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Power Flow Control Using Phase Shift Transformers

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Abstract

The present paper examines and tests an alternative method to control and redirect electric power flow through certain paths (transmission lines). The control and redirecting of power flow is achieved through the use of phase shift transformers PSTs. An algorithm is presented which searches for a proper phase shift angle introduced by a PST at any given location.

The proposed method is based on modelling the PST and the power system employing Newton-Raphson load flow approach.

Finally, the installation of series of PSTs on the interconnected power systems aims at mitigating uncontrolled parallel flows and unbalanced sharing of power among transmission lines.

The obtained results showed the effectiveness of the proposed method in sharing and controlling the electrical power flow among different interties of the 5-bus network on which the study applied.

Keywords: Phase shifting transformers, Power flow control, Newton Raphson method, Power system.

السيطرة على سريان القدرة باستخدام محولات إزاحة الطور

الخلاصة

إن البحث الحالي هو اختبار لطريقة بديلة لإعادة توجيه سريان القدرة والتحكم بها في خطوط نقل القدرة الكهربائية . إن توجيه القدرة والسيطرة عليها تمت باستخدام محولات إزاحة الطور، والخوارزمية المقدمة في البحث الحالي تبحث عن انسب إزاحة طورية للمحولة عند الموقع المختار.

إن الطريقة المقترحة تعتمد تمثيل محولة إزاحة الطور وإضافتها في خطوط النقل برمجياً واعتمدت طريقة نيوتن رافسن لحساب سريان القدرة الكهربائية. كما إن نصب محولات إزاحة الطور المتوالية يهدف إلى تخفيف أحمال خطوط النقل غير متوازنة التحميل وإعادة توزيعها بشكل متوازن.

وبينت النتائج التي تم الحصول عليها فاعلية الطريقة في إعادة توزيع سريان القدرة والسيطرة عليها في مختلف خطوط نقل القدرة في المنظومة ذات الخمس عموميات التي طبقت عليها الطريقة المقترحة وفاعليتها في تقليل الفقدان الكلي في المنظومة.

الكلمات الدالة: محولات إزاحة الطور، السيطرة على سريان القدرة ، طريقة نيوتن رافسن ، منظومة القدرة الكهربائية.

Introduction

Recently, high voltage transmission systems have become increasingly loaded by electrical power systems. As loading increases, the security of power system decreases. The loss of a transmission system in such power system (networks) becomes a serious problem[1]. Multiple lines may be overloaded after the loss of a transmission line. This causes serious reliability and security problems in the network[1,2]. Line overloading is typically caused by generator outages, transmission line outages and excessive power wheeling etc. In any of the above cases, overloading can be alleviated by redirecting power flow from overloaded lines to less loaded lines. One of the ways of achieving real power flow control and redirection under above conditions, for maintaining a secure, efficient and economical operation of the power systems is through adjustment of phase shifting transformers PSTs[1-4].

The PST is a device that allows dispatchers to change the phase shift between two point voltages in the system, or two system voltages, thereby helping them to control real power transfer between these points (or systems)[3,5].

PSTs are a series connected three-phase transformers which generates a quadrature component of voltage. These can be inserted into the transmission systems via a series connected boosting transformers[2,6].

PST also provides series compensation to enhance power system stability[7,8]. In this paper the line power flow is controlled by PST and power loss reduction in whole system in addition to representation of the PST will be discussed.

Modelling and Representation of PSTs for Load Flow

In general, the PST is an equipment which shifts the phase angle of the voltage and the current to a prescribed value and controls the power flow in the line that inserted in by varying the phase angle between the two buses of the line[2,6]. The variation of the phase angle is carried out by inserting and adding a quadrature component voltage to the source line to neutral voltage[9]. The quadrature PST schematic diagram for phase shifting is given in Fig.(1).

The purpose of the phase shifter is to change the phase angle of the voltage and the current. The phase shifting transformers are connected in series with transmission line between bus i and j as shown in Fig.(2), and employed for the purpose of load flow solutions[10], which is used to form the Y-bus matrix. So the off diagonal elements of the admittance matrix for the phase shifting transformer are unsymmetrical, and they are also dependent on the phase shift angle (ψ) . i.e.

$$Y_{ij} \neq Y_{ji} \qquad \text{.....(1)}$$

The elements of the admittance matrix $Y_{ij} = G_{ij} + jB_{ij}$ and the admittance relationships are [4, 10]:

$$Y_{ij} = (b^t \sin\Psi - g^t \cos\Psi) - j(g^t \sin\Psi + b^t \cos\Psi) \qquad \text{.....(2)}$$

and

$$Y_{ji} = -(b^t \sin\Psi + g^t \cos\Psi) + j(g^t \sin\Psi - b^t \cos\Psi) \qquad \text{.....(3)}$$

$$Y_{ii} = Y_{ii}^{old} + Y^t \qquad \text{.....(4)}$$

$$Y_{jj} = Y_{jj}^{old} + Y^t \qquad \text{.....(5)}$$

where Y^t *and* Ψ: are the admittance and the angle of PST, and Y_{jj}^{old} : is the self admittance of the bus j before connection of the PST, and g^t , b^t are the conductance and susceptance of PST.

Power Flow Control and Phase Shifter Adjustment

The real power flow in a transmission line connected between any two buses in a power system is dependent on voltage phase angle difference between the two buses[4,11]. To obtain a general equation, which relates the real power flow in a transmission line to a phase shift angle, assume a PST connected between bus i and j with an ideal turns ratio and shifting angle ψ, ($T = 1.0\angle\Psi$) in series with the transformer admittance

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$Y^t = |y^t| \angle \alpha$ So that at the ith side of the PST, the MVA, S_i , is given by:

$$S_i = P_i + jQ_i \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

$$and\ \ V_i = |V_i| \angle \delta_i \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

$$V_j = |V_j| \angle \delta_j \ldots\ldots\ldots\ldots\ldots\ldots(8)$$

Substituting phase shifter variables in real power flow equation, Pij can be computated by [1,2,3]:

$$P_{ij} = g\, V_i^2 - V_i V_j Y^t \cos \beta_{ij} \ldots\ldots\ldots\ldots(9)$$

Where g is the conductance of line i-j and:

$$\beta_{ij} = \delta_i - \delta_j - \Psi - \alpha \ldots\ldots(10)$$

Thus Newton-Raphson load flow method mismatch function is [12]:

$$\Delta P_i = P_i^{sp} - P_{i,cal} \ldots\ldots\ldots\ldots\ldots\ldots(11)$$

$$\Delta Q_i = Q_i^{sp} - Q_{i,cal} \ldots\ldots\ldots\ldots\ldots\ldots(12)$$

$$P_{i,cal} = \sum_{i=1}^{n} V_i V_j Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i) \ldots\ldots\ldots(13)$$

$$Q_{i,cal} = \sum_{i=1}^{n} V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i) \ldots\ldots\ldots(14)$$

where:

$$P_i^{sp} = P_{i,gen} - P_{i,load}$$

$$Q_i^{sp} = Q_{i,gen} - Q_{i,load}$$

And θ_{ij} is the angle of Admittance for line ij.

Therefore the Jacobian elements that affected by PST change and can be divided into three categories[10]:

A. The partial derivatives of real and reactive power (P_i *and* Q_i) in bus i with respect to δ_j *and* V_j and (P_j , Q_j) in bus j with respect to δ_i *and* V_i are outlined as:

$$\frac{\partial P_i}{\partial \delta_j} = -V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i) \ldots(15)$$

$$\frac{\partial Q_i}{\partial \delta_j} = V_i V_j Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i) \ldots(16)$$

$$\frac{\partial P_i}{\partial V_j} = V_i Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i) \ldots\ldots(17)$$

$$\frac{\partial Q_i}{\partial V_j} = V_i Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i) \ldots\ldots(18)$$

The following partial derivatives are also affected:

$$\frac{\partial P_j}{\partial \delta_i}, \frac{\partial Q_j}{\partial \delta_i}, \frac{\partial P_j}{\partial V_i}, \frac{\partial Q_j}{\partial \delta_i}$$

B. The partial derivatives of real power flow (P_{ij}) with respect to δ_i *and* V_i , (i=2,3..,n) add a new row to Jacobian which are:

repeated until the difference between the calculated value and a specified value is less than or equal a specified tolerance (0.01), which means that for each Ψ value, during the process, there is a value of real power and a value for each variable of any bus. PST has been inserted in three different lines, and the following three cases have been studied, with bus 1 considered as slack bus in all cases.

Case Study 1

The PST is connected between bus 2 and 4. Table (1) shows the results of this case with and without connecting the PST. The value of power flow through the lines 1,2 and 2,4 before inserting PST are (88.8) and (27.9) MW respectively, while the real power flow through the same lines after insertion of PST are (49.36) and (85.44) MW respectively. This shows that the percentage increase in line 2,4 loadibility is 67%, and the percentage decrease in line 1,2 loadibility is 44.5% in addition to percentage decreases in loadibility of the other lines. Therefore the power flow direction is altered and exchanged from one direction to a new direction. All these effects and variations in power system variables are due to addition of a few degrees (0.0553 rad) in bus 2 voltage angle and 7% increase to its voltage as a result of PST connection between bus 2 and bus 4.

Case Study 2

In this case the PST has been located between bus 3 and bus 2, i.e. PST is inserted in line 2,3. The results, shown in Table (2) indicated that the real power transmitted in line 2,3 is increased to (48.75) MW compared with (24.7) MW in the absence of PST. However, in line 1,2 the real power transmitted is decreased to (50.45) MW while it was (88.8) MW with no PST, i.e. 44.41% of line 1,2 load is transmitted to a new region in the system by the line 2,3 in which the PST is connected, and 48.1% of line 1,2 load is transmitted by remnant lines. In other words, the loadibility of line 2,3 was increased by 48.1% and that of line 1,2 was decreased to 44.41% whereas the inserted phase shift to bus 2 voltage angle was (0.0764 rad). Also the calculated system losses indicated that the minimum losses occurred in case 2

Case Study 3

When the PST is connected between bus 2 and 5, i.e in line 2,5, real power flow in this line is increased to (56.69)MW compared with (54.8) MW in the absence of PST. However, the reduction in line 1,2 loadibility is 25.85%. This indicates that the other lines shared the difference between the above loadibilities. This is clear in results shown in Table (2) concerned with case 3 where Ψ is (0.0622 rad.).

Conclusions

1. The technique outlined in this paper enables certain lines, lines with PST, in power system to increase their loadibilities. So it can be employed to redirect and control real power flow between two points in a power system, or between two power systems.

2. Also this method, i.e inserting PSTs, in individual lines reduces total system losses. The obtained results indicated also that PST location affects on minimising the system losses.

3. It can also be concluded that PSTs are inserted only into a line directly connected to a generation bus, i.e. inserting PSTs into lines connecting load buses have less effectiveness.

References

1. Paul E. Rylatt, George J. Cokkin- ides, "A Method for Planning Phase-Shifting Trans-Formers Using Linearized Network Sensi- Tivities", IEEE Proceding-1989 southeaston, pp. 832-835.

2. Z.X.Han,"Phase Shifter and Power Flow Control" , IEEE transaction on power Apparatus and System, Vol. PAS-101,No.10, October 1982.

3. Chung – Neng Huang, "Feature Analysis of Power Flows Based on the Allocations of Phase-shifting Transformers", IEEE Transaction on power system, Vol. 18, No. 1, February 2003.

4. R.D. Youssef, "Phase-Shifting Trans-formers in Load Flow and Short Ciruit Analysis: Modelling and Control", IEEE Proceedings - C, Vol. 140, No. 4, July 1993.

5. Y.L. Tanand Y. Wang, "Nonlinear Exitation and Phase Shifter Controller for Transient Stability Enhancement of power system using adaptive control Law", Electrical power and Energy system, Vol. 18,No.6,PP.397-403, 1996.

6. Paola Bresesti, Marino Sforna, Viltorio Allegranza, Danide Canever and RiccardoVailati, "Application of Phase Shifting Transformers for a Secure and Efficient Operation of the Interco-nnection Corridors", IEEE power Engineering Society general meeting, 2004, PP. 1192 - 1197.

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7. O'Kelly, D. and Musgrave, G. "Improvement of power system transient stability by phase shift insertion", IEEE Proceeding, Vol. 120, PP. 247-252,1973.

8. Edris, Abdel - Aty, "Enhancement of first swing stability using high speed phase shifter" IEEE Trans. Vol. PWRS, PP.1113-1118, 1991.

9. UCTE, "Union for the coordination ordination of Transmission of Electricity, "UCTE system Adequacy Retrospect 2002", Available :http//www.ucte.org/publicationslibrary/e_default_2003.asp

10.Norris M. Peterson and W.scott Meyer, "Automatic Adjustment of Transformer and phase- shifter Taps in the Newton power flow", IEEE Trans .on power apparatus and systems Vol. PAS- 90 On. 1, January / February 1971.

11.R. Grunbaum, R. Sharma, and J. P. charpentier, "Improving the efficiency and quality of A.C transmission system", ABB power system- Joint world Bank, Tech. Rep., March 2000.

12.John J. Grainer and William D. Stevevson Jr, "Power system analysis",

13.McGraw – Hill, Inc, 1994.

Glenn W. stag and Ahmed H. El-Abiad, "Computer Methods in Power System Analysis", McGraw – Hill, 1968.

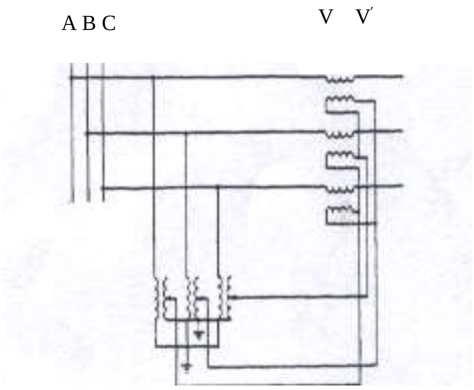

Fig.(1) Quadrature PST Schematic diagram

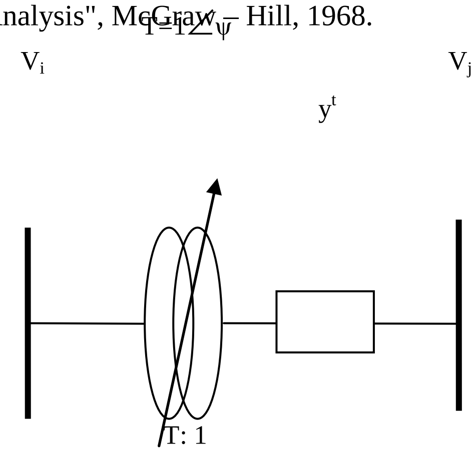

Fig.(2) Phase shifting transformer

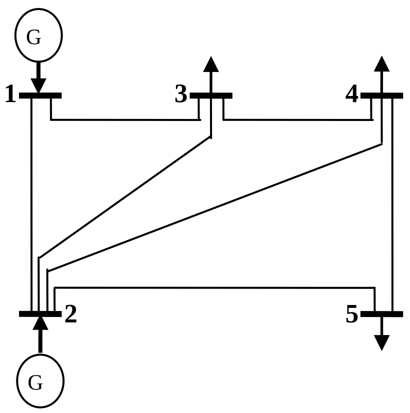

Fig. (3) Sample system for load flow solution.

Table (1) Bus voltages for three cases

Bus No.	Bus voltage			
	Normal case	**Case 1**	**Case 2**	**Case 3**
1	1.06+j0	1.06+j0	1.06+j0	1.06+j0
2	1.046-j0.051	1.052-0.028	1.049-j0.029	1.042-j0.03
3	1.02-j0.089	1.053-0.033	1.049-j0.032	1.041-j0.028
4	1.019-j0.095	1.031-0.037	1.032-j0.036	1.039-j.031
5	1.012-j0.109	1.029-j0.07	1.025-0.074	1.033-j0.052

Table (2) The real power flow in lines

Bus Code	Power flow MW			
	Normal case	**Case 1**	**Case 2**	**Case 3**
1-2	88.8	49.36	50.45	55.82
2-1	-87.4	-48.9	-49.5	-54.23
1-3	40.7	14.04	14.48	13.74
3-1	-39.5	-13.9	-14.33	-13.6
2-3	24.7	2.22	48.75	26
3-2	-24.3	-2.21	-47.25	-25.46
3-4	18.9	15.52	14.29	10.48
4-3	-18.9	-15.5	-14.27	-10.47
4-5	6.3	22	17.99	8.99
5-4	-6.3	-21.6	-17.75	-8.93
2-5	54.8	39.97	43.75	56.69
5-2	-53.7	-39.39	-42.56	-55.5
2-4	27.9	85.44	4.83	30.95
4-2	-27.4	-82.91	-4.82	-30.1
Ψ(rad)	---	0.0553	0.0764	0.0622
Losses (MW)	4.6	4.41	4.06	4.38