Journal of Marine Science and Technology

Volume 24 | Issue 5 Article 2

GENERATION CONTROL SCHEMES FOR PREVENTING OVERLOADING OF EHV SUBSTATION MAIN TRANSFORMER

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Acknowledgements

This work was supported in part from Research Grants Nos. 98A60207 and 100A60202.

Journal of Marine Science and Technology, Vol. 24, No.5, pp. 913-918 (2016)
DOI: 10.6119/JMST-013-0627-1

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Key words: power flow control, transformer overloading, direct transfer trip, generation reduction.

ABSTRACT

The main purpose of this paper is to study the control of power plant generation under outage of main transformer in the adjoining substation. The control of power plant generation aims to prevent overloading of the remaining transformer and hence to maintain system operation security. The proposed control methods include two schemes of operation on the generating units: Direct Transfer Trip (DTT) and Generation Reduction (GR). A sample local power system with an EHV substation and two generation plants is investigated and thus the two control schemes are illustrated by analyzing system power flow and system dynamics. It is found that, in view of preventing substation transformers from overloading, the DTT scheme results in a better system performance than the GR scheme does.

I. INTRODUCTION

The main function of transmission line is to deliver electric energy from generating plants to system load centers. Voltage of electric energy from generating plants will be raised through the transformer to the transmission voltage level and the electric energy is to be dispatched by the system control center. The electric energy from the transmission system will be processed by the substation transformer for voltage step-down to appropriate levels and then be consumed by system loads at different voltage levels. For the longitudinal power system under study, which can be divided geographically into northern, central, southern and eastern areas for the purpose of system analysis, all 345 kV extra-high voltage (EHV) lines constitute the trunk transmission network (Rogers, 2000). There is a deficit in generation for the northern area, and power flows from the central and southern areas with surplus in power supply injected into the northern area. In additional to generating plants of the vertically integrated utility company owned by the government, there are independent power producers (IPPs) supplying electric power to the transmission network with 345 kV and 161 kV. In the year of 2012, independent power producers provided 17.4% of the total electricity supplied by the utility.

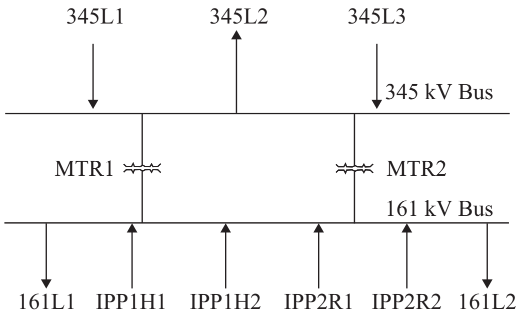

Fig. 1. Local power system under study.

The electric power generated from an IPP plant will first be delivered to an adjoining substation for further connection with the transmission system. The total capacity of the transformers in the substation will determine the permissible power output from the IPP plant to be transmitted to the transmission system. Once an event happens with one of the substation transformer, the total transformer capacity will be degraded and certain suitable control action should be taken to prevent system insecurity (Cheung et al., 2009; Walling, 2011). In this paper, we consider an EHV substation located in the central area of the study system with power lines directly from two nearby IPP plants as shown in Fig 1. The substation has two main transformers, denoted as MTR1 and MTR2, both with voltage ratio 345 kV/161 kV. The two power plants, IPP1 and IPP2, supply electric power, by way of the source lines IPP1H1, IPP1H2, IPP2R1, and IPP2R2, to the local 161 kV load through the 161 kV bus and lines 161L1 and 161L2 as well as to the 345 kV transmission system via the two main transformers and the 345 kV bus. In case of one of the main transformers being tripped, it is necessary to prevent the remaining transformer

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Table 1. Generator ratings.

Plant	Generator	Turbine	MW	MVAR
IPP1	G1	Gas	160	30
	G2	Gas	160	30
	G3	Steam	160	30
IPP2	G1	Gas	160	30
	G2	Gas	160	30
	G3	Steam	160	30

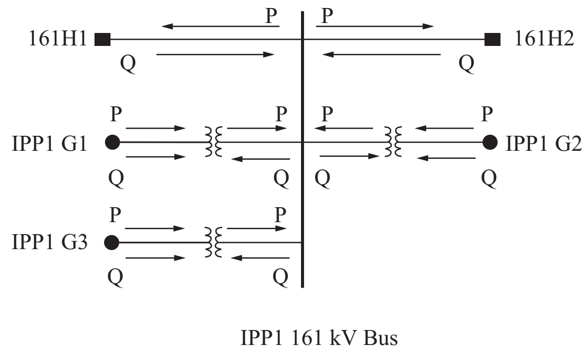

Fig. 2. IPP1 power flow.

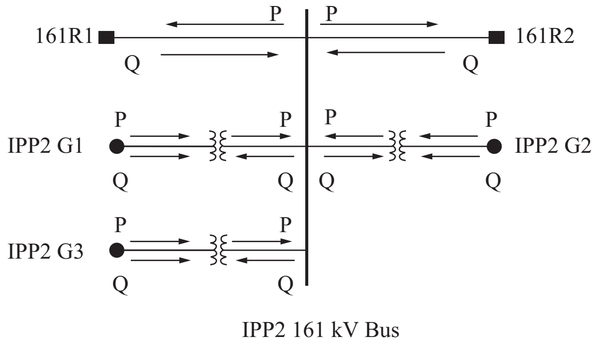

Fig 3. IPP2 power flow.

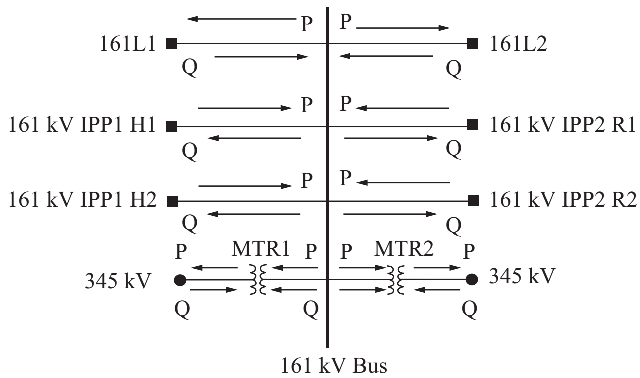

Fig. 4. Substation 161 kV power flow.

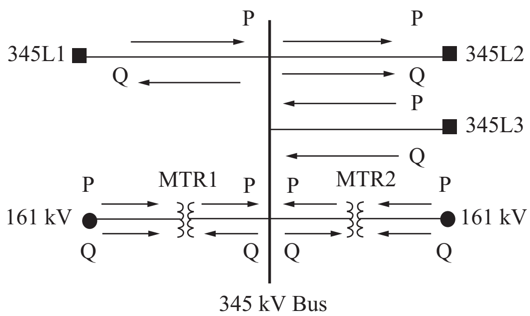

Fig. 5. Substation 345 kV power flow.

working overload because there are only two transformers in the substation. The IPP plants shall immediately take control action to adjust their output power generation to prevent the remaining transformer working overload as well as to maintain system stability.

The objective of this paper is to study the control of output power generation of the two IPP plants under the tripping of a main transformer in the EHV substation as described above (Chamia and Liberman, 1978; Paithankar, 1997; Sleva, 2009). The control of power plant generation aims to prevent overloading of the remaining transformer and hence to maintain system operation security (Grigsby, 2007). The proposed control schemes include the schemes of direct transfer trip (DTT) and generation reduction (GR). The local power system is to be investigated in details, and thus the two control schemes are illustrated and compared by analyzing system power flow and system dynamics, including voltage stability and dynamic responses under different control schemes.

II. STUDY SYSTEM OVERVIEW

There are two IPP plants in the local power system under study as shown in Fig. 1. Both IPP plants install combined-cycle units and each plant has three generators of which the two generators G1 and G2 are driven by gas turbines and generator G3 is driven by a steam turbine which utilizes the heat recovered from the gas turbines of G1 and G2. The real and reactive power ratings of all generators in the IPP plants are shown in Table 1. The electric power generated from the IPP plants is injected into the 161 kV bus of the adjoining EHV substation, with part of the electric power supplying the local load through lines 161L1 and 161L2 and part of the electric power delivered to the 345 kV transmission system for dispatch through MTR1 and MTR2.

The power flow diagrams for the two IPP plants, the 161 kV bus, and the 345 kV bus in the local power system under study are depicted in Figs. 2-5. Fig. 2 shows that through their own transformers, the three generators in plant IPP1 are first connected to the plant 161 kV bus (IPP1 161 kV Bus). The generated power of IPP1 plant is then delivered to the substation 161 kV bus by way of two lines, namely 161H1 and 161H2. Likewise, as shown in Fig. 3, the three generators in plant IPP2 are connected to the plant 161 kV bus (IPP2 161 kV bus) via their respective transformers and then to the substation through the two lines 161R1 and 161R2. Under normal operation, the

Table 2. 161 kV power flow.

Branch	P (MW)	Q (MAVR)
IPP1 H1	235.3	29.5
IPP1 H2	235.3	29.5
IPP2 R1	238.8	29.5
IPP2 R2	238.8	29.5
MTR1	302	12.3
MTR2	303	12.5
161L1	165.9	40.6
161L2	158.8	53.2

Table 3. 345 kV power flow.

Branch	P (MW)	Q (MVAR)
MTR1	302	16.2
MTR2	303	16.1
345L1	510	99.5
345L2	1165.3	58.2
345L3	69.1	189.3

real power and reactive power in the 161 kV and 345 kV networks are tabulated in Table 2 and Table 3, respectively.

As shown in Fig. 4, Fig. 5 and Table 2, IPP1 and IPP2 together inject around 950 MW into the 161 kV bus of the adjoining EHV substation both for power demand of local 161 kV loads through lines 161L1 and 161L2, and for system dispatch over 345 kV transmission system by way of transformers MTR1, MTR2, and then lines 345L1, 345L2 and 345L3. The voltage of the electric power to be delivered to the trunk transmission system must be stepped up from 161 kV to 345 kV using transformers. In the EHV substation there are two main transformers, MTR1 and MTR2, each with a capacity of 500MVA. If one of the main transformers, say MTR1, happens to be out of service, then from Table 2, the remaining MTR2 has to transfer a total amount power of 605 MW which exceeds the capacity of the transformer and will be very likely to cause a problem of system security. Therefore, the generation output from the two IPP plants has to be controlled for adjusting the power flow of MTR2 to prevent working overload.

III. PROPOSED SOLUTION METHODS

In case of any event occurrence causing MTR1 to become out-of-service, as mentioned in the previous section, the generation output from the two IPP plants should be readjusted to prevent MTR2 from overloading. Under this condition, power flows of the 161 kV network and the 345 kV network are shown in Fig. 6 and Fig.7, respectively. To account for the system security, it is mandatory that the real and reactive power flowing MTR2, which is the total generation from IPP1 and IPP2, flowing through lines IPP1H1, IPP1H2, IPP2R1, and IPP2R2, subtracted by the demand of local 161 kV loads, supplied via lines 161L1 and 161L2, be no more than the capacity of

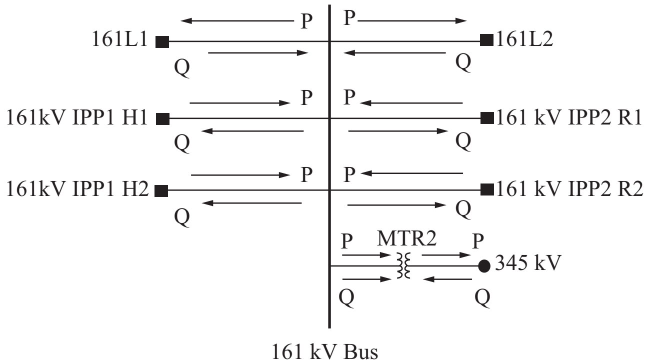

Fig. 6. 161 kV power flow under MTR1 out-of service.

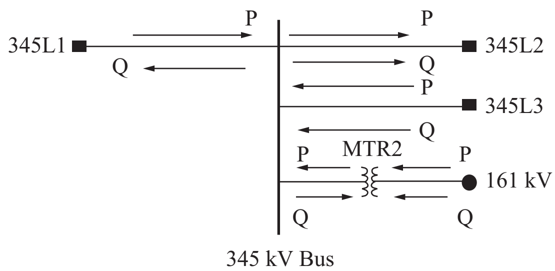

Fig. 7. 345 kV power flow under MTR1 out-of-service.

MTR2. The control action on the adjustment of generation output of the two IPP plants should follow such constraint. Note that the power demands of the local 161 kV loads are normally supposed to be maintained. The proposed control schemes on the generation output of the plants to maintain safety operation include: (1) Executing the tripping of specific plant generators by using the Direct Transfer Trip (DTT) scheme and (2) Performing the Generation Reduction (GR) of specific power plants.

1. Direct Transfer Trip Scheme (DTT)

The Direct Transfer Trip (DTT) scheme to trip certain generator is a feasible and fast method for modulating power generation under overloading conditions (Wright and Christopoulos, 1993; Kasztenny and Kezunovic, 1998; Behrendt et al., 2001). The DTT scheme is used to trip the generating unit in the IPP1 plant or that in the IPP2 plant in order to protect MTR2 from working overload. An advantage of DTT scheme lies in the fast transfer time which can be less than one cycle (16 ms for the 60 Hz system) with highly reliable responses. A DTT command will be sent separately in the substation 161 kV system to both IPP1 G1 and IPP2 G1 once an event of MTR1 tripping is detected. The interface between the substation 161 kV network and the substations in the IPP plants can be a fiber optic line, as shown in Fig. 8. The DTT scheme is a direct and efficient solution to achieve a high-speed communication link for sending the signal of detecting MTR1 tripping to the generation control system with a view to preventing MTR2 working overload. The interface between two terminals can also be

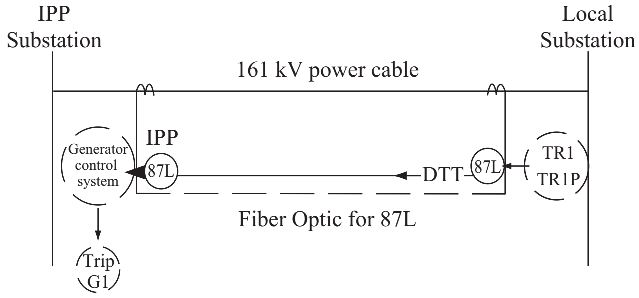

Fig. 8. DTT scheme for fiber optic interface.

multiplexing devices. Tripping signals can deliver to opposite terminal by multiplexers channels transfer. In case of events, DTT function is a popular way to trip specific circuit breakers to perform the function of safety protection.

2. Generation Reduction (GR) Scheme

If the MTR2 overload situation is not alleviated in time under MTR1 outage, the process of event cascading may start, leading to system security problems. For performing reduction of generation output for IPP plants, it must be allowed for performing the actual rate of change for the sake of reliability.

For the method of generation reduction (GR) under the above-mentioned initial power flow conditions with a safety limitation around 475 MW for the main transformer, a 50% generation reduction in the two IPP plants will be a suitable solution. Hence, the method of GR is a feasible scheme to prevent MTR2 working overload, but it should be considered that reducing the output power of a generating unit will take time to adjust the generation control system according to the characteristics of the generating unit and its associated apparatus.

IV. POWER FLOW ANALYSIS

1. Power Flow under Direct Transfer Trip (DTT) Scheme

In case of MTR1 outage, both the G1 unit of IPP1 plant and the G1 unit of IPP2 plant will be tripped out by using the DTT scheme to keep MTR2 in safe operation. Under such a generation control scheme, each gas turbine driven G2 unit in either IPP plants retains 50% power of the original output, and each G3 unit of the two IPP plants will thus get a 50% percent reduction in power output since one half of the recovered heat source from steam turbine has been dropped. Therefore, a total amount of 50% reduction in generation output from the two plants can be achieved. After the DTT scheme is initiated, the power flow of each IPP plant and the local 161 kV and 345 kV networks are recalculated and listed in Tables 4-7. It is found that the DTT scheme will yield a power flow condition which prevents MTR2 (with a loading duty of 155 MW) from operating overload and thus system operation security can be maintained.

2. Power Flow under Generation Reduction (GR) Scheme

Table 4. IPP1 power flow under DTT scheme.

Device	P (MW)	Q (MVAR)
G1	0	0
G2	160	22.4
G3	80	5.1
161H1	119.8	13.8
161H2	119.8	13.8

Table 5. IPP2 power flow under DTT scheme.

Device	P (MW)	Q (MVAR)
G1	0	0
G2	160	19.5
G3	80	4.8
161R1	120.5	12.1
161R2	120.5	12.1

Table 6. Substation 161 kV power flow under DTT scheme.

Branch	P (MW)	Q (MVAR)
MTR2	155.1	60.2
161L1	165.9	40.6
161L2	158.8	53.2
161H1	119.7	7.3
161H2	119.7	7.3
161R1	120.5	9.5
161R2	120.5	9.5

Table 7. Substation 345 kV power flow under DTT scheme.

Branch	P (MW)	Q (MVAR)
MTR2	155.1	60.2
345L1	584.2	117.5
345L2	832.5	62.2
345L3	93.3	239

The generation output of the two IPPs plants is to be adjusted by the GR control scheme under MTR1 outage. To reduce the power output of unit G1 in each of the two IPP plants is a proper solution to prevent MTR2 from working overload. By using the GR control scheme, there will be a 50% generation reduction on the unit G1 in each IPP plant and each unit G3 of the two IPPs plants will then get a 25% percent of reduction in power output since one fourth of the recovered heat source for steam turbine has been eliminated. Therefore, the GR scheme can result in a total amount of 25% reduction in generation output from the two plants. Following the GR scheme, the power flow of each IPP plant and the local 161 kV and 345 kV networks are recalculated and listed in Tables 8-11. It is found that the DR scheme will bring forth a power flow condition which is able to prevent MTR2 (with

Table 8. IPP1 power flow under GR scheme.

Device	P (MW)	Q (MVAR)
G1	79.9	5.7
G2	159.6	23.1
G3	119.8	12.0
161H1	179.6	20.4
161H2	179.6	20.4

Table 9. IPP2 Power Flow under GR Scheme.

Device	P (MW)	Q (MVAR)
G1	80	4.9
G2	160	20.1
G3	120	11.1
161R1	180.5	18.0
161R2	180.5	18.0

Table 10. Substation 161 kV power flow under GR scheme.

Branch	P (MW)	Q (MVAR)
MTR2	395.1	17
161L1	165.9	40.6
161L2	158.8	53.2
161H1	179.6	20.4
161H2	179.6	20.4
161R1	180.5	18
161R2	180.5	18

Table 11. Substation 345 kV power flow under GR scheme.

Branch	P (MW)	Q (MVAR)
MTR2	395.1	17
345L1	584.2	117.5
345L2	1070.5	62.2
345L3	93.3	196.2

395.1 MW power loading) from working overload and thus can assure system operation security.

V. VOLTAGE STABILITY ANALYSIS

Voltage stability concerns the ability of a power system to maintain steady voltages at all buses in the system under conditions with normal operation as well as some contingency (Grigsby, 2007). Voltage collapse is the process by which the sequence of events accompanying voltage instability leads to a low unacceptable voltage level. The relationships between the voltage at the receiving bus and the load power can be demonstrated by Fig. 9 which is referred to as the P-V curve (Kundur, 1994; Taylor, 1994; Van Cutsem and Vournas, 1998; Grigsby, 2007). The P-V curve shows the voltage collapse

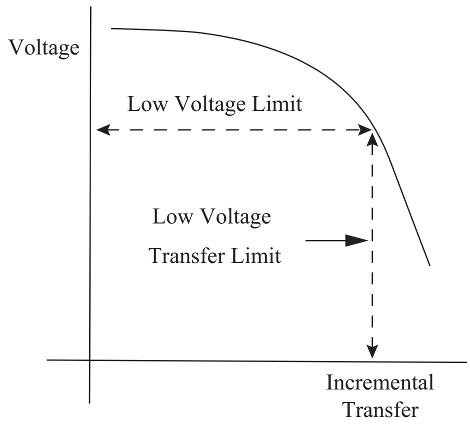

Fig. 9. Relationship of voltage and incremental power transfer.

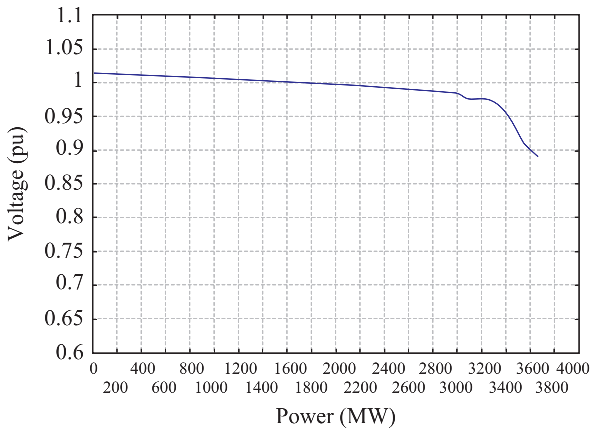

Fig. 10. P-V curve in normal condition.

point of the bus in the power system network and the maximum transfer of power between buses before the point of voltage collapse is reached. Voltage instability occurs at the knee points of the P-V curves where the voltage drops rapidly with an increase in the transfer power flow. The P-V curve is obtained through a series of power flow solutions. As power transfer increased, voltage decreased at some buses on the transfer path. Transfer can continue to increase until the solution identifies a condition of voltage collapse (Huang and Tseng, 2012).

The P-V curves under the normal condition, the DTT scheme and the GR scheme are to be figured out in order to verify the feasibility of the previously mentioned two control generation schemes.

In the normal condition with both MTR1 and MTR2 in operation, the P-V curve is shown in Fig. 10 in which the horizontal axis indicates the real power and the vertical axis denotes the voltage of the 345 kV bus, respectively. It is found that the maximum transfer power is around 3500 MW with the acceptable voltage level of about 0.9 pu beyond which the voltage will tend to collapse.

In case of the out-of-service event of MTR1, the PV curve of the 345 kV bus after the initiation of the DTT control scheme, which is to trip the G1 units of both IPP1 and IPP2, is

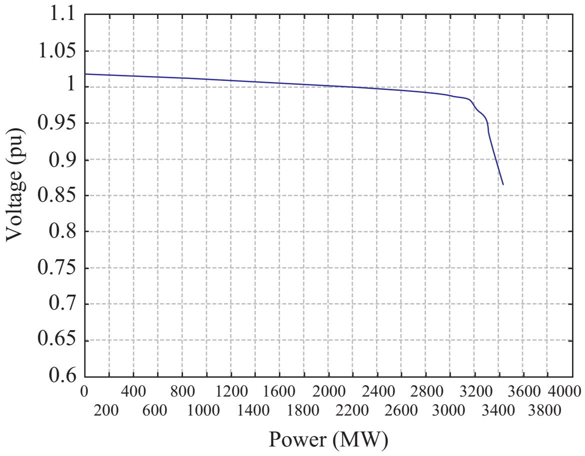

Fig. 11. P-V curve after DTT scheme.

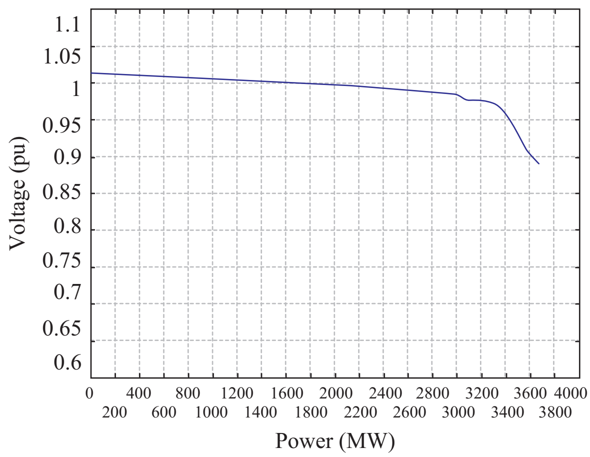

Fig. 12. P-V curve after GR scheme.

shown in Fig. 11. With the acceptable voltage level of about 0.9 pu, the maximum power transfer is around 3350 MW which is a little less than that in the normal operation with both MTR1 and MTR2 in service. The DTT scheme does not make harmful impacts on the system voltage stability.

On the other hand, the GR control scheme, which will result in 50% generation reduction on the G1 unit in each IPP plant and thus a 25% percent of reduction in power generation of the G3 unit of each IPP, has the effect of a total amount of 25% reduction in generation output from the two plants. The P-V curve of the 345 kV bus after application of the GR control scheme is depicted in Fig. 12 from which the maximum transfer power is around 3500 MW with the acceptable voltage level of about 0.9 pu. Therefore, the GR scheme is also a feasible control method with affecting the system voltage stability.

From the above P-V curves associated with the two control schemes, it is can be inferred that both the two control scheme are feasible with only minor effects on the system voltage stability, although the maximum power transfer is smaller under the execution of the DTT scheme.

VI. CONCLUSION

The objective of this paper is to investigate two generation control methods, the Direct Transfer Trip (DTT) scheme and the Generation Reduction (DR) scheme, to prevent the only in-service main transformer of an EHV substation in which initially two main transformers have been in normal operation, from overloading, in case that one of the main transformer happens to be out of service, for the purpose of maintaining the system operation security. The DTT scheme has the feature of possessing a high-speed communication link for tripping generating units while the GR scheme is capable of retaining higher power loading yet with more complicated operating procedure. From the results of power flow analysis and voltage stability analysis, it is found the implementation of both generation control schemes will result in sound operating conditions at which the only service main transformer will not be working overload, and at the same time will attain the goal of keeping the system in secure operation.

ACKNOWLEDGMENT

This work was supported in part from Research Grants Nos. 98A60207 and 100A60202.

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