Application of Phase Shifting Transformer in Indian Power System

Tirupathi Reddy, Aruna Gulati, M. I. Khan, and Ramesh Koul

***Abstract*—The country is poised to double the power generation by 2012. With the result the transmission & distribution is increasing many fold. The optimal use of existing infrastructure needs to be done in order to contain investment. It is therefore necessary to load the existing lines to optimal capacity rather than providing the additional corridor. Sometimes it is necessary to provide additional corridor in order to maintain system's reliability and availability. Over loading of subsystem in a power system sometimes may pose stability issues, which may lead to unwanted tripping, equipment failures which will result long repair/ replacement cycle and heavy revenue losses. Under these conditions, to ensure economical and reliable operation of the grid, power through the lines should be controlled within their capabilities. In case of HVDC systems, the power is automatically controlled as desired by the operator however, control of power in AC network requires special technology to be implemented on case to case basis. Operating efficiency of electric transmission system can be improved by using appropriate FACTS devices. Phase shifting transformer is one of the FACTS family, which can be used for power control in a network. For demonstrating the ability of the phase shifting transformer in regulating the power flow in an alternate transmission network, simulation of Maharashtra zone and Utter Pradesh zone of an Indian grid is considered. From power flow solution, various overloaded lines and the alternate under loaded lines are identified. Different cases are simulated to regulate the power using phase shifting transformer. By introducing phase shifting transformer in to the actual network of the Indian Grid, power flows in the area of interest is re validated and application of PST is justified.**

***Index Terms*—Phase shifting transformer, power flow control, over loaded lines, PSS/E**

I. Introduction

Indian economy is growing at a fast pace. GDP is expected to grow at a rate of 8 to 10%. Infrastructure including power is the main factor for the growth. The demand for power is increasing steadily.

The estimated peak demand amounting to 110000 MW in 2006-07 is expected to grow to 1,50,300 MW in 2011-12. Thus, the installed capacity of 1,39,372 MW in 2006-07 is planned to be 2,03,529 MW by 2011.-12.

To meet this target, Government has decided to develop large capacity power projects at national level. Already seven Ultra Mega Power Projects (UMPP) of 4000 MW each have been identified. These are planned at pit head and coastal sites. Three pit head sites are Sasan in M. P., Akaltara in Chattisgarh and a site to be decided in Orissa.

Four coastal sites are in Andhra Pradesh, Gujarat, Maharashtra and Karnataka [1].

Transmission grid is used as a transport medium between generation and load centers. Transmission planning has to be done in such a way that besides conserving Right of Way (ROW) for new lines, optimum utilization of existing lines has to be made.

Physical path between generation and load centers for power transmission is a group of alternate paths.

There could be uneven loading of parallel transmission lines due to different impedances caused by the tower geometry, conductor sizing, number of sub-conductors and line length. The distribution of the power flow between two parallel lines is dictated by their impedances. The line with the smaller impedance carries more power and vice versa. In most situations, one of the two lines will be operating well below its nominal rating because otherwise parallel line with lower impedance would be overloaded [2].

Due to uneven loading of interconnectors in meshed networks, the total power transmission from generation to load center, is lower than expected when looking at the capacities of the lines.

In view of above, the power flows need to control in order to achieve the optimum utilization of transmission lines capacity. A phase shifting transformer (PST) can be employed for power control in transmission lines.

Transformers are used to transport electrical power between different voltage levels of the electric grid. Special transformers used to create a phase shift between the primary side voltage and secondary side voltage, are termed phase shifting transformers. The purpose of this phase shift is to control the power flow over transmission lines. Both the magnitude and direction of power flow can be controlled by varying the phase shift [3].

II. Phase Shifting Transformer

The active power and reactive power transmission over a transmission line is given by the following equations:

$$P = \frac{|Vs| \quad |Vr|}{XL} \sin\delta \tag{1}$$

$$Q = \frac{|Vs| \quad |Vr|}{XL} \left(\cos\delta - \frac{|Vr|}{|Vs|} \right) \tag{2}$$

where *Vs*, *Vr* are sending end and receiving end voltages respectively. δ is power angle, XL is line reactance.

The active power is proportional to the voltages on the sending and receiving side and to the sine of the electrical

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angle between both sides; it is also inversely proportional to the line reactance. Altering the active power can be done by altering the voltages, but this has a bigger influence on the reactive power, so this method is not very effective.

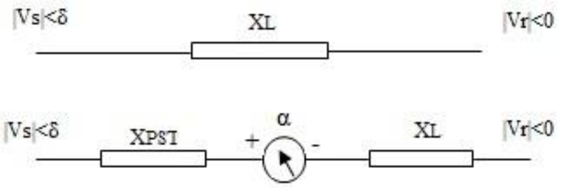

Fig. 1. Model of transmission line without and with a PST [2]

The method discussed is the method of altering the electrical angle, as shown in Fig. 1. The PST is modeled as a reactance (X_{PST}) in series with a phase shift. The power flow through the line is increased by adding an angle α to the existing angle δ. The phase shift is controllable within certain limits [2]. Equation (1) becomes:

$$P = \frac{|Vs| \quad |Vr|}{XL + X_{PST}} \sin(\delta + \alpha) \qquad (3)$$

Fig. 2 shows connection diagram of conventional phase shifting transformer. It consists of an excitation transformer (ET), a boosting transformer (BT), and set of mechanical switches. Basic function of PST is to control power flow through the transmission line. This is accomplished by modifying the voltage phase angle by inserting a variable voltage (VB) in series with transmission line. This voltage is provided by the excitation transformer, amplitude is controlled by tap changer. The leakage reactance (X_{PST}) of boosting transformer is in series with the line impedance [4].

III. Main Categories Of PSTS

For influencing the real power flow, the most often used are the quadrature symmetric or the quadrature non-symmetric PST's.

A quadrature type phase shifter is a unit where the boost voltage, which creates the phase shift between source and load terminals, is perpendicular to the line voltage at one terminal, or to a combination of the line voltages at source and load terminals.

The term "symmetric" means, that under no load condition the voltage magnitude at load side is always equal to the voltage magnitude at the source side, independent from the phase angle.

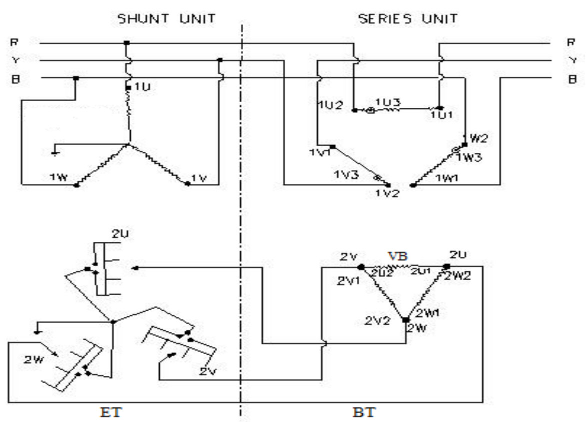

Fig. 2. Connection diagram of phase shifting transformer [5]

Quadrature non-symmetric devices add a quadrature voltage to the input voltage. The output voltage is the vector sum of these two perpendicular voltages (therefore the output voltage is boosted by a small amount).

Voltage phasor diagrams for different transformers are shown in the Fig. 3. The voltage control by classical regulating transformer is shown in Fig. 3a, the phase angle control by quadrature symmetric PST is shown in Fig. 3b and Fig. 3c shows the phase angle control by quadrature non-symmetric PST [6].

IV. PST Model in PSS/E Software

PSS/E software is used for modeling the system. The equivalent circuit of Fig. 4 used to represent adjustable phase shifters. These units use tapped zigzag-connected windings to produce an adjustable phase shift between primary and secondary windings.

PSS/E allows the user to specify both the amplitude winding ratios and phase shift of transformer. The phase shift angle is the angle by which winding 1 leads winding 2. PSS/E power flow solution includes logic for automatic adjustment of both turns ratio (t) and phase shift. It must be noted that the automatic adjustment of turns ratio does not alter phase shift and, more importantly, that PSS/E assumes that turns ratio is independent of adjustment of phase shift. Power distribution over the lines depends on the voltage shift between the voltage at transformer terminals as well as on the impedances [7].

V. Simulation and Results

Bulk power generation and heavy loads are situated far away from each other. Existing transmission lines get overloaded with the new generation planning; especially lines with lower impedance will get over load. In order to maintain reliability, new transmission lines need to be erected, which requires additional expenditure. Alternatively, the existing infrastructure could be used with optimization using FACTS devices [8]. The device should be placed either in lightly loaded line or in over loaded lines to optimize loading conditions. Many other aspects such as space availability need to be considered.

With the addition of generation and transmission system some times, more than one bus need to be created. It has been observed that in a multi bus configuration of substation sometimes some buses may not be able to support the load/generation, e. g. at Kottagudem Thermal Power Station, Vizag, 400 kV bus is connected to 220 kV bus through a conventional ICT. Some of the 220 kV lines which are already over loaded could further over load. Under such conditions PST between 400 kV Land 220 kV buses not only load the 400 kV lines to the possible extent but also relieve the over loaded 220 kV lines to its nominal capabilities.

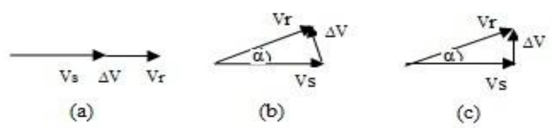

Fig. 3. Voltage phasor diagrams for different transformers [6]

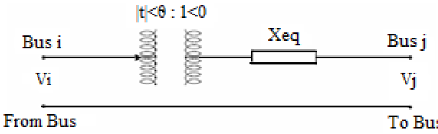

Fig. 4. Transformer equivalent circuit representing phase shift [7]

The aim of this paper is to study various applications of PST in power flow control. The system data for load flow studies consists of the data pertaining to transmission lines, generating transformers, interconnecting transformers, HVDC converters, generation, substation-wise load distribution, shunt compensation and series compensation etc. M/s Power Grid Corporation of India Limited (PGCIL) has provided the network steady state data of 2012 for peak load. The data are also verified by M/s Central Electricity Authority (CEA).

Various cases in Maharashtra zone and Utter Pradesh zone of Indian grid have been studied, to demonstrate the PST application in order to optimize the utilization of the existing infrastructure without over loading.

We used PSS/E software for simulation and prepared SLDs of interest of area as discussed and shown in further sections.

A. *Maharashtra Zone*

1) *SLPR22 Region*

There is a 332 MW load connected at OSMNBD bus, which is supplying by two lines, 1) from PARL22 to OSMNBD 2) from SLPR22 to OSMNBD. But, line between PARL22 & OSMNBD loaded to 280 MW (full load consideration is 200 MW) and line between SLPR22 & OSMNBD is loaded to 65.3 MW only as shown in Fig. 5.

We could make use of line between SLPR22 & OSMNBD to relieve the overloaded line between PARL22 & OSMNBD. A PST is introduced in line between SLPR22 & OSMNBD at SLPR22 bus and increased power in this line to 150 MW in the same direction. The line between PARL22 & OSMNBD got relieved from over load as shown in Fig. 6.

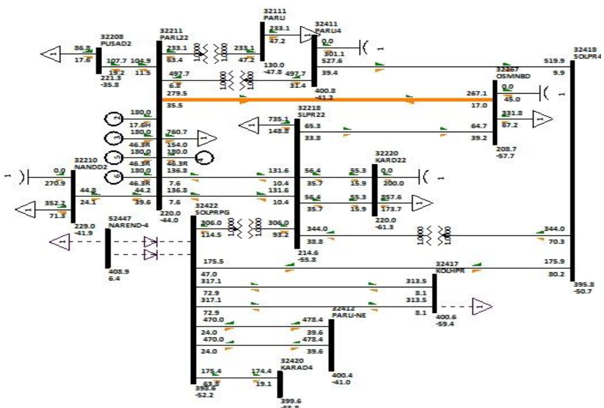

Fig. 5. Network connected to SLPR22 bus without PST

The very purpose of PST is to change the power angle of bus where it is connected. It can be observed that power angle can be controlled at specific location which will also have an effect in the entire network around PST.

The effect will be maximum at the bus in question and will be comparatively less on further buses. Hence, there will be incremental change in power flow scenario around further buses.

2) *KOYAN Region*

LPRSRM bus is supplying 187.2 MW load. The power is loaded from KOYNA2 through 220 kV line which is loaded to 268.9 MW. Balance power of 81.7 MW is flowing from LPRSRM to KNDLG2 as shown in Fig. 7. The capability of line between KOYNA2 to LPRSRM is only 200 MVA, which means, it is loaded to 145 %. In order to relieve this line from over loading, PST is proposed at LPRSRM bus, in line between LPRSRM and KNDLG2, which can load the line between LPRSRM and KNDLG2 line to 81.6 MW in reverse direction, there by relieving the line between KOYNA2 and LPRSRM to its capability as shown in Fig. 8. Also it is ensuring that no other lines in the vicinity are getting overloaded.

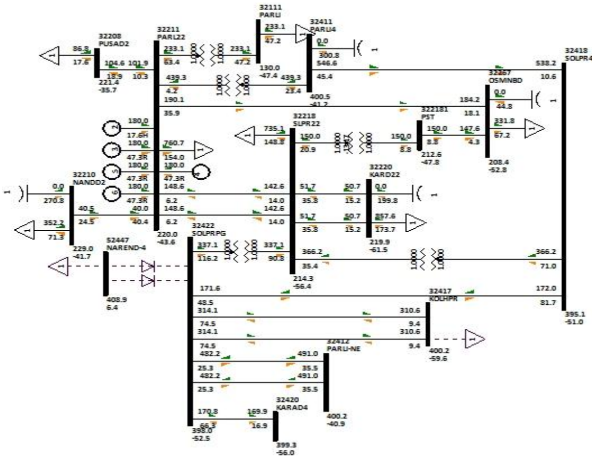

Fig. 6. Network connected to SLPR22 bus with PST

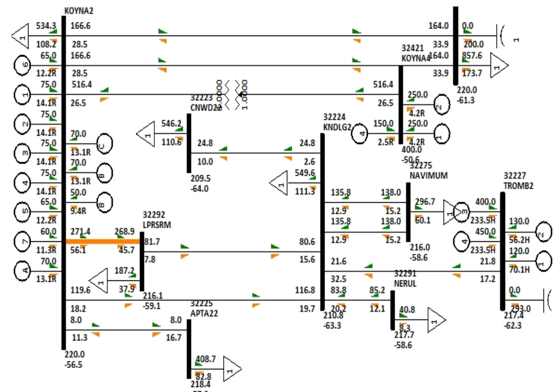

Fig. 7. Network connected to LPRSRM bus without PST

B. *Utter Pradesh Zone*

We simulated Utter Pradesh zone of Indian power system, identified an over loaded 400 kV line from UNNAO4 to PANKI4 as shown in Fig. 9.

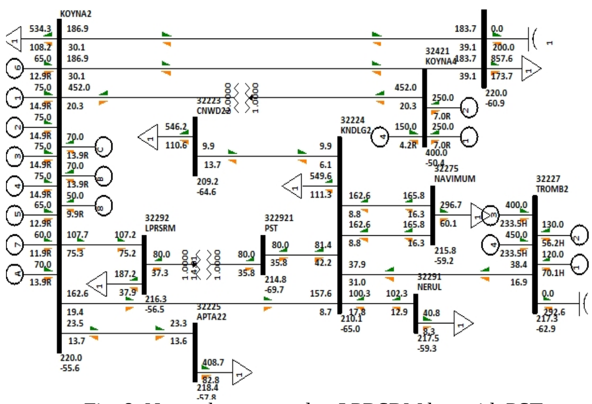

Fig. 8. Network connected to LPRSRM bus with PST

There are alternate lines, which are under loaded. If we limit the power flow in line between UNNAO4 & PANKI4 to ≤ 500 MW, it will get relieve from over load. Part of the power is diverted through alternate lines.

PST is considered in line between UNNAO4 & PANKI4 at UNNAO4. PST decreased the power in line between UNNAO4 & PANKI4 from 663.8 MW to 450 MW as shown in Fig. 10.

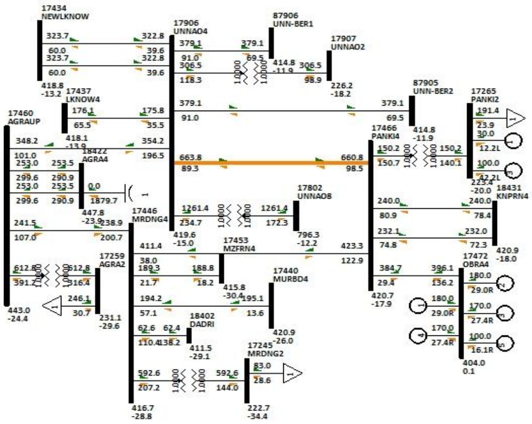

Fig. 9. Network around UNNA04 bus without PST

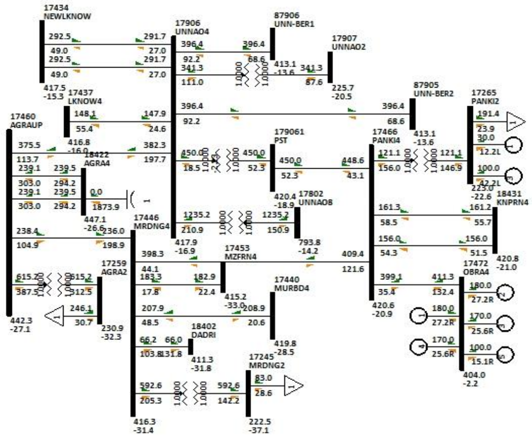

Fig. 10. Network around UNNA04 bus with PST

VI. Conclusions

The paper has discussed the accelerated growth of Indian power sector and the need for installing the PST in transmission network. There could be such situations in entire Indian grid where application of PST for control of the power could be studied. The paper discussed the basic principle of PST and types of PSTs. From simulation results, it is clear that PST can be used for control of active power distribution over the transmission lines. In case A.1, we proposed PST in under loaded line for sharing load from over loaded line. In case A.2, PST used to change the direction of the power flow in alternate under loaded line. In case B, PST is introduced in overloaded line itself, to limit power flow within its capability in the same direction. The paper has reviewed different applications of PST for power control like relieving over loaded lines.

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