Centralized Control Algorithm for Power System Performance using FACTS Devices in the Korean Power System

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Abstract – This paper presents a centralized control algorithm for power system performance in the Korean power system using Flexible AC Transmission Systems (FACTS) devices. The algorithm is applied to the Korean power system throughout the metropolitan area in order to alleviate inherent stability problems, especially concerns with voltage stability. Generally, control strategies are divided into local and centralized control. This paper is concerned with a centralized control strategy in terms of the global system.

In this research, input data of the proposed algorithm and network data are obtained from the SCADA/EMS system. Using the full system model, the centralized controller monitors the system condition and decides the operating point according to the control objectives that are, in turn, dependent on system conditions.

To overcome voltage collapse problems, load-shedding is currently applied in the Korean power system. In this study, the application of the coordination between FACTS and switch capacitor (SC) can restore the solvability without load shedding or guarantee the FV margin when the margin is insufficient. Optimal Power Flow (OPF) algorithm, for which the objective function is loss minimization, is used in a stable case.

The results illustrate examples of the proposed algorithm using SCADA/EMS data of the Korean power system in 2007.

Keywords: Coordinated control, Voltage stability, Optimal power flow, FACTS, CPF (Continuation Power Flow), Korean power systems

1. Introduction

In a deregulated environment, economic operation is a major concern for power systems. Deregulation vertically changes an integrated power system into market-based operation. Power systems are operated near the stability limit due to the competition and growth of demands, and it is difficult to predict the behavior of power systems. Voltage stability problems are issues in terms of planning and operating power systems [1]-[3].

In general, voltage instability or collapse can be contained in a preventive or corrective manner [4]-[7]. Preventive control is performed before voltage instability, allowing the operating point to move far from the saddle node bifurcation. Corrective control moves an operating point from unsolvable to solvable. Corrective control should be quickly carried out to prevent transient voltage collapse of systems. Corrective control is divided into restoring power flow solvability and searching for the minimum load-shedding direction using sensitivity analysis. However, it is difficult to control unsolvable cases to mitigate voltage instability because the Jacobian matrix cannot be formed in such case. Many methods have been suggested to handle insolvability problems [8]-[14]. Unsolvable cases can be analyzed by steady state or static method in [8]-[14].

In recent years, various voltage control methods for power system stability have been proposed, in which the voltage control schemes have a hierarchical structure with primary, secondary, and tertiary voltage [15]-[25]. In [21]-[23], secondary voltage control has been implemented to regulate pilot bus voltage, which is the representative bus in voltage control area. Hierarchical control algorithms can achieve considerable performance in terms of stability issues in power systems. In [24]-[25], online voltage control algorithm has been implemented in the BPA (Bonneville Power Administration) system.

Flexible AC Transmission System (FACTS) has been developed to enhance voltage stability limits [26]-[30]. In the Korean power system, one FACTS device has been installed, and two others are to be installed in 2010 to mitigate voltage instability problems. This paper defines the control objectives of FACTS controllers and establishes the operating strategy in the Korean power system. This paper suggests a coordination algorithm between multiple FACTS and Switched Capacitor (SC), which can be used to enhance voltage stability or minimize active power loss in Korean power system.

This paper consists of five sections. The characteristics

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of the Korean power system are briefly presented in Section 2. Centralized control algorithm using coordination between multiple FACTS and SC is described in Section 3. Results of the proposed algorithm are illustrated in Section 4, and the algorithm is tested on the SCADA/EMS data of Korean power system in 2007. Finally, the conclusions are discussed in Section 5.

2. The Korean Power System

Fig. 1 shows a map of major power plants and interface lines between metropolitan and non-metropolitan regions in the Korean power system. More than 40% of the total load demands are concentrated in the metropolitan region, whereas the majority of generation is scattered over the non-metropolitan region Fig. 1. The generation cost in non-metropolitan regions is cheaper than in metropolitan regions.

The interface lines from the non-metropolitan to the metropolitan areas consist of four routes of 345kV lines and two routes of 765kV lines. While the system is economically operated, an increase in the interface flow inevitably leads to voltage instability due to a lack of reactive power in the metropolitan region. In [31], the authors suggested a method for calculating interface flow margin, which determines the maximum interface-flow constraint arising from voltage instability. Fig. 2 shows the map of major substations and power plants in the metropolitan region. As can be seen, generators are concentrated in the western metropolitan area. The eastern metropolitan area needs reactive-power sources because considerable power is supplied through the interface line in the eastern and southern areas. If a route outage between Seoinchon C/C and Yangju occurs, the system would have some problems, such as lack of reactive power due to circulating flows. Thus, load-shedding scenarios are established to ensure voltage stability. However, the amount of load shedding depends on the line loading from Seoinchon C/C to Yangju.

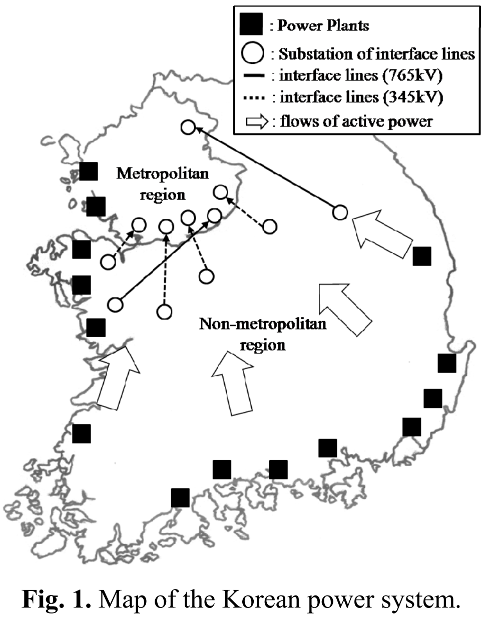

Fig. 1. Map of the Korean power system.

Table 1. Installation status of FACTS devices in the Korean power system

Site	Type	Capacity	
		max	min
Yangju	SVC	100 MVar	-100 MVar
Migeum	STATCOM	100 MVar	-100 MVar
Dongseoul	SVC	200 MVar	-200 MVar

In previous studies, researchers have evaluated the economic aspects and studied the extent to which interface flow limitations could be alleviated by FACTS devices [32]-[34]. Installation of FACTS in the metropolitan region could alleviate interface flow constraint, and the benefits from the alleviation of congestion have been estimated at several million dollars per year [32]-[34].

Consequently, FACTS devices will be installed in the metropolitan region. Table I shows the sites, types, and capacities of the FACTS devices in the Korean power system. These sites, which are the most important buses in terms of voltage stability, have been suggested through system studies [32]-[34].

Total reactive power resources in the metropolitan area are about 12,000 MVar. The reactive power capabilities of generators in this area are about 6,000 MVar, and the conventional capacitor/reactor bank is about 6,000 MVar.

The conventional capacitor/reactor banks are manually operated in the Korean power system. Therefore, if a fault occurs, these devices cannot be adjusted immediately to increase the reactive power reserves. Only the capacitor/reactor banks in the three substations, where FACTS devices have been installed, can be adjusted to increase reactive power resources through the allocation of the FACTS. Total reactive power resources reaches about 800 MVar in the three substations.

Unfortunately, a coordination algorithm, which is suitable for the Korean power system, has not yet been developed. To alleviate the abovementioned problems, this paper suggests a coordinated control algorithm, which uses multiple FACTS controllers. In the next section, a coordinated control algorithm compatible that is compatible with the Korean power system is suggested.

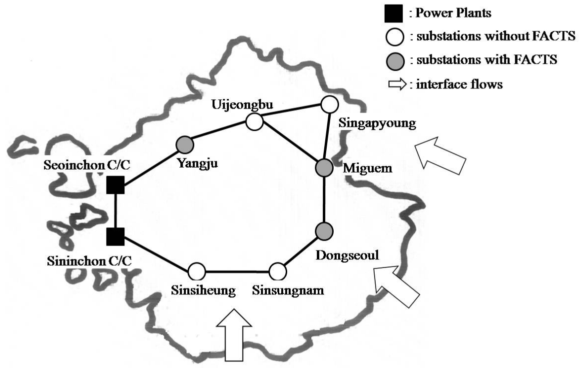

Fig. 2. Map of the metropolitan region in the Korean power system.

Fig. 1 represents the Jeju system. The total peak load of Jeju Island is approximately 500 MW, and 150 MW is transmitted over HVDC under normal condition. As of 2006, major generators in the Jeju system consist of two units (100 MW) in the South Jeju bus and one unit (75 MW) in the Jeju bus. The three generators and the transmitted power through HVDC line supply most of the loads in Jeju Island. As HVDC consumes reactive power for the substantial transmission of active power, compensation of reactive power in the system is essential. Reactive-power compensation is carried by filters and synchronous condensers (2 x 55 MVar) in the Jeju system.

Table 1 shows in detail the HVDC operation criterion recommended by the KPX (Korea Power eXchange; Independent System Operator). According to Table 1, the HVDC system operates in frequency control mode, that is, the HVDC system manages system frequency in Jeju. If the generators experience accident in the Jeju AC system, the HVDC system would be able to guarantee active power balance.

3. Centralized Control Strategies using Multiple FACTS in the Korean Power System

3.1 Overall Scheme of Centralized Control

The coordinated control strategies are generally divided into local and centralized control [35]. The former is a coordinated control strategy at a single substation and the latter is a coordinated control strategy, which yields a desired global system. This paper is concerned with a centralized control strategy in terms of the entire system. Fig. 3 shows the framework for centralized coordinated control. To assess voltage stability on the basis of online measurements, input data are obtained from the SCADA/EMS system, which contains the global system data. Using the full system model, the centralized controller continuously monitors the system state and decides the operating point so that the system operates within the stability boundary, despite the influence of a credible contingency.

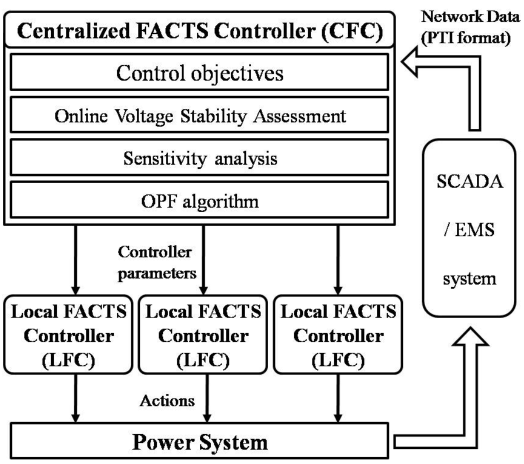

Fig. 3. Framework for the centralized control of multiple FACTS.

In a stable situation, the controller is able to determine the operating point for optimal operation using OPF algorithm. The output of the coordinated controller periodically goes into the local controller and is shown to the system operator for the purpose of monitoring the system status through a graphic user interface.

As shown in Fig. 4, the reactive-power reserve of FACTS devices can increase through coordinated control with switched capacitors in a substation. An increase in the reactive-power reserve of FACTS devices, which rapidly compensates for disturbances, enhances the voltage stability margin. When the system becomes unstable following the contingency, the controller increases the reactive-power reserve to increase the voltage stability margin, that is, the operating point of the FACTS devices moves into the inductive region for an increase in the reactive-power reserve through coordinated control with a switched shunt.

If the contingency actually occurs, the reactive-power reserve can guarantee voltage stability.

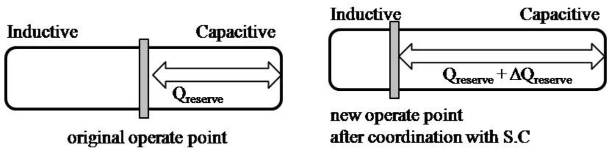

Fig. 4. Enhancements in the Q reserve of FACTS devices through coordination with SC.

3.2 Proposed Algorithm for Centralized Control

In this paper, the system states are classified into "emergency," "alarm," and "normal." The "emergency" condition implies that the system will be unstable if a contingency occurs. Special protection schemes, e.g., load-shedding scenarios, are usually applied to overcome the emergency conditions. The "alarm" condition implies that the system is still unstable due to scarcity of the voltage stability margin even though the conditions are not as dire as those of an emergency. "Emergency" and "alarm" could be called abnormal conditions that need modification of the operating point of FACTS towards the inductive region for voltage stability enhancement. The "normal" state implies that system is stable despite the occurrence of a critical contingency.

First, the emergency state is rapidly screened to examine whether or not the system remains stable after specific contingencies, such as route outages between Seoinchon C/C and Yangju. If the power flow diverges, coordinated control should be performed for convergence of the power flow. Otherwise, the coordinated control algorithm performs FV analysis to examine whether or not the interface flow margin is sufficient. If the margin is insufficient, coordinated control should be performed to ensure adequate interface-flow margin. Otherwise, an optimal power flow algorithm is executed to minimize the loss of the transmission line.

3.2.1 Emergency Screening

Regarding emergency screening, the specific contingencies that need special protection schemes due to the divergence of the power flow equations are determined through a preliminary study. In the "emergency" case, it is difficult to analyze the systems through general power flow equations because the power flow solution does not exist following a contingency. Therefore, this paper suggests an algorithm, which is able to investigate the nonlinear effects of transmission branch parameter variations for analyzing the emergency state. In this paper, such analysis is denoted as YV analysis. When either a power flow solution does not exist after a branch outage and/or the power flow does not converge within a reasonable number of iterations, YV analysis can trace the power flow solution according to the variations of the transmission line parameters via continuation. Fig. 5 represents the transmission line equivalent π circuit for the purpose of YV analysis. As shown in Fig. 5, the parameter (λ) is incorporated into the power flow equation to implement the variation of the branch parameter. The flow of active and reactive power from bus i to bus j is represented by:

$$P_{ij}(V_i, V_j, \lambda) = (1-\lambda)\left\{|V_i|^2 G_{ii}^* + |V_i||V_j|\left[G_{ij}^*\cos(\theta_{ij}) + B_{ij}^*\sin(\theta_{ij})\right]\right\} \quad (1a)$$

and

$$Q_{ij}(V_i, V_j, \lambda) = (1-\lambda)\left\{-|V_i|^2 B_{ii}^* + |V_i||V_j|\left[G_{ij}^*\sin(\theta_{ij}) - B_{ij}^*\cos(\theta_{ij})\right]\right\}, \quad (1b)$$

respectively, where Gii*, Gij*, and Bij* are the admittances of the removed branch.

As the continuation parameter (λ) increases, the system graduates from the pre-contingency system to the power system with branch outages. This means that when λ is zero, the original power-flow equations are obtained; when λ reaches 1.0, the new power-flow equations, which represent the network with the branch totally removed, are obtained.

Fig. 6 shows the result of YV analysis. If λ cannot reach 1.0 (case 2), coordinated control is needed for power flow convergence. Sensitivity factors are used to portion out the insurance of the reactive-power reserves among the FACTS devices. Tangent vector is used to find weak buses and to analyze the sensitivity factor with respect to voltage stability.

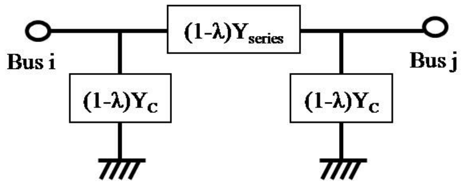

Fig. 5. Representation of the transmission line (equivalent π circuit).

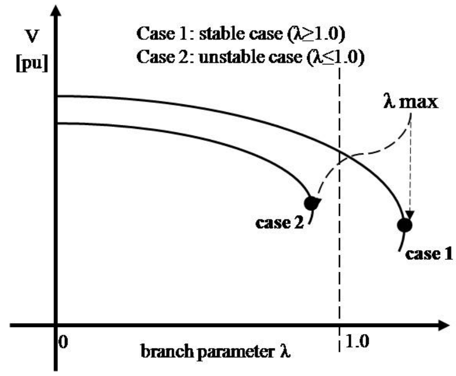

Fig. 6. The branch-parameter variation curves for stable and unstable cases.

In [38], the weakest bus, j, is represented by:

$$\left|\frac{dV_j}{Cd\lambda}\right| = \max\left[\left|\frac{dV_1}{Cd\lambda}\right|, \left|\frac{dV_2}{Cd\lambda}\right|, \ldots, \left|\frac{dV_n}{Cd\lambda}\right|\right], \quad (2)$$

where j reaches its steady-state voltage stability limit, dλ approaches zero, the ratio dVj/Cdλ becomes infinite or equivalent, and the ratio Cdλ/dVj tends to be zero. The ratio Cdλ/dVj, which is easier to handle numerically, can be defined as a voltage stability index for the entire system. The minimum real part of the eigenvalue of the Jacobian [39], and the minimum singular value of the Jacobian in [40] are defined as voltage stability indexes. The bus sensitivities from tangent vector analysis indicate how weak a particular bus is near the critical point and help determine the areas close to voltage instability. The greater the bus sensitivity value, the weaker the bus is.

The Q reserves of the FACTS controllers are adjusted in accordance with the sensitivity factors for the buses where the FACTS devices are installed. The Q reserves of each FACTS controller are determined to achieve convergence of the power-flow equations.

3.2.2 Alarm Screening

This strategy can be performed after emergency screening. Supposing a power system is divided into two regions, A and B, which are linked with interface lines without any loss of generality (Fig. 7), and assuming that the cost of generation in region A is cheaper than in region B, therefore, it is more economical to increase the interface flow

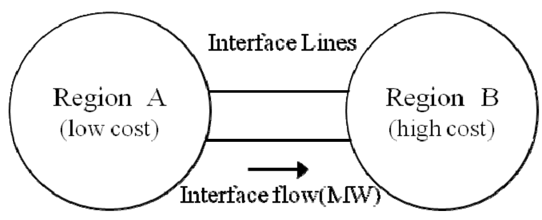

Fig. 7. A two-region power system with interface lines.

from region A to region B because the generation in region B is decreased, whereas that in region A is increased. If the interface flow continues to increase, it will eventually be constrained by voltage stability. To implement an algorithm for interface flow analysis, the parameter, μ, which represents the shift in generation, is incorporated into the power flow equations. The active power variations in the generation in regions A and B are as follows:

$$P_{GAi} = P_{GAi0} + k_{GAi} P_{GB0,total}, \quad (3a)$$

$$P_{GBi} = P_{GBi0} - \mu k_{GBi} P_{GB0,total} \text{ and} \quad (3b)$$

$$\Delta P_{GB0,total} = \sum_{i \in B} \mu k_{GBi} P_{GB0,total},$$

where

P_{GAi0} and P_{GBi0} are the original values of the active-power generation at bus *i* in regions A and B, respectively;

$P_{GB0,total}$ is the original total generation in region B;

$\Delta P_{GB0,total}$ is the total decrease in generation in region B; and

k_{GAi} and $k_{GBi}$are the fractions of the variation in generation at bus *i* in regions A and B, respectively.

To determine the voltage stability limits of the interface flows, interface lines and severe contingencies are chosen, and the FV curve is drawn (Fig. 8).

If the interface flow margin is insufficient, the margin should be increased through insurance from the reactive-power reserves of the FACTS devices. Similarly, for the "emergency" state, sensitivity factors are used for coordinated control, and FV analysis is repeated until the margin is sufficient.

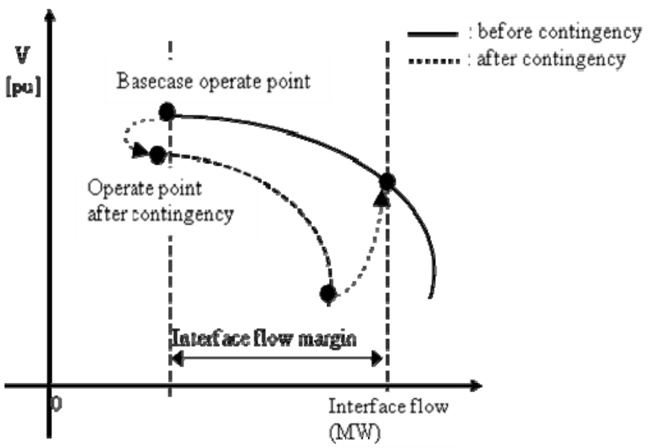

Fig. 8. The illustration of the interface-flow curves.

3.2.3 Normal State

In this state, the voltage stability margin is sufficient even though the influence of contingencies is considered. In this case, the objective of coordinated control would be to achieve an economical operation. OPF algorithm could be used for the loss minimization of transmission lines. The objective function and constraints are as follows:

Objective function

$$Min \quad f(x) = \sum [V_i^2 G_{ij} + V_j^2 G_{ij} - 2V_i V_j G_{ij} \cos(\delta_i - \delta_j)], \quad (4)$$

Constraints

$$P_{Gi} - P_{Li} = V_i \sum_i V_i Y_{i,j} \cos(\delta_i - \delta_j - \theta_{i,j}), \quad (5a)$$

$$Q_{Gi} - Q_{Li} = V_i \sum_i V_i Y_{i,j} \sin(\delta_i - \delta_j - \theta_{i,j}), \text{ and} \quad (5b)$$

$$V_{\min} \le V \le V_{\max}. \quad (6)$$

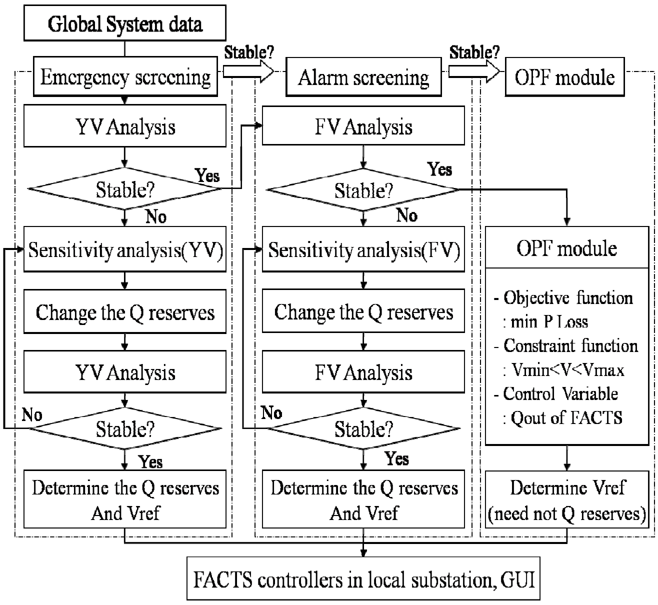

Fig. 9. Flowchart of the coordinated controller for FACTS devices.

The flow of the coordinated control algorithm for the FACTS devices, shown in Fig. 9, is as follows:

Step 1) Input the SCADA/EMS data.

Step 2) Solve for the power flow and perform YV analysis for specific contingencies that are determined by the preliminary study. If the result of YV analysis is stable, go to Step 6. Otherwise, go to the next step.

Step 3) Perform sensitivity analysis for each bus where the FACTS devices are installed.

Step 4) After increasing the Q reserves in relation to the sensitivity factors of the buses, perform YV analysis then go to Step 3. This iteration is repeated until the system becomes stable.

Step 5) Determine the Q reserves and reference voltages of the buses for convergence. Go to Step 12.

Step 6) Execute the FV algorithm. If the FV margin is sufficient, go to Step 10.

Step 7) Analyze the sensitivities of the buses for guaranteeing the FV margin after a contingency.

Step 8) After increasing the Q reserves in relation to the modified sensitivities, conduct FV analysis then go to Step 7. Repeat this iteration until the system escapes the "alarm" state.

Step 9) Determine the Q reserves and reference voltages of the buses for ensuring the FV margin. Go to Step 12.

Step 10) Execute OPF algorithm for the power-loss minimization because the system state is stable even if a contingency occurs.

Step 11) Determine the reference voltage of each substation for loss minimization.

Step 12) Terminate the algorithm for coordinated control.

Table 2. The contingency sets for illustrative purposes

No. of contingency	Name of Contingency	Remarks
ctg 1	Seoinchon-Yangju (2 ckt)	(Load shedding)
ctg 2	Hwasung-Asan (2 ckt)	
ctg 3	Singapyong-Sintaebek (1 ckt)	765 kV
ctg 4	Sinansung-Sinseosan(1 ckt)	765 kV

※ Load shedding scenarios about ctg 1

Line loading of the route of Seoinchon-Yangju (MW)	2,100~2,350	2,350~2,550	2,550~2,750
Amount of Load Shed (MW)	200	450	650

4. Simulation Results for the Korean Power System

This section provides the results of coordinated control through multiple FACTS devices in the Korean power system. The algorithm is implemented in FORTRAN and Visual C++. In the simulation, the data set was collected from the SCADA/EMS system in the Korean power system from January (winter off-peak data) to August (summer peak data) of 2007. The data set, which has been slightly modified for simulation, includes 229 snapshot data.

4.1 Credible Contingency Set

The contingency set in Table 2 is determined by the off-line system study [32]-[34]. The route lines of "ctg 1" exist in the metropolitan region. The lines of "ctg 2," "ctg 3," and "ctg 4" are the interface lines. The route outage of the 345kV lines are denoted by "ctg 1" and "ctg 2," while the one circuit outage of the 765kV lines are denoted by "ctg 3" and "ctg 4."

Given that the system might experience voltage collapse after "ctg 1," the system operator has established the load shedding scenario as shown in Table 2. The amount of load shed is determined by the line loading (MW) of the route.

4.2 Emergency Screening

YV analysis is done to check the solvability of the power flow. In YV analysis, the margin (α) is considered due to the uncertainties of the system modeling and mathematical errors; the higher the value, the more stable the power system is. However, more reserve is required to obtain more margins against a severe contingency. These are not realistic in terms of power system operations. Hence, we suppose that the margin alpha is 0.5%, and this margin can be adjusted in case of more stable operation or an empirical knowledge of the operators. This means that the parameter λ should reach 1.005 to ensure stability.

As shown in Table 3, there are 13 very unstable cases requiring corrective control and that these need about 200 MW load shedding to guarantee system stability.

We performed sensitivity analysis for each bus where FACTS devices are installed, using the tangent vectors at the knee point in the YV curve. Table 4 shows the results of the required delta Q reserve and reference voltage for solving the insolvability problems according to the result of the sensitivity analysis. In Table 6, "ΔQ reserve" refers to the supplementary Q reserve at each substation for stability. If the Q outputs of the FACTS devices are zero, the Q reserves at the Yangju, Miguem, and Dongseoul substations are at the base values of 100, 100 and 200 MVar, respectively, as shown in Table 1. Therefore, the total Q reserves of each bus are the summation of the ΔQ (i.e., incremental) reserves and the original Q reserves.

In all emergency cases, the application of the coordination (Table 4) changes the maximum value of λ to 1.005, thereby restoring system stability.

Table 3. Results of YV analysis

Data (date-time)	YV result (λ max)	Line loading between Seoinchon and Yangju	Amount of load shed
Aug-xx-10:55	0.983	2266.3 MW	200 MW
Aug-xx-11:10	1.003	2186.3 MW	200 MW
Aug-xx-11:25	0.993	2226.6 MW	200 MW
Aug-xx-11:40	0.995	2209.0 MW	200 MW
Aug-xx-11:55	0.996	2219.3 MW	200 MW
Aug-xx-12:10	0.995	2215.4 MW	200 MW
Aug-xx-12:25	1.002	2170.3 MW	200 MW
Aug-xx-13:10	0.989	2272.9 MW	200 MW
Aug-xx-13:25	0.991	2201.0 MW	200 MW
Aug-xx-13:40	0.997	2205.9 MW	200 MW
Aug-xx-13:55	0.995	2210.0 MW	200 MW
Aug-xx-14:05	0.997	2190.3 MW	200 MW
Aug-xx-14:35	0.994	2211.4 MW	200 MW

Table 4. The ΔQ reserve and Vref of each bus for system stability in unstable cases

Data (date-time)	Yangju		Miguem		Dongseoul	
	△Qres (Mvar)	Vref (pu)	△Qres (Mvar)	Vref (pu)	△Qres (Mvar)	Vref (pu)
Aug-xx-10:55	74.41	1.014	50.19	1.011	25.40	1.012
Aug-xx-11:10	43.33	1.017	19.99	1.015	11.68	1.018
Aug-xx-11:25	81.37	1.016	81.74	1.013	61.89	1.015
Aug-xx-11:40	60.07	1.015	51.83	1.011	38.09	1.013
Aug-xx-11:55	76.35	1.017	84.07	1.015	64.59	1.017
Aug-xx-12:10	60.83	1.019	57.18	1.015	31.99	1.017
Aug-xx-12:25	45.69	1.023	25.45	1.018	3.86	1.020
Aug-xx-13:10	78.35	1.022	88.93	1.015	57.72	1.016
Aug-xx-13:25	60.75	1.012	56.81	1.011	32.44	1.012
Aug-xx-13:40	44.21	1.022	64.86	1.020	40.94	1.020
Aug-xx-13:55	73.95	1.019	84.80	1.018	66.25	1.019
Aug-xx-14:05	75.34	1.019	84.23	1.017	65.43	1.018
Aug-xx-14:35	59.76	1.021	51.97	1.019	38.27	1.020

Table 5. Results of the FV analysis

Data (date-time)	Unstable Contingency	FV result (% margin)	Line loading between Seoinchon and Yangju
Aug-xx-16:05	ctg 1	3.95 %	2030.9 MW
Aug-xx-16:40	ctg 1	2.34 %	2036.4 MW
Aug-yy-13:07	ctg 1	4.95 %	1273.8 MW
Aug-yy-13:22	ctg 1	4.87 %	1245.3 MW
Aug-yy-13:52	ctg 1	4.83 %	1263.0 MW

Table 6. The △Q reserve and Vref of each bus for ensuring the FV margin

Data (date-time)	Yangju		Miguem		Dongseoul	
	△Qres (Mvar)	Vref (pu)	△Qres (Mvar)	Vref (pu)	△Qres (Mvar)	Vref (pu)
08-22-16:05	24.84	1.027	26.71	1.023	23.46	1.023
08-22-16:40	24.86	1.027	26.66	1.023	23.48	1.023
08-26-13:07	-1.96	1.018	9.37	1.005	67.59	1.004
08-26-13:22	-1.86	1.021	9.14	1.008	67.72	1.009
08-26-13:52	-1.94	1.019	9.30	1.007	67.63	1.008

4.3 Alarm Screening

This module checks whether the voltage stability margin is sufficient or not. In this paper, it is supposed that the criterion of the FV margin is 5%. As shown in Table 5, there are five alarm cases that do not have sufficient margin although power flow converges. We can also see that the FV margin is insufficient but only in the "ctg 1" contingency case. The line loadings between Seoinchon and Yangju are less than 2,100 MW, which is the load shedding boundary.

We also performed sensitivity analysis for each bus where FACTS devices are installed, using the tangent vectors at the knee point in the FV curve. Table 6 shows the results on the required Q reserves and reference voltages for ensuring the FV margin. In all the unstable cases, the application of the coordination (Table 6) guarantees the criterion of the FV margin at 5%, ensuring that the system is stable.

4.4 Loss Minimization for Economical Operation

The stable cases do not need supplementary reactive-power reserve for voltage stability. In this case, OPF algorithm is performed in the interest of economic operation. The objective function of the OPF algorithm is the loss minimization of the transmission lines.

There are two cases for this simulation. The first case ignores the losses of FACTS devices, whereas the other considers the losses. When the ratio of the losses of the FACTS devices to the Q outputs of those devices is 5%, that is, if the Q output of a FACTS device is 100 MVar, the loss is 5 MW. The result of optimal power flow for loss minimization is shown in Table 7. The total loss of the lines changes from 660.04 to 656.39MW in the former case. In the latter case, the loss changes from 660.04 to 659.61 MW. If the loss of the FACTS devices is neglected, the benefit of loss reduction is 3.65 MW; otherwise, the benefit is 0.43 MW. In Table X, the Q output is the required reactive-power for loss minimization. Thus, the ability of FACTS to control for loss minimization is not so efficient in the Korean power system.

Table 7. Q reserve and V_{ref} of each bus for loss minimization

Case	Substation	Yangju	Migeum	Dongseoul
Ignore losses of FACTS devices	Total Q reserve	6.6 MVar	66.1 MVar	0.0 MVar
	Q output	93.4MVar	33.9MVar	200.0MVar
	V ref (pu)	1.023	1.022	1.026
Consider losses of FACTS devices	Total Q reserve	90.4 MVar	87.0 MVar	187.3 MVar
	Q output	9.6 MVar	13.0 MVar	12.7 MVar
	V ref (pu)	1.015	1.013	1.015

4.5 The implementation of the Proposed Algorithm

The proposed algorithm will be implemented in an online SCADA/EMS system from 2010-2011. The algorithm will use the snapshot data from SCADA/EMS system. The SCADA/EMS system of the Korean system periodically generates snapshot data every five minutes. Therefore, the algorithm is executed periodically every five minutes. The controller result also periodically goes into the local controller every five minutes. The simulation time performed at each case is usually several seconds (4-5 sec) by Pentium 4 processor. The credible contingency has four cases in the paper. Therefore, a contingency analysis is performed for about 20 seconds. In addition, the total time to perform the proposed control is about 20-60 seconds.

5. Conclusions

This paper discusses a centralized-control strategy for voltage stability, which uses multiple FACTS and SC in the Korean power system. The control objectives of the FACTS controllers are defined below.

1. If the system is unstable, the objective of coordinated control is to enhance stability, specifically to:
A) To reduce the amount of load shedding against the severe contingency (Yangju-Seoinchon) (Table 2 represents the load shedding scenarios) and
B) To guarantee the interface flow margin (the FV margin), which is the inherent voltage stability index of the Korean power system.

If the system is stable, the objective of coordinated control is the economic operation of the power system.

The 229 sets of network data obtained from the SCADA/EMS system are analyzed in the Korean power system. The 13 cases require 200 MW load shedding to achieve stability. The application of the coordination can restore the solvability of the cases without load shedding. The five cases require coordination between FACTS and SC due to the insufficiency of the FV margin. The coordination can guarantee the 5% margin. In case of stability, the objective function is the loss minimization of the transmission lines. There are two cases for simulation. The first case ignores the losses of FACTS devices, whereas the other considers the losses.

Load shedding scenario should be modified according to the allocation of the reactive power reserves of FACTS. Coordination with the setting of load shedding scenarios will be investigated in future research.

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