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Power Flow Control in AC Transmission System Using Phase Shifting Transformer (PST); A Review

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Abstract - *Over the years, power system engineers have faced difficulties in achieving the best possible power flow. To guarantee the best possible power flow, the power system has integrated a number of techniques and technologies, from traditional to the usage of contemporary FACTS devices. Numerous power system issues, such as line overloading, voltage instability, transient instability, power system congestion, and others, can be mitigated by the FACTS devices. By altering its phase angle, a phase shifting transformer (PST), a FACTS device, can regulate power flow issues in a network. PST may reroute and redistribute power flow from overloaded lines to the less laden ones when it is put in the proper places on the power system. The power flow regulation method based on PST has good steady-state effect. It can improve the utilization efficiency of power grid assets and optimize the power flow distribution in a short time and at low cost.*

Key Words: Phase Shifting Transformer, Power System, Power flow control, MATLAB,

1.INTRODUCTION

Over time, the security of the power system has been continuously endangered by transients, the loss of one or more system components, and the addition of an ever-increasing load. Because an outage or transmission line breakdown could cause overload on other lines, increased power demand poses a significant challenge to the power system's ability to handle load. As a result, the transmission lines may break in a cascade, which could lead to a partial or complete system failure.

With the development and wide application of new energy, power systems are becoming more and more complex. Transmission lines are characterized by long distance, high voltage, and large capacity. The grid connection of new energy leads to the decline of power system reliability, and transmission lines may have overload, circulation, and other problems. How to regulate and optimize the power flow distribution and enhance the reliability of power system has become a hot issue. In the past, the above problems were solved by controlling the operation mode of power system, such as adjusting transformer tap, changing the operation mode of generator set, and switching compensation device. These methods have some limitations and cannot flexibly regulate the power flow.

Overloading on of transmission lines in the power system can be mitigated by appropriate redistribution of power flow from the overloaded lines to the less loaded lines. One of the effective techniques used to control power flow in a system is the installation of phase shifting transformers (PST) on appropriate lines. PST is FACTS device controls the active power flow by means of varying its phase angle between the primary side voltage and the secondary side voltage. This helps to regulate the flow of power on the lines and between the buses in the power system [14]. This phase shift of the PST controls the active power flow, both in magnitude and direction.

The primary purpose of power flow analysis is to enhance power quality through system operation and planning. They identify and alert users to overloaded components in the voltage profiles. Additionally, the power flow system can be used to estimate the system's future load demand and analyze reliability indices. The extremely prevalent Two popular power flow techniques in transmission systems, Gauss-Seidel and Newton-Raphson, perform worse in distribution systems due to their reduced resilience. This happens as a result of the network's distribution nature, which is designed with a dial or weakly meshed topology and a very high R/X ratio. Numerous approaches, including Z-bus Gauss techniques and backward-forward sweep, have been proposed to reduce these issues. Moreover the direct approach (DA) also proposed which is the very efficient and unique. The direct approach (DA) technique save time for performing LU factorization which involves backward and forward substitution of the admittance matrices or jacobian, which are commonly manual formulations. Thus, the design of direct approach (DA) allows the application of real-time in the smart grid. Therefore, reference used DA methods to analyze optimal power flow (OPF) in FACTS distribution network for industrial grid.

2. POWER SYSTEM ANALYSIS MODEL

In order to determine the state of the transmission system, it is crucial to ascertain the voltages and the entering power at difference buses. Thus, the voltage angle is always set to a reference bus number, which produce 4N-1 variable. When two voltages and injection power are unknown, there will be

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two balance equation of power i.e 2N-1 equations. Therefore, we must assign 2N variables for the transmission system

Power system analysis models are mathematical representations that simulate the behavior of electrical power systems under various conditions, including normal operation and disturbances. These models help engineers analyze and predict system performance, design components, and ensure reliable and efficient power delivery.

$$[Vec(R_j)]^T (y_{PF} \otimes y_{PF}) - \alpha = 0 \quad J=1,\ 2N\text{-}1 \qquad ......1$$

Where R and α are the matrix and the right-hand side, respectively regarding either the power injection or the . From the equation (1) the system is overestimated, which means=square of voltage magnitudes; and y v PF only 2N-1 which indicate one slack bus to analyze for the power system. Also v can be denoted as the optimization solution

$$Y_{PF}^{SOL} = \arg_{min} \begin{bmatrix} Ve(R_1)^T \\ \vdots \\ Vec(R_{2N-1})^T \end{bmatrix} (y_{PF} \otimes y_{PF}) - \begin{pmatrix} \alpha_1 \\ \vdots \\ \alpha_{2N-1} \end{pmatrix} = \arg_{min} (A_{PF} (y_{PF} \otimes y_{PF}) - b_{PF}) \qquad .....2$$

Hence, if solution in equation (1) and (2) are equal then

$$A_{PF} \left(Y_{PF}^{SOL} \otimes Y_{PF}^{SOL} \right) - b_{PF} = 0$$

3. PHASE SHIFTING TRANSFORMERS

PSTs, also known as Phase Angle Regulators (PAR), are characterized by having a secondary voltage with a controlled phase-shift in relation to the primary voltage. They are simply special transformers used to create a phase shift between the primary side voltage and secondary side voltage. 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. The same amount of active power can be transported over the transmission line with a smaller value of delta ,i.e. the phase angle between source and receiving end.

They are based on one 3-phase core. The phase shift is obtained by connecting the windings in an appropriate manner. This PST is also known as single core design because it is manufactured using one single core. It is used at lower voltages, for smaller phase shifts and smaller PST ratings. In addition, it has also fewer winding segments and it does not need a separate excitation transformer. The short-circuit impedance of a PST of single core design is very low at tap positions near 0-degree phase angle shift, hence the ratio between the external fault currents passing through the PST and its rated current may become very high, especially in systems with low fault current impedance

Asymmetrical PST

The asymmetrical single-core PST is also known as half-tap PST due to having just half of a full regulating winding. When the PST is working under no-load conditions, the voltage magnitude on the load side is different from the one on the source side. Frequently, the difference increases as the phase angle shift α increases. In this type of transformer, the commutation between the advance and retard modes is done by a switch in each phase that connects the excitation windings to the series windings.

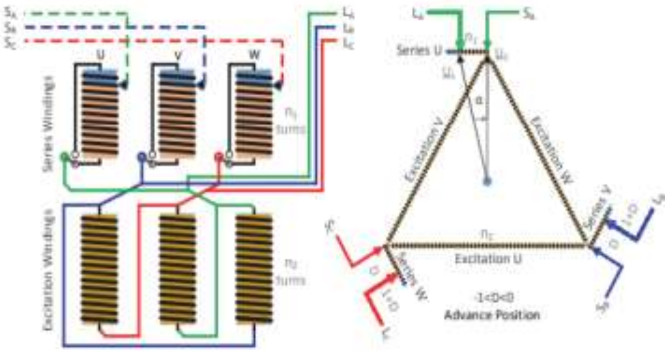

Figure 3.1.a and 3.1.b shows Schematic representation and phasor diagram of a single-core asymmetrical type PST

Symmetrical PST

The single-core symmetrical type is also known as "Standard/Extended-delta single-core PST". In the symmetrical type, the voltage magnitude under no-load conditions is identical in source and load sides, with the phase angle shift having no effect on them. In this type of transformer, the commutation between advance and retard modes is done by two switches per phase. This differs from the single switch in the asymmetrical type due to the fact that the series windings on this type of PST are in fact split in two.

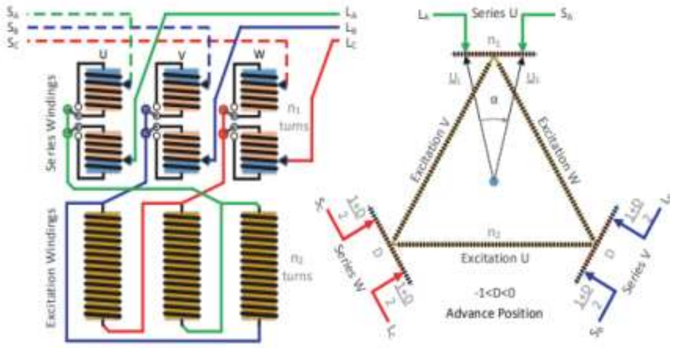

Figure 3.2.a and 3.2.b shows Schematic representation and phasor diagram of a single-core symmetrical type PST respectively.

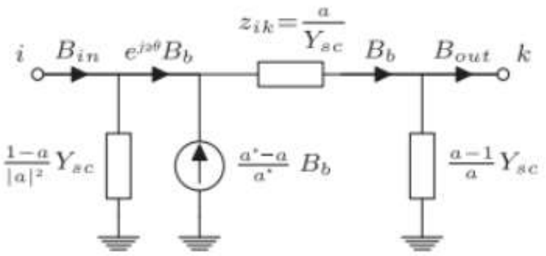

Figure 3.3 Phase shifting transformer model

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When we are approaching a mesh grid system into a power grid with PST, there are many changes to be made in equations. While calculating its effect on the system we have to consider many situations.

The series impedance zik shown in figure is used to represent the impedance between nodes i and k within the BCBV matrix. Ysc stands for its short circuit admittance.

B out=a* B in

With phase shifting transformer that a is now a complex number, i.e. a=|a|eiθ; |a| being the regulation between the primary and secondary voltage magnitudes and θ being the phase shift. If it is a simple tap changing transformer angle θ will be equal to 0. ie a won't have any angle only magnitude.

The calculation of the current injection augmented vector I, YB has to include new shunt admittance terms at the sending bus, i, and receiving bus, k.

The phase shifting transformers are usually used in power system for control of power flow in a transmission lines. The control of power flow is very important for determination of system market at different operators. Thus, phase shifting transformer (PST) gives total reliable and cheap solution for power flow control compared with FACTS devices. Also, phase shifting transformers (PST) are uniquely designs and model with standard power transformers. These transformers are design for various applications but depend on the power system modes. They always design and model in single-core (direct) and two-core (indirect) designs. They also design based on the modes of operation either symmetrical or asymmetrical. In reference [23], the researcher design symmetrical system that changes the phase angle when the source magnitude and Load voltages are equal but asymmetrical changes the voltage magnitude and phase shift which also cause the tremendous changes in reactive power flow. The active power flow in a transmission line is

$$P = \frac{|V_1||\bar{V_2}|}{Z_L} Sin\alpha$$

Hence V1 and V2 are sending and receiving side voltages respectively, α is the phase shift between V1 and V2 and ZL is the reactance of the transmission line. The flow of the active power in the transmission line can be done by controlling the voltages.

4. CONCLUSIONS

In this paper, the working principle, topological structure, selection research, mathematical model, power flow control function, and economic analysis of high voltage phase shift transformer were studied. PST s avoid risk of overloading in transmission grids and help to deviate power flow in our required direction. PST s exist in different forms, The type and specification is chosen according to the requirement of power flow in the transmission system. . The asymmetrical version is relatively simple compared to the symmetrical PST but changes the voltage amplitude. The indirect configuration offers an easier modular design, but the overall cost is higher than the direct version. The active power flow on the line is increased by controlling the phase angles between sending end and receiving end voltages. The phase angles are controlled by changing the tap position on the OLTC. In this paper, Direct Symmetrical Delta hexagonal type PST is chosen for the connections of transformer

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