Enhancement of Interface Flow Limit using Static Synchronous Series Compensators

Seul-Ki Kim†, Hwachang Song*, Byoungjun Lee and Sae-Hyuk Kwon****

Abstract - This paper addresses improving the voltage stability limit of interface flow between two different regions in an electric power system using the Static Synchronous Series Compensator (SSSC). The paper presents a power flow analysis model of a SSSC, which is obtained from the injection model of a series voltage source inverter by adding the condition that the SSSC injection voltage is in quadrature with the current of the SSSC-installed transmission line. This model is implemented into the modified continuation power flow (MCPF) to investigate the effect of SSSCs on the interface flow. A methodology for determining the interface flow margin is simply briefed. As a case study, a 771-bus actual system is used to verify that SSSCs enhance the voltage stability limit of interface flow.

Keywords - Interface Flow Limit, Modified Continuation Power Flow, SSSC, Voltage Stability

1. Introduction

Increased use of transmission facilities owing to higher industrial demand and deregulation of the power supply industry has provided the necessity for exploring new ways of maximizing the power transfers of existing transmission facilities, while maintaining acceptable levels of system reliability and stability [1]. In such an environment, application of the Flexible AC Transmission System (known as FACTS) in power systems has become an issue of great concern. The FACTS facilitates power flow control, increased power transfer capability, and enhances the security and stability of power systems without expanding transmission and generation utilities.

Excellent applications of FACTS controllers, such as the unified power flow controller (UPFC) at Inez Substation, and the Static Synchronous Compensator (STATCOM) at Sullivan Substation, have yielded successful results [2]. It has been shown in recent case studies that FACTS can provide a more flexible stability margin to power systems and also improve power transfer limit in either shunt or series compensation [3, 4].

This paper focuses on studying the effect of SSSCs on the voltage stability limit of interface flow. Interface flow limit is defined as the maximum power transfer that can be allowed through interface lines connecting two regions of a power system in terms of the steady-state voltage stability. The interface flow limit is traced using the modified continuation power flow (MCPF). A voltage varying curve with respect to gradual increase of interface flow, i.e. interface flow versus voltage (*f*-*v*) curve, is drawn by MCPF. Using *f*-*v* curves, the voltage stability limit of interface flow is determined [5, 6].

In Section 2, a power flow model of a SSSC is proposed to make a practical study of the influence of SSSCs on the interface flow limit. The SSSC, a gate turn-off (GTO) thyristor based series voltage source inverter (VSI), injects the series-compensating voltage almost in quadrature with the line current, controlling the line impedance and active power flow. The SSSC power flow model is obtained by adding such control characteristics to the VSI injection model [7, 8]. Section 3 provides brief explanations on the MCPF algorithm and the procedure for determining the limit of interface flow. Also, incorporation of the SSSC power flow model into MCPF is illustrated. In Section 4, a 771-bus real system is utilized to examine how the interface flow limit may be increased. The numerical results are illustrated.

2. Implementation of SSSC Power Flow Model

2.1 SSSC Power Flow Analysis Model

The injection voltage by a SSSC has a phase angle difference of 90° or –90° with the SSSC-installed line current (hereafter it is called *right angle difference condition*), which means that the SSSC produces or absorbs no active power and generates or consumes reactive power only. The injection voltage that is in quadrature with the line current emulates an inductive or a

† Corresponding Author: Power Conversion and System for RES Research Group, Korea Electro-technology Research Institute, Korea. (blksheep@keri.re.kr)
* Department of Electrical Engineering, Kunsan University, Kunsan 573-701, Korea.
** Department of Electrical Engineering, Korea University, Seoul 136-701, Korea.
Received: September 4, 2005 ; Accepted: December 7, 2005

capacitive reactance in series with the transmission line. This emulated variable reactance, inserted by the series VSI influences the power flow in the transmission line [9].

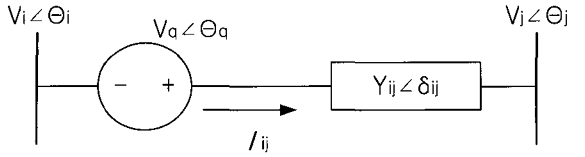


Fig. 1. Series voltage source inverter

Fig. 1 shows a VSI inserted in series with the transmission line i-j. $V_i\angle\theta_i$, $V_j\angle\theta_j$, $V_q\angle\theta_q$ and $Y_{ij}\angle\delta_{ij}$ are the sending bus voltage, the receiving bus voltage, the SSSC injection voltage, and the line admittance, respectively. As given in Equation (1), the series VSI can be modeled with an ideal series voltage Vq, which is controllable in magnitude and phase.

$$\begin{aligned} V_q &= rV_i \\ \theta_q &= \theta_i + \Gamma \end{aligned} \tag{1}$$

Where r (0<r < rMAX) and Γ (0< Γ <2 π) are control variables to determine the magnitude and phase angle of the injection voltage, respectively.

A SSSC can be regarded as the series VSI of which injection voltage has a right phase angle difference with the line current. As mentioned earlier, the right angle difference condition implies that the active power exchange between the SSSC and the line equals zero. To satisfy the right angle difference condition, the real part of apparent power generated across the SSSC must be zero, which establishes Equation (2). At the same time, the SSSC should regulate the real power flow of the transmission line i-j at a certain desired value specified by its power control strategy. For active power transfer into the bus j, Pjtotal , to equal the desired active power flow of Pdes, Equation (3) must be satisfied. Therefore, the two control variables, r and Γ, may be obtained by solving Equations (2) and (3).

$$\begin{aligned} &Real\{\bar{V}_q \cdot \bar{I}_{ij}\} \\ &= V_i\cos(\Gamma - \delta_{ij}) + rV_i\cos\delta_{ij} - V_j\cos(\theta_{ij} + \Gamma - \delta_{ij}) = 0 \end{aligned} \tag{2}$$

$$\begin{aligned} &P_{des} - P_j^{total} \\ &= P_{des} - V_iV_jY_{ij}\cos(\theta_{ij} + \delta_{ij}) + V_j^2 Y_{ij}\cos\delta_{ij} \\ &- rV_iV_jY_{ij}\cos(\theta_{ij} + \delta_{ij} + \Gamma) = 0 \end{aligned} \tag{3}$$

Where Θij = Θi − Θj.

The SSSC model is obtained by substituting rsssc and Γ_{sssc} for r and Γ in the VSI injection model [8]. Fig. 2 indicates the proposed SSSC power flow model, which is seen as two dependent loads added to both ending buses of the SSSC-installed branch. The dependent loads at bus i and j are described by Equations (4) and (5), respectively.

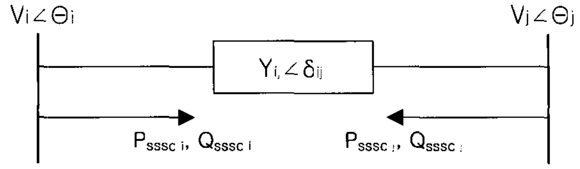


Fig. 2. SSSC power flow model.

$$\begin{aligned} P_{SSSCi} &= r_{SSSC}V_i^2 Y_{ij}\cos(\delta_{ij} + \Gamma_{SSSC}) \\ Q_{SSSCi} &= -r_{SSSC}V_i^2 Y_{ij}\sin(\delta_{ij} + \Gamma_{SSSC}) \end{aligned} \tag{4}$$

$$\begin{aligned} P_{SSSCj} &= -r_{SSSC}V_iV_jY_{ij}\cos(\theta_{ij} + \delta_{ij} + \Gamma_{SSSC}) \\ Q_{SSSCj} &= r_{SSSC}V_iV_jY_{ij}\sin(\theta_{ij} + \delta_{ij} + \Gamma_{SSSC}) \end{aligned} \tag{5}$$

2.2 Modification of Jacobian Matrix

It is necessary to reformulate the power equations and modify the jacobian matrix in order to incorporate the SSSC model in a power flow program, whether in a conventional power flow or the modified CPF, since the SSSC model is expressed as dependent loads consisting of the state variables of power flow equations. Reformulation can be achieved by adding the dependent loads to the load demand terms in the power flow equations, as shown in Equations (6) and (7).

$$PGi - (PLi + PSSSCi) = PTi \tag{6}$$

$$QGi - (QLi + QSSSCi) = QTi \tag{7}$$

where

PGi , Q Gi : active and reactive power generation at bus i
PLi , Q Li : active and reactive power demand at bus i
PTi , Q Ti : active and reactive power injection into bus i

Table 1. Modification of jacobian matrix

$H_{i,i}=H^0_{i,i}$	$N_{i,i}=N^0_{i,i}+2P_{SSSCi}$
$H_{i,j}=H^0_{i,j}$	$N_{i,j}=N^0_{i,j}$
$H_{j,i}=H^0_{j,i}+Q_{SSSCj}$	$N_{j,i}=N^0_{j,i}+P_{SSSCj}$
$H_{j,j}=H^0_{j,j}-Q_{SSSCj}$	$N_{j,j}=N^0_{j,j}+P_{SSSCj}$
$J_{i,j}=J^0_{i,j}$	$L_{j,i}=L^0_{j,i}+2Q_{SSSCi}$
$J_{i,j}=J^0_{i,j}$	$L_{i,j}=L^0_{i,j}$
$J_{j,i}=J^0_{j,i}-P_{SSSCj}$	$L_{j,i}=L^0_{j,i}+Q_{SSSCj}$
$J_{j,j}=J^0_{j,j}+P_{SSSCj}$	$L_{j,i}=L^0_{j,i}+Q_{SSSCj}$

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}=\begin{bmatrix}H & N\\ J & L\end{bmatrix}\begin{bmatrix}\Delta\theta\\ \Delta V/V\end{bmatrix}$$

When an SSSC is located in the branch i-j, the jacobian matrix elements corresponding to the bus i and bus j should be modified. Table 1 presents the modified jacobian matrix in the power flow solving module. The superscript 0 denotes the original jacobian elements before SSSC applications.

3. Determination of Interface Flow Limit

3.1 Modified Continuation Power Flow (MCPF)

Based on the robust convergent characteristics of CPF, the MCPF has been developed for tracing the voltage stability limit of interface flow electrically connecting two specified regions of a power system. The CPF has a load parameter as a continuation parameter, whereas the MCPF has a generation shift parameter, which, as a continuation parameter, enables gradual increase in interface flow between two regions of a power system until the system voltage collapses [6].

Consider that a power system is divided into Region A and Region B connected with interface lines, as shown in Fig. 3. Assume that the generation cost of Region B is higher that that of Region A. Then active power flow from Region A to Region B through interface lines is naturally increased by decreasing the generation in Region B while increasing that in Region A for reducing total generation cost. Based on the above concept, the original power flow equations are modified into the reformulated MCPF Equations (5) and (6), containing a continuation parameter representing increase in interface flow.

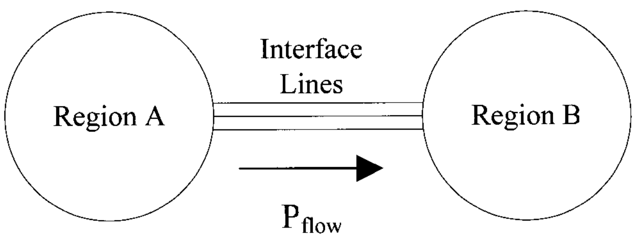


Fig. 3. Two-region power system with interface lines

For the region A,

$$\begin{aligned} &P_{Ti}(\underline{\delta},\underline{V}) - (P_{Gi0} + k_{GAi}\Delta P_{GB,total}) + P_{Li0} = 0 \\ &Q_{Ti}(\underline{\delta},\underline{V}) - Q_{Gi} + Q_{Li0} = 0 \end{aligned} \quad (5)$$

For the region B,

$$\begin{aligned} &P_{Ti}(\underline{\delta},\underline{V}) - (P_{Gi0} - \mu k_{GBi} P_{GB0,total}) + P_{Li0} = 0 \\ &Q_{Ti}(\underline{\delta},\underline{V}) - Q_{Gi} + Q_{Li0} = 0 \\ &\Delta P_{GB,total} = \sum_{j\in SB} \mu k_{GBi} P_{GB0,total} \end{aligned} \quad (6)$$

where the following notations are made;

μ = generation shift parameter
PGi0 = original active power generation at bus i
kGAi = fraction factor of Δ*PGA,total* at bus i in region A
kGBi = fraction factor of Δ *PGB,total* at bus i in region B
PGB0,total = original total generation in region B
Δ *PGA,total* = total generation increase in region A
Δ *PGB,total* = total generation decrease in region B
SA = set of bus in region A
SB = set of bus in region B

kGAi and *kGBi* are generation fraction factors that correspond to the changing pattern of generation in each bus. *PLi0* and *QLi0* denote active power load and reactive power load at each bus I, respectively. Generation shift parameter μ is not only used to increase interface flow but also provides information on the levels of generation in region A and region B. Generation of this system totally depends on the parameter μ. Fig. 4 depicts *f-v* curve prepared by the MCPF. Interface flow margin denotes the margin between interface flow at critical point and the initial flow at base point.

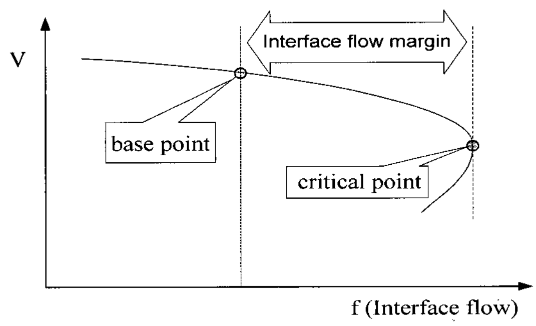


Fig. 4 Interface flow – voltage (f-v) curve.

3.2 Procedure for Determining Interface Flow Limit

The interface flow limit can be systematically determined by f-v curves of the worst contingency case and normal case. The procedure is illustrated with Fig. 5.

Step 1 Perform the specified contingencies.
Step 2 Construct f-v curve for each contingency.
Step 3 Select the worst contingency that has the least interface flow margin and find the value of parameter μ.
Step 4 Find interface flow of normal case at the point P2 that has the same value of parameter μ as the point P1 in step 3.

Step 5 To consider the uncertainties relating to unknowns in data, equipment performance, and network condition, 95% of the interface flow obtained in Step 4, corresponding to P3 is determined as interface flow limit.

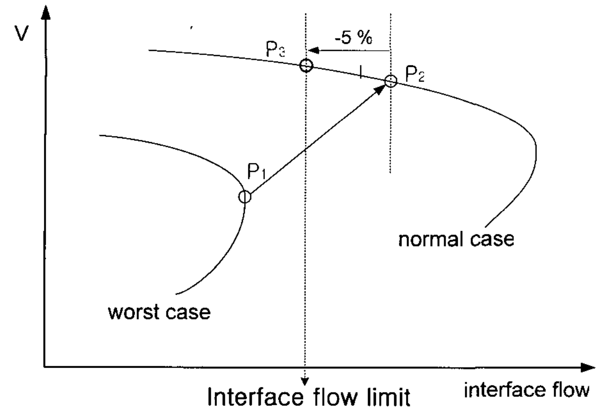


Fig. 5 Determination of interface flow limit

If less flow than interface flow limit is transferred between two regions, even though the worst case occurs, the system can avoid voltage collapse.

3.3 Implementation of SSSC Model into MCPF

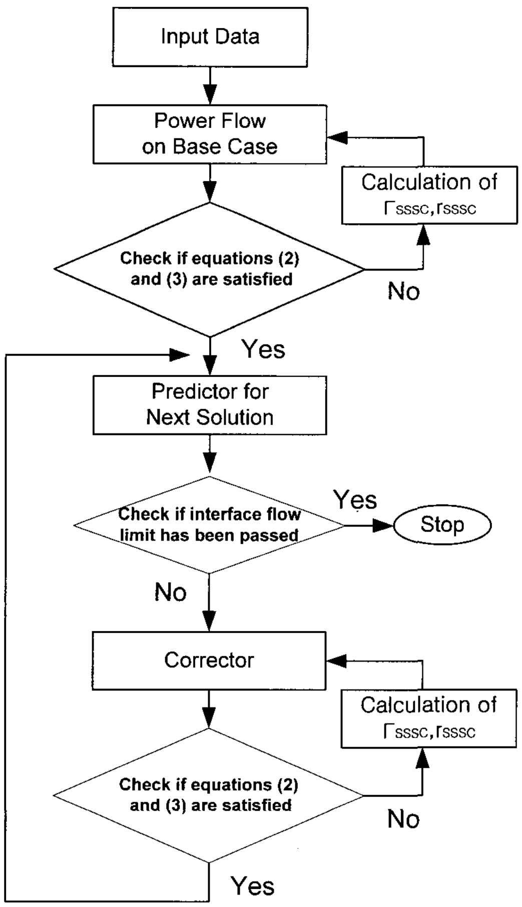


Fig. 6. Flow chart for implementation into MCPF

Fig. 6 presents the flow chart for implementation of the SSSC model into the MCPF. Applying the locally parameterized continuation method, the MCPF is composed of a predictor and a corrector. In the predictor, the initial guess of the next solution is determined using the tangent vector of the known solution. In the corrector, the next solution is calculated using the Newton–raphson method. The basic principle of the locally parameterized continuation method and its application to power flow equation are well established in the literature [10].

4. Case Study

When SSSCs are installed in a power system with the specified interface lines connecting two regions, how interface flow limit can be enhanced by power flow control of SSSCs is examined. For case study, a KEPCO 771-bus system, shown in Fig. 7, is used. The MCPF is used as the simulation tool.

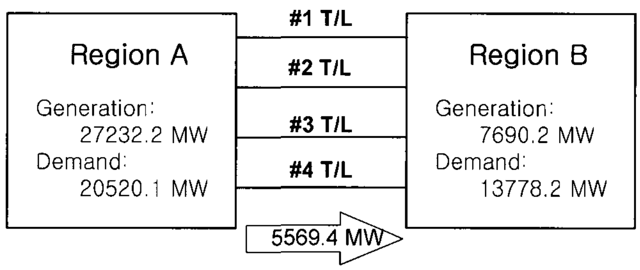


Fig. 7. 771-bus system

This system consists of 771 buses and 1437 branches. Interface flow is transferred from Region A to Region B through four 365kV interface routes (2 lines per route), i.e. #1 T/L, #2 T/L, #3 T/L, and #4 T/L, as given in Fig. 7. Since the generation cost of Region B is much higher than that of Region A, greater interface flow from Region A to Region B shows that the entire power system is in better economical operation in view of generation cost. The total amount of generation and load demand are 34922 MW and 34298 MW, respectively. At base case, total losses are 624.1 MW. 5569.4 MW of interface flow is being provided from Region A to Region B. Some portion of active power flow, 518.6 MW, is transferred through 154kV lines between two regions in addition to 5569.4 MW. In this study, however, transfer capability of the four 365kV interface routes is considered. Contingencies considered are as follows

- #1 T/L route outage (2 line outages)
- #2 T/L route outage (2 line outages)
- #3 T/L route outage (2 line outages)
- #4 T/L route outage (2 line outages)

4.1 Interface Flow Limit before SSSC Application

The interface flow limit of the 771-bus real system is step by step determined according to the procedure suggested in Section 3.2.

First, f-v curves are constructed to obtain interface flow margins for the normal case and all the specified outages. The worst contingency case is selected by interface flow margins. Table 2 presents interface flow margins and parameter μ at the critical point of the f-v curve, calculated by subtracting interface flows at base points (μ = 0) from those at critical points, for the normal case and 4 specified outages. #1 T/L outage has the worst contingency since its interface flow margin of 276.4 MW, or its value of parameter μ at critical point is the smallest. Interface flow of the normal case at the point, which has the same value of parameter μ (= 0.2023) that the critical point of #1 T/L outage case has, is 5842.4 MW. Finally, considering uncertainties, interface flow limit is determined as follows. Fig. 8 illustrates how determination of interface flow limit proceeded in the 771-bus real system. The system is being operated with interface flow of 5569.4 MW, slightly more than 5550.3 MW, from Region A to Region B as shown in Fig. 8. If #1 T/L outage occurs, voltage stability cannot be absolutely guaranteed. For more secure operation, therefore, proper corrective measures need to be taken.

Table 2. Interface flow margins in the normal case and four outage cases

State of power system	Interface flow at base point	Interface flow at critical point	Interface flow margin
Normal case	5569.4 MW (μ= 0)	6973.8 MW (μ= 1.0253)	1404.4 MW
#1 T/L outage	5325.6 MW (μ= 0)	5602.0 MW (μ= 0.2023)	276.4 MW
#2 T/L outage	5486.0 MW (μ= 0)	6669.8 MW (μ= 0.8827)	1183.8 MW
#3 T/L outage	5460.2 MW (μ= 0)	6495.9 MW (μ= 0.7706)	1035.7 MW
#4 T/L outage	5234.2 MW (μ= 0)	5523.1 MW (μ= 0.2165)	288.9 MW

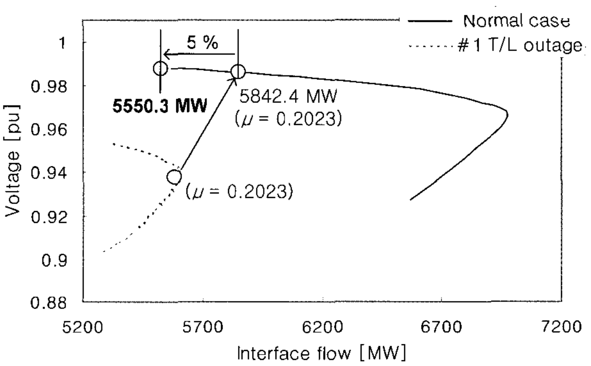


Fig. 8. Interface flow limit before SSSC application

4.2 SSSC Application Strategy

The basic concept of increase in interface flow limit is to enlarge interface flow margin for the worst contingency case. Fig. 9 shows the concept that interface flow limit can be enhanced by increasing interface flow margin of the worst contingency case. The solid line arrow represents determination of interface flow limit before SSSC application and the dotted line arrow is for SSSC control. By compensating a specified transmission line in the worst case, the critical point **w** goes to a new critical point **w*** as indicated in Fig. 9. As a result, the point, which has the same value of parameter μ as the critical point of the worst case, moves from **P** to **P***.

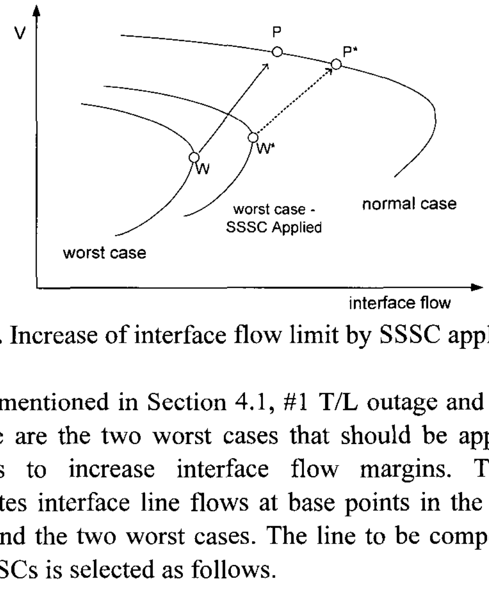


Fig. 9. Increase of interface flow limit by SSSC application

As mentioned in Section 4.1, #1 T/L outage and #4 T/L outage are the two worst cases that should be applied to SSSCs to increase interface flow margins. Table 3 indicates interface line flows at base points in the normal case and the two worst cases. The line to be compensated by SSSCs is selected as follows.

- <u>In case of #1 T/L outage</u>: Comparing each interface flow in case of #1 T/L outage with that in normal case, #2 T/L is highly stressed. Since the flow is relatively close to its heat rating, as shown in Table 3, capacitive compensation of #2 T/L may cause overflow. Also, #4 T/L compensation is impossible in #4 T/L outage. Therefore, #3 T/L is selected to be a proper route for SSSC installation.
- <u>In case of #4 T/L outage:</u> When #4 T/L outage occurs, #1 T/L, #2 T/L, and #3 T/L are candidate interface routes for compensation. #1 T/L is much more distant from #4 T/L than #2 T/L and #3 T/L, so the T/L is inappropriate for reactive compensation. The #2 T/L compensation has the possibility of overflow for #1 T/L outage as mentioned above. For #3 T/L, this route is located close to #4 T/L and takes a large portion of flow, which used to be transferred through #4 T/L in the normal case. Besides, there is still sufficient margin to its heating rate as given in Table 3. Accordingly, #3 T/L is considered to be the best route for compensation

in case of #4 T/L outage.

Table 3. Interface flow at base point in normal case and two worst cases

Interface line	Normal case	#1 T/L outage	#4 T/L outage	Heating rate
#1 T/L	1499.9	0	1687.4	4384
#2 T/L	830.0	1501.9	1169.7	2192
#3 T/L	1228.7	1536.8	2377.1	4384
#4 T/L	2010.8	2286.9	0	4384
Total	5569.4	5325.6	5234.2	15344

** Unit: MW, MVA for heating rate*

4.3 SSSC Application

Based on control strategies suggested in the previous section, SSSC is installed along #3 T/L in this case study. This route is compensated in both the #1 T/L outage and #4 T/L outage. Full compensation, in which control variable **r** of SSSC injection voltage is **rMAX** (= 0.1), is applied.

Table 4 and Table 5 present interface flow changes at base point ($\mu = 0$) by SSSC application in #1 T/L outage and #4 T/L outage respectively. Table 4 shows that #3 T/L and #4T/L relieved #2 T/L of some flow and total flow became increased by SSSC control in the case of #1 T/L outage. In Table 5, it is also shown that #3 T/L compensation led to increase in #3 T/L flow and total flow.

Table 4. Interface flow changes at base point for #1 T/L outage

Interface lines	Before SSSC appl.	After SSSC appl.
#1 T/L	0 MW	0 MW
#2 T/L	1501.9 MW	1419.8 MW
#3 T/L	1536.8 MW	1894.0 MW
#4 T/L	2286.9 MW	2055.4 MW
Total	5325.6 MW	5369.2 MW

Table 5. Interface flow changes at base point for #4 T/L outage

Interface lines	Before SSSC appl.	After SSSC appl.
#1 T/L	1687.4 MW	1629.8 MW
#2 T/L	1169.7 MW	1065.2 MW
#3 T/L	2377.1 MW	2616.4 MW
#4 T/L	0 MW	0 MW
Total	5234.2 MW	5311.4 MW

The final results are presented in Table 6 and Fig. 10. Results of SSSC application demonstrate that interface flow margin increased from 276.4 MW to 406.8 MW for the #1 T/L outage case and to 543.4 MW for the #4 T/L outage case, respectively, as given in Table 6. #1 T/L outage is still the worst case. Interface flow limit increased from 5550.3 MW, original interface flow limit, to 5673.3 MW by 120.3 MW. Fig. 10 depicts determination of interface limit after SSSC application. Total capacity of the two SSSCs implemented, which was required for full compensation, was 200 MVA (100 MVA per SSSC).

Table 6. Interface flow limit in SSSC application

	Before SSSC appl.	After SSSC appl.
Interface flow margin (#1 T/L outage)	276.4 MW	406.8 MW
Interface flow margin (#4 T/L outage)	288.9 MW	543.4 MW
Interface flow limit	5550.3 MW	5676.3 MW

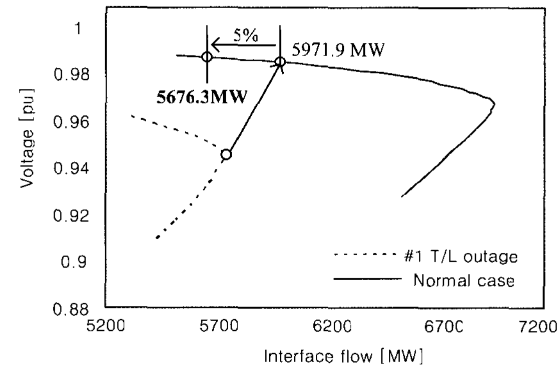


Fig. 10. Interface flow limit

5. Conclusions

This paper addressed enhancing interface flow limit through SSSC application in a power system with specified interface lines electrically connecting two regions.

A power flow model of SSSC was proposed to be incorporated into MCPF, a tool for finding the voltage stability limit of interface flow. The SSSC model was obtained by considering the right angle difference characteristic in the injection model of a series voltage-sourced inverter.

The 771-bus real system was used for investigating SSSC application effect on interface flow limit in terms of the steady-state voltage stability. The simulation results indicated a considerable increase in interface flow limit by SSSC compensation. Further study on impacts of various FACTS controllers such as UPFC, STATCOM, etc. should be carried out to seek for the most effective way of increasing the interface flow limit.

References

[1] N.G. Hingorani, High Power Electronics and Flexible AC Transmission Systems, *IEEE Power Engineering Review*, pp. 3-4, July 1988.

[2] A. Edris, FACTS Technology Development: An

Update, *IEEE Power Engineering Review*, No. 3, Vol. 20, March 2000.

[3] C.A. Canizares, Z.T. Faur, "Analysis of SVC and TCSC Controllers in Voltage Collapse", *IEEE Trans. Power Systems*, Vol. 14, No. 1, February 1999.

[4] C.A. Canizares, Using FACTS Controllers to Maximize Available Transfer Capability, *Bulk Power Systems Dynamics and Control IV-Restructuring,* August 24-28, 1998, Santorini, Greece.

[5] H. Song, S. Kim, B. Lee, S.H. Kwon, V. Ajjarapu, Determination of Interface Flow Margin for Voltage Stability Analysis Using the Modified Continuation Power Flow, in *Proc. 2000 IEEE Power Engineering Society Summer Meeting,* pp. 32-37.

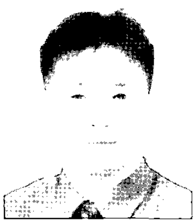
[6] B. Lee, H. Song, S.-H. Kwon, G. Jang, J. Kim and V. Ajjarapu, "A Study on Determination of Interface Flow Limits in the KEPCO System Using Modified Continuation Power Flow (MCPF)", *IEEE Trans. Power Systems,* Vol. 17, No. 3, pp. 557-564, August 2002.

[7] L. Gyugyi, C.D. Schauder, K.K. Sen, "STATIC SYNCHRONOUS SERIES COMPENSATOR: A SOLID-STATE APPROACH TO THE SERIES COMPENSATION OF TRANSMISSION LINES", *IEEE Trans. Power Delivery*, Vol. 12, No. 1, January 1997.

[8] M. Norooizian, L. Angquist, M. Ghandhari, G. Andersson, "USE OF UPFC FOR OPTIMAL POWER FLOW CONTROL", *IEEE Trans. Power Delivery*, Vol. 12, No. 4, October 1997.

[9] K. K. Sen, "SSSC – Static Synchronous Series Compensator: Theory, Modeling, and Applications", *IEEE Trans. Power Delivery*, Vol. 13, No. 1, January 1998.

[10] V. Ajjarapu and C. Christy, "The continuation power flow: A tool for steady-state voltage stability analysis", *IEEE Trans. Power Systems*, Vol. 7, pp. 416-423, February 1992.



Seul-Ki Kim
He received his B.S. and M.S. degrees in Electrical Engineering from Korea University, Seoul, Korea, in 1998 and 2000, respectively. Currently, he is a Senior Researcher in the Power Conversion and System for Renewable Energy Sources Research Group of the Korea Electrotechnology Research Institute, Changwon, Korea. His interests include modeling and analysis of distributed generations, voltage stability, and power flow analysis in power systems.

Hwachang Song
He received his B.S., M.S., and Ph.D. degrees in Electrical Engineering from Korea University, Seoul, Korea in 1997, 1999, and 2003, respectively. Currently, he is an Assistant Professor in the Department of Electrical Engineering at Kunsan University, Kunsan. From 2003 to 2004, he was a Researcher in the Advanced Power System Research Center at Korea University and was a Visiting Scholar at Iowa State University, Ames. His interests include voltage stability, optimization, and control in power systems.

Byoungjun Lee
He received his B.S. degree from Korea University, Seoul, Korea, in 1987, and his M.S. and Ph.D. degrees in Electrical Engineering from Iowa State University Ames, in 1991 and 1994, respectively. Currently, he is a Professor in the Department of Electrical Engineering at Korea University. From 1994 to 1995, he was a Postdoctoral Research Associate at the same university. From 1995 to 1996, he was a Senior Research Engineer with the Mitsubishi Electric Corp., Kobe, Japan.

Sae-Hyuk Kwon
He received his B.S. and M.S. degrees in Engineering Education from Seoul National University, Seoul, Korea, in 1974 and 1976, respectively. He received his M.S. and Ph.D. degrees in Electrical Engineering from Iowa State University, Ames. Currently, he is a Professor in the Department of Electrical Engineering at Korea University, Seoul, Korea.