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POM/OPM/BOR를 이용한 한국계통의 결정론적 신뢰도 평가

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Deterministic Reliability Evaluation of Korea Power System by POM/OPM/BOR

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Abstract - This paper illustrates 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 bases the philosophy of the marginality and the limitation of physical quantity (voltage and thermal in main) under contingency analysis. The POM/OPM/BOR tools have been developed by V&R (Vaimann and Research) in USA. Before case studies, main frame and feature of the tools are introduced in brief. Case studies of the actual power system of Korea are demonstrated for checking the application possibility of POM/OPM/BOR.

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 importancein 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, the 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 technical papers that specifically deal with 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 first objective 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 quantity (voltage, thermal and stability) under contingency analysis. The POM/OPM/BOR tools have been developed by V&R (Vaiman and Research) in USA. Main frame and feature of the tools are introduced in brief. Case studies of the actual system in 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. The most powerful and sophisticated application is the 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.

Main program of the Package

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

-Automatically generates contingency lists
-Analyzes N1, N2, 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.

2.2 BOR Feature

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.

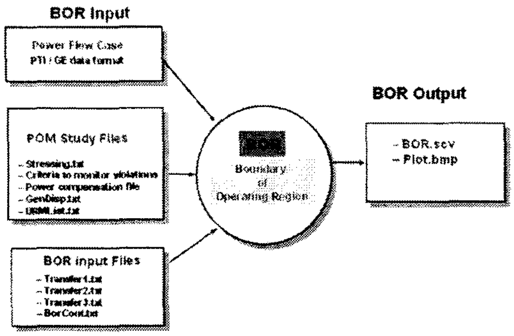


Fig.1 BOR functional structure

2.3 Users

In present, seventeen users, who are AEP, ATC, BPA, ConEd, Entergy,EPRI Solution, Idaho Power, ISO New England, KCPL,KPRQC/KEPCO/KPX, KeySpan/LIPA, Midwest ISO, ONS, NYPA, Tri-State G&T,TVA, are grouped and annual user group meeting has been opened.

3. DRAFT CASE STDUY FOR KOREA POWER SYSTEM

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

3.1 Solution Parameters Used for Study

The study was performed for the base case *2006(Ver28).raw*. The Korean 2006 year power system network consists of over 1660 buses and 2000 branches.
The following solution parameters are used:
- 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 following constraints are simultaneously monitored during the study:
- Voltage stability constraint
- Voltage stability constraint is always monitored within the entire power system network.
- Thermal constraint

100% of Rating B(rating for summer emergency condition) is monitored as the thermal constraint on all branches 69kV and above within the entire power system network.
- Voltage constraint

Low voltage limit of 0.92 p.u. is monitored at all buses 69kV and above within the entire power system network.
Options for constraint monitoring were selected as shown in Fig.2.

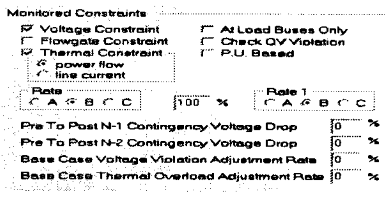


Fig.2 Options pane for constraint monitoring

3.3 Working in POM Basic Mode

POM works in several modes: Basic, Advanced, and Automatic. 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 and Oneline

(1) Performing Operations in POM Basic Mode

Details of post-contingency violation are shown in the INFORMATION pane. Simultaneously three curves that correspond to the monitored constraints are drawn in the GRAPHICAL pane. 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). The new system state is reflected in DATA Tables.

Generator and Branch Contingency

A generator (generator 25251) and a branch (765 kV line 1020-5010 "2") contingency was applied while scaling the load in the entire network. Fig.3 demonstrates the results of executing this activity. Fig. 3 shows that 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 with the assumption that the system load is scaled by 100 MW.

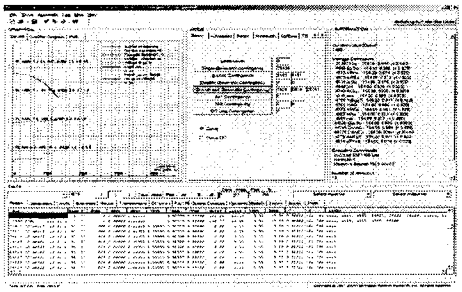


Fig. 3 Voltage assessment in POM Basic Mode

(2) Performing Operations in POM Basic Mode with OPM

Optimal Mitigation Measures (OPM) application is fully integrated into the POM interface as Fig. 4.

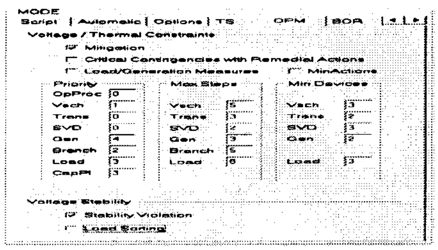


Fig.4 OPM options pane

From Fig.4, it follows that 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)

All other mitigation measures were disabled. A generator (generator 25251) and a branch (765 kV line 1020-5010 "2") contingency was applied with OPM enabled. This is the same contingency as shown in Fig.3. The results are shown in Fig.5. Fig.5 shows that violation occurs at load level 2,600MW. Thus, the maximum load level at which violations didn't occur is 2,500MW with the assumption that 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 (Fig. 3). The maximum load level increases from 1,300 MW to 2,500MW after the OPM is applied.

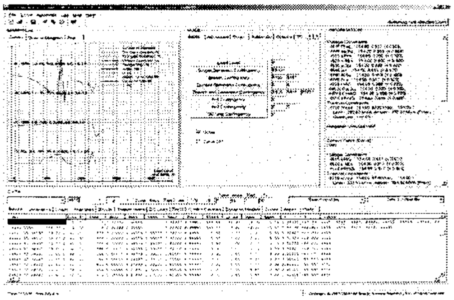


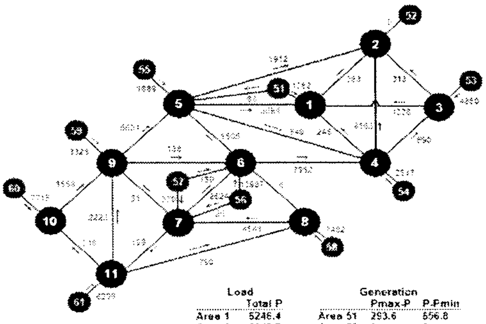
Fig. 5 Voltage assessment in POM Basic Mode with OPM

3.4 Working in POM Advanced Mode

Advanced mode offers extended options for manual investigation of particular N-N 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.

(1) Computing Area Line Flows

When working in Advanced mode, it is recommended to enable on-line Help tips by just pressing the F2 key on the keyboard. The on-line Help tips reduce the probability of errors while entering the commands, and make the process easier and faster. AreaTransfer command computes real power flows in MW between control areas connected by tie-lines. Flows on each tie-line are calculated and reported. The results of simulation are shown in Fig.6.



Load	Total P		Generation	Pmax-P	P-Pmin
Area 1	5246.4		Area 51	293.6	656.8
Area 2	5948.7		Area 52	0	0
Area 3	3872.5		Area 53	455	1408
Area 4	5911.2		Area 54	0	845
Area 5	3196.5		Area 55	375	522
Area 6	4279.7		Area 56	39.64	341.94
Area 7	1993.9		Area 57	249.4	121.2
Area 8	3628.8		Area 58	19.3	1484.21
Area 9	6235.1		Area 59	56	1007
Area 10	5428.7		Area 60	1075	2395
Area 11	3071.7		Area 61	463.01	1288.92

Fig. 6 Area transfer results

(2) Simulating a Power Transfer in POM Advanced Mode

A power transfer is simulated in Advanced mode according to the following scenario:
- generation is increased in the source system (area 60 > 70% and area 61 > 30%)
- load is increased in the sink system (area 1).

Branch contingency 1020-5010 "2" is applied during transfer simulation. Power transfer is simulated with the transfer step of 25MW.

The results of simulation are shown in Fig.7

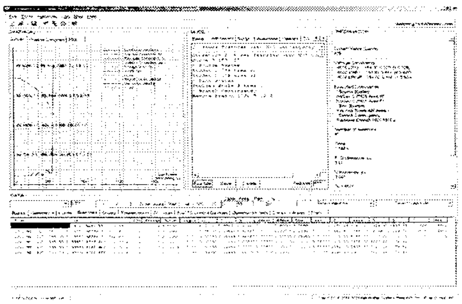


Fig.7 Simulating a Power Transfer

(3) Simulating a Power Transfer in POM Advanced Mode with OPM Enabled

Fig.8 shows that 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 from 400 MW to 1,000 MW. 250% is increased.

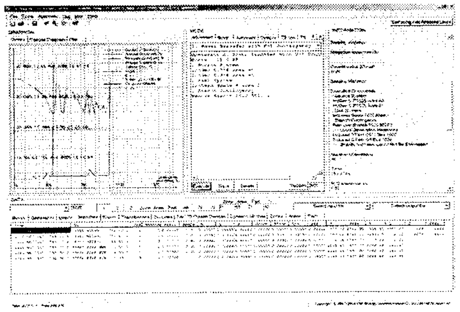


Fig.8 Simulating a Power Transfer with OPM Enabled

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. Status of computations and computation results are shown on the INFORMATION and are written to text and database files. Summary reports are automatically created.

(1) 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. Lines and two transformers 69 and above and all in-service generators from the entire network were selected for N-1 contingency analysis.

(2) 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.

(3) Performing Massive Contingency Analysis with OPM Enabled in POM Automatic Mode

The same massive contingency analysis was performed with OPM enabled. Parameters of OPM were selected as shown in Fig.5. 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 a projection onto different planes, such as:

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

BOR also computes two types of indices for each run:
- An index corresponding to the area of each projection (S)
- An index corresponding to the volume of the entire operating region (V)

If two transfers are simultaneously modeled, graphical results are available in 2form. 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. Each point within and on the boundary corresponds to such operating conditions (i.e., such combinations of transfers) that no constraints are being violated. The boundary is a multi-colored graph. Each color on a boundary corresponds to violation of one of the following constraints and limits that occur beyond the operating region:
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.

Graphical results are available from BOR interface and can be saved as a *.bmp file and Excel graph. Computation results, including type, location and amount of violation are written to an Excel file. BOR can also determine power transfer scenarios to achieve the maximum transfer capability. It also determines power transfer scenarios to achieve the minimum cost.

(1)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 source system (areas 55, 57 and 60) and increasing load in the sink system (area 2). Participating factors are 45% for area 55, 25% for area 57 and 30% for area 60.

Transfer 2:

increasing generation in the source system (area 60) and increasing load in the sink system (area 3).
Transfer 3:
increasing generation in the source system (area 51 and area 60) and increasing load in the sink system (area 4). Participating factors are 25% for area 51 and 75% for area 60.

It is noted that any user-specified power transfer scenarios may be simulated in BOR that include increasing/decreasing generation or load. BOR interface with results in 2-dimensional form is shown in Fig.9.

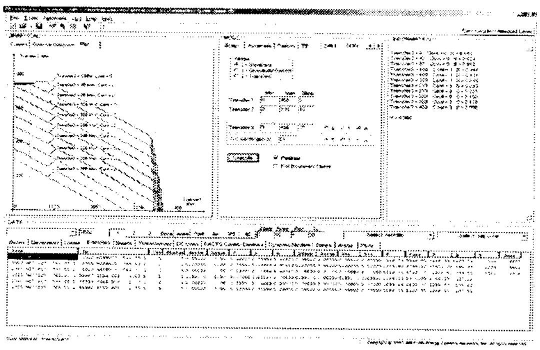


Fig.9 BOR Interface with Results for Three Simultaneous Power Transfers

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

1. A particular contingency was tested using POM. The maximum loadability for this contingency was increased by the remedial actions optimally selected by OPM.
2. Maximum transfer capability was determined using POM. Maximum transfer capability was then increased using OPM.
3. Massive contingency analysis was performed and critical contingencies were identified using POM. Then, OPM was used to mitigate post-contingency violations.
4. Three simultaneous power transfers were simulated using BOR. Transfer results are represented in 2-dimensional and 3-dimensional forms.
5. Load-load nomograms were constructed using BOR.

5. Acknowledgement

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