A Novel Method to Reduce Current Magnitude During Parallel Operation Period of Electric Power Distribution Feeder

Shu-Chen Wang, Chi-Jui Wu, and Hsin-Chun Tsai

***Abstract*—**A novel approach to reduce the current magnitude during feeder load transferring is presented in this paper. No matter in planning, designing, or system dispatching, it is desired to give un-interrupted electric power to customers. However, when the loading of a distribution system power feeder is too high or the feeder needs to be maintained, the feeder load should be transferred to other feeder. The un-interrupted type means that the electric power supplied to customers will not be interrupted during feeder load transferring. However, there are several factors to affect the feeder current magnitude during load transferring, such as transformer impedances, primary side power level, and original loading of the feeder. If the current is too high, the feeder protection system will trip the feeder breakers to shut down the power supply system. A novel approach is presented to reduce the feeder current magnitude during load transferring. The phasor measurement units (PMU) will be used to obtain the synchronous voltage magnitude and phase angle of the transformers, of which feeders are transferred. A power conditioner is installed in the secondary side of the transformer. Then the phase angle values from the PMUs will be sent to the power conditioner and the suitable phase shifting will be used to reduce the phase angle difference between the two transformers. The simulation results show the feeder current magnitude will be greatly reduced during load transferring.

Keywords—Electric power distribution system, Load transferring, Power feeder, Phasor measurement unit, Power reliability.

I. INTRODUCTION

Feeder load transferring is a common practice in the operation of electric power distribution systems [1-7]. The customers load on a feeder of a transformer would be transferred to a feeder of another transformer if there are system faults on the original feeder. In order to improve the power quality and power reliability, the un-interrupted type is a more popular way today. In the radial type of electric power distribution systems, feeders are connected to individual transformers in different substations. In the un-interrupted power supply type of load transferring, there is a period when feeder load is supplied parallel from two transformers. If the primary side of one transformer is greatly stronger than that of the other transformer, active power may be delivered from one transformer to the other. This will cause abnormal feeder current during the load transferring period, and the protection relay of the transformer would be actuated to trip the breaker and cause a black down of electric power.

Several approaches could be used to reduce abnormal feeder current during feeder load transferring [8-10]. The on-load tap changer (OLTC) of a power transformer is installed in the substation to modify the output voltage magnitude of the transformer. Then before the load transferring, the output voltage of related transformers can be tuned to be appropriated, so that the reactive components of feeder currents during load transferring can be reduced. The other method is to modify the power flow conditions if the primary side system of the power transformer. The phase angle difference and voltage magnitude difference of the feeder sides of the related transformers can be tuned to as low as possible. However, this method will affects the operation of the transmission system [11-14].

In this paper, a novel approach by using the phasor measurement units (PMU) [15-16] will be used to obtain the synchronous voltage magnitude and phase angle of the related transformers, where the load transferring between them are required. A power conditioner is installed in the secondary side of one of the transformers. Then the phase angle values from the PMUs will be sent to the power conditioner and the suitable phase shifting will be used to reduce the phase angle difference between the two transformers. This method will reduce the abnormal power flow between these transformers. The simulation results show the feeder current magnitude will be greatly reduced during load transferring.

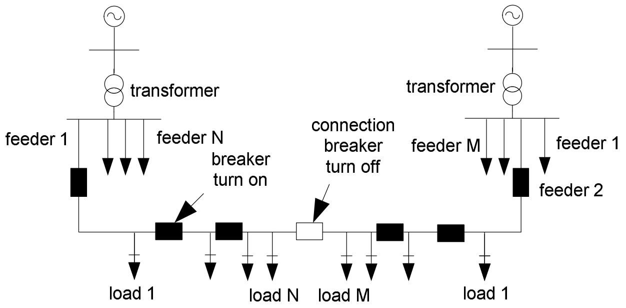

Fig.1. Structure of feeder load transferring.

Manuscript received on April 8, 2011.

Shu-Chen Wang is with the Department of Computer and Communication Engineering, Taipei College of Maritime Technology, Taipei, Taiwan. Chi-Jui Wu and Hsin-Chun Tsai are with the Department of Electrical Engineering, National Taiwan University of Science and Technology. Taipei, Taiwan (cjwu@mail.ntust.edu.tw).

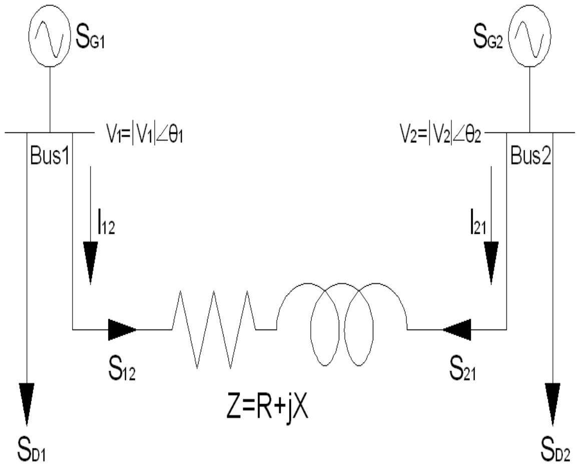

Fig. 2 Power flow on an electrical distribution feeder between two buses.

Fig. 3 Tuning of OLTC by using look-up table method.

II. STRUCTURE OF FEEDER LOAD TRANSFERRING

The illustration diagram for feeder load transferring is shown in Fig. 1. Before load transferring, the feeder connection breaker is at open state, and the transformer i and transformer j will supply their own load. If the load on feeder 1 of transformer ii will be transferred to the feeder 2 of transformer j, then the feeder connection break will be closed. During the load transferring stage, the transformer i and transformer j are connected through these two feeders. The power supply to customers on both feeders will be continuous. This means the un-interrupted load transferring. After several seconds, the feeder breaker near transformer i will be opened. And the load on both feeder 1 and feeder 2 is supplied by transformer j. It means after load transferring. However, for example, if the primary side of transformer j is greatly stronger than that of transformer i, during the load transferring, active power may be provided by the primary side of transformer j to the primary side of transformer i through the feeders and transformers.

The differences of voltage phase angle and voltage magnitude of the two terminal buses of an electrical power distribution feeder will affect the flow conditions of active power and reactive power. For the system in Fig. 2, assume

$$V_1 = |V_1|\angle\theta_1$$

$$V_2 = |V_2|\angle\theta_2$$

$$Z = R + jX$$

$$\delta = \theta_1 - \theta_2$$

Then

$$I_{12} = \frac{V_1 - V_2}{Z}$$

The apparent power from the bus is as follows.

$$\begin{aligned} S_{12} &= P_{12} + jQ_{12} = V_1\left(I_{12}\right)^* \\ &\cong \frac{1}{R^2+X^2}\left(R|V_1|^2 - R|V_1||V_2|\cos\delta + X|V_1||V_2|\sin\delta\right) \\ &+ j\frac{1}{R^2+X^2}\left(X|V_1|^2 - X|V_1||V_2|\cos\delta + R|V_1||V_2|\sin\delta\right) \end{aligned} \tag{1}$$

$$\begin{aligned} S_{21} &= P_{12} + jQ_{12} = V_1\left(-I_{12}\right)^* \\ &\cong \frac{1}{R^2+X^2}\left(R|V_2|^2 - R|V_1||V_2|\cos\delta + X|V_1||V_2|\sin\delta\right) \\ &+ j\frac{1}{R^2+X^2}\left(X|V_2|^2 - X|V_1||V_2|\cos\delta + R|V_1||V_2|\sin\delta\right) \end{aligned} \tag{2}$$

Usually, of X/R ratio of a power line is high, then we can obtain

$$\begin{aligned} S_{12} &= P_{12} + jQ_{12} \\ &= \frac{|V_1||V_2|}{X}\sin\delta + j\frac{1}{X}\left(|V_1|^2 - X|V_1||V_2|\cos\delta\right) \end{aligned} \tag{3}$$

$$\begin{aligned} S_{21} &= P_{21} + jQ_{21} \\ &= \frac{|V_1||V_2|}{X}\sin\delta + j\frac{1}{X}\left(|V_2|^2 - X|V_1||V_2|\cos\delta\right) \end{aligned} \tag{4}$$

In a power system, the phase angle difference between two buses is usually small, then $\cos\delta \approx 1$. And

$$P_{12} = \frac{|V_1||V_2|}{X}\sin\delta \tag{5}$$

$$Q_{12} = \frac{|V_1|}{X}\left(|V_1| - |V_2|\right) \tag{6}$$

$$P_{21} \cong -\frac{|V_1||V_2|}{X}\sin\delta \tag{7}$$

$$Q_{21} \cong \frac{|V_2|}{X}\left(|V_2| - |V_1|\right) \tag{8}$$

If δ is positive, the phase angle of bus 1 leads that of bus 2. Active power will be sent from bus 1 to bus 2. By the way, if the voltage magnitude of bus 1 is greater than that of bus 2, reactive power will be sent from bus 1 to bus 2.

In the un-interrupted power supply type of load transferring, there is a period when feeder load is supplied parallel from two transformers. If the primary side of one transformer is greatly stronger than that of the other transformer, there is larger phase angle difference between them. Then active power may be delivered from one transformer to the other. Also reactive power will be delivered. This will cause abnormal feeder current magnitude during the load transferring period, and the protection relay of the transformer would be actuated to trip the breaker and cause a black down of electric power.

In recent years, the on-load tap changer (OLTC) on a power transformer is used to adjust the secondary side voltage of the transformer according to the system or loading conditions. There are several terminals on the primary side or secondary side of a power transformer. The output voltage can be adjusted up to ±10% from the nominal values. The power will not be interrupted if the scheme of OLTC is used. The look-up table method can be used to determine the tap position as shown in Fig. 3. The daily loading condition and voltage profile of the transmission system are used to set the operation rules. Usually ±1.25% voltage magnitude can be adjusted for each tap step. In the load transferring of power transformers, if the voltage magnitudes of transformers before load transferring have large difference, the OLTC can be used to adjust voltage magnitude of any one transformer, so that the reactive power flow can be reduced.

III. RESULTS OF FEEDER LOAD TRANSFERRING WITHOUT PMU AND POWER CONDITIONER

Two cases of feeder load transferring are evaluated. The first one is from Jiang-Tsuey (S/S) to Sheh-How (D/S) as shown in Fig. 4. Both secondary sides are the 11.4-kV system. While the primary side of the Jiang-Tsuey (S/S) is a 69-kV system, that of the Sheh-How (D/S) is a 161-kV system. The other case is from Jiang-Tsuey (S/S) to Puu-Chyan (S/S) as shown in Fig. 5. Both secondary sides are an 11.4-kV system. Both primary sides are a 161-kV system. The system load means the loading conditions of the 69-kV and 161-kV systems. The feeder load means the loading conditions on the feeders having relation with load transferring.

The simulation results of feeder load transferring from Jiang-Tsuey (S/S) to Sheh-How (D/S) are given in Table 1 and 2 for the conditions of 20% and 80% system loading, respectively. It can be found that under the conditions of 80% system loading, the feeder currents of Sheh-How (D/S) during load transferring are larger than 600 A for each case. The value of 600 A is the normal relay current setting of the feeders. Under the conditions of 20% system loading, the feeder currents of Sheh-How (D/S) during load transferring are larger than 600 A if the feeder loading is equal to or greater than 40%. The results in TABLE I and II mean that it is hard to have feeder load transferring between Jiang-Tsuey (S/S) and Sheh-How (D/S).

The simulation results of feeder load transferring from Jiang-Tsuey (S/S) to Puu-Chyan (S/S) are given in TABLE III and IV for the conditions of 20% and 80% system loading, respectively. It can be found that It can be found that under the conditions of 80% system loading, the feeder currents of Puu-Chyan (S/S) during load transferring are larger than 600 A for each case. The conditions of 20% system loading are safer.

TABLE V and VI give the phase angle difference and voltage magnitude difference of betweens secondary sides of transformers before load transferring on conditions of 80% and 20% system loading, respectively. It can be found that if the system loading is high, the phase angle difference values are so high between to cause the high feeder currents during load transferring periods.

The feasible conditions of load transferring between D/S and S/S are given in TABLE VII for the system without PMU and power conditioners. The conditions are determined by the requirement that the feeder current magnitude during the period of load transferring should be less than 480A, which is the limit of safe current. It can be found that since the primary side of a D/S is 161-kV and that of an SS is 69-kV, it is hard to have safe conditions for load transferring. Those conditions between S/S and S/S are given in TABLE VIII. There are several cases for safe load transferring.

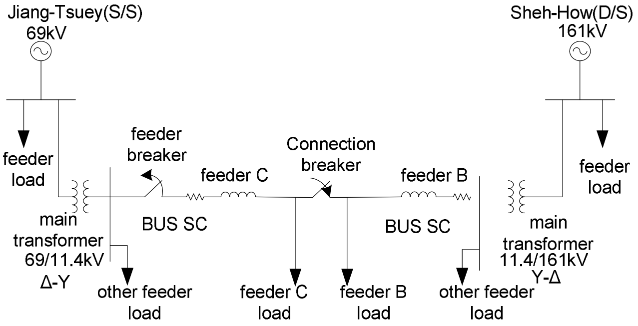

Fig.4. Feeder load transferring from Jiang-Tsuey (S/S) to Sheh-How (D/S).

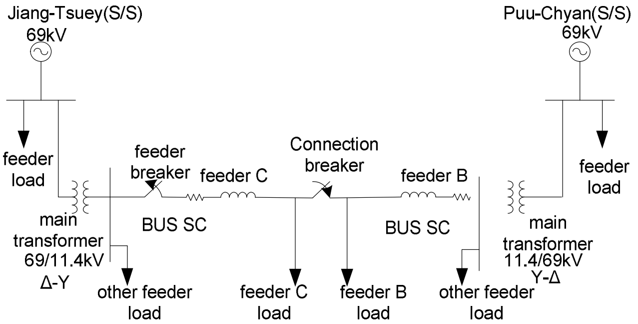

Fig.5. Feeder load transferring from Jiang-Tsuey (S/S) to Puu-Chyan (S/S).

TABLE I

Results of Feeder Load Transferring from Jiang-Tsuey (S/S) to Shen-How (D/S) on Conditions of 20% System Loading

System loading	Feeder loading	Feeder current of Jiang-Tsuey (S/S) (A)			Feeder current of Sheh-How (D/S) (A)		
		Before load transferring	During load transferring	After load transferring	Before load transferring	During load transferring	After load transferring
20%	20%	88	390	0	101	573	189
20%	40%	177	335	0	203	702	379
20%	60%	266	282	0	305	832	570
20%	80%	356	231	0	407	963	763

TABLE II

Results of Feeder load transferring from Jiang-Tsuey (S/S) to Sheh-How (D/S) on conditions of 80% system loading

System loading	Feeder loading	Feeder current of Jiang-Tsuey (S/S) (A)			Feeder current of Sheh-How (D/S) (A)		
		Before load transferring	During load transferring	After load transferring	Before load transferring	During load transferring	After load transferring
80%	20%	95	1999	0	103	1804	192
80%	40%	191	1744	0	206	2135	386
80%	60%	287	1684	0	310	2271	580
80%	80%	384	1650	0	414	2434	776

TABLE III

Results of Feeder load transferring from Jiang-Tsuey (S/S) to Puu-Chyan (S/S) on conditions of 20% system loading

System loading	Feeder loading	Feeder current of Jiang-Tsuey (S/S) (A)			Feeder current of Puu-Chyan (S/S) (A)		
		Before load transferring	During load transferring	After load transferring	Before load transferring	During load transferring	After load transferring
20%	20%	88	61	0	94	213	183
20%	40%	177	89	0	189	302	368
20%	60%	266	171	0	284	393	556
20%	80%	356	261	0	381	485	746

TABLE IV

Results of Feeder load transferring from Jiang-Tsuey (S/S) to Puu-Chyan (S/S) on conditions of 80% system loading

System loading	Feeder loading	Feeder current of Jiang-Tsuey (S/S) (A)			Feeder current of Puu-Chyan (S/S) (A)		
		Before load transferring	During load transferring	After load transferring	Before load transferring	During load transferring	After load transferring
80%	20%	95	469	0	99	658	192
80%	40%	191	376	0	199	755	387
80%	60%	287	287	0	299	852	586
80%	80%	384	207	0	400	955	787

TABLE V

Phase angle difference and voltage magnitude difference of between secondary sides of transformers before load transferring on conditions of 80% system loading

System loading	Feeder loading	Jiang-Tsuey (S/S) to Sheh-How (D/S)	Jiang-Tsuey (S/S) to Puu-Chyan (S/S)
		Phase angle difference/ voltage magnitude difference	Phase angle difference/ voltage magnitude difference
80%	20%	12.5/ 0.701	5.2/ 0.251
80%	40%	12.7/ 0.722	5.2/ 0.248
80%	60%	13/ 0.745	5.3/ 0.246
80%	80%	13.2/ 0.767	5.3/ 0.253

TABLE VI

Phase angle difference and voltage magnitude difference of between secondary sides of transformers before load transferring on conditions of 20% system loading

System loading	Feeder loading	Jiang-Tsuey (S/S) to Sheh-How (D/S)	Jiang-Tsuey (S/S) to Puu-Chyan (S/S)
		Phase angle difference/ voltage magnitude difference	Phase angle difference/ voltage magnitude difference
20%	20%	3/ 0.077	1.1/ 0.009
20%	40%	3.2/ 0.094	1.1/ 0.019
20%	60%	3.4/ 0.11	1.1/ 0.079
20%	80%	3.5/ 0.127	1/ 0.025

TABLE VII
FEASIBLE CONDITION OF LOAD TRANSFERRING BETWEEN D/S AND S/S

Feeder loading System loading	20%	40%	60%	80%
20%	Y	Y/N	N	N
40%	N	N	N	N
60%	N	N	N	N
80%	N	N	N	N

TABLE VIII
FEASIBLE CONDITION OF LOADING TRANSFERRING BETWEEN S/S AND S/S

Feeder loading System loading	20%	40%	60%	80 %
20%	Y	Y	Y	N
40%	Y	Y	Y	N
60%	Y	N	N	N
80%	N	N	N	N

IV. WAMS MONITORING SYSTEM

The technique of the wide area measurement system (WAMS) came from the theory of sequence components for distance protection relay [24-29]. In order to monitor the dynamic and transient behaviors of the 345-kV network, the Taipower had installed 10 WAMS units. Fig. 6 shows the schematic arrangement of the WAMS hardware. The functions of the WAMS include the power system real-time monitoring, the analysis of dynamical behaviors, fault recording, and the steady state analysis of phasor recording.

The block diagram of the synchronous phasor measurement unit (PMU) in the WAMS is shown in Fig. 7. The PMU is composed of the signal conditioning unit (SCU), the measurement unit (MU), and the satellite signal synchronizing unit (SSU). To acquire the phase angles and bus frequency data among substations, a global reference is needed. The time stamp of the PMU is the same as the global positioning system (GPS). The data from different PMU is delivered to the central control unit by optical fibers. The data are then computed by using the discrete Fourier transform algorithm on a common time base. The symmetrical components of voltages and currents are computed from the instantaneous values to obtain the phasor values.

The synchronous phasor values of the transformers where the load transferring is required are obtained. Since the values are measured at the same time clocking, the phasor values can be used to evaluation the safe conditions of load transferring. It should be determined by system study that either the values of primary side or secondary side of transformers are useful to evaluate the safe conditions of load transferring.

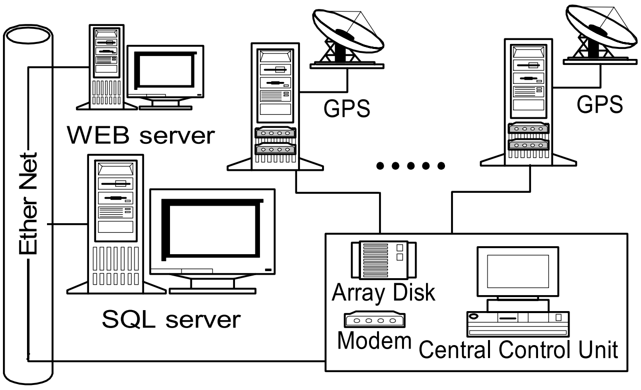

Fig. 6. Schematic arrangement of the WAMS hardware.

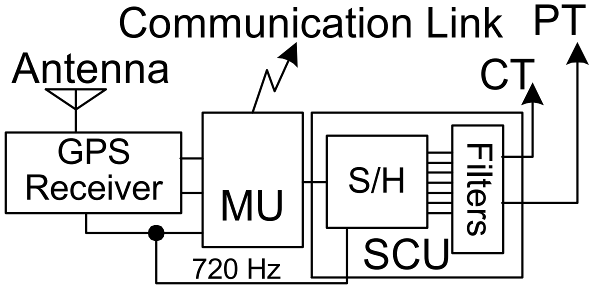

Fig. 7. Block diagram of synchronous phasor measurement system.

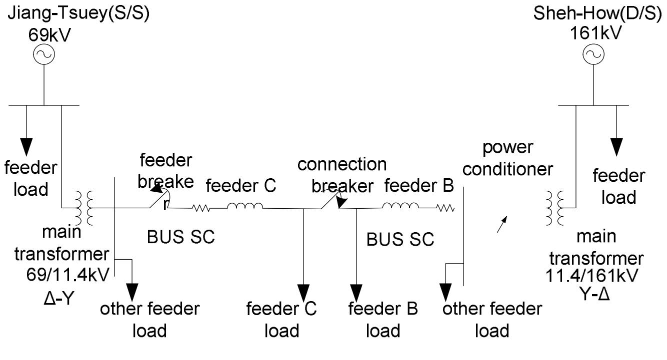

Fig. 8. A power conditioner installed in the secondary side of transformer of Sheh-How (D/S).

TABLE IX

Feeder current and power of the system with power conditioner and OLTC under 80% system loading and 80% feeder loading(before feeder load transferring）

	Jiang-Tsuey (S/S)	Sheh-How (D/S)
	power(MW+jMVAR)/ curent(A)	power(MW+jMVAR)/ curent(A)
OLTC TAP: N Power conditioner: 0°	6.53+j2.17/ 384	7.56+j2.51/ 414
OLTC TAP: 8R Power conditioner: 3.3°	6.53+j2.17/ 349	7.57+j2.51/ 414
OLTC TAP: 7R Power conditioner: 13.3°	6.53+j2.17/ 353	7.57+j2.51/ 414
OLTC TAP: 6R Power conditioner: 13.3°	6.53+j2.17/ 357	7.57+j2.51/ 414
OLTC TAP: 6R Power conditioner: 14.3°	6.53+j2.18/ 357	7.56+j2.51/ 414
OLTC TAP: 6R Power conditioner: 15.4°	6.53+j2.17/ 357	7.57+j2.51/ 414

TABLE X

Feeder current and power of the system with power conditioner and OLTC under 80% system loading and 80% feeder loading(during feeder load transferring）

	Jiang-Tsuey (S/S)	Sheh-How (D/S)
	power(MW+jMVAR)/ curent(A)	power(MW+jMVAR)/ curent(A)
OLTC TAP: N Power conditioner: 0°	-30.9-j5.1/ 1668	45.1+j9.98/ 2453
OLTC TAP: 8R Power conditioner: 3.3°	6.52+j5.77/ 449	7.57-j1.1/ 395
OLTC TAP: 7R Power conditioner: 13.3°	6.61+j4.07/ 402	7.49+j0.592/ 389
OLTC TAP: 6R Power conditioner: 13.3°	6.71+j2.34/ 369	7.39+j2.33/ 402
OLTC TAP: 6R Power conditioner: 14.3°	9.46+j1.89/ 501	4.64+j2.77/ 280
OLTC TAP: 6R Power conditioner: 15.4°	12.2+j1.44/ 639	1.88+j3.21/ 193

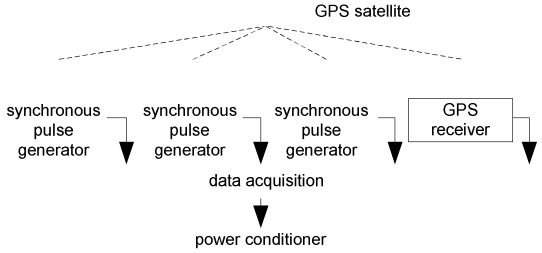

Fig.9. Phasor measurement unit to send synchronous voltage phasor values of transformer to power conditioner.

TABLE XI

Feeder current and power of the system with power conditioner and OLTC under 80% system loading and 80% feeder loading(after feeder load transferring）

	Jiang-Tsuey (S/S)	Sheh-How (D/S)
	power(MW+jMVAR)/ curent(A)	power(MW+jMVAR)/ curent(A)
OLTC TAP: N Power conditioner: 0°	0/ 0	14.1+j4.71/ 776
OLTC TAP: 8R Power conditioner: 3.3°	0/ 0	14.1+j4.69/ 775
OLTC TAP: 7R Power conditioner: 13.3°	0/ 0	14.1+j4.69/ 775
OLTC TAP: 6R Power conditioner: 13.3°	0/ 0	14.1+j4.69/ 775
OLTC TAP: 6R Power conditioner: 14.3°	0/ 0	14.1+j4.69/ 776
OLTC TAP: 6R Power conditioner: 15.4°	0/ 0	14.1+j4.69/ 775

TABLE XII

Feasible Conditions of Load Transferring between D/Sand S/S for System with PMU and Power Conditioner

Feeder loading System loading	20 %	40 %	60 %	80 %
20%	Y	Y	Y	N
40%	Y	Y	Y	N
60%	Y	Y	Y	N
80%	Y	Y	Y	N

TABLE XIII

FEASIBLE CONDITIONS OF LOAD TRANSFERRING BETWEEN S/S AND S/S FOR SYSTEM WITH PMU AND POWER CONDITIONER

Feeder loading System loading	20 %	40 %	60 %	80 %
20%	Y	Y	Y	N
40%	Y	Y	Y	N
60%	Y	Y	Y	N
80%	Y	Y	Y	N

V. EFFECT OF PMU AND POWER CONDITIONER ON FEEDER LOAD TRANSFERRIN

To reduce the phase angle difference between secondary sides of transformers before load transferring, a series power conditioner can be installed in the secondary side of a transformer, as shown in Fig. 8. Then the equivalent phase angle of the transformer can be modified. To determine the setting values of the power conditioner, the synchronous voltage phasor values of transformers in different substations can be obtained from the phasor measurement unit (PMU), as shown in Fig.9. From the simulation results in TABLE IX, X, and XI, it can be found that when the OLTC and the power conditioner are used, the feeder current magnitude can be greatly reduced. The phase angle shifted by the power conditioner has significant influence. The operation condition of OLTC to modify the output voltage magnitude of the transformer also has effect to reduce the reactive component of the feeder current during load transferring.

The feasible conditions of loading transferring between D/S and S/S are given in TABLE XII for the system with PMU and power conditioners. Those conditions between S/S and S/S are given in TABLE XIII. The conditions are also determined by the requirement that the feeder current during the period of load transferring should be less than 480A, which is the limit of safe current. It can be found that the safe load transferring conditions are improved by PMU and power conditioner. It is also true in the load transferring between S/S and S/S if the PMU and power conditioners are used.

It is found that the OLTC and power conditioners can be used to reduce the differences of phase angle and voltage magnitude of transformers before load transferring. If the differences of phase angle and voltage magnitude are small, the active power and reactive power between the two transformers are also small. This can ensure the safe conditions of feeder load transferring. It needs to evaluate in advance the acceptable differences of phase angle and voltage magnitude. The OLTC is a discrete controller. So the difference of voltage magnitude can not be reduced to zero. And there is still the reactive power flow. By the way, the loading conditions on the feeders still have effect on the current magnitude during the feeder load transferring. The System loading conditions and feeder loading conditions are important.

VI. CONCLUSIONS

The conditions in the current magnitude of electric power distribution systems during feeder load transferring are analyzed in this paper. Since the system loading condition in the 69-kV and 161-kV sides of the 69/11.4-kV and 161/11.4-kV transformers will affect the phase angle difference, the phasor measurement unit can mitigate the angle difference to reduce the feeder current during load transferring. The feeder currents during load transferring period are affected by the phase angle difference and voltage magnitude difference of the transformers in different substations. The coordination of power conditioners and on-load tap changers can greatly reduce the angle difference, and then reduce the feeder current during load transferring. With the usage of PMU and power conditioners, the synchronous phasor values can be obtained and the exact phase difference is also obtained. This can ensure that there is a safe condition for feeder load transferring. The voltage magnitude is nearly a steady state value, so that the traditional method can be used to obtain the values.

ACKNOWLEDGMENT

The paper is supported by the National Taiwan University of Science and Technology and National Science Council of Taiwan, project number, NSC 100-3113-E-194 -001 and 99-2221-E-011-147-MY3.

REFERENCE

[1] H. Saadat, “Power System Analysis”, McGraw-Hill, 1999.

[2] T. Gonen, “Electric Power Distribution System Engineering”, McGraw-Hill, 1986.

[3] L. M. Faulkenberry and W. Coffer, “Electrical Power Distribution and Transmission”, Prentice-Hall, 1996.

[4] J. Pansini,”Guide to Electrical Power Distribution Systems”, Pennwell, 1996.

[5] W. H. Kersting,” Distribution System Modeling and Analysis”, CRC Press, 2002.

[6] J. M. Gers and E. J. Holmes, “Protection of Electricity Distribution Networks”, IEE, 1998.

[7] E. Lakervi and E.J. Holmes,”Electricity Distribution Network Design”, Second Edition, IEE, 2003.

[8] R. Ibrahim, A.M. A. Haidar, M. Zahim, H. Iu, “The Effect of DVR Location for Enhancing Voltage Sag”, Proceedings of the 9th WSEAS International Conference on Application of Electrical Engineering, pp. 92-98, 2009.

[9] A. A. Koolaiyan, A. Sheikholeslami , R. A. Kordkheili, “A New Voltage Sag and Swell Compensator Switched by Hysteresis Voltage Control Method”, Proceedings of the 8th WSEAS International Conference on Electric Power Systems, High Voltages, Electric Machines

(POWER '08), pp. 71-76, 2008.

[10] Y. H.Chan and C. J. Wu, “Voltage Sag Analysis of Industry Power System Considering CBEMA Curve”, Proceedings of the 10th WSEAS/IASME International Conference on Electric Power Systems, High Voltages, Electric Machines (POWER '10) pp. 107-111, 2010.

[11] P. P. Bedekar, S. R. Bhide, and Vijay S. Kale, “Optimum Time Coordination of Overcurrent Relays in Distribution System Using Big-M (Penalty) Method”, WSEAS Trans. on Power Systems, vol. 4, no. 11, pp. 341-350, 2009.

[12] I. Yilmazlar and G. Kokturk, “Failure Analysis in Power System by the Discrete Wavelet Transform”, WSEAS Trans. on Power Systems, vol. 5, no. 3, pp. 243-252, 2010.

[13] A. F. B. Abidin, A. Mohamed, H. Shareef, “A New Detection Technique for Distance Protection during Power Swings”, Proceedings of the 9th WSEAS International Conference on Applications of Electrical Engineering, 2010.

[14] Z. Chen, F. Li, L. Fan, and P. Zhang, “Review of PMU-based Online Applications for Dynamic Simulation, Fault Detection, and Cascading Failure Prevention”, Proceedings of the 8th WSEAS International Conference on Electric Power Systems, High Voltages, Electric Machines (POWER '08), pp. 212-216, 2008.

[15] A. G. Phadke, T. Hlibka, M. Ibrahim, M. G. Adamiak, “A microcomputer based symmetrical component distance relay” in *Proc. 1979 IEEE Power Industry Computer Applications Conf.*, pp. 47-55.

[16] A. G. Phadke, M. Ibrahim, T. Hlibka, “Fundamental basis for distance relaying with symmetrical components”, *IEEE Trans. Power App. Sys.*, vol. PAS-96, no. 2, pp. 635-646, 1977

Biographies

Shu-Chen Wang was born in Taiwan, 1969. She received the B. Sc., M. Sc., and Ph.D. degree from the Department of Electrical Engineering, National Taiwan Ocean University in 1992, 1994, and 2007, respectively. Currently she is an associate professor in the Department of Computer and Communication Engineering, Taipei College of Maritime Technology. Her current research interests include fuzzy theory, control system, and power system dynamics.

Chi-Jui Wu received the B. Sc., M. Sc., and Ph.D. degree in electrical engineering all from the National Taiwan University in 1983, 1985, and 1988, respectively. In 1988, he joined the Department of Electrical Engineering, National Taiwan University of Science and Technology as an associate professor. Now he is a full professor. He has been active in practical problems and got many projects from private companies, independent research institutes, and governments. His current research interests lie in electric power quality, power electromagnetic interference, and power system stability.

Hsin-Chun Tsai was born in Taiwan, R.O.C. in 1987. He received the B. Sc degree in Electrical Engineering from the National Taiwan University of Science and Technology, Taipei, Taiwan, R.O.C. in 2009. He is currently a Ms. C. student in the Electrical Engineering Department, National Taiwan University of Science and Technology. His major research fields are system analysis and smart grid in electric power systems.