

Assessment of Total Transfer Capability Using IPLAN: An Application of UPFC for Total Transfer Capability Enhancement

Byung Ha Lee[†], Jung-Hoon Kim*, No-Hong Kwak** and Woon-Hee Lee***

Abstract - Power transfer capability has been recently highlighted as a key issue in many utilities. It is determined by the thermal stability, dynamic stability and voltage stability limits of generation and transmission systems. In particular, voltage stability affects power transfer capability to a great extent in many power systems. This paper presents a tool for determining total transfer capability from a static voltage stability viewpoint using IPLAN, which is a high level language used with the PSS/E program. The tool was developed so as to analyze static voltage stability and to determine the total transfer capability between different areas from a static voltage stability viewpoint by tracing stationary behaviors of power systems. A unified power flow controller (UPFC) is applied for enhancing total transfer capability between different areas from the viewpoint of static voltage stability. Evaluation of the total transfer capability of a practical KEPCO power system is performed from the point of view of static voltage stability, and the effect of enhancing the total transfer capability by UPFC is analyzed.

Keywords: F-V curve, IPLAN, repeated power flow, total transfer capability, UPFC, voltage stability

1. Introduction

Power transfer capability has been recently highlighted as a key issue in many utilities. As part of the restructuring of KEPCO (Korea Electric Power Corporation), the monopolistic company was divided into several companies and so the exact evaluation of the total transfer capability (TTC) between different areas is required for further commercial activity as transmission systems become more stressed and complicated. For the purpose of determining power transfer capabilities based on thermal and voltage limits, linear programming, linear DC power flow, and distribution factors were applied [1, 2]. It was shown that the interchange capability is additionally determined by dynamic stability limits via an energy margin calculation [3]. In [4], the maximum power transfer limits of different compensation schemes were considered from the point of view of voltage stability. A planning tool that provides a graphical display of the set of all feasible and secure inter-area megawatt transfers was also presented [5]. The real power transfer capability of a large scale power system was

determined using the simulation tool known as CPFLOW [6].

A simple, efficient, and non-iterative method was proposed in order to compute available transfer capability (ATC) between any two locations in the transmission system and ATC's for any selected transmission paths between them [7]. An algorithm to incorporate stability constraints to calculate TTC was proposed and the WSCC-9 bus system was used as the test system to demonstrate the methodology [8].

Power transfer capability is limited by thermal stability, dynamic stability and voltage stability in generation and transmission systems. In particular, voltage stability affects the power transfer capability to a great extent in many cases.

The availability of high power GTO thyristors has led to the development of controllable reactive power sources, using electronic switching converters, for use in power transmission systems, and has made flexible ac transmission systems (FACTS) possible. The Unified Power Flow Controller (UPFC) is a general form of equipment that can control all three line parameters (voltage, impedance, and phase angle) and also influence the flow of power. It was shown that the UPFC is able to control both the transmitted real power and independently, the reactive power flows [9]. The results of computer simulations showing the performance of the UPFC under different system conditions were also presented. A mathematical model for the UPFC referred to as the UPFC injection model was derived [10].

[†] Corresponding Author: Dept. of Electrical Engineering, University of Incheon, Korea. (bhlee@incheon.ac.kr)

* Dept. of Electrical and Electronic Engineering, Hongik University, Korea. (kimjh@hongik.ac.kr)

** Power System Lab., Korea Electric Power Research Institute, Korea. (nhkwak@kepri.re.kr)

*** System Operation & Control Dept., Korea Power Exchange, Korea. (oonhilee@kpx.or.kr)

Received May 24, 2005 ; Accepted June 30, 2005

This model was used to demonstrate some of the features of the UPFC for optimal power flow control applications. A real and reactive power coordination controller for UPFC's was proposed [11]. A real power coordination controller was designed to avoid instability of DC link capacitor voltage during transient conditions and a reactive power coordination controller was designed to limit excessive voltage excursions during reactive power transfer. UPFC's can also enhance voltage stability effectively by dynamic reactive power compensation in addition to power flow control.

This paper presents a new analysis tool, called the voltage stability program by repeated power flow method (VREP), for determining the total transfer capability using IPLAN, which is a high level language used with PSS/E program. Furthermore, it is shown that the total transfer capability can be enhanced using the UPFC by application to the power system of the Korea Electric Power Corporation (KEPCO). The tool was developed so as to analyze static voltage stability and to determine the total transfer capability between different areas from a static voltage stability viewpoint by tracing stationary behaviors of power systems such as P-V (power-voltage) and F-V (power flow-voltage) curves. Here, only TTC is considered as power transfer capability. The critical nose point is determined by the repeated power flow method using the simulation tool, which was developed by way of IPLAN. The repeated power flow method has benefits of reflecting practical power system operations and using well-known commercial programs. The procedure of the developed tool is explained in detail and this tool is applied to a practical power system of KEPCO. The UPFC is applied to enhance total transfer capability from the point of view of static voltage stability and the effect of applying the UPFC to a KEPCO power system is analyzed. A voltage instability index is used in order to select the effective place of installing the UPFC. Evaluation of the total transfer capability from the point of view of static voltage stability is performed for a KEPCO power system with a UPFC and the effect of enhancing total transfer capability by the UPFC is analyzed and compared to the power system without UPFC.

2. Determination of Maximum Power Transfer Capability from a Voltage Stability Point of View

The repeated power flow method is a method to obtain either a P-V or F-V curve by calculating power flow solutions due to generation and load variation repeatedly with a commercial power flow package until they are not solved corresponding to generation and load variation. The generation and load are varied according to a specific

scenario and power flow is solved for each changed condition. The procedure of the repeated power flow method is as follows:

1. Input the power system data.
2. Solve the set of initial power flow equations.
3. Input the buses at which generation and load are to be varied and also input the quantity of variation step.
4. Change generation and load according to a scenario and solve the set of power flow equations corresponding to the changed condition.
5. Check the convergence of the power flow solution. If it converges, go to step 3 to calculate the next point and if it does not converge, stop the repeated calculation of power flow equations.
6. Determine an approximate critical point of voltage collapse. Plot P-V and F-V curves using the calculated values.

An approximate voltage collapse point can be obtained by way of this method. The exact critical point of voltage collapse can be calculated by the continuation power flow method [12]. Continuation power flow is an iterative process that is primarily divided into two steps: predictor and corrector. In the predictor step, linear approximation is used to predict the next solution for a change in one of the state variables. This solution is used as the initial condition for the second step. In the corrector step, the approximate solution is corrected by using a parameterization scheme. The parameterization scheme provides a means of identifying each point along the solution path and plays an integral part in avoiding singularity in Jacobian. This method has a benefit of calculating the correct critical point avoiding singularity in Jacobian, but has some difficulty in reflecting practical generation and load variation such as ELD (economic load dispatch). The above repeated power flow method offers benefits of making practical generation and load variation such as ELD available, and of using well-known commercial programs for power system analysis.

Power transfer capability has recently become a key issue in many utilities. In order to determine the inter-area maximum power transfer capability, a power system is divided into two areas, i.e. an area of importing real power and an area of exporting real power. The power transfer between two areas is calculated repeatedly as the generation in an area of exporting real power increases and the generation in an area of importing real power decreases step-by-step with the load fixed. This procedure according to each contingency is executed by the repeated power flow method until power system equations are not solved following step-by-step generation variations. Thus, the F-V curve corresponding to each contingency is obtained and the contingency where the power transfer capability is the

least becomes the most severe contingency and the power transfer capability in the normal power system corresponding to this case is the maximum power transfer capability or total transfer capability (TTC). A step-by-step solution procedure is summarized as follows:

1. A scenario for increasing power transfer is selected.
2. The power system is divided into two areas, i.e. an area of importing real power and an area of exporting real power in order to determine the inter-area maximum power transfer capability.
3. Generation powers are varied by one variation step according to the scenario. The generators in the area of importing real power decrease their powers, while the generators in the area of exporting real power increase their powers by one step according to the merit order.
4. The power flow calculation is performed at the normal state. If it converges, the power transfer at this stage is determined and progression to the next stage can be realized. Otherwise, go to the previous stage 3 so as to revise the data for convergence.
5. The power flow calculation is performed for all the selected contingencies. If the power flow calculation converges for all the selected contingencies, go to the previous stage 3 in order to increase the power transfer. Otherwise, the power transfer at the normal state just before divergence becomes the inter-area maximum power transfer capability. The critical point (here an approximate critical point) on the F-V curve of the most severe contingency (P_{f1} point in Fig. 1) corresponds to the point (P_{f10} point in Fig. 1) in the normal power system, where it is the inter-area maximum power transfer capability.

The concept of these stages is shown in Fig. 1.

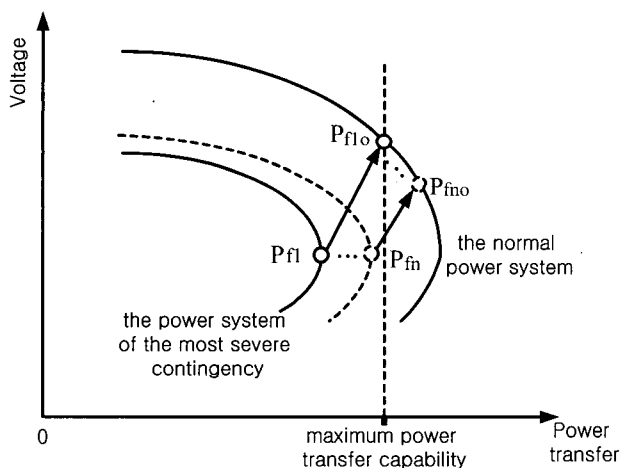


Fig. 1 A maximum power transfer capability

3. A Practical Tool for Determining TTC by Tracing F-V Curves

Power transfer capability is limited by thermal stability, dynamic stability and voltage stability of generation and transmission systems and then voltage stability affects the power transfer capability to the greatest extent in the KEPCO power system. A tool for determining the maximum power transfer capability or TTC from a static voltage stability point of view using IPLAN is presented here. The IPLAN program makes efficient running of the PSS/E package possible. The practical tool (VREP: Voltage stability program by the Repeated Power flow method) was developed so as to analyze static voltage stability and to determine the total transfer capability between different areas from a static voltage stability viewpoint by tracing steady state stationary behaviors of power systems such as P-V and F-V curves. An approximate critical point is automatically determined using the simulation tool based on the repeated power flow method, which was developed with IPLAN.

For determining TTC, a scenario for increasing power transfer is initially selected. The various scenarios for changing generation and load levels can be considered in the tool. A practical generation and load variation such as ELD can also be considered as a scenario. The power system is divided into an area of importing real power and an area of exporting real power and the inter-area transfer lines are selected for estimating the maximum power transfer capability. The merit order is a generation priority order for ELD used in KEPCO. The cases of contingencies are too numerous and it is very difficult and laborious to consider all of them. Therefore, contingency screening is performed before evaluating the maximum power transfer capability. N contingencies are selected in order of the severe degree and 20 contingencies are considered here.

The contingency where the power transfer limit is the least becomes the most severe contingency. The power transfer limit under voltage stability viewpoint is determined using the F-V curve in the most severe contingency. The inter-area maximum power transfer capability from a voltage stability viewpoint is calculated when the generation powers corresponding to the critical point in the case of the most severe contingency are generated in the normal power system, and then this maximum power transfer capability becomes the total transfer capability if the system at the specified operating point satisfies the other limits such as thermal limits and dynamic stability limits. In the KEPCO power system, the total transfer capability is determined by voltage stability limit and it means that the KEPCO power system is transiently stable at the critical points of F-V curves in the cases of all the contingencies considered. In addition to the

transfer capability of a practical KEPCO power system is performed from a static voltage stability point of view. The power system considered here is a pre-estimated power system of KEPCO at the peak time of summer 2005. The practical power system includes the following:

Transformers: 317, Maximum load: 53,100 MW,

In the KEPCO power system, most of the loads are concentrated in the Kyung-In region surrounding the city of Seoul, the capital of Korea and on the contrary, most of the large power plants with low-priced generation costs are located in regions far from Seoul, i.e., southern, south-western and south-eastern areas of Korea. Therefore, the power transfer going from the south of Korea to the Kyung-In region is considerably heavy and the power transfer from the south of Korea to the Kyung-In region plays an important role in the power supply and industry of Korea. Fig. 4 briefly describes the essential power transfer in the KEPCO power system. Therefore, this system is divided into two areas, that is, Kyung-In region and the southern region of Korea for evaluating this power transfer capability. The inter-area transfer lines for evaluating this inter-area power transfer capability are shown in Table 1.

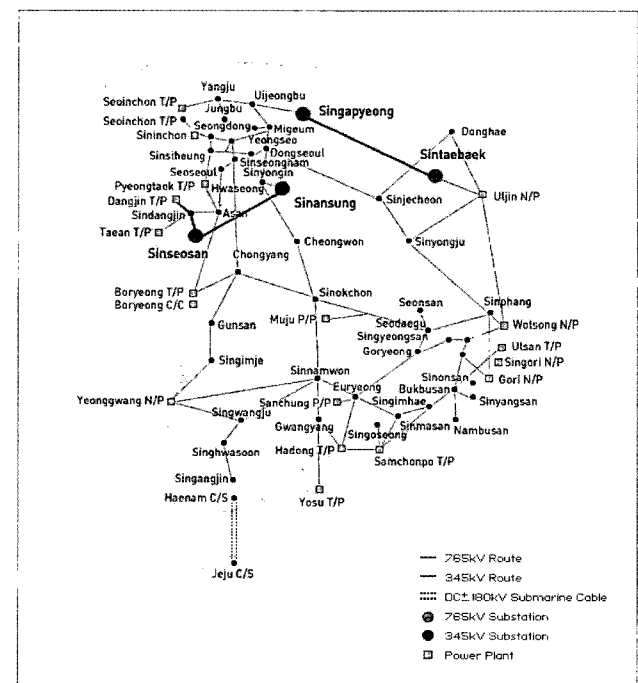


Fig. 3 The 345kV and above transmission systems of KEPCO.

4.2 UPFC model for power flow studies

The UPFC resulted from new FACTS technology can

The developed tool is applied to the practical power system of KEPCO. Evaluation of the maximum power

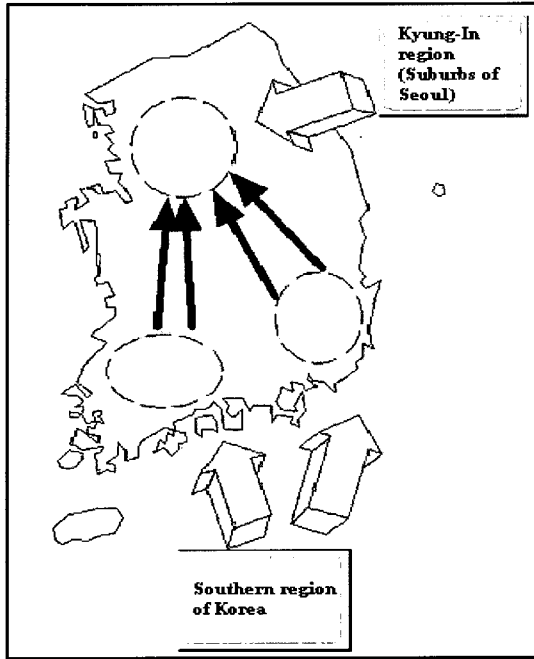


Fig. 4 The essential power transfer in the KEPCO power system.

Table 1 Inter-area transfer lines.

NO	Inter-area transfer lines	
	From bus	To bus
1	6951	4400
2	6950	4401
3	6030	4010
4	5010	1020
5	6800	4601
6	6801	4600
7	5700	2500
8	5700	2501
9	4800	4700

generate or absorb reactive power rapidly and control power flow with voltage stability enhancement. The UPFC consists of two switching inverters, which are voltage-sourced inverters using GTO thyristor valves. These two inverters are operated from a common dc link provided by a dc storage capacitor and each inverter can independently generate or absorb reactive power at its own ac output terminal. The basic function of inverter 1 with shunt compensation is to supply or absorb the real power demanded by inverter 2 with series compensation. Inverter 1 can also generate or absorb controllable reactive power, if it is desired. Inverter 2 provides the main function of the UPFC by injecting an ac voltage with controllable magnitude and phase angle in series with a line via an insertion transformer. Transmission line current flows through this insertion voltage source resulting in real and

reactive power exchange between it and the ac system.

In this paper, static voltage stability is analyzed and so it is not necessary to consider the dynamic model of the UPFC. Then, the UPFC injection model is used as a model of the UPFC for power flow studies and this model was proposed in [10]. Suppose a series connected voltage source is located between nodes i and j in a power system. The series voltage source converter can be modeled with an ideal series voltage \bar{V}_s in series with a reactance X_s . A fictitious voltage behind the series reactance \bar{V}_i' in Fig. 5 can be expressed as

$$\bar{V}_i' = \bar{V}_i + \bar{V}_s \quad (1)$$

The circuit in Fig. 5 can be expressed equivalently by replacing the voltage source \bar{V}_s by the current source $\bar{I}_s = -jb_s \bar{V}_s$ as shown in Fig. 6, where $b_s = \frac{1}{X_s}$.

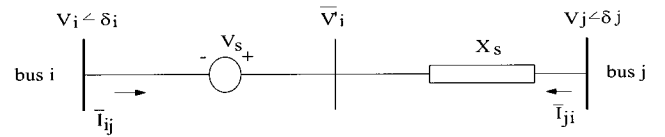


Fig. 5 Representation of a series connected voltage source converter

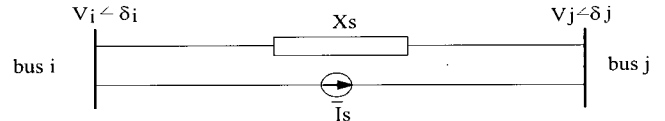


Fig. 6 Replacement of a series voltage source by a current source

The reactive power is delivered or absorbed by the shunt connected voltage source of the UPFC and can be modeled as a separate controllable shunt reactive source. It is also used to provide the active power that is injected to the network via the series connected voltage source. Consequently, the UPFC injection model in Fig. 7 can be expressed as follows [10]:

Here,

$$P_{si} = \alpha b_s V_i V_j \sin(\delta_i - \delta_j + \gamma) \quad (2)$$

$$Q_{si} = \alpha b_s V_i^2 \cos \gamma \quad (3)$$

$$P_{sj} = -\alpha b_s V_i V_j \sin(\delta_i - \delta_j + \gamma) \quad (4)$$

$$Q_{sj} = -\alpha b_s V_i V_j \cos(\delta_i - \delta_j + \gamma) \quad (5)$$

where

$$V_s = \alpha V_i, \quad 0 < \alpha < \alpha_{\max} \quad (6)$$

$$\delta_s = \delta_i + \gamma, \quad 0 < \gamma < 2\pi \quad (7)$$

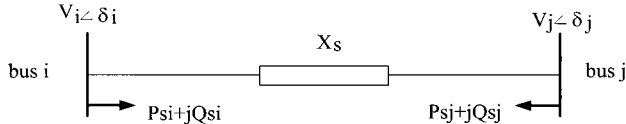


Fig. 7 UPFC injection model

4.3 Simulations

The basic scenario for evaluating the power transfer going north from the south of Korea to Kyung-In region is as follows:

- The loads of all areas are constant.
- The generation in Kyung-In area decreases and the generation in the south area of Korea increases step by step until the solution of the power flow diverges.

The repeated power flow method is applied by decreasing the generation power by 0.2% per step in an area of importing real power and by increasing the generation power by 0.2% per step in an area of exporting real power according to the given merit order. The outage of lines (N-1 route or N-2 circuits) is considered as the contingencies. The power transfer limits are determined according to each contingency and the most severe contingency with the least power transfer limit is also determined comparing the power transfer limits with one another. The ranking of the line contingencies according to power transfer limits is shown in Table 2.

The most severe contingency with the least power transfer limit in this case is the outage of the lines from 6030 bus (Sinseosan S/S) to 4010 bus (Sinansung S/S), when the maximum power transfer capability is 11676.8 [MW]. In order to mitigate the impact of this severe contingency, the generator 1 of Dangjin T/P is tripped to be out of service and the shunt reactors connected to the buses of Sinseosan S/S and Sinansung S/S are cut off. The line flows of the inter-area transfer lines when the generation powers corresponding to the case of the most severe contingency are generated in the normal power system are shown in Table 3. The F-V curve corresponding to the most severe contingency is shown in Fig. 8. The vertical axis represents a bus voltage magnitude and the horizontal axis represents the power transfer. The generators have both minimum generation power levels and maximum generation power levels. So generation power does not vary continuously but varies discretely in practical commitment of generators. For this reason, the F-V curve in Fig. 8 is not altogether smooth.

Table 2 The ranking of the severe line contingencies

Ranking	Lines of contingency			Power transfer limit [MW]
	From bus	To bus	Circuit	
1	6030	4010	1	11676.8
	6030	4010	2	
2	5010	1020	1	11677.2
	5010	1020	2	
3	6951	4400	1	11755.6
	6950	4401	2	
4	6800	4601	1	11907.4
	6801	4600	1	
5	6600	4900	1	11993.4
	6600	4900	2	
6	5500	5700	1	12105.7
	5500	5700	2	
7	5600	5700	1	12245.5
	5600	5700	2	
8	10300	8800	1	12247.0
	10300	8800	2	
9	5700	2500	1	12308.9
	5700	2501	2	
10	6300	6950	1	12314.6
	6300	6951	2	

Table 3 The line flows of the inter-area transfer lines in the case of maximum power transfer

NO	Inter-area transfer lines		Line flows (MW)
	From bus	To bus	
1	6951	4400	1290.6
2	6950	4401	1317.5
3	6030	4010	2748.7
4	5010	1020	2867.3
5	6800	4600	930.2
6	6801	4601	905.7
7	5700	2500	499.6
8	5700	2501	502.6
9	4800	4700	614.6
Total (maximum power transfer)			11676.8

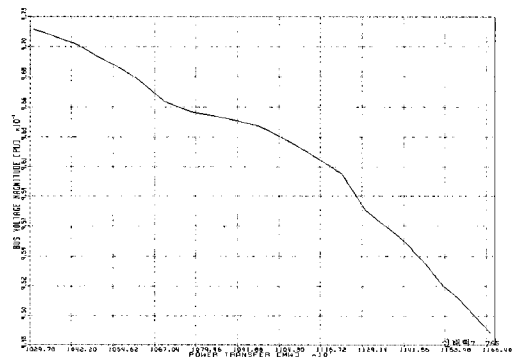


Fig. 8 The F-V curve corresponding to the most severe contingency (the simulation result by VREP)

The following voltage instability index (I_{VI}) is used in order to select the effective place of installing UPFC.

$$I_{VI} = -dV_i / d\lambda \quad (8)$$

where dV_i is the differential change in voltage of bus i and $d\lambda$ is the differential change in generation power. The bus with the largest voltage instability index is selected as the place of installing the UPFC and this is 4600 bus (Seoseoul S/S). A UPFC is installed at the 4600 bus side of the line between 4600 bus and 2400 bus (Yungseo S/S). A UPFC is also installed at the 37th bus (8600 bus; Seodeagu S/S) in the voltage instability index in order to illustrate its effect. The UPFC is installed at the 8600 bus side of the line between 8600 bus and 6600 bus (Sinokcheon S/S). The UPFCs with 200 [MVA], 400 [MVA] and 600 [MVA] are installed respectively and it is assumed that the series rating of the UPFC is identical to its shunt rating. The total transfer capabilities determined by the VREP according to UPFC ratings are shown in Table 4. The maximum power transfer capability in the case in which the UPFC is installed at the bus with the largest voltage instability is much higher than that in the case in which the UPFC is installed at the bus with the 37th voltage instability index. The total transfer capabilities according to locations of UPFCs are compared to each other in Fig. 9. We know that the voltage instability index

can be used in order to select the effective place of installing the UPFC. The simulation results show that a UPFC installed at the bus with the largest voltage instability index can enhance the total transfer capability very effectively.

5. Conclusion

This paper presents a tool for determining the total transfer capability using the IPLAN, which is a high level language used in conjunction with the PSS/E program. The tool 'VREP' was developed so as to analyze static voltage stability and to determine the inter-area total transfer capability from a static voltage stability viewpoint by tracing stationary behaviors of power systems such as P-V and F-V curves. The repeated power flow method is applied by decreasing the generation power in an area of importing real power and by increasing the generation power in an area of exporting real power according to the given merit order. Thus, an approximate critical nose point of the F-V curve and the total transfer capability corresponding to the most severe contingency are automatically determined using the simulation tool. This tool is applied to the practical power system of KEPCO at the peak time of summer 2005. Evaluation of the total transfer capability of a practical KEPCO power system according to the selected scenario is performed from a static voltage stability point of view.

The effect of enhancing the total transfer capability by a UPFC is analyzed and compared to the power system without a UPFC. The simulation results show that a UPFC can enhance the total transfer capability very effectively.

Table 4 Comparison of total transfer capabilities

Rating of UPFC (MVA)	Total transfer capability (MW)	
	Installation at 4600 bus	Installation at 8600 bus
0	11676.8	11676.8
200.0	11733.3	11707.4
400.0	11787.8	11737.9
600.0	11834.0	11768.3

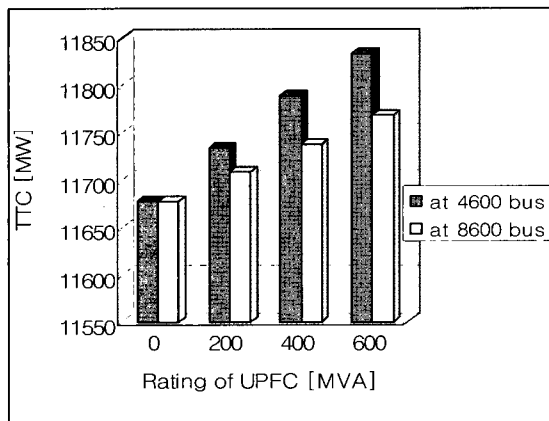


Fig. 9 Comparison of the total transfer capabilities according to locations of the UPFC

Acknowledgements

This work was supported by the University of Incheon and the Korea Power Exchange.

References

- [1] G. L. Landgren, S. W. Anderson, "Simultaneous Power Interchange Capability Analysis", IEEE Trans.-PAS, Vol. 92, No. 6, pp. 1973-1986, 1973.
- [2] L. L. Garver, P. R. Van Horne, K. A. Wirgau, "Load Supplying Capability of Generation-Transmission Networks", IEEE Trans.-PAS, Vol. 98, No. 3, pp. 957-962, 1979.
- [3] P. W. Sauer, K. D. Demaree, and M. A. Pai, "Stability Limited Load Supply and Interchange Capability", IEEE Trans.-PAS, Vol. 102, No. 11, pp. 3637-3643,

1983.

- [4] C. S. Indulker, B. Viswanathan, and S. S. Venkata, "Maximum Power Transfer Limited by Voltage Stability in Series and Shunt Compensated Schemes for A.C Transmission Systems", IEEE Trans.-PD, Vol. 4, No. 2, pp. 1246-1252, 1989.
- [5] S. Wunderlich, T. Wu, R. Fischl, and R. O'Connell, "An Inter-Area Transmission and Voltage Limitation (TVLIM) Program", IEEE Trans.-PS, Vol. 10, No. 3, pp. 1257-1263, 1995.
- [6] A. J. Flueck, H. D. Chang, and K. S. Shah, "Investigating the Installed Real Power Transfer Capability of a Large Scale Power System Under a Proposed Multiarea Interchange Schedule Using CPFLOW", IEEE Trans.-PS, Vol. 11, No. 2, pp. 883-889, 1996.
- [7] G. Hamoud, "Assessment of Available Transfer Capability of Transmission Systems", IEEE Trans.-PS, Vol. 15, No. 1, pp. 27-32, 2000.
- [8] X. Yu, C. Singh, S. Jakovljevic, D. Ristanovic, and G. Huang, "Total transfer capability considering FACTS and security constraints", IEEE, pp. 73-78, 2003.
- [9] L. Gyugyi, et al., "The unified power flow controller: A new approach to power transmission control", IEEE Trans.-Power Delivery, Vol. 10, No. 2, pp. 1085-1097, 1995.
- [10] M. Noroozian, L. Angquist, M. Ghandhari, G. Andersson "Use of UPFC for optimal power flow control", IEEE Trans.-Power Delivery, Vol. 12, No. 4, pp. 1629-1634, 1997.
- [11] S. Kannan, S. Jayaram, and M.M.A. Salama, "Real and reactive power coordination for a unified power flow controller", IEEE Trans.-PowerSystems, Vol. 19, No. 3, pp. 1454-1461, 2004.
- [12] V. Ajjarapu and C. Christy, "The Continuation Power Flow: A Tool for Steady State Voltage Stability Analysis", IEEE Trans.-PS, Vol. 7, No. 1, pp. 416-423, 1992.



Byung Ha Lee

He received his B.S. and M.S. degrees in Electrical Engineering from Seoul National University, Korea, in 1978 and 1980, respectively and his Ph.D. degree in Electrical Engineering from Pennsylvania State University, University Park, U.S.A. in 1991. From 1979

to 1994, he was with the Korea Electric Power Corporation. He joined the faculty of the University of Incheon, Korea, in 1994 where he is currently a Professor of Electrical Engineering. His interests include power system control, voltage stability, robust control, FACTS and power system operation.



Jung-Hoon Kim

He received his B.S. and M.S. degrees in Electrical Engineering from Seoul National University, Korea, in 1978 and 1981, respectively and his Ph.D. degree in Electrical Engineering from Seoul National University, Korea in 1985. He joined the faculty of Hongik

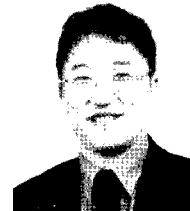
University, Korea, in 1981 where he is currently a Professor of Electrical and Electronic Engineering. His interests include the areas of power system operation and power system planning.



No-Hong Kwak

He received his B.S. and M.S. degrees in Electrical Engineering from Yonsei University, Korea, in 1978 and 1980, respectively. He also received his Ph.D. degree in Electrical Engineering from Yonsei University, Korea, in 1990. From 1991 to 1992, he was a

Visiting Researcher at MIT, USA. He is currently a leader of power quality and reliability areas in the Power System Lab. of KEPRI.



Woon-Hee Lee

He received his B.S. degree in Electrical Engineering from Busan National University, Korea, in 1986. He worked for KEPCO from 1987 to 2001 where his main job was in the area of Protection Engineering. He is currently a Deputy Manager at the

System Operation & Control Department of the Korea Power Exchange where he is in charge of outage scheduling of transmission network facilities.