X are line impedance and reactance respectively,

Q_j and is the reactive power at the receiving end, V_i and V_j are sending end and receiving end voltages.

5 Contingency Analysis

Contingency analysis aims at studying the effect of the outage of components of power system like transmission lines, transformers and generators on the power system network. Contingencies referring to disturbances such as transmission line outages or generator outages may cause large amount of load may stay connected or removed and thus resulting a change in either the state or configuration of the power system. Contingencies may result in severe changes of the operating parameters. Consequently, planning for contingencies forms an important aspect of secure operation of the power system network. Contingency analysis helps the power system engineer at many stages like network design, programmed maintenance, network expansion and also in the identification of network weaknesses and thus serve as an important tool for estimating security of the power system during operation and planning. Contingency analysis allows the power system to be operated defensively. Majority of the faults occurring in the power system network can cause serious troubles within a small time if the operator could not take fast remedial action. Keeping in view of these, modern computers are equipped with contingency analysis programs which model the power system network and are used to know outage events and give alert to the operators of potential overloads and voltage violations.

The most difficult practical problem to manage within contingency analysis is the correctness of the method and the speed of solution of the model used. The operator should have an idea of the performance of the existing network which is instable condition and also he should possess the knowledge of the effect of a particularly contingency like outage of a particular generator or transmission line.

Recently, due to the problems such as the congestion management, the minimization of the operational cost and the overall generating cost, the additional degree of freedom possessed by the FACTS devices have aroused great interest in the application of the FACTS devices, especially the UPFC, the IPFC and the generalized Unified Power Flow Controller (GUPFC), in the OPF control. However, very few publications have focused on the comparison between the performance of the UPFC and the IPFC in the OPF control. This paper proposes an algorithm for optimal location of the IPFC to improve voltage stability under the over loaded line outage contingency in a power system network.

6 Performance Index

The contingency analysis process gives an idea about the effect of individual contingency cases, hence the above process take large time to evaluate the contingency in the power system network. The contingency analysis is selected by calculating a kind of severity indices known as Performance Indices PI [13]. These indices values are calculated using the conventional power flow algorithms for individual contingencies. Based on the line flow limit in overloaded lines, contingencies are ranked in a manner where the highest value of PI is ranked first. This will continues till the no severe contingencies are found.

There are two kinds of performance indices used in power system networks, one is active power performance index (PI_P) and other one is reactive power performance index (PI_V). The active power performance index (PI_P) reflects the violation of line active power flows and is given as

$$PI_P = \sum_{i=1}^{L} \left(\frac{P_i}{P_{i^{max}}}\right)^{2n} \tag{6}$$

where: P_i = active power flow in line I, P_i^{max} = maximum active power flow in line i

n = specified exponent, L = number of transmission lines in the power system

The maximum power flow in each line will be calculated as

$$P_i^{max} = \frac{V_i * V_j}{X} \tag{7}$$

And other performance index parameter which is used in reactive performance index corresponding to the bus voltage magnitude violations. The value can be evaluated as below

$$PI_V = \sum_{i=1}^{N_{pq}} \left[\frac{2(V_i - V_{inon})}{V_{imax} - V_{imin}}\right]^2 \tag{8}$$

where V_i = voltage at bus I, V_{imax} and V_{imin} max. and min. values voltage limits,

V_{inon} = average value of V_{imax} and V_{imin}, N_{pq} = total number of voltage buses.

7 Results and Conclusions

The proposed method is implemented in MATLAB working platform. The performance of proposed method is tested with IEEE 30 bus system. Initially severity indices known as Performance Indices are calculated and are ranked in a manner where the highest value of PI is ranked first. Based on the line flows (MVA) outage lines (lines which are overloaded) and contingency rank have been determined and are indicated in Tables 1 and 2 respectively. Also line flows under rank 1 contingency criterion are provided in Table 3.

Table 1 Over loaded lines of IEEE-30 bus system during contingency analysis

S. no.	Outage line	Overloaded lines	Line flow (MVA)	Line limit (MVA)	PI
1	1–2	1–3	312.783	130	2.406
		2–4	66.2477	65	1.0192
		3–4	281.6728	130	2.1667
		4–6	175.1941	90	1.9466
		6–8	40.2057	32	1.2564
2	1–3	1–2	274.0404	130	2.108
		2–4	86.1364	65	1.3252
		2–6	92.7082	65	1.4263
		6–8	35.5403	32	1.1106
3	2–4	1–2	163.1902	130	1.2553
		2–6	82.8385	65	1.2744
		6–8	34.3948	32	1.0748
4	3–4	1–2	271.089	130	2.0853
		2–4	84.8975	65	1.3061
		2–6	91.7550	65	1.4116
		6–8	35.2239	32	1.1007
5	2–5	1–2	171.3989	130	1.3185
		2–4	77.6706	65	1.1949
		2–6	105.4337	65	1.6221
		4–6	121.4176	90	1.3491
		5–7	110.1903	70	1.5741
		6–8	35.8277	32	1.1196
6	2–6	1–2	163.1085	130	1.2547
		2–4	74.6436	65	1.1484
		4–6	114.4738	90	1.2719
		6–8	36.3001	32	1.1344

(continued)

Table 1 (continued)

S. no.	Outage line	Overloaded lines	Line flow (MVA)	Line limit (MVA)	PI
7	4−6	1−2	203.7972	130	1.5677
		2−6	98.9857	65	1.5229
		4−12	66.9868	65	1.0306
8	5−7	1−2	183.331	130	1.4102
9	6−7	1−2	189.9598	130	1.4612
10	6−8	1−2	180.4949	130	1.3884
		6−28	48.2618	32	1.5082
11	9−10	1−2	179.4047	130	1.38
12	12−14	1−2	180.0452	130	1.385
13	12−15	1−2	180.6197	130	1.3894
14	12−16	1−2	180.1352	130	1.3857
15	14−15	1−2	179.8402	130	1.3834
16	16−17	1−2	179.9547	130	1.3843
17	15−18	1−2	180.042	130	1.3849
18	18−19	1−2	179.897	130	1.3838
19	19−20	1−2	179.8863	130	1.3837
20	10−20	1−2	179.9755	130	1.3844
		15−18	16.3239	16	1.0202
21	10−17	1−2	179.8006	130	1.3831
22	10−21	1−2	180.0833	130	1.3853
23	10−22	1−2	179.8806	130	1.3837
24	21−22	1−2	179.833	130	1.3833
25	15−23	1−2	180.0283	130	1.3848
26	22−24	1−2	179.8826	130	1.3837
27	23−24	1−2	179.8725	130	1.3836
28	24−25	1−2	179.7933	130	1.383
29	25−27	1−2	179.8072	130	1.3831
30	27−29	1−2	180.1101	130	1.3855
31	27−30	1−2	180.2028	130	1.3862
32	29−30	1−2	179.9245	130	1.384
33	8−28	1−2	179.8769	130	1.3837
34	6−28	1−2	179.9431	130	1.3842
		6−8	46.3583	32	1.4487

Table 2 Contingency ranking

S. no.	Outage line	Severity index	Rank	S. no.	Outage line	Severity index	Rank
1	**1−2**	**8.7949**	**1**	18	18−19	1.3838	23
2	1−3	5.9701	3	19	19−20	1.3837	24
3	2−4	3.6045	7	20	10−20	2.4046	10
4	3−4	5.9037	4	21	10−17	1.3831	31
5	2−5	8.1783	2	22	10−21	1.3853	17
6	2−6	4.8094	5	23	10−22	1.3837	25
7	4−6	4.1212	6	24	21−22	1.3833	30
8	5−7	1.4102	12	25	15−23	1.3848	20
9	6−7	1.4612	11	26	22−24	1.3837	26
10	6−8	2.8966	8	27	23−24	1.3836	28
11	9−10	1.38	34	28	24−25	1.383	33
12	12−14	1.385	18	29	25−27	1.3831	32
13	12−15	1.3894	13	30	27−29	1.3855	16
14	12−16	1.3857	15	31	27−30	1.3862	14
15	14−15	1.3834	29	32	29−30	1.384	22
16	16−17	1.3843	21	33	8−28	1.3837	27
17	15−18	1.3849	19	34	6−28	2.8329	9

Table 3 Line flows under rank-1 contingency

From bus	To bus	S flow	MVA limit	Margin limit	From bus	To bus	S flow	MVA limit	Margin limit
1	3	312.783	130	−182.783	15	18	7.8404	16	8.1596
2	4	66.2477	65	−1.2477	18	19	4.4918	16	11.5082
3	4	281.6728	130	−151.673	19	20	6.0022	32	25.9978
2	5	56.1075	130	73.8925	10	20	8.3951	32	23.6049
2	**6**	**29.0091**	**65**	**35.9909**	10	17	5.7973	32	26.2027
4	6	175.1941	90	−85.1941	10	21	18.5089	32	13.4911
5	7	52.5367	70	17.4633	10	22	8.7761	32	23.2239
6	**7**	**67.9993**	**130**	**62.0007**	21	22	2.503	32	29.497
6	8	40.2057	32	−8.2057	15	23	7.3842	16	8.6158
6	9	26.9166	65	38.0834	22	24	6.1744	16	9.8256
6	10	13.8073	32	18.1927	23	24	3.7824	16	12.2176
9	11	22.8785	65	42.1215	24	25	1.7065	16	14.2935
9	10	26.1654	65	38.8346	25	26	4.2654	16	11.7346
4	12	51.2579	65	13.7421	25	27	3.5429	16	12.4571
12	13	21.8916	65	43.1084	28	27	17.5846	65	47.4154
12	14	8.8638	32	23.1362	27	29	6.4196	16	9.5804
12	15	21.8485	32	10.1515	27	30	7.2948	16	8.7052
12	16	10.7842	32	21.2158	29	30	3.7553	16	12.2447
14	15	2.3373	16	13.6627	8	28	2.9555	32	29.0445
16	17	6.8978	16	9.1022	6	28	17.8011	32	14.1989

Table 4 Voltage magnitudes

Bus no.	Without	Case-1	Case-2	Case-3	Case-4	Case-5
1	1.06	1.06	1.06	1.06	1.06	1.06
2	1.045	1.045	1.045	1.045	1.045	1.045
3	1.020837	1.025552	1.026262	1.022836	1.027562	1.028899
4	1.012045	1.017312	1.018126	1.013987	1.019689	1.021329
5	1.01	1.01	1.01	1.01	1.01	1.01
6	1.010358	1.012468	1.014425	1.008207	1.017257	1.018915
7	1.002434	1.008811	0.987926	1.011041	0.989551	1.007447
8	1.01	1.01	1.01	1.01	1.01	1.01
9	1.05003	1.052258	1.053166	1.049843	1.054598	1.055624
10	1.043259	1.046638	1.047412	1.043946	1.048805	1.050049
11	1.082	1.082	1.082	1.082	1.082	1.082
12	1.056788	1.060382	1.061079	1.058948	1.062047	1.062608
13	1.071	1.071	1.071	1.071	1.071	1.071
14	1.041741	1.045531	1.046298	1.043947	1.047366	1.047985
15	1.036974	1.040737	1.041437	1.038896	1.042522	1.043316
16	1.043858	1.047362	1.048051	1.04534	1.04918	1.05008
17	1.03811	1.041537	1.042275	1.039022	1.043587	1.044746
18	1.027036	1.030706	1.031431	1.028529	1.032634	1.033607
19	1.024284	1.027888	1.02863	1.025524	1.029902	1.030974
20	1.028245	1.031795	1.032542	1.029343	1.033842	1.034962
21	1.030907	1.034646	1.035438	1.031939	1.036849	1.038095
22	1.031462	1.035296	1.03609	1.032596	1.037502	1.038743
23	1.026122	1.030367	1.031134	1.02817	1.032377	1.033345
24	1.02006	1.024951	1.025818	1.022314	1.027272	1.028448
25	1.016386	1.023951	1.024958	1.020853	1.026661	1.028042
26	0.998691	1.014721	1.015737	1.011594	1.017456	1.01885
27	1.022661	1.027435	1.028538	1.024079	1.030396	1.031884
28	1.006813	1.008988	1.010474	1.005733	1.012628	1.013898
29	1.00281	1.007686	1.008812	1.004258	1.01071	1.012228
30	0.991328	0.996262	0.997402	0.992794	0.999323	1.00086

Base on the results of line flows it can be concluded that the best location of IPFC will be such that interline power flow takes place between lines 2–6 and 6–7. In short it is read as 2–6–7 (Tables 4, 5 and 6).

IPFC LOCATION: 6–2–7

Voltage values

Case-1 Vseij = 0.02; Thseij = 072; Vseik = 0.10; Thseik = 360
Case-2 Vseij = 0.04; Thseij = 144; Vseik = 0.08; Thseik = 288
Case-3 Vseij = 0.06; Thseij = 216; Vseik = 0.06; Thseik = 216

Table 5 Line apparent power flows

Line no	Without	Case-1	Case-2	Case-3	Case-4	Case-5	Line limit
1	179.8264	59.47208	55.5219	54.12143	50.8346	55.39428	130
2	83.26183	39.46966	45.68394	46.30381	48.67692	42.05647	130
3	45.95788	29.43964	38.35691	39.58179	43.71073	33.89528	65
4	77.92641	36.66613	42.43029	43.01274	45.24646	39.02199	130
5	83.11859	66.29842	47.44745	61.02156	57.29246	54.24907	130
6	61.95546	22.31943	28.5559	13.29143	14.05878	38.07222	65
7	71.65108	30.93591	45.40385	46.29661	53.76256	38.53168	90
8	18.11872	21.45945	17.58856	16.86571	16.74498	8.707027	70
9	37.54465	17.24524	22.74425	18.61146	11.93575	18.12826	130
10	30.60232	12.07611	13.68856	14.3966	18.1302	21.37357	32
11	28.76067	15.30788	14.55741	15.37277	13.9281	14.25033	65
12	15.84003	11.27801	10.96543	10.94006	10.80724	11.13735	32
13	16.13931	24.80973	24.54832	25.52792	24.14602	23.86569	65
14	28.55022	33.38389	32.85225	32.85906	32.55582	33.07232	65
15	46.48143	28.80205	29.78736	29.44849	30.43123	29.69254	65
16	10.72805	21.46567	21.28129	21.87821	21.0439	20.91633	65
17	8.249855	8.343178	8.421711	8.468506	8.452871	8.348217	32
18	19.23466	19.6677	20.01886	20.17301	20.17465	19.73776	32
19	8.00534	8.235117	8.604458	8.752462	8.779008	8.319786	32
20	1.750135	1.827968	1.901815	1.947566	1.932963	1.830703	16
21	3.976752	4.211036	4.604166	4.726869	4.806056	4.331541	16
22	6.281252	6.363855	6.580712	6.649777	6.68563	6.429352	16
23	2.896999	2.978454	3.195705	3.259423	3.306035	3.048629	16
24	7.208406	7.127738	6.94041	6.858115	6.864059	7.089788	32
25	9.680744	9.595946	9.400787	9.317149	9.319372	9.554902	32
26	6.88069	6.708984	6.510201	6.291977	6.482794	6.775726	32
27	18.62382	18.75347	18.69912	18.7068	18.66702	18.71564	32
28	8.855086	8.953484	8.916976	8.922268	8.895382	8.927963	32
29	2.391588	2.563762	2.581609	2.589027	2.590211	2.567308	32
30	5.900249	6.223063	6.412591	6.536692	6.488813	6.224871	16
31	6.400275	6.861728	6.754018	6.774447	6.688916	6.782285	16
32	2.291648	2.593784	2.805286	2.911114	2.905035	2.62386	16
33	2.26144	0.34264	0.468959	0.574455	0.539754	0.333524	16
34	4.262281	3.501428	3.501428	3.501428	3.501428	3.501428	16
35	4.848405	3.21335	3.065147	2.972533	3.013456	3.208899	16
36	18.85763	17.08748	16.96832	16.84874	16.93703	17.12148	65
37	6.411282	6.409487	6.409076	6.410746	6.408387	6.407838	16
38	7.284724	7.282545	7.282046	7.284073	7.28121	7.280544	16
39	3.753032	3.75254	3.752428	3.752885	3.752239	3.752089	16
40	0.666002	2.93711	3.508159	1.966458	4.445017	5.053087	32
41	18.71879	14.71428	14.69893	14.44456	14.88212	15.19993	32

Table 6 Total power losses

	Without	Case-1	Case-2	Case-3	Case-4	Case-5
P loss, MW	17.64796	5.634803	5.532813	5.820498	5.966696	5.671125
Q loss, MVAr	34.41422	−4.34473	−8.96334	−4.67502	−4.00816	−7.57269

Case-4 Vseij = 0.08; Thseij = 288; Vseik = 0.04; Thseik = 144
Case-5 Vseij = 0.10; Thseij = 360; Vseik = 0.02; Thseik = 072.

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