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Minimization of Interrupted Power Using Coordinated Control of Multiple Unified Power Flow Controllers, Generators and Load Shedding

Ken-ichi Kawabe, and Akihiko Yokoyama, *Member, IEEE*

***Abstract*--Our study aims at minimization of power not supplied (PNS) under the severe fault condition such as a tripping of transmission lines. In this paper, we propose a new static control method which can minimize PNS by coordinately controlling multiple unified power flow controllers (UPFCs), generators and loads. The proposed method is based on multiple optimal power flow (OPF) calculations, and determines not only control variables of UPFCs but also which and how much generators and loads should be shed after the fault. Digital simulations are carried out with the IEEE RTS-24 system. Two simulation cases, with and without UPFCs, are compared and the results shows that reduction of PNS can be accomplished by controlling UPFCs with the proposed method. Furthermore, it is made clear that the multiple OPFs, which consider the priority loads to be shed, are very effective on reduction of total PNS.**

***Index Terms*-- Coordinated Control, Emergency Control, FACTS, Power Not Supplied, Unified Power Flow Controllers.**

I. INTRODUCTION

POWER supply reliability standards are generally determined so that any power supply interruptions caused by single contingencies and a large-scale power supply interruption caused by multiple contingencies do not occur. However, large-scale cascading blackouts triggered by multiple contingencies such as tripping of double circuits of transmission lines happened around the world of late years. After these recent wide-area blackouts, it is needed for the future power system operation to work on not only preservation of N-1 security criterion but also the minimization of interrupted power caused by the severe fault.

When we try to improve the reliability of power supply, it is also important to consist with economic efficiency. From the economic point of view, it is not preferable to reinforce the power grid or install electrical equipment in the grid only for the severe faults which can lead to cascading blackouts because these faults rarely happen unlike single contingencies. One of the economical ways to improve the reliability for such infrequent severe faults is to develop a new control method which can make the best use of existing equipment in the emergency state. In addition to the current existing equipment such as generators, we can consider the flexible AC transmission system (FACTS) devices as the equipment available in the future grid.

The advanced FACTS technology enables us to control transmission power flow and to improve system stability for effective utilization of the power grid by controlling the system parameters. Nowadays UPFC [1] is one of the most advanced high-power FACTS devices to improve system stability and control power flow. One of the purposes of applying UPFC is available transfer capability (ATC) enhancement. At present, a phase shifter is the most cost-effective device to improve ATC constrained by thermal capacity limits of transmission lines. However, under the condition that ATC is limited by the transient stability constraints, UPFC can be the most cost-effective device compared with other devices. Thus, applications of UPFCs for improving ATC have been investigated [2].

It is a well-known idea among FACTS researchers that FACTS devices can also be used for resolving transmission line overloads due to a line outage. A fuzzy logic based approach is proposed to determine the FACTS setting for overload resolution in the N-1 steady state in [3]. Cascading blackout prevention with multiple UPFCs has been investigated in [4]. However most papers consider only particular fault cases that line overloads can be resolved completely with the installed FACTS devices. In reality, some fault cases lead to severe transmission line overloads which cannot be completely resolved even with the action of FACTS devices because power flow control capability of each device is limited by the ratings of their converters or transformers. In that case, we must shed generators and loads to resolve the line overloads and avoid cascading line outages. There is no control method that is applicable to such severe fault cases and it is still a research subject how to control FACTS devices, generators and loads coordinately for minimizing the interrupted power under the severe fault condition.

Therefore, we aim at minimization of Power Not Supplied (PNS) under the severe fault condition such as tripping of double circuits of transmission lines. This paper proposes a new control method that can make the best use of the available equipment in modern power system for minimization of PNS in the emergency state. At present, we consider multiple

Ken-ichi Kawabe is with the Department of Electrical Engineering, the University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan (e-mail: k-kawabe@syl.t.u-tokyo.ac.jp)

Akihiko Yokoyama is with the Department of Advanced Energy, the University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8568, Japan (e-mail: yokoyama@syl.t.u-tokyo.ac.jp)

UPFCs, generators and loads as the available equipment in the grid. The UPFCs are assumed to be installed for effective utilization of the grid in the normal state. The proposed method is based on multiple OPF calculations, and determines not only control variables of UPFCs but also which and how much generators and loads should be shed to minimize PNS after a fault. Digital simulations are carried out with the IEEE RTS-24 system and numerical results show the proposed method is effective for PNS minimizing.

II. Modeling of Unified Power Flow Controller

UPFC consists of two voltage-sourced converters (VSCs) which are coupled via a common dc link as shown in Fig. 1 (a). Two converters are connected to the grid through shunt and series transformers, respectively. Generally, single series, shunt connected VSC cannot generate active power when there is no other power source connected to them, because the exchanges of active power between the VSC and the ac system leads to voltage drop or rise of dc capacitor. Therefore the ac output voltage is limited at 90 degrees with respect to the ac current, leading or lagging. On the other hand, the series connected transformer of UPFC can inject angularly unconstrained voltage as shown in Fig.2, because two VSCs of UPFC can exchange active power through their common dc link and maintain its voltage by supplying or absorbing real power to or from the grid via shunt connected transformer. Hence, UPFC can control power flow flexibly by injecting voltage ($|V_U|$, Φ) and provide independently controllable shunt reactive compensation (Q_{inj}).

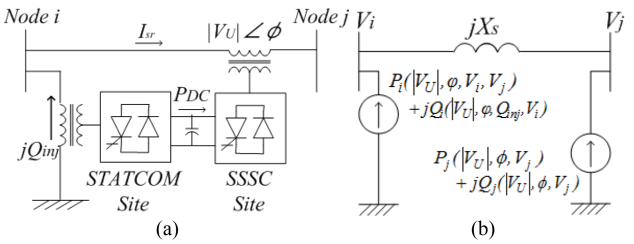

Fig. 1. Structure of UPFC (a) and its power injection model (b).

In this paper, as our study focuses on steady-state power flow control at present, the UPFC is modeled as a power injection model [5] for the OPF calculation as shown in Fig. 1(b). Each power source is a function of UPFC variables and voltages of buses where the UPFC is installed.

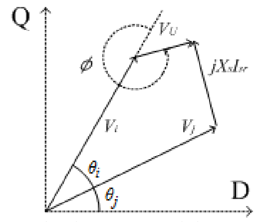

Fig. 2. Phasor diagram of voltages around the UPFC installation site.

III. Minimization of PNS Based on OPF Control

In this paper, we propose a new control method to minimize PNS through the coordinated-control of multiple UPFCs, generators and loads. The proposed control method is based on multiple OPF calculations. The general OPF problem can be formulated as:

$$\textit{Minimize} \quad f(\mathbf{x},\mathbf{u}) \tag{1}$$

$$\textit{Subjected to} \quad h(\mathbf{x},\mathbf{u}) = 0 \tag{2}$$

$$g(\boldsymbol{x},\boldsymbol{u}) \leqslant 0 \tag{3}$$

where **x** is the vector of state variables containing the magnitudes and angles of bus voltages, and **u** is the vector of control variables such as the outputs of generators, loads, and the control parameters of UPFCs.

Fig. 3 shows the flowchart which describes the proposed method. In this method, two post-disturbance intervals are defined and two different control schemes are proposed for each interval. The intervals aforementioned are defined as follows:

Interval 1 Time interval from the end of the transient stability region up to ten and several minutes, determined by a short-term rating of transmission lines, e.g. 15 minutes

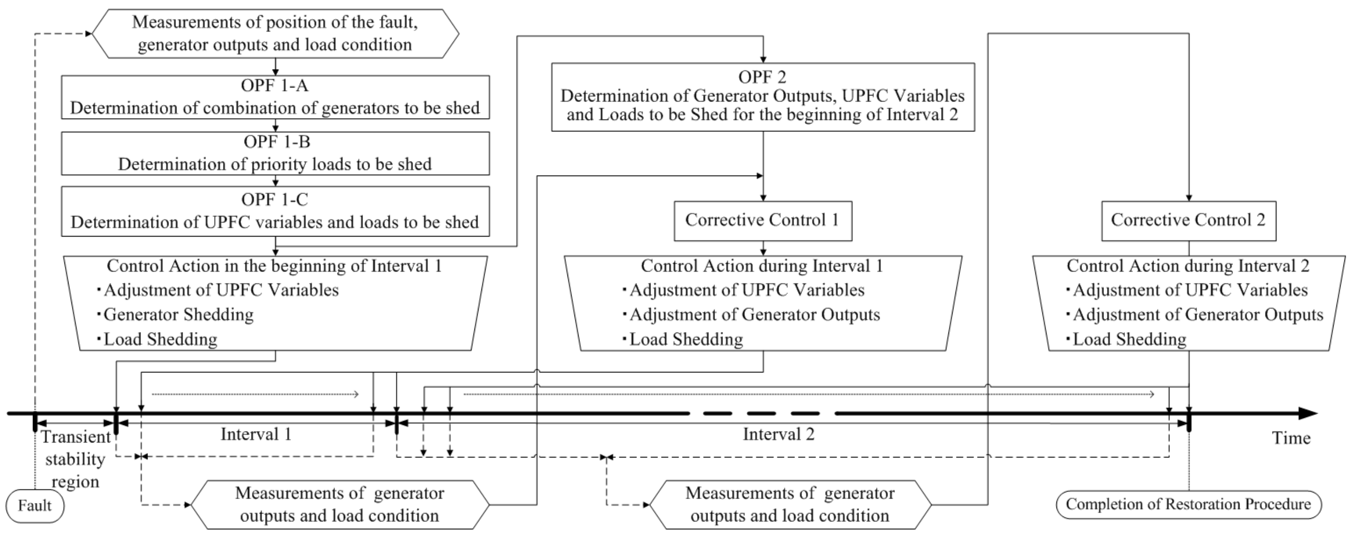

Fig. 3. Flowchart of minimization of PNS.

Interval 2 Time interval from the end of interval 1 up to the restoration, e.g. several hours, several days

The proposed control scheme handles these two intervals differently as shown in Fig. 3 due to the different system constraints associated with different intervals. The constraints corresponding to each interval are:

--At the beginning of Interval 1, the outputs of generators cannot be adjusted and generator units are shed to alleviate line overloads caused by a fault. Furthermore the short term rating, which is larger than normal rating, of transmission lines can be taken into consideration in order to avoid excessive generator shedding and supply power to loads as much as possible during Interval 1.

--At the beginning of Interval 2, the outputs of generators can be adjusted continuously. In addition, the transmission line thermal ratings need to be reset at their normal ratings.

When we deal with more kinds of the transmission line ratings, we can consider them by splitting Interval 2 into multi-intervals corresponding to the kinds of ratings.

A. Control at the beginning of Interval 1

In Interval 1, PNS is generated by shortage of power supply due to shedding of generators and incremental loss under the assumption that hot spinning reserve is not considered. Here, PNS is minimized by the proposed method with particular attention to the following three main points:

(1) Selection of optimum generators to be shed immediately after a fault: PNS is generated mainly by shedding of generators. The optimum generators to be shed are selected so that the amount of them is minimized in coordination of control of UPFCs. It is accomplished by OPF 1-A.

(2) Selection of optimum loads to be shed: Since locations of loads to be shed have influence on the load flow conditions, the optimum locations of loads to be shed should be selected. And we also consider the loads which should be shed with higher priority than the other loads in Interval 1 to minimize the total PNS after the fault. These are accomplished by OPF 1-B and OPF 1-C.

(3) Minimization of incremental transmission loss: In addition to the capacity of generators to be shed, incremental transmission loss due to the fault is also taken into account as PNS under the assumption that generator outputs cannot be adjusted for several minutes after the fault. Accordingly, we recalculate control variables of UPFCs after selecting the generators to be shed for minimizing incremental transmission loss. It is accomplished by OPF 1-C.

According to the points aforementioned, three OPF problems are solved by the beginning of Interval 1, i.e. OPF 1-A, OPF 1-B and OPF 1-C. OPF 1-A determines which generator should be shed to relieve line overloads triggered by a transmission line outage. In this OPF calculation, the selection of generators to be shed and control of multiple UPFCs are coordinated to minimize the total capacity of generator shedding. OPF 1-B determines a set of loads which could be shed with higher priority for minimization of the total PNS including PNS in Interval 2. Finally, OPF 1-C determines the UPFC variables and the optimal loads to be shed so that the transmission loss is minimized under the condition that the outputs of generators are fixed to the values determined by OPF 1-A. And the loads to be shed in OPF 1-C calculation are determined from the loads with higher priority identified by OPF 1-B calculation.

OPF1-A:

The main purpose of OPF 1-A is to determine the optimal generators to be shed in order to alleviate the line overloads. In this OPF, we have to deal with both continuous and discrete variables because generator outputs cannot be adjusted continuously right after the fault due to their low ramp rates, therefore they take zero output values or the current output values. Although this type of optimization problem is known as a mixed integer programming, we solve this problem by using nonlinear programming with the following objective function:

$$f(\boldsymbol{x},\boldsymbol{u}) = \sum_i^G \left(P_{g,initial,i} - P_{g,i}{}^2 / P_{g,initial,i} \right) \tag{4}$$

where G is the set of generators in the system, $P_{g,initial}$ and P_g are output of each generator before and after the fault respectively. With the objective function (4), we can consider the outputs of generators to be shed as close to the binary values mentioned before as possible. In this calculation, the output of the generator to be shed last is often determined to be in a value between zero and $P_{g,initial}$. We set the output to be zero when we use it in the following OPF calculations.

In Interval 1, transmission thermal limits are set at its short term rating as the constraints.

OPF 1-B:

In OPF 1-B, the load flow conditions are calculated by minimizing the following objective function:

$$f(\boldsymbol{x},\boldsymbol{u}) = \sum_i^M \left(P_{L,shed,i} \right) \tag{5}$$

where $P_{L,\,shed}$ is loads to be shed and M is the number of loads in the network.

Here, the loads need to be forecasted because this OPF is calculated right after the fault occurs. Generators which are determined to be shed in OPF 1-A calculation are fixed to zero and other generators are assumed to be adjustable continuously. Transmission thermal limits are set at its normal rating in Interval 2.

With this calculation, we can select the most effective loads to be shed in Interval 1 for minimizing PNS in Interval 2. The loads identified in OPF 1-B are considered as loads which should be shed with priority in OPF 1-C. By shedding such loads preferably in Interval 1, PNS can be minimized in Interval 2.

OPF 1-C:

In this OPF, control variables of UPFCs and loads to be shed are determined. Since the incremental loss also leads to PNS as well as the capacity of generators to be shed, UPFCs are controlled for loss minimization with the following objective function:

$$f(\boldsymbol{x},\boldsymbol{u}) = \sum_i^M \left(\alpha \bullet P_{L,shed\,1,i} + P_{L,shed\,2,i} \right) \tag{6}$$

TABLE I
PNS IN EACH CASE

Case	PNS in Interval 1 (p.u.) (Shed Generators, Incremental Loss)	PNS in Interval 2 (p.u.)	Total PNS (p.u.)
I	1.577 (1.50 at bus 22, 0.077)	0	1.577
II	0.562 (0.50 at bus 22, 0.062)	0	0.562

where $P_{L,\ shed\ 1}$, $P_{L,\ shed\ 2}$ are a part of to be shed with priority and the remaining part of a given load P_L, respectively. M is the number of loads in the network. In (6), $P_{L,\ shed\ 1}$ obtained in OPF 1-B are preferably shed depending on a weighting factor α (<<1). The outputs of generators are fixed to the values determined by OPF 1-A.

B. Control at the beginning of Interval 2

At the beginning of Interval 2, additional PNS is generated by decrease of transfer capability due to the change of transmission line thermal rating from the short-term rating to the normal rating. The additional PNS is calculated by solving OPF 2. OPF 2 determines the control variables of UPFCs, generators and loads for minimizing the total capacity of loads to be shed at the beginning of Interval 2 using the objective function (5). In Interval 2, the outputs of generators can be adjusted continuously. Thus the variables of generator outputs can take continuous values in this OPF 2.

In actual case as shown in Fig.3, a corrective control scheme is required to adjust the control variables from the values determined in OPF 1-A, OPF 1-B and OPF 1-C to the values determined in OPF 2. In the corrective control, we should correct the load forecasting error in OPF 1-B and OPF 2. Another corrective control method is required for load following in Interval 2.

In this paper, however we assume the interrupted power at the beginning of Intervals 1 and 2 to be the PNS in each interval.

IV. NUMERICAL EXAMPLES

The test system used for numerical simulation is the IEEE RTS-24 system [6]. We modify the test system by adding two buses, buses 25 and 26, with installation of UPFCs. Winter peak load pattern is used here. To realize a severe loading condition, the thermal constraints of transmission lines are set to be 60% of the original values.

Since one of the main purposes in this research is to verify the effect of UPFC's power flow control on reduction of PNS, the bus voltage constraints are alleviated by installing the variable susceptance B_{phase} as the voltage control equipment at all buses except buses where UPFCs are installed.

In the test system, two UPFCs are installed. The rating of series transformer voltage and the capacity of each converter of the UPFC, are set at 0.2 (p.u.) and 160 (MVA), respectively. The locations of the UPFCs are determined to ensure the effective utilization of the power grid. Therefore, we allocate them at places that reduce the generation cost. The initial values of the generator outputs were fixed at the values obtained from economic load dispatching (ELD) considering UPFCs as shown in APPENDIX.

A. Fault 1

The tripping of transmission line between buses 3 and 24 is assumed as "fault 1". In this condition, line between buses 14 and 16 exceeds its thermal limit due to the fault.

In order to verify effect of multiple UPFCs on reduction of PNS, the following two cases listed below are compared. The results of both cases are given in Table I.

Case I: Generators and loads are controlled by the proposed method, and UPFCs are bypassed after the fault.

Case II: Generators, loads and UPFCs are controlled by the proposed method.

As shown in Table I, it can be seen that in case I three generators are selected as the optimum generators to be shed in Interval 1 by the proposed method. Since no load is shed in Interval 2, the sum of the total capacity of shed generators and the incremental loss is interpreted as the total PNS in case I.

Fig. 4 describes the power flow conditions in Interval 1 in case I. In Fig.4, three generators at bus 22 are shed to alleviate the overload of line between buses 14 and 16 triggered by the fault.

On the other hand, in case II, the capacity of the generator shedding in Interval 1 is reduced from 1.50 (p.u.) to 0.50 (p.u.) as shown in Table I. As a result, the total PNS in case II

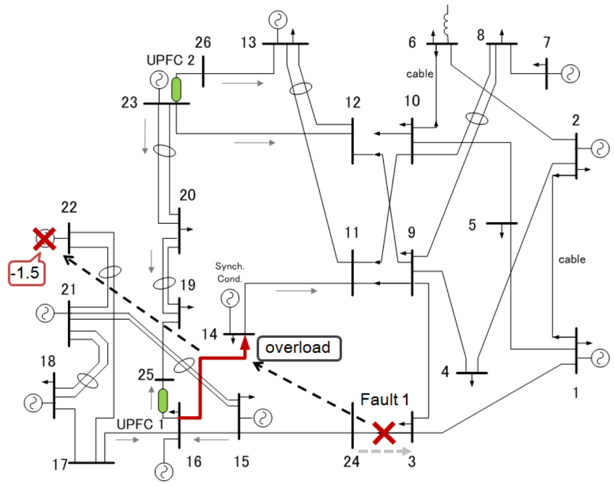

Fig. 4. Power flow condition right after the fault 1 in case I.

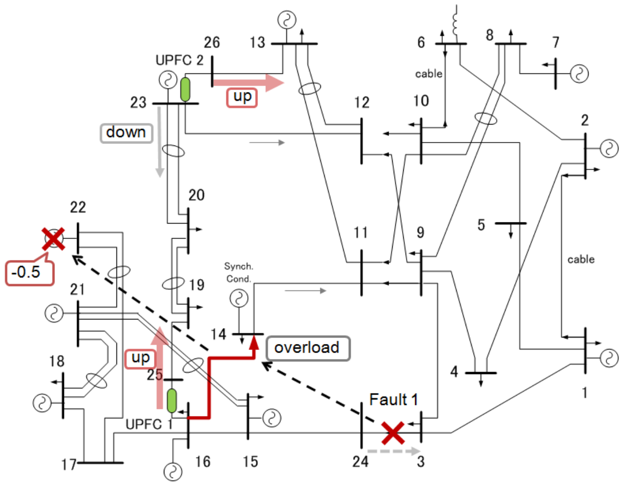

Fig. 5. Power flow condition right after the fault 1 in case II.

TABLE II
UPFC VARIABLES IN THE INTERVAL 1 IN CASE I

No	Node i	Node j	Qinj (p.u.)	Vu (p.u.)	Φ (p.u.)
1	23	13	0.726	0.200	1.607
2	16	19	-0.620	1.685	1.643

TABLE III
LOADS TO BE SHED AND MAGNITUDE OF THEM IN EACH CASE

Bus	Load (p.u.)	Load to be shed in Case I (p.u.)		Load to be shed in Case II (p.u.)	
		Interval 1	Interval 2	Interval 1	Interval 2
1	1.08	0	0	0	0
2	0.97	0	0	0	0
3	1.80	0.121	0	0.562	0
4	0.74	0	0	0	0
5	0.71	0	0	0	0
6	1.36	0.008	0	0	0
7	1.25	0	0	0	0
8	1.71	0	0	0	0
9	1.75	0	0	0	0
10	1.95	0	0	0	0
13	2.65	0	0	0	0
14	1.94	1.449	0	0	0
15	3.17	0	0	0	0
16	1.00	0	0	0	0
18	3.33	0	0	0	0
19	1.81	0	0	0	0
20	1.28	0	0	0	0

is smaller than that in case I. The power flow condition in Interval 1 in case II is given in Fig. 5, which shows that the overload at line between buses 14 and 16 is alleviated by increasing the power flow from bus 25 to bus 19 due to the action of the UPFC 1 and decreasing power from bus 23 to bus 20 due to the action of the UPFC 2.

We can see from Fig. 6 the active power flows at the main transmission lines around the UPFC installation sites in Interval 1 and those before the fault in more details.

This result demonstrates that the reduction of PNS can be accomplished by using multiple UPFCs with the proposed method. Table II shows the UPFC variables in OPF 1-C in case II. It can be seen that the series transformer of UPFC 1 near the overloaded line injects the voltage at its maximum rating to control the power flow. And Table III shows the positions and the amount of loads to be shed in each case.

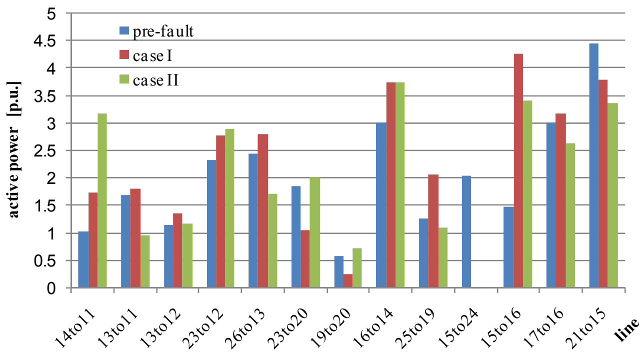

Fig. 6. Power flow condition right after the fault 1 in case II.

B. Fault 2

The tripping of transmission lines between buses 13-11 and 13-12 which are on the common right of way is assumed as

TABLE IV
PNS IN EACH CASE

Case	PNS in Interval 1 (p.u.) (Shed Generators, Incremental Loss)	PNS in Interval 2 (p.u.)	Total PNS (p.u.)
I	1.146 (1.032 at bus 13, 0.115)	0.132	1.279
II	1.069 (1.032 at bus 13, 0.037)	0.204	1.273

"fault 2". The comparison of PNS between cases I and II is also studied in Table IV just as in the case of fault 1. As shown in Table IV, the difference between cases I and II in fault 2 is not so large compared to that in fault 1 because the generator shedding at bus 13 cannot be avoided even with the action of UPFCs in Interval 1. These results mean that the effect of multiple UPFCs on reduction of PNS is accomplished mostly by reduction of the total capacity of generator shedding and it depends on locations of the UPFCs and the fault.

Moreover, Table IV indicates that the additional PNS in Interval 2 arises from the shortage of transmission capability from supply area at the left hand side of the system to demand area at the right hand caused by the change of the transmission line thermal ratings from the short term rating to the normal rating. As shown in Fig.7, the powers through the line between buses 23-12 and the line between buses 16-14 are limited by their thermal ratings in addition to the disconnection of lines between buses 13-11 and 13-12 due to the fault. In this power flow condition, UPFCs and loads should be controlled to maximize the power from bus 15 to bus 24, while generators are adjusted to supply as much power as possible to loads under the transmission line thermal ratings.

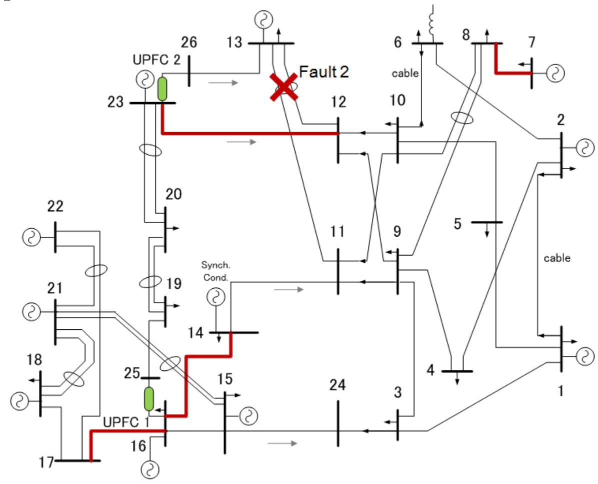

Fig. 7. Power flow condition in Interval 2 in case II.

This result shows that it is also important to consider the reduction of PNS in Interval 2. For this reason, in addition to OPF 2, OPF 1-B have been done to reduce PNS in Interval 2 by foreseeing the power flow conditions in Interval 2 and by identifying the loads which should be shed prior to the other loads in Interval 1. In order to clarify the effect of OPF 1-B on reduction of PNS in Interval 2, one more test case mentioned below is simulated under the fault 2.

Case III: Generators, loads and UPFCs are controlled by the proposed scheme without OPF 1-B.

TABLE V
PNS IN EACH CASE

Case	PNS in Interval 1 (p.u.) (Shed Generators, Incremental Loss)	PNS in Interval 2 (p.u.)	Total PNS (p.u.)
II	1.069 (1.032 at bus 13, 0.037)	0.204	1.273
III	1.016 (1.032 at bus 13, -0.015)	0.490	1.506

TABLE VI
LOADS TO BE SHED AND MAGNITUDE OF THEM IN EACH CASE

Bus	Load (p.u.)	Load to be shed in Case II (p.u.)		Load to be shed in Case III (p.u.)	
		Interval 1	Interval 2	Interval 1	Interval 2
4	0.74	0	0	0.025	0
6	1.36	0	0	0.686	0
8	1.71	0	0	0.305	0
14	1.94	1.069	0.204	0	0.490

Table V shows the comparison of PNS between cases II and III and it can be seen that the total PNS in case III is larger than that in case II due to the additional PNS in Interval 2. In case II, PNS in Interval 2 is reduced because the optimal positions of the loads to be shed, which are obtained from OPF 1-B, are considered in Interval 1.

Table VI shows the locations of the loads to be shed in each case. The major difference between cases II and III in Table VI is the locations of the loads to be shed in Interval 1. In case III, loads are shed in Interval 1 at buses 4, 6 and 8, which are different from the location of the load to be shed in the following interval. On the other hand, in case II, load at bus 14 is shed in Interval 1, which is the same load as that to be shed in the following interval 2.

In the proposed method, OPF 1-B clarifies that loads at bus 14 is the optimal load to be shed to maximize the power through line between buses 15 and 24 and minimize PNS in Interval 2. Thus we can consider the load which should be shed with the first priority in Interval 1. As a result, we can reduce the amount of PNS in Interval 2 by shedding the load at bus 14 preferably in Interval 1.

V. CONCLUSION

This paper aims at minimization of PNS under the severe fault condition such as tripping of double circuits of transmission lines. As one of the possible ways to prevent the infrequent cascading failure and alleviate the power interruption, we propose a use of existing equipment such as multiple UPFCs, generators and loads in the future grid from the economic point of view.

A new control scheme is presented that can make the best use of the above equipment in the emergency state for minimization of PNS after a fault. The proposed control scheme is based on multiple OPF calculations in two intervals following the fault with the different system constraints. It is worthwhile to note that the selection of generators to be shed and control of UPFCs are coordinated by using the particular objective function and optimum loads which should be shed with higher priority are considered by foreseeing the load flow conditions of the following interval in the proposed OPF calculations.

Simulations were carried out for two severe fault cases. The results from the comparison study, with and without UPFCs, show that UPFCs have the possibility of the reduction of PNS in case of an infrequent severe fault such as double-circuit line trip and that the effect on the reduction of PNS depends upon the locations of the UPFCs and the fault. And it has also been made clear that calculating the loads which have the higher possibility to be shed in the following Interval 2 and considering them in OPF in Interval 1 in advance is effective for reduction of the total PNS.

Since the proposed control scheme determines each control variable only at the beginning of Interval 1 and Interval 2, two corrective control schemes that can adjust each control variable continuously in the transition from the beginning of Interval 1 to the beginning of Interval 2 and in Interval 2 have to be studied. In the corrective control schemes, inaccuracies in load forecasting should be corrected. Besides, it is also indispensable to develop dynamical control scheme in the transient stability region that can improve the transient stability by using multiple UPFCs.

VI. APPENDIX

For the main simulation, we need to prepare the normal state of the system. They are obtained from ELD with UPFCs at buses 16 and 23. The results of ELD with and without UPFCs for the basis of comparison are shown in this section.

Table VII shows generating cost sought in the ELD with and without UPFCs. The cost decreases by the installation of UPFCs.

Table VIII shows the pattern of the generator outputs with and without UPFCs, locations, sizes and types of all generators. It can be seen from Table VIII that, compared with the case without UPFCs, a part of the generation from the expensive oil-fired plants at bus 13 is replaced by the cheaper coal-fired plants at buses 15 and 16 so as to reduce the system production cost in the case with UPFCs. Due to the action of UPFCs, It is accomplished by increasing the power flow from bus 25 to bus 19 and the power from bus 26 to 13 to maintain the power between buses 16 to 14 under its thermal rating as

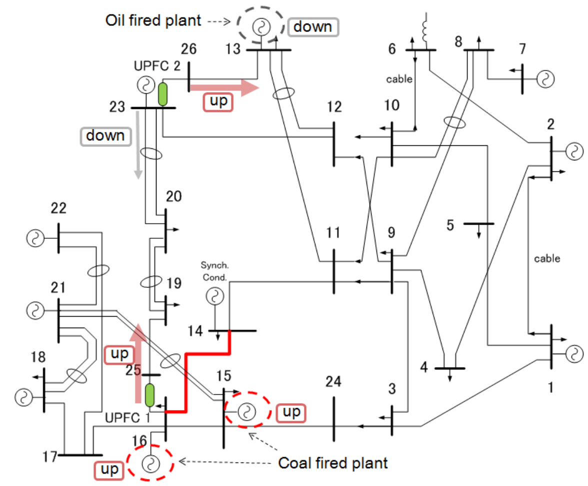

Fig. 8. Redispatching of generator outputs by installing UPFCs in ELD control.

TABLE VII

GENERATING COST

	with UPFCs ($/hr]	w/o UPFCs ($/hr)
Cost	572494	573330

TABLE VIII

OUTPUTS OF GENERATORS

No.	Bus	Pg (p.u.) with UPFCs	Pg (p.u.) w/o UPFCs	Size (p.u.)	Type
1	1	0	0	0.20	Oil
2	1	0	0	0.20	Oil
3	1	0.76	0.76	0.76	Coal
4	1	0.76	0.76	0.76	Coal
5	2	0	0	0.20	Oil
6	2	0	0	0.20	Oil
7	2	0.76	0.76	0.76	Coal
8	2	0.76	0.76	0.76	Coal
9	7	0.767	0.767	1.00	Oil
10	7	0.766	0.767	1.00	Oil
11	7	0.767	0.767	1.00	Oil
12	13	1.031	1.328	1.97	Oil
13	13	1.031	1.329	1.97	Oil
14	13	1.032	1.328	1.97	Oil
15	15	0	0	0.12	Oil
16	15	0	0	0.12	Oil
17	15	0	0	0.12	Oil
18	15	0	0	0.12	Oil
19	15	0	0	0.12	Oil
20	15	1.55	0.997	1.55	Coal
21	16	1.55	1.067	1.55	Coal
22	18	3.838	4	4.00	LWR
23	21	4	4	4.00	LWR
24	22	0.5	0.5	0.50	Hydro
25	22	0.5	0.5	0.50	Hydro
26	22	0.5	0.5	0.50	Hydro
27	22	0.5	0.5	0.50	Hydro
28	22	0.5	0.5	0.50	Hydro
29	22	0.5	0.5	0.50	Hydro
30	23	1.55	1.55	1.55	Coal
31	23	1.55	1.55	1.55	Coal
32	23	3.5	3.5	3.50	Coal

TABLE IX

UPFC VARIABLES IN THE NORMAL STATE

No.	Node i	Node j	Qinj (p.u.)	Vu (p.u.)	Φ (deg]
1	23	13	-0.844	0.135	1.308
2	16	19	-0.850	0.155	1.626

shown in Fig.8. The control variables of UPFCs in the normal state obtained from ELD with UPFCs are given in Table IX. In the main simulation, the power flow condition obtained from ELD with UPFCs is used as the normal state before the fault occurs.

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VIII. BIOGRAPHIES

Ken-ichi Kawabe was born in Tokyo, Japan, on June 1, 1984. He received the B.S. from Waseda University, Tokyo, Japan, in 2007. He has been engaged in research of power system engineering in the University of Tokyo. His research interests include preventive and corrective actions in the emergency state in power systems. He is a member of IEEJ.

Akihiko Yokoyama (M’78) was born in Osaka, Japan, on October 9, 1956. He received the B.S., M.S., and Dr. Eng. degrees from the University of Tokyo, Tokyo, Japan, in 1979, 1981, and 1984, respectively. He has been with Department of Electrical Engineering, University of Tokyo, since 1984 and currently is a Professor in charge of power system engineering. He is a member of IEEJ, IEEE, and CIGRE.