Identification of Wheeling Paths and MW- Redispatching for Transmission Loading Relief by Extended Sensitivity Analysis

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Abstract: - This paper proposes the practical method for MW- redispatching and identifying wheeling paths taking transmission line constraint into account based on an extended sensitivity analysis. Because the decision for the MW- dispatch/ scheduling is requested to be very fast, the method proposed here brings the efficiency of computations by utilizing the existing practical approaches for obtaining the optimal solution. So, in this paper, a method of MW- redispatching by using the practical sensitivity-based technique, which is used for identifying the wheeling paths in overloaded states is proposed. By the proposed method, the MW-redispatching problem without using OPF solutions can be solved. On the other hand, in deregulated electricity markets, appropriate and efficient levying of the wheeling rate is one of the critical issues. It is obvious that if wheeling paths from suppliers to customers could be identified appropriately, it becomes possible to set up the proper and fair wheeling rate according to the degree of power flow in each wheeling path. Until now, we have reported that it is possible to identify paths of the wheeling in any situation effectively by making use of the sensitivities calculated by an extended sensitivity analysis. In the previous research based on the sensitivity analysis, constrains on transmission lines have not been taken into consideration. Then, in this paper, the method of identifying wheeling paths is presented taking transmission line constrains into account based on an extended sensitivity analysis. In order to show the validity of the proposed method, a series of simulations on the IEEE 30-bus test system are conducted and numerical results are demonstrated.

Key-Words: - Wheeling path, Sensitivity analysis, Wheeling rate, Congestion management, Deregulation, Electricity market

1 Introduction

Liberalization of electricity markets has been progressed all over the world [1-9]. In Japan, all high-voltage customers, who make up 63% of the total load, have already been deregulated and the full liberalization will be discussed in 2013. Also, 18 power producers and suppliers (PPS) have participated into the electricity markets by 2006. Under such circumstances, it is indispensable to set up fair and transparent wheeling rates for market participants in deregulated electricity markets.

In April 2005, according to the political requirement to accelerate power transaction in wider areas, Electric Power Industry Law was revised and the postage stamp method for wheeling was adopted. So, the pancake problem was solved and the wheeling charge was set to be constant regardless of transaction traversing different areas. However, power system in Japan is spread over lengthwise from north to south and the capacity of tie lines is small. Therefore, wheeling between distant places may deteriorate the power system operation e.g.

transmission congestion and system instability. As the current wheeling rate was set to be constant, the wheeling charge does not contribute to restrain these deterioration problems. Moreover, in the current levying scheme, a part of the wheeling charge on PPS, e.g. the transmission loss charge of wheeling and the connection charge for transfer is put a strain on customers. That is, the charge on non-eligible customers increases. At present, because the charge to be paid by those customers is not large, it does not come to a big issue. However, it is necessary in the near future to improve the wheeling levying scheme from the viewpoint of fairness and transparency of the wheeling charge.

So, if wheeling paths from suppliers to customers could be identified appropriately, it becomes possible to set up the proper and fair wheeling rate according to the degree of power flow in each wheeling path. Moreover, such a wheeling rate also can send valuable economic signals to new independent power producers and players in the market. Until now, we have reported that it is possible to identify paths of the wheeling in any situation effectively by making use of the sensitivities calculated by an extended sensitivity analysis [10]. In the identification method, wheeling paths among the suppliers (or generators) and the customers can be any combination, such as single-to-single, plurality-to-single and plurality-to-plurality. In the previous research, constrains on transmission lines have not been taken into consideration. However, in reality, it is necessary to incorporate these constrains in the congestion management, such as capacity and operational limits on power flow in transmission lines. Then, in this paper, the method of identifying wheeling paths is introduced taking transmission line constrains into account. It means to identify wheeling paths after redispatching generations to fulfill constraints in transmission lines.

On the other hand, the generation redispatching in the overloaded power system is also an important task for network operators [11,12]. The dispatcher can deal with the control setting to eliminate under/over-voltages or reduce line overloads. The optimal MW- dispatch/scheduling in deregulated electricity markets should be generally conducted every thirty minutes or even five minutes for large-scale power systems. Because the decision for the MW- dispatch/ scheduling is requested to be very fast, the method proposed here brings the efficiency of computations by utilizing the existing practical approaches for obtaining the optimal solution. So, in this paper, a method of MW- redispatching by using the practical sensitivity-based technique, which is used for identifying the wheeling paths in overloaded states is proposed. Previously, MW-redispatching problem is solved mainly by the OPF solutions that are very time consuming [13-18]. However, by the proposed method here, obtained data, which are calculated for identifying the wheeling paths, can be diverted for MW-redispatching too. Therefore, we can solve the MW-redispatching problem without using OPF solutions. Moreover, by using the obtained data for the power flow, we can reuse the data, which are calculated for identifying the wheeling paths.

The paper is organized as follows. In the next section, first, we explain how to obtain the sensitivity matrix taking generator and load characteristics of a system into consideration. Next, the explanation of the generation distribution factor is described. Then, how to obtain the sensitivity matrix by introducing the concept of the generation distribution factor is presented. Finally, a computational method of MW- redispatching and identifying wheeling paths after MW- redispatching is shown. In section 3, in order to show the validity of the proposed method, a series of simulations on the IEEE 30-bus test system are conducted and numerical results are demonstrated. Section 4 concludes the paper.

2 Sensitivity in Power System Operation

In order to obtain the sensitivity matrix to be used for MW- redispatching and identifying wheeling paths after the MW- redispatching, it is necessary to introduce the concept of the generation distribution factor [19-22] into sensitivity derivation.

For calculating the sensitivity including the generation distribution factor, first, we explain how to obtain the sensitivity matrix taking generator and load characteristics of a system into consideration.

2.1 Extended sensitivity analysis

In the extended sensitivity analysis, generator characteristics (generation capacity, speed regulation, and dispatching strategies) and load characteristics (voltage, frequency elasticity and constant power features) can be taken into account by expanding the sensitivity matrix in the process of Jacobian derivations. Inclusion of system characteristics requires the expansion of the power flow equation. Let the power flow of the general N-node T-branch power system be described by the simple vector equation.

$$\boldsymbol{G}(\boldsymbol{X},\boldsymbol{U},\phi(\boldsymbol{X}),\beta(\boldsymbol{U}))=0 \tag{1}$$

where $\boldsymbol{X}$ is dependent variable vector (2N dimensional vector). Here, vector $\boldsymbol{X}$ comprises unknown variables in a usual power flow calculation; $\boldsymbol{U}$ is a controllable variable vector (M dimensional vector) Here, M is the number of the operating (manipulated) variables in system analysis and control; $\phi(\boldsymbol{X})$ is a 2N-dimensional vector function of $\boldsymbol{X}$; $\beta(\boldsymbol{U})$ is a 2N-dimensional vector function of $\boldsymbol{U}$. By the introduction of the functions $\phi(\boldsymbol{X})$ and $\beta(\boldsymbol{U})$, defined anew, various kinds of system characteristics in the power system can be modeled.

If the dependent variable vector $\boldsymbol{X}$ changes from $\boldsymbol{X_0}$ to $\boldsymbol{X_0}+\Delta\boldsymbol{X}$ in accordance with the change of controllable vector by $\Delta\boldsymbol{U}$, then

$$\frac{\partial \boldsymbol{G}}{\partial \boldsymbol{X}}\Delta\boldsymbol{X}+\frac{\partial \boldsymbol{G}}{\partial \boldsymbol{U}}\Delta\boldsymbol{U}+\frac{\partial \boldsymbol{G}}{\partial \phi}\cdot\frac{\partial \phi}{\partial \boldsymbol{X}}\Delta\boldsymbol{X}+\frac{\partial \boldsymbol{G}}{\partial \beta}\cdot\frac{\partial \beta}{\partial \boldsymbol{U}}\Delta\boldsymbol{U}=0 \tag{2}$$

Therefore, the sensitivity matrix of the power system expressed by (1) is given by:

$$\boldsymbol{S_m}=\frac{\partial \boldsymbol{X}}{\partial \boldsymbol{U}}=-(\frac{\partial \boldsymbol{G}}{\partial \boldsymbol{X}}+\frac{\partial \boldsymbol{G}}{\partial \phi}\cdot\frac{\partial \phi}{\partial \boldsymbol{X}})^{-1}\cdot(\frac{\partial \boldsymbol{G}}{\partial \boldsymbol{U}}+\frac{\partial \boldsymbol{G}}{\partial \beta}\cdot\frac{\partial \beta}{\partial \boldsymbol{U}}) \tag{3}$$

$\frac{\partial \boldsymbol{G}}{\partial \phi}\cdot\frac{\partial \phi}{\partial \boldsymbol{X}}$ and $\frac{\partial \boldsymbol{G}}{\partial \beta}\cdot\frac{\partial \beta}{\partial \boldsymbol{U}}$ are expansion terms caused by introducing the functions $\phi(\boldsymbol{X})$ and $\beta(U)$ into the power flow (1). It is obvious from (3) that if the first derivatives of functions ϕ and β with respect to $\boldsymbol{X}$ and $\boldsymbol{U}$ exist, these expansion terms can be computed easily.

(3) is the fundamental equation for determining various basic data to be used in system operation. Each basic data is obtained in a systematic way from the expanded sensitivity matrix by simply changing the expansion terms representing the system characteristics.

2.2 Generation distribution factor

Next, we describe generation distribution factor, which plays an important role in MW- redispatching and identifying wheeling paths after the MW-redispatching.

Generation distribution factors represent the effect of a one-per-unit change in the output of a generator on line power flows. This factor is also a useful measure for generation shifting in preventive and emergency control. Rescheduling or generation shifting is executed as a means for correcting a potentially dangerous state into a securer operating state. In generation shifting, the power balance between generator outputs must be maintained. Policy of maintaining power balance in the system is incorporated using redistribution coefficients.

Redistribution coefficient is explained as follows. When the real power output of the m-th generator is increased by ΔP_m , the static deviation in system frequency Δf is

$$\Delta f=\frac{\Delta P_m}{K_L+\sum\limits_{\substack{i\\ i\neq m}}\left(\frac{P_{R_i}}{R_i\cdot f_0}\right)} \tag{4}$$

where Δf is the static deviation in system frequency caused by the change of the real power in system; K_L is the load characteristic coefficient; P_{R_i} is the rated capacity of the i-th generator; R_i is the speed regulation of the i-th generator; f_0 is the rated frequency.

Against the frequency deviation after governor response, real generations of l-th generator will change by governor response as follows,

$$\Delta P_{lm}=-\left(\frac{P_{R_l}}{R_l\cdot f_0}\right)\Delta f \tag{5}$$

where ΔP_{lm} is the change in the l-th real generation caused by the change in the m-th real generation.

From (4) and (5)

$$\begin{aligned}\Delta P_{lm}&=-\left(\frac{P_{R_l}}{R_l\cdot f_0}\right)\left(K_L+\sum_{\substack{i\\ i\neq m}}^{L}\frac{P_{R_i}}{R_i\cdot f_0}\right)\Delta P_m\\&=-K_{kl}\times\Delta P_l\end{aligned} \tag{6}$$

K_{kl} is referred to as the redistribution coefficient showing the change in m-th real generation of the m-th generator. By making use of this coefficient, it is possible to express the situation that the initial power allocation is transferred to a new state according to system characteristics due to imbalance of power caused by change in generation outputs.

When generation distribution factor is computed by using the redistribution coefficient explained above, the constraint on power balance is described by:

$$\Delta P_m=\sum_{\substack{i\\ i\neq m}}\Delta P_{im} \tag{7}$$

When the generation shifting has been conducted keeping power balance in the system, the deviation Δf becomes zero, in other words, the effect of load characteristics disappears. It can be shown that (8) and (9) should hold in order for the relation (7) to be satisfied.

$$\Delta P_{lm} = -\frac{P_{R_l} \cdot \Delta P_m}{R_l \cdot f_0 \cdot \sum\limits_{\substack{i \\ i \neq m}} \frac{P_{R_i}}{R_i \cdot f_0}} = -K_{lm} \cdot \Delta P_m \tag{8}$$

where

$$K_{mm} = -1 \tag{9}$$

K_{lm} in (8) is referred to as the redistribution coefficient for computing the generation distribution factors. When generation shifting is determined by (8), the imbalance of real power is redistributed in accordance with each generator characteristic, e.g., capacity, speed regulation, etc. In (8), if the speed regulation of each generator is the same, the imbalance is redistributed proportionally to each generator capacity. Furthermore by assigning 1 to a particular K_{lm}, the l-th generator is intended as the slack generator.

2.3 Sensitivity matrix including the generation shift distribution factor

When the generation distribution factor is computed, minor modifications of power system equations are necessary by introducing coefficient K_{lm}. In the generation shifting, the control variable is ΔP_m, the change in m-th node output. Power flow equations for each node can be modified as follows;

(i) Power flow equations for m-th node

$$\begin{aligned} G_{2m-1} &= C_m - (P_m + \Delta P_m) \\ &+ E_m \sum_{\alpha} E_\alpha \{G_{m\alpha} cos(\theta_m - \theta_\alpha) + B_{m\alpha} sin(\theta_m - \theta_\alpha)\} \end{aligned} \tag{10}$$

$$\begin{aligned} G_{2m} &= D_m + Q_{mset} \\ &+ E_m \sum_{\alpha} E_\alpha \{G_{m\alpha} sin(\theta_m - \theta_\alpha) - B_{m\alpha} cos(\theta_m - \theta_\alpha)\} \end{aligned} \tag{11}$$

(ii) Power flow equations for l-th node

$$\begin{aligned} G_{2l-1} &= C_l - (P_{lset} - K_{lm} \cdot \Delta P_m) \\ &+ E_l \sum_{\alpha} E_\alpha \{G_{l\alpha} cos(\theta_l - \theta_\alpha) + B_{l\alpha} sin(\theta_l - \theta_\alpha)\} \end{aligned} \tag{12}$$

$$\begin{aligned} G_{2l} &= D_l - Q_{lset} \\ &+ E_l \sum_{\alpha} E_\alpha \{G_{l\alpha} sin(\theta_l - \theta_\alpha) - B_{l\alpha} cos(\theta_l - \theta_\alpha)\} \end{aligned} \tag{13}$$

(iii) Power flow equations for other nodes

$$\begin{aligned} G_{2k-1} &= C_k - P_k \\ &+ E_k \sum_{\alpha} E_\alpha \{G_{k\alpha} cos(\theta_k - \theta_\alpha) + B_{k\alpha} sin(\theta_k - \theta_\alpha)\} \end{aligned} \tag{14}$$

$$\begin{aligned} G_{2k} &= D_k - Q_k \\ &+ E_k \sum_{\alpha} E_\alpha \{G_{k\alpha} sin(\theta_k - \theta_\alpha) - B_{k\alpha} cos(\theta_k - \theta_\alpha)\} \end{aligned} \tag{15}$$

where P_{set}, Q_{set} are specified real and reactive power generations.

Jacobian matrix $\boldsymbol{G_X}$ is the same form as the matrix for power system equations without modifications. On the other hand, the controllable variable in this case is ΔP_m, and the elements of the Jacobian matrix $\boldsymbol{G_U}$ with the modification terms are derived as follows:

(i) When $n = m$ (m-th node),

$$\frac{\partial g_{2m-1}}{\partial \boldsymbol{U}} = \frac{\partial g_{2m-1}}{\partial P_m} = -1 \tag{16}$$

$$\frac{\partial g_{2m}}{\partial \boldsymbol{U}} = \frac{\partial g_{2m}}{\partial P_m} = 0 \tag{17}$$

(ii) When $n = l$ (l-th node),

$$\frac{\partial g_{2l-1}}{\partial \boldsymbol{U}} = \frac{\partial g_{2l-1}}{\partial P_m} = K_{lm} \tag{18}$$

$$\frac{\partial g_{2l}}{\partial \boldsymbol{U}} = \frac{\partial g_{2l}}{\partial P_m} = 0 \tag{19}$$

(iii) When $n \neq m,l$ (other nodes)

$$\frac{\partial g_{2k-1}}{\partial \boldsymbol{U}} = \frac{\partial g_{2k-1}}{\partial P_m} = 0 \tag{20}$$

$$\frac{\partial g_{2k}}{\partial \boldsymbol{U}} = \frac{\partial g_{2k}}{\partial P_m} = 0 \tag{21}$$

Here, $\beta(\boldsymbol{U})$ of (1) corresponds to $-K_{lm} \cdot \Delta P_m$ of (12) and $\frac{\partial G}{\partial \boldsymbol{\beta}} \cdot \frac{\partial \boldsymbol{\beta}}{\partial U}$ of (3) corresponds to K_{lm} of (18).

Also, correspondence of m-th node and l-th node in MW- redispatching and identifying wheeling paths after MW- redispatching is shown as follows:

(i) MW- redispatching

m-th node: Generator node which performs the wheeling before MW- redispatching

l-th node: Generator node targeted for MW- redispatching

(ii) Identifying wheeling paths after MW- redispatching
m -th node: Demand node which performs the wheeling
l -th node: Generator node which performs the wheeling after MW- redispatching
In order to carry out the MW- redispatching and identification of wheeling paths after MW- redispatching, it is necessary to obtain the sensitivity constants with regard to line power flows.
Sensitivity constants for line power flows are described by:

$$\begin{aligned}\boldsymbol{S_F} &= \frac{\Delta \boldsymbol{F}(\boldsymbol{X_0},\boldsymbol{U_0})}{\Delta \boldsymbol{U}} \\ &= \boldsymbol{F_X}(\boldsymbol{X_0},\boldsymbol{U_0}) \cdot \frac{\partial \boldsymbol{X}}{\partial \boldsymbol{U}} + \boldsymbol{F}_U \cdot (\boldsymbol{X_0},\boldsymbol{U_0})\end{aligned} \tag{22}$$

where $\boldsymbol{F}$ is an T-dimensional column vector function with $\boldsymbol{f_l}$ as its component. And it is written as follows:

$$\boldsymbol{F} \equiv col(f_1, f_2, \cdots .f_l, \cdots, f_T) \tag{23}$$

$\boldsymbol{S_F}$ is the sensitivity matrix representing the change in power flow due to a change $\Delta \boldsymbol{U}$ in the regulating devices. Let $\boldsymbol{F}$ be the line power flow from node k to node m. Then,

$$\boldsymbol{F}(\boldsymbol{X},\boldsymbol{U}) \equiv \boldsymbol{F}(E_k, E_m, \theta_k, \theta_m, \boldsymbol{U}) \tag{24}$$

Partial derivatives, $\boldsymbol{F_X}$ and $\boldsymbol{F_U}$ can be obtained easily by simple calculations. $(\partial \boldsymbol{X} / \partial \boldsymbol{U})$, i.e., $\partial E_k / \partial \boldsymbol{U}$, $\partial E_m / \partial \boldsymbol{U}$, $\partial \theta_k / \partial \boldsymbol{U}$ and $\partial \theta_m / \partial \boldsymbol{U}$ are the sensitivities of E_k, E_m, θ_k and θ_m to the unit amount of change in a regulating device, which is already known as the elements of the sensitivity matrix $\boldsymbol{S}$. Thus the sensitivity constants for line power flows can be calculated from (22).
Thus, the generation distribution factor is obtained from (3) and (22) while use is made of (16) through (21) in computing the Jacobian matrix $\boldsymbol{G_U}$.

2.4 Computational method of MW- redispatching and identification of wheeling paths after MW- redispatching

By use of those equations derived so far, the MW- redispatching and identification of wheeling paths after MW- redispatching will be carried out according to the following procedure.

[Step1]Calculate power flows and check the power flow profile when wheeling is carried out.

[Step2]Check the existence of line flow congestion. When line flow congestion has not occurred, it moves to a procedure [Step3]. When line flow confusion has occurred, it moves to a procedure [Step4].

[Step3]The redistribution coefficient of the generator, which is performed wheeling, is set as 1. Then, it moves to the procedure [Step7].

[Step4]According to section 2.3, at generator nodes, the generation shift distribution factor of each generator is determined.

[Step5]According to the amount of the generation distribution shift factor of each generator calculated in the procedure [Step4], redispatched generators and the amount of generation changes are obtained. To put it concretely, the amount of generation changes is determined so as to eliminate overloaded power flows by dividing the overloaded flows by generation shift distribution factor of each generator.

[Step6]Redistribution coefficient is normalized as values from 1 to 0 based on the amount of generation change calculated in the procedure [Step5]. When each generator's output is 80[MW] and 20[MW] after MW- redispatching, each redistribution coefficients are set as 0.8 and 0.2 respectively according to the output ratio of these generators.

[Step7]According to section 2.3 regarding node classification, the sensitivity is calculated with regard to line power flows by using (3) and (22).

[Step8]According to the coefficient of the sensitivity with respect to line power flow, wheeling paths are identified

Though, above procedure is only for the case of wheeling from single generator to single customer, even for the case of wheeling from plural generators, it is able to determine the redispatching by the same procedure because of the superposition principle can be utilized among each wheeling [23,24].
The flow of computation for MW- redispatching and identification of wheeling paths are shown in Fig.1.

3 Advantages of Proposed Method and Application to a Test System

In this chapter, first, in order to show the validity of the proposed method, comparisons of computational

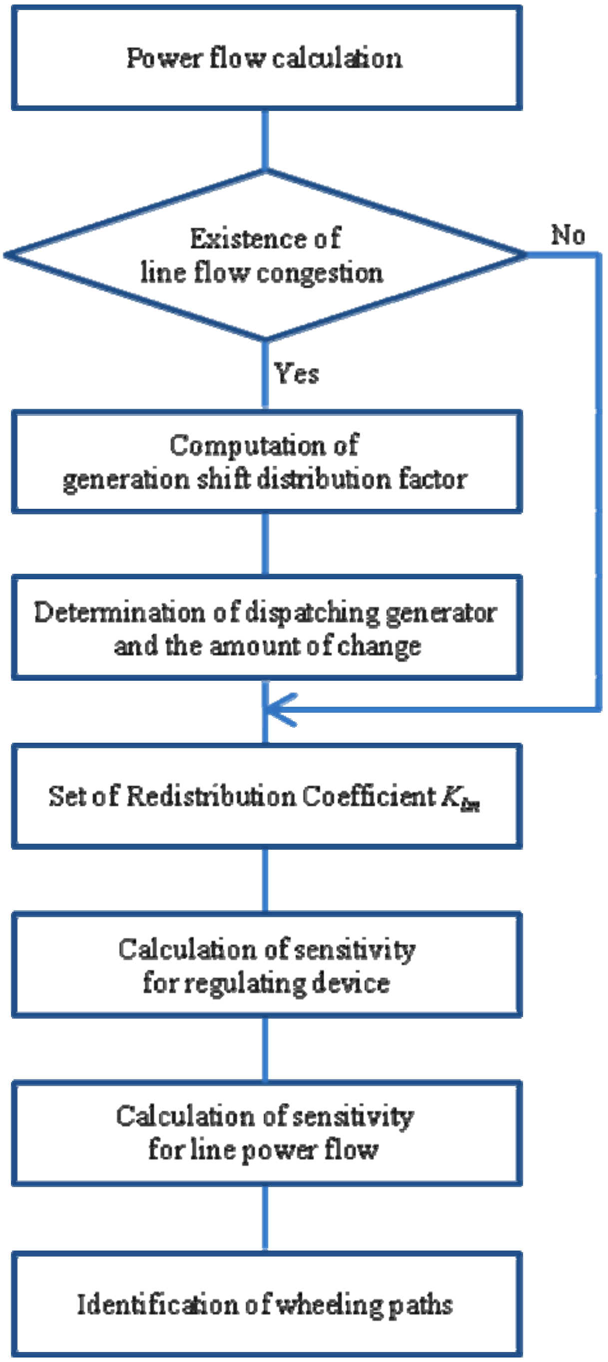

Fig.1 Computational Flow for MW- redispatching and identification of wheeling paths

methods between MW- redispatching and identifying wheeling paths after the MW- redispatching are described. Moreover, by comparing the matrix between the proposed method and conventional power flow calculations, we can verify that proposed method is a very fast and practical computation method. Because, the proposed method can use the calculated value of power flow calculations and does not need any OPF calculations for the MW- redispatching. Then, the MW- redispatching by using the newly proposed sensitivity-based technique and identifying wheeling paths after the MW- redispatching presented in this paper has been applied to a test power system (IEEE 30-node standard system) as is shown in Fig.2.

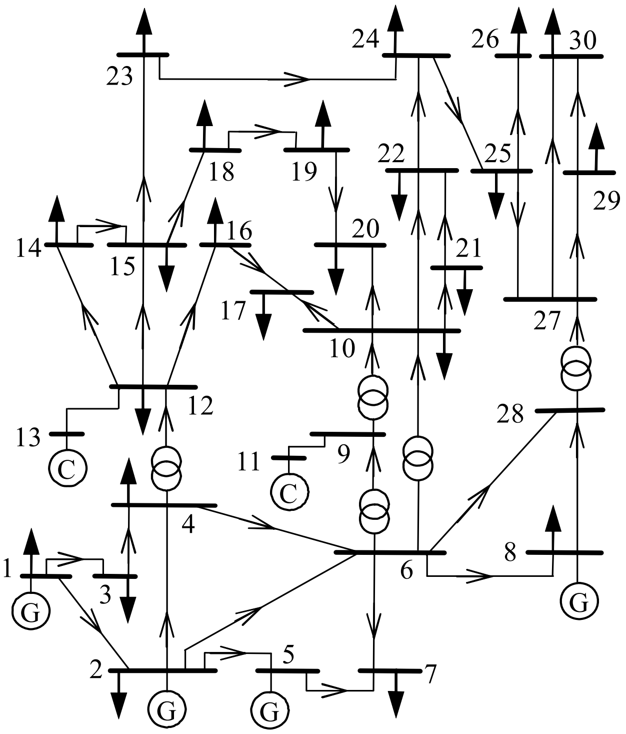

Fig.2 IEEE 30 node test system

Table 1 Correspondence of Branches and Nodes

branch	node	branch	node	branch	node
1	1-2	15	4-12	29	21-22
2	1-3	16	12-13	30	15-23
3	2-4	17	12-14	31	22-24
4	3-4	18	12-15	32	23-24
5	2-5	19	12-16	33	24-25
6	2-6	20	14-15	34	25-26
7	4-6	21	16-17	35	25-27
8	5-7	22	15-18	36	28-27
9	6-7	23	18-19	37	27-29
10	6-8	24	19-20	38	27-30
11	6-9	25	10-20	39	29-30
12	6-10	26	10-17	40	8-28
13	9-11	27	10-21	41	6-28
14	9-10	28	10-22		

3.1 Advantage of proposed method

First, by comparisons of the computational method of MW- redispatching and the method of identifying wheeling paths after the MW- redispatching proposed in this paper, it is shown that classification of nodes is different, but there is a characteristic common to both methods in calculating the sensitivity by using (3) and (22). So, the proposed method enables us to determine MW- redispatching and identifying wheeling paths after the MW- redispatching only by changing the set of each node. It is very useful for computational efficiency compared with OPF calculation.

Next, the relevance between the proposed method and power flow calculation is discussed. When power flow is calculated by the Newton-Raphson method, the updating equation is given by:

$$\begin{bmatrix} \boldsymbol{E} \\ \boldsymbol{\theta} \end{bmatrix}_{(n+1)} = \begin{bmatrix} \boldsymbol{E} \\ \boldsymbol{\theta} \end{bmatrix}_{(n)} - \begin{bmatrix} \dfrac{\partial \boldsymbol{P}}{\partial \boldsymbol{E}} & \dfrac{\partial \boldsymbol{P}}{\partial \boldsymbol{\theta}} \\ \dfrac{\partial \boldsymbol{Q}}{\partial \boldsymbol{E}} & \dfrac{\partial \boldsymbol{Q}}{\partial \boldsymbol{\theta}} \end{bmatrix}_{(n)}^{-1} \begin{bmatrix} \boldsymbol{\Delta P} \\ \boldsymbol{\Delta Q} \end{bmatrix}_{(n)} \quad (25)$$

Here, considering the Jacobian matrix in (25) indicate the partial differential of the power flow equation by $\boldsymbol{E}$ and θ, it is the same as Jacobian matrix $\boldsymbol{G}_x$, which calculate the sensitivity. Therefore, $\boldsymbol{G}_x$-element of P-Q assignment node can use the calculated value obtained by power flow calculation. Also, because of $\boldsymbol{G}_x$-element of other nodes are constant, $\boldsymbol{G}_x$ is calculated easily by modifying the power flow calculation codes.

Among a series of procedure described in chapter 2.4 (that is, power flow calculation, MW- redispatching and identifying wheeling paths after the MW- redispatching), there are many common characteristics. This is the remarkable advantage of the proposed method from the viewpoint of overall computational efficiency.

3.2 Application to a test system

In this application, in order to bring out a variety of wheeling paths among suppliers and customers, rotary condensers at Node 5 and 8 in the original test system are replaced by generators. The direction of arrows in the figure shows that of power flows at a base load condition.

In this case, we assumed 55.0MW wheeling between Node 1 to 24. Also, transmission line constrain between Node 4 to 12 was assumed to be 70.0MW. In this condition, when all wheeling is performed between Node 1 to 24, line power flow between Node 4 to 12 become 71.04MW, so this wheeling can't perform. So, MW- redispatching is performed to generator of Nodes 2,5 or 8.

The generation shift distribution factor between Node 4 to 12 and the amount of change required to release the transmission congestion and are shown in Table 2. From Table 2, by performing the MW- redispatching to Node 8 generator, transmission congestion can be solved most efficiently. Then we decided to perform the MW- redispatching to Node 8 generator and identifying wheeling paths after the MW- redispatching.

Table 2 shows that the amount of MW- redispatching is 28.8MW. Based on the amount of MW- redispatching, the obtained redistribution coefficient, sensitivity factors for power flows have been shown in Table 3, and also results of identifying the wheeling path for this case have been illustrated in Fig.3. The sign of sensitivities in Table 3 takes positive when the power flow increases by increase of a specific generator output, and correspondence of branch numbers in Table 3 and node numbers in Fig's 2 and 3 are shown in Table 1. The MW- redispatching is carried out to generator 8 to release the transmission congestion between Node 4 to 12, and we can identify that wheeling is carried out through Nodes 8-28-27-25-24.

Table 2 Generation shift distribution factor and the amount of MW- redispatching

Generator	Generation shift distribution factor	The amount of MW- redispatching [MW]
2	0.0054	192.6
5	0.0189	52.3
8	0.0361	28.8

Table 3 Sensitivities of power flows by wheeling among nodes 1,8-24

branch	sensitivity	branch	sensitivity
1	0.4157	22	-0.0068
2	0.2567	23	-0.0065
3	0.1621	24	-0.0074
4	0.2441	25	0.0077
5	0.0801	26	-0.0547
6	0.1685	27	0.3539
7	0.0317	28	0.2318
8	0.0769	29	0.3427
9	-0.0764	30	0.2959
10	-0.3954	31	0.5671
11	0.3490	32	0.2826
12	0.1905	33	-0.2128
13	0.0002	34	0.0002
14	0.3488	35	-0.2278
15	0.3622	36	0.2404
16	0.0001	37	0.0006
17	0.0647	38	0.0007
18	0.2410	39	0.0002
19	0.0561	40	0.1224
20	0.0622	41	0.1214
21	0.0551		

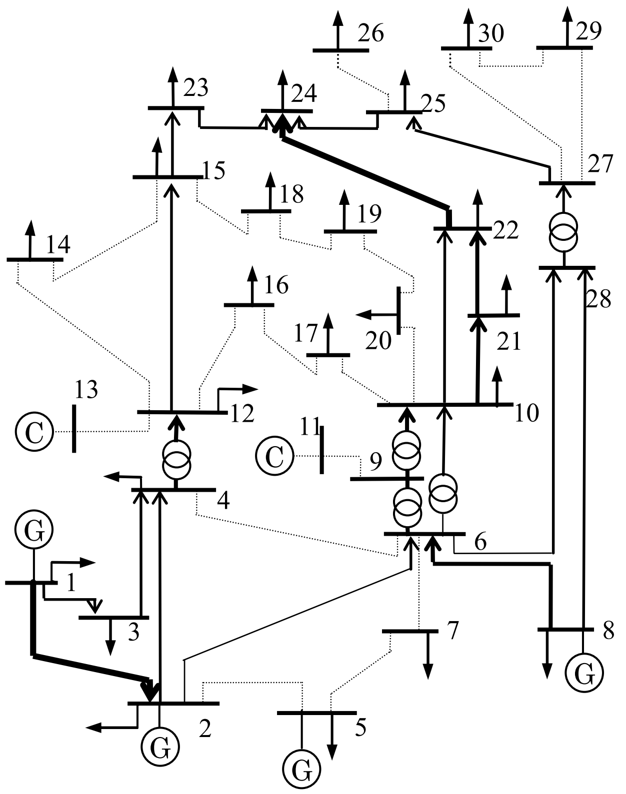

Fig.3 Paths of wheeling among nodes 1,8-24

4 Conclusions

In this paper, we propose the method of identifying wheeling paths after the MW- redispatching to release the transmission congestion. Also, we propose the method of MW- redispatching by using the new sensitivity-based technique in overloaded states.

By comparing the simulated results of MW-redispatching, identifying wheeling paths after the MW- redispatching with those of the conventional power flow calculation, the proposed method is proved to be very fast and effective, because the method can determine the MW- redispatching without calculating the OPF and these computations can use the calculated values of the previous power flow calculation.

Then, in order to show the validity of the proposed method, a series of simulations on the IEEE 30-bus test system have been conducted and numerical results are demonstrated. As the results of applications, by using the sensitivity with regard to line powers flow obtained by the extended sensitivity analysis, obtained sensitivities show which redispatching of generator outputs has the largest effectiveness to release the transmission line congestion. Furthermore, the use of the coefficient of sensitivity allows the redispatching of the amount of generations to release the transmission congestion and the identification of wheeling paths after redispatching. Also, by utilizing the identified wheeling paths obtained based on the proposed method, fair and transparent pricing for each wheeling according to the degree of responsibility of power flows would be decided.

Further directions of this study will be to develop the wheeling charge levying based on the identified wheeling paths and decision procedure of redispatching generator not only based on generation shift distribution factor but also based on the generation cost (that is the redispatching cost or the bid price about changing of generation output).

References:

[1] S. Krajcar, A. Curkovic and D. Skrlec, Liberalization of Croatian electricity market and restructuring of Croatian power utility, *WSEAS Trans. on Systems*, Issue 1,Vol.2, 2003, pp. 17-23.

[2] T. J. Hammons, Status of international interconnections and electricity deregulation in Africa, *39th International Universities Power Engineering Conference*, 6-8 Sept. 2004, Vol.1, pp. 26-33.

[3] Y. Ni, J. Zhong and H. Liu, Deregulation of power systems in Asia: special consideration in developing countries, *IEEE Power Engineering Society General Meeting*, 12-16 June 2005, Vol.3, pp. 2876-2881.

[4] T. Ariu and H. Goto, Assessment of electric retail competition and customer choice of power suppliers in the UK, Germany and France, CRIEPI Research Report, Y06009, 2007.

[5] M. Yazima et al., Overall evaluation of the electricity liberalization system in Japan: Prospect and issues learning from the experiences in the US and Europe, CRIEPI Research Report, Y05, 2007.

[6] S. I. Palamarchuk, M. A. Lamoureux and N. I. Voropai, Status of Russian power sector liberalization, *Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies*, 6-9 April 2008, pp. 82-88.

[7] M. Goto and M. Maruyama, Recent trend of electricity liberalization in the EU: Current status of regulatory reform and trade under BETTA in UK, CRIEPI Research Report, Y07014, 2008.

[8] F. H. Erdogan, S. Cetinkaya and E. Dusmez Tek, Market liberalization process and market arrangements in Turkey, *5th International*

Conference on the European Electricity Market, 28-30 May 2008, pp. 1-6.

[9] J. Torriti, A review of the European Commission's impact assessment for the third legislative package on energy markets liberalisation, *5th International Conference on the European Electricity Market*, 28-30 May 2008, pp. 1-10.

[10] H. Hamada, M. Marmiroli and R. Yokoyama, Identification of wheeling paths by an extended sensitivity analysis, *WSEAS Trans. on Power Systems*, Issue 2,Vol.3, 2008, pp. 28-36.

[11] I. Androcec and I. Wangensteen, Different methods for congestion management and risk management, *The 9th International Conference on Probabilistic Methods Applied to Power Systems*, 11-15 June 2006, pp. 1-6.

[12] T. S. Chung, D. Z. Fang and X. Y. Kong, Power market congestion management incorporating demand elasticity effects, *WSEAS Trans. on Power Systems*, Issue 7,Vol.1, 2006, pp. 1378-1382.

[13] D. I. Sun, B. Ashley, B. Brewer, A. Hughes, and W. F. Tinney, Optimal power flow by Newton approach, *IEEE Trans. Power Apparat. Syst.*, Vol. PAS-103, 1984, pp. 2864-2880.

[14] G. P. Harrison and A. R. Wallace, Optimal power flow evaluation of distribution network capacity for the connection of distributed generation, *IEE Proc. Generation, Transmission and Distribution*, Issue 1,Vol.152, 2005, pp. 115-122.

[15] W. Chengmin and J. Chuanwen, A new arithmetic of optimal power flow problem aiming at inequality constraints, *WSEAS Trans. on Circuits and Systems*, Issue 8,Vol.4, 2005, pp. 985-991.

[16] K. Liu, W. Sheng and Y. Li, Research on parallel algorithm of DC optimal power flow in large interconnection power grids, *International Conference on Electrical Machines and Systems*, 27-29 Sept. 2005, Vol.2, pp. 1031-1036.

[17] H. Wang, C. E. Murillo-Sánchez, R. D. Zimmerman and R. J. Thomas, On computational issues of market-based optimal power flow, *IEEE Trans. Power Syst.,* Vol.22, 2007, pp. 1185-1193.

[18] E. E. Costa, L. D. B. Terra and G. L. Jamil, Applying mathematical programming elements to answer market needs, *WSEAS Trans. on Computer Research*, Issue 1,Vol.3, 2008, pp. 74-80.

[19] J. W. Bialek, Topological generation and load distribution factors for supplement charge allocation in transmission open access, *IEEE Trans. Power Syst.*, Vol.12, 1997, pp. 1185-1193.

[20] B. M. Weedy and B. J. Cory, *Electric power systems*, Wiley, 1998.

[21] R. Baldick, Variation of distribution factors with loading, *IEEE Trans. Power Syst.*, Vol.18, 2003, pp. 1316-1323.

[22] T. Ogawa, S. Kadota and S. Iwamoto, Transmission line loss allocation using power flow tracing with distribution factors, *IEEE PES General Meeting*, 24-28 June 2007, pp. 1-7.

[23] R. Yokoyama, S. Narita, and Y. Tamura, *Security monitoring and control in power system operation*, Waseda University, 1973.

[24] E. Shimoda, T. Ohtaka and S. Iwamoto, Power flow tracing using power flow equations, *2004 National Convention IEE Jpn.*, Vol.6, 2004, pp. 95-96.

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