Reliability Management of Korea Power System Operation by POM/OPM/BOR

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Abstract—This paper illustrates the potential applications of POM/OPM/BOR, which are used for deterministic reliability evaluation in the operation mode (operational planning and operating) in Korea power system. Deterministic reliability evaluation in this paper is based on the philosophy of the marginality and the limitation of physical quantities such as voltage and line flow under contingency analysis. The POM/OPM/BOR tools have been developed by V&R Energy Systems Research, Inc. (V&R) in USA. The main frame and features of the tools are introduced in brief, followed by case studies using the actual model of Korea power system. The case studies are demonstrated to verify the application possibility of POM/OPM/BOR.

Keywords: reliability evaluation, transmission system, KEPCO, POM, OPM, BOR, AC contingency analysis, optimal mitigation measures, secure operating region

1. Introduction

Restructuring in the electric power industry has already resulted in system operation at higher transfer levels increasing the potential for security limit violations [1]. Therefore, fast transfer capability assessment is of paramount importance in the open power market to provide reliable and secure transfer of power to the customers. More accurate and fast assessment of transfer capability limits on flowgates (transfer paths or interfaces) is more critical than ever before [1]-[4].

Over the last two decades, considerable progress has been made in the areas of power system security and transfer capability calculations [5]. A number of methods have been presented in numerous technical papers that specifically deal with the computation of security and transfer capability limits [5]-[11]. Conventional studies on power system transfer capability are based on linear models such as distribution factors or transportation models [6]-[7], and very few are of non-linear nature [8]-[11]. The primary shortcomings of these tools are their accuracy; in most cases, they address only thermal constraints and do not deal with voltage constraints or instability (voltage, transient or oscillatory).

This paper presents non-linear security-based approach tools, Physical and Operational Margins (POM), Optimal Mitigation Measures (OPM), and Boundary of Operating Region (BOR) for transfer capability assessment considering any type of security violations in brief. The primary purpose of the paper is to check the possibility of application of POM/OPM/BOR, well-known tools for deterministic reliability evaluation for the operation mode (operational planning and operating) in Korea Power System. Deterministic reliability evaluation in this paper is based on the philosophy of the marginality and the limitation of physical quantities such as voltage, thermal and stability under contingency analysis. The POM/OPM/BOR tools have been developed by V&R Energy Systems Research, Inc. (V&R) in USA. The main frame and features of the tools are introduced in brief. Case studies of the actual power system of Korea are demonstrated not only for benchmarking the result from POM/OPM/BOR but also for investigating the potential use of POM/OPM/BOR.

2. POM/OPM/BOR

2.1 POM/OPM Features

POM/OPM/BOR software is owned and developed by V&R Energy Systems Research, Inc. in USA. This is very powerful and sophisticated application suite on the market providing fastest solution of load flows, transient analysis, and real time analysis. The suite can graphically display boundaries of operating reliability, determine optimum mitigation measures, and optimal rank of transmission expansion projects. Therefore, it can be used for planning and operations environments. All programs in the package are fully integrated and utilize the same interface that is Microsoft Windows-based. Any software configuration is available, based on a customer request.

POM is the main program of the Package

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1) Performs massive AC contingency analysis for large power system models:

- Automatically generates contingency lists
- Analyzes N-1, N-2, N-3 and complex contingencies
- Identifies critical contingencies and associated violations

2) Monitors user-defined constraints:

-Simultaneously monitors voltage stability, voltage, and thermal constraints

-Computes voltage stability margins

-Monitors flowgates

The power transfers are simulated while monitoring voltage, thermal and voltage stability constraints.

Optimal Mitigation Measures (OPM) is fast and efficient remedial actions or transmission expansion planning program to maintain and increase power system reliability. OPM relieves thermal, voltage and voltage stability violations identified by POM, increases voltage stability margins, transfer capability

2.2 BOR Features

BOR identifies and illustrates a region within which the system operation is secure.

BOR determines:

- Simultaneous power transfer limits
- Effects of outages on secure region of operation
- Effects of remedial actions on secure region of operation

BOR Functional Structure is shown in Fig. 1.

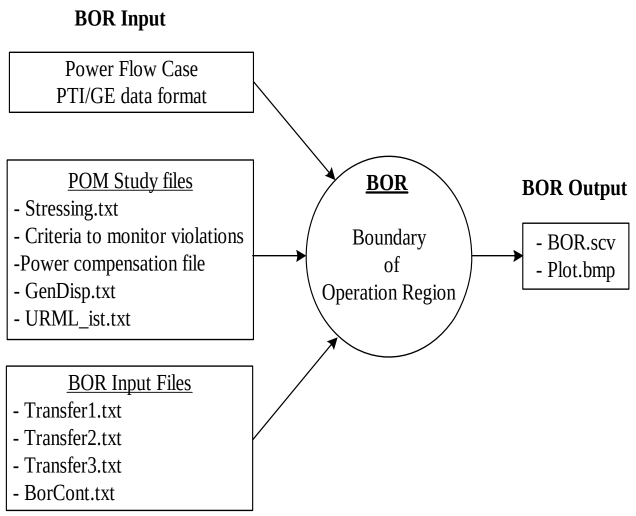

Fig.1 BOR functional structure

3. Draft Case Study For Korea Power System

In this paper, case study was performed using the base case 2006(Ver28).raw in PTI version 28 format of Korea Power System by programs POM, OPM and BOR.

3.1Solution Parameters Used for Study

The study was performed using the 2006 summer peak KEPCO-system which has about 11 control areas with 1,660 buses and 2,000 branches. The following solution parameters are used for the case study:

- Tap adjustment and phase shift adjustment disabled
- DC taps and switched shunts fixed
- Area interchange disabled
- Tolerance is 1 MW/MVAR
- Load is scaled within the entire power system network
- How are the loads scaled or increased compensated?

3.2 Monitored Constraints

The monitored constraints are voltage stability, volatge and thermal constraints which are simultaneously monitored during the study. The first one, voltage stability constraint is always monitored within the entire power system network. Low voltage limit of 0.92 p.u. is monitored at all buses 69kV and above within the entire power system network. The second one, thermal constraint 100% of Rating B (rating for summer emergency condition) is monitored on all branches 69kV and above within the entire power system network. The options for constraint monitoring were selected as shown at Fig.2.

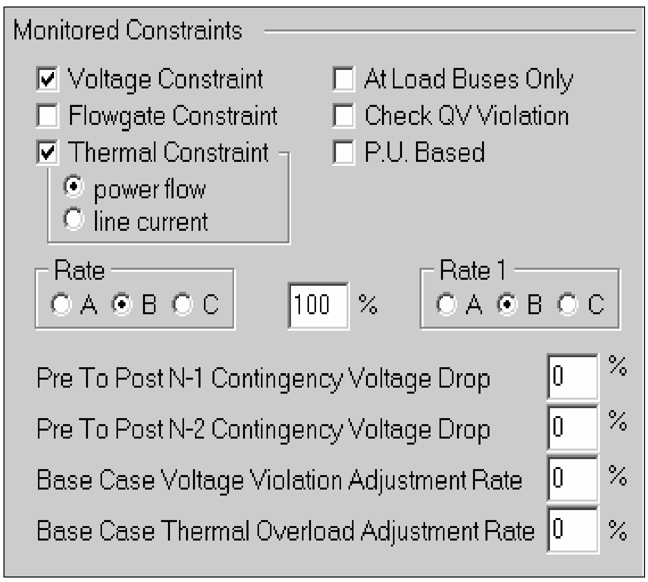

Fig.2 Options pane for constraint monitoring

3.3 Working in POM Basic Mode

POM works in several modes such as Basic, Advanced, and Automatic mode. Basic mode is intended for fast investigation of a particular N-1, N-2 or complex contingency as well as visual representation of monitored constraints. After an outage and/or load or power transfer increase is executed in Basic mode, changes to the power flow case are reflected in the data tables and oneline diagram

Performing Operations in POM Basic Mode

A generator (generator 25251) and a branch (765 kV line 1020-5010 "2") contingency was applied while scaling the load in the entire network. The voltage violation occurs at load level of 1,400 MW. Thus, the maximum load level at which violations do not occur is 1,300 MW since the system load is scaled by 100 MW. The details of post-contingency violations and the monitored constraints are shown at Table 1 and Fig. 3. The x-coordinate is the value of load scaling. To represent a voltage stability constraint, the vertical scale shows the number of iterations of the Newton method at each load step (red curve). If voltage constraint is enforced, the y-coordinate represents a steady-state voltage level at each load step (green curve). If thermal constraint is enforced, y-coordinate represents rating of branches (pink curve).

Table I The details of post-contingency violations, Load Level = 1400 MW

Bus	Base voltage (KV)	Vol. Magnitude [p.u]
2535	154	0.894
4445	154	0.882
4515	154	0.874
4520	154	0.873
4530	154	0.875
4540	154	0.876
4740	154	0.896
4745	154	0.899
4750	345	0.911
4765	154	0.886
4775	154	0.901
4825	154	0.914
4865	154	0.917
44630	154	0.876
44765	154	0.888
44775	154	0.901
4776	154	0.901
4516	154	0.874

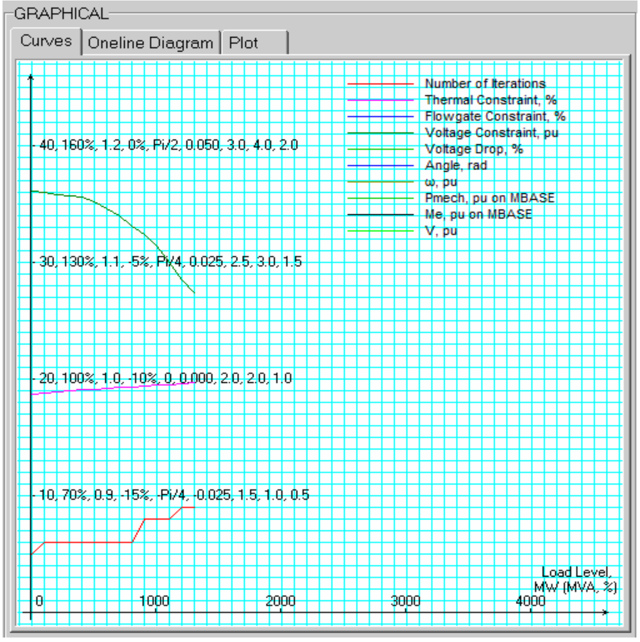

Fig. 3 Voltage assessment in POM Basic Mode

Performing Operations in POM Basic Mode with OPM

Optimal Mitigation Measures (OPM) application is fully integrated into the POM interface. The following mitigation measures were selected:

- MVar (Vsch) and MW (Gen) redispatch
- Branch switching on- and off-service (Branch)
- Capacitor placement (Cap)
- Load curtailment (Load)

The same contingencies are applied to evaluate the impact on the load increase due to the mitigation measures identified by OPM. The violation occurs at load level 2,600MW. Thus, the maximum load level at which violations didn't occur is 2,500MW since the system load is scaled by 100 MW. After the OPM is utilized, the maximum load level is significantly increased as compared to the case when OPM was not applied. The maximum load level increases from 1,300 MW to 2,500MW after the OPM is applied as shown at Table 2 and Fig.4.

Table II The details of post-contingency violations, Load Level = 2600 MW

Bus	Base voltage (KV)	Vol. Magnitude [p.u]
2535	154	0.917
4445	154	0.903
4515	154	0.896
4520	154	0.896
4530	154	0.899
4540	154	0.899
4740	154	0.919
4745	154	0.917
4765	154	0.908
44530	154	0.899
44765	154	0.908

4516	154	0.896

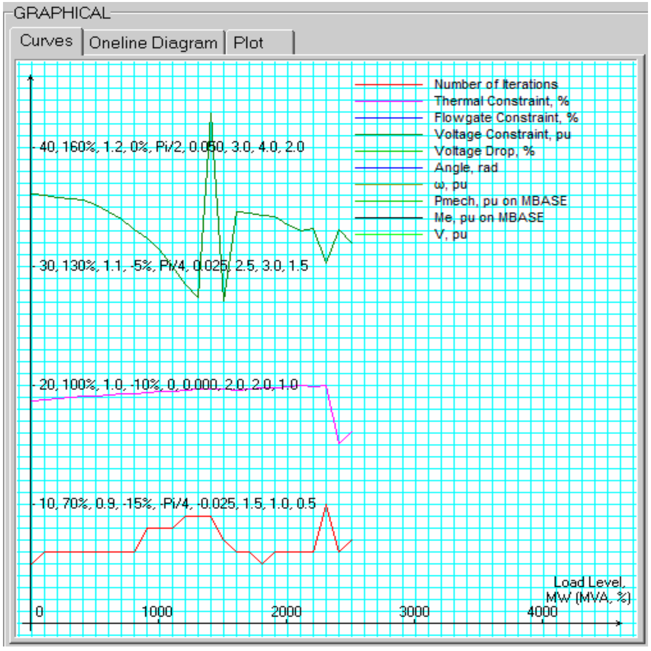

Fig. 4 Voltage assessment in POM Basic Mode with OPM

3.4 Working in POM Advanced Mode

Advanced mode offers extended options for manual investigation of particular N-1 or N-2 or complex contingencies. However, it provides more extended options for contingency analysis as well as a comprehensive list of commands, including simulation of power transfers and determining limits.

Computing Area Line Flows

Area Transfer command computes real power flows in MW between control areas connected by tie-lines. Flows on each tie-line are calculated and reported as shown at Fig. 5 and Table 3.

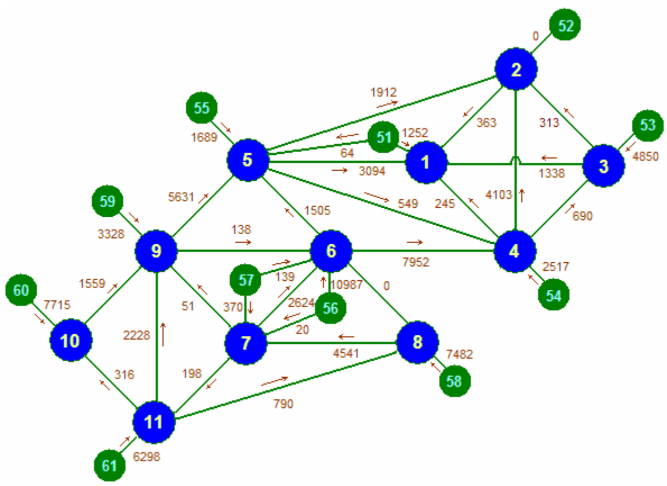

Fig. 5 Area transfer results

Table Ⅲ Area power flow transfer between control areas

Load		Generation		
Area	Total load [MW]	Area	Pmax-P [MW]	P-Pmin [MW]
1	6,246.4	51	293.6	656.8
2	5,948.7	52	0	0
3	3,872.5	53	455	1,408
4	5,911.2	54	0	845
5	3,196.5	55	375	522
6	4,279.7	56	39.64	341.94
7	1,993.9	57	249.4	121.2
8	3,628.8	58	19.3	1,484.21
9	6,295.1	59	56	1,007
10	6,428.7	60	1,075	2,395
11	3,071.7	61	463.01	1,288.92

Simulating a Power Transfer in POM Advanced Mode

A branch (765 kV line 1020-5010 "2") contingency is selected. The power transfer is simulated with the transfer step of 25 MW. The generation at area 60 and area 70 is increased in the source system 70% and 30%, respectively. Load is increased in the sink system, area 1. The violation of voltage constraint occurs at transfer level of 425 MW. Thus, the maximum transfer capability is 400 MW as shown at Fig. 6

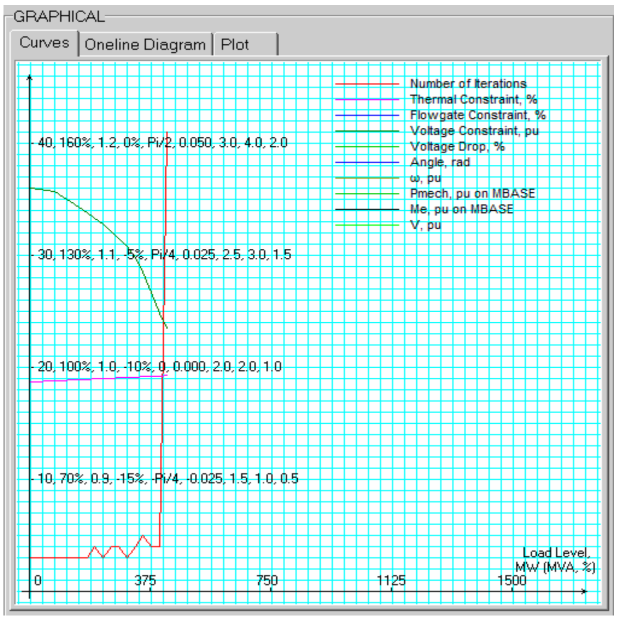

Fig.6 Simulating a Power Transfer

Simulating a Power Transfer in POM Advanced Mode with OPM Enabled

The voltage violations occur at transfer level of 1,025 MW. Thus, the maximum transfer capability while applying the branch contingency with OPM enabled is 1,000 MW. As a result of using OPM, the transfer capability has increased by 250%, from 400 MW to 1,000 MW, as shown at Fig. 7.

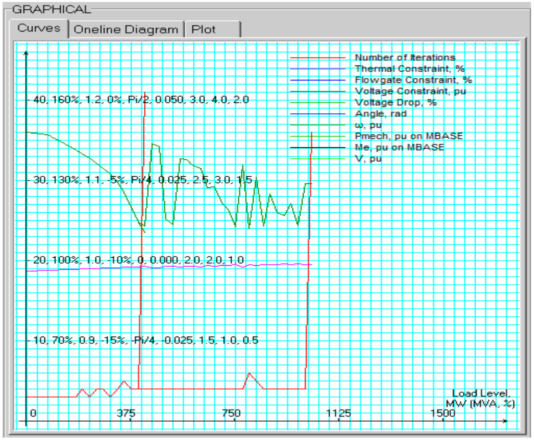

Fig.7 Simulating a Power Transfer with OPM Enabled

3.5 Working in POM Automatic Mode

Automatic mode is intended for massive contingency analysis. It allows the user to identify critical contingencies and violations caused by these contingencies.

Creating Lists of N-1 and N-2 Contingencies for Contingency Analysis

The POM can automatically create lists of N-1 and N-2 contingencies based on the user-specified rules.

Performing Massive Contingency Analysis in POM Automatic Mode

POM allows the user to perform massive contingency analysis on the base case, at different load and transfer levels. POM found 25 critical contingencies out of 1357 contingencies applied. Critical are contingencies that cause violation of at least one of the monitored constraints. Contingency analysis results are written to an ASCII file and an MS© Access database.

Performing Massive Contingency Analysis with OPM Enabled in POM Automatic Mode

The same massive contingency analysis was performed with OPM enabled. As a result, post-contingency violations after all 25 critical contingencies identified by POM were alleviated and mitigation measures for each contingency were identified by OPM. Computation time of POM-OPM run is 100 sec.

3.6 Determining Boundary of Secure Operating Region for Three Simultaneous Power Transfers in BOR

BOR is a fast tool to identify and illustrate a region within which the system operation is secure. BOR can be shown as projections onto different planes, such as:

- Power transfers
- Load and generation
- Interface and/or tie-line flows

If two transfers are simultaneously modeled, graphical results are available in 2-dimensional form. If three transfers are simultaneously modeled, graphical results are available in 2- and 3-dimensional form. Graphical output is a boundary of the operating region. Each point on the boundary corresponds to at least one of the constraints being violated. Operating within the boundary is secure. The boundary is a multi-colored graph. Each color on a boundary corresponds to violation of one of the following constraints:

- Pink: Thermal violation
- Green: Voltage range violation
- Dark green: Pre- to post-contingency voltage drop violation
- Tile: Flowgate violation
- Red: Voltage stability violation
- Black: User-specified transfer limit is reached but no violations are identified
- Black (thin): All available generation (load) in source/sink subsystems has been used.

BOR can also determine power transfer scenarios to achieve the maximum transfer capability. It also determines power transfer scenarios to achieve the minimum cost.

Determining Boundary of Secure Operating Region for Three Simultaneous Power Transfers

Three power transfers are simulated in BOR according to the following scenario:

Transfer 1: increasing generation in the areas 55, 57 and 60 which participating factors are 45%, 25% and 30%, respectively. The load is increased in area 2.

Transfer 2: increasing generation in the area 60 .The load is increased in the area 3.

Transfer 3: increasing generation in the areas 51 and 60 which participating factors are 25% and 75%, respectively. The load is increased in area 4.

The boundary of secure operating regions is built in the 2-dimensional form as shown at Fig. 8

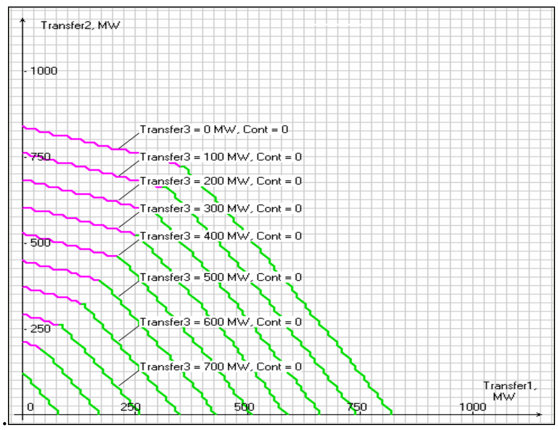

Fig.8 Projections of the Boundaries on the Plane (Transfer 1, Transfer 2)

The boundary of the secure operating region could be also built in 3-dimensional form as shown at Fig 9.

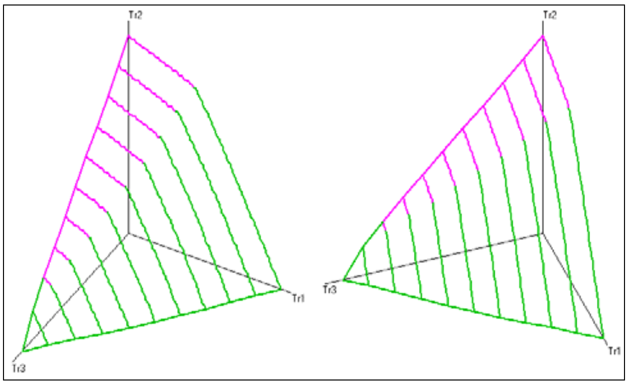

Fig.9 Boundaries of Secure Operating Region in 3-D Form

BOR can be used to determine the dependence of any power system parameters. For example, load is simultaneously changed in two different control areas. The secure operating region while simultaneously changing load in control areas 1 and 5 is shown at Fig.10.

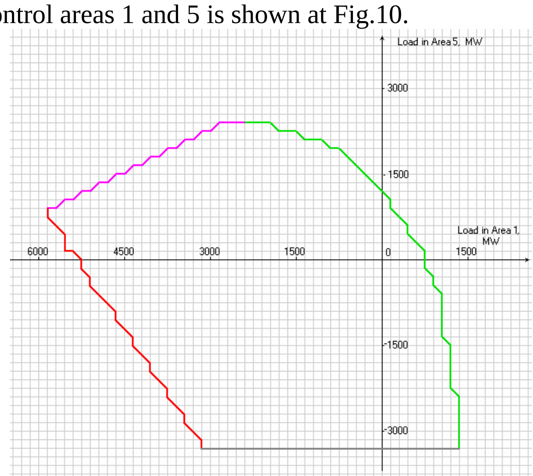

Fig.10 Boundaries of Secure Operating Region while Simultaneously Changing Load in Areas 1 and 5

4. Conclusions

POM-OPM-BOR tools were used for simulation of the KEPCO-system. POM-OPM-BOR incorporates non-linear approach allowing users to simultaneously monitor a number of constraints including: voltage constraint (voltage range and/or pre- to post-contingency voltage drop), thermal constraint, flowgate constraint, voltage stability constraint. At first, a particular contingency was tested using POM. The maximum load ability for this contingency was increased by the remedial actions optimally selected by OPM. Next,, maximum transfer capability was determined using POM. Maximum transfer capability was then increased using OPM. Then,, massive contingency analysis was performed and critical contingencies were identified using POM. Then, OPM was used to mitigate post-contingency violations. Also, three simultaneous power transfers were simulated using BOR. Transfer results are represented in 2-dimensional and 3-dimensional forms. The study was concluded by constructing, load-load nomograms using BOR.

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