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Original Research Paper

Engineering

A STUDY ON POWER TRANSFER CAPABILITY OF 400 KV TRANSMISSION LINES BY EMPLOYING PHASE SHIFTING TRANSFORMER

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ABSTRACT Phasor simulations play a critical role in analyzing the dynamic behavior of power networks, ensuring effective power flow control under diverse operating conditions. This technology supports both active and reactive adjustments to optimize power flow and maintain system stability. In power transmission networks (PTNs), incorporating Phase-Shifting Transformers (PSTs) along with preventive and corrective control strategies enhances system controllability and reliability. This paper studies and analyzes the power transfer capability of 400 kV transmission lines using Phase-Shifting Transformers through simulation methods.

KEYWORDS : Phase Shifting Transformers (PSTs), Power Transmission Networks (PTNs), Power Flow controllability, Phasor Simulation, Line Outage Response.

INTRODUCTION

Since 1930s, Phase Shifting Transformers (PSTs) have found application in managing power flow within transmission lines during steady operational states. Their main purpose is to exert control over loop currents, ensuring that power follows the intended route as stipulated. These transformers, however, are not designed to amplify power transfer along extended lines.

With the integration of power electronic controllers, PSTs can achieve accelerated operations, enabling real-time adjustments to power flow dynamics. This dynamic adaptability plays a crucial role in enhancing overall system stability and reinforcing measures for dynamic security. These advanced iterations of PSTs are recognized as Static Phase Shifting Transformers (SPSTs) or Thyristor Controlled Phase Angle Regulators (TCPARs), with thyristor devices being the primary choice for achieving these objectives. It's pertinent to mention that innovations in this domain extend beyond conventional approaches. The emergence of Voltage Source Converter (VSC) based Flexible Alternating Current Transmission System (FACTS) controllers have introduced new possibilities. These advancements even allow the application of devices resembling the Unified Power Flow Controller (UPFC) for SPST functions. In a nutshell, the journey of Phase Shifting Transformers spans decades, transforming from their original static form to dynamic solutions managed by electronics. This evolution encompasses various adaptations, encompassing traditional thyristor-based systems to modern VSC-based FACTS controllers like the UPFC. These technological strides collectivelycontribute to refining power flow control, bolstering stability and enhancing dynamic security across intricate power transmission networks.

Figure 1

The normal application involves a power transformer with a tab changer for in phase voltage control in case of a parallel circuit and system interconnection special fees regulation. Transformers are sometimes necessary the application of regulating Transformers involves a detailed study of the requirements in phase coordinator and phase angle voltage control requirements and the choice of auto transformer 2 winding Transformer and supplementary diagram and vector diagram.

II. Basic Principal Of PSTs

Consider an ideal phase shifting transformer shown in Fig.2 The transformer's turns ratio is characterized by a complex value with a magnitude of one (α = e ^ jϕ),where ϕ signifies the phase angle shift, which can be either positive or negative. This signifies that the transformer's primary and secondary sides are intrinsically synchronized in terms of voltage magnitude.

input and output voltages This technology finds applications in power systems where precise phase angle manipulation is crucial for grid stability, control, and optimization. In the given context, the relationships between the voltages and currents in a transformer are described by the following equations:

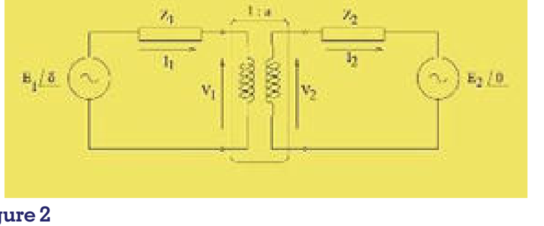


Figure 2

Voltage Ratio and Current Ratios: The voltage reationship between the primary and secondary sides of a transformer is given by:

$$V2 = \alpha \cdot V1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Additionally, the current ratio can be expressed as:

$$I1 = \alpha \cdot I2 = e{-}j\phi \cdot I2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

This is derived from the fact that an ideal transformer has no active or reactive power losses, leading to the equality of apparent power products:

$$V1 \cdot I1 = V2 \cdot I2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Current Calculation: With the relationship between secondary current and voltage given as:

$$I2 = \frac{(V2 - E2)}{Z2}$$

Substituting this into Eq. (2), we find the primary current:

$$I1 = \frac{[\alpha \cdot (\alpha V1 - E2)]}{Z2} = \frac{V1 - \alpha \cdot E2}{Z2} \quad \ldots (4)$$

By employing this innovative design, a phase shifting transformer enables controlled adjustment of the phase relationship between

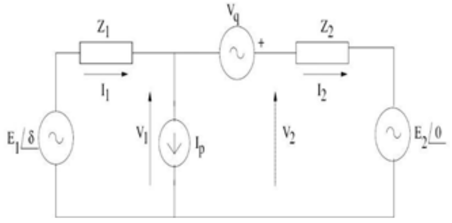


Figure.3

Equation(4)correspondstothecircuit representation depicted in Figure 2.

Neglecting Losses: When neglecting losses in the circuit components,

$$ej\phi \sim 1 + j\phi$$

For small value of ϕ the voltage components:

$$V1 - V2 = (1 - \alpha)V1 = -j\phi V1$$
$$= -Vq \ldots (9)$$

And for the current components

$$I1 - I2 = (\alpha \cdot -1)\,/I2 = -j\phi I2$$
$$= Ip \ldots (10)$$

From Equations 9 and 10, we can formulate a representation of a Power System Stabilizer (PST), as illustrated in Figure 3.

In this representation, the injected voltage Vq acts in quadrature to the voltage $V1$. The current Ip represents the shunt current drawn by the PST. Notably, there is a direct relationship:

$$V1 \cdot Ip = Vq \cdot I2 \ldots (11)$$

Where,

$$Z1 = jx1, Z2 = jx2 \ldots (5)$$

the power flow equation becomes:

$$P = \frac{\{E1E2 \sin(0 + \phi)\}}{x1 + x2} \quad \ldots (6)$$

Here, ϕ is a phase angle that can be adjusted within the range

$$\phi min < \phi < \phi max \quad \ldots (7)$$

limits are symmetric around zero, meaning $\phi min = -\phi max$. These limits are directly linked to the Power System Transmitter (PST) rating.

The question that arises now is how do we arrange for the phase shift ? Noting that

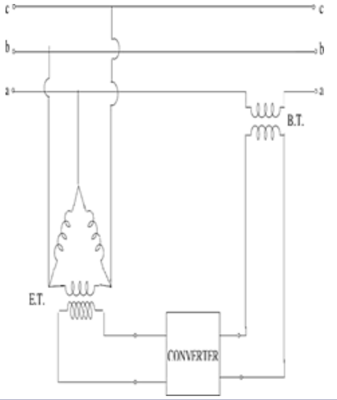


Figure 4

Highlighting that the complex power drawn by the shunt current source (Ip) compensates for thepower provided by the series quadrature voltage (Vq).

In the context of a three-phase system with balanced source voltages applied to the primary windings of the PST, which are interconnected in a delta configuration, certain phase relationships are present. For instance, the voltage Vcb (Vc - Vb) leads Va by 90°. Likewise, Vac leads Vb, and Vba leads Vc by 90 ° each. This configuration leads to a PST design depicted in Figure 4. For clarity, the detailed illustration in Figure 4 only depicts one phase of the Excitation Transformer (ET) and Boost Transformer (BT), while the arrangement in the other two phases remains analogous Within this configuration, the secondary windings of the Excitation Transformer (ET), connected in shunt, provide power to the Boost Transformer (BT), which is connected in series with the power line. A converter, as shown in Figure 4, is positioned between the Excitation TL -Transformer (ET) and Boost Transformer (BT) to regulate both the magnitude and polarity of the quadrature voltage introduced in series.

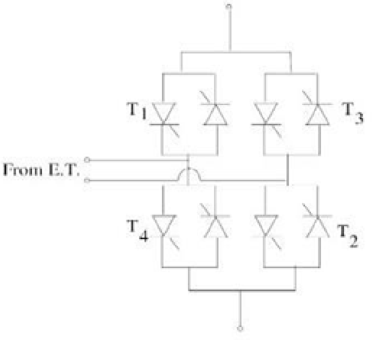


Figure 5

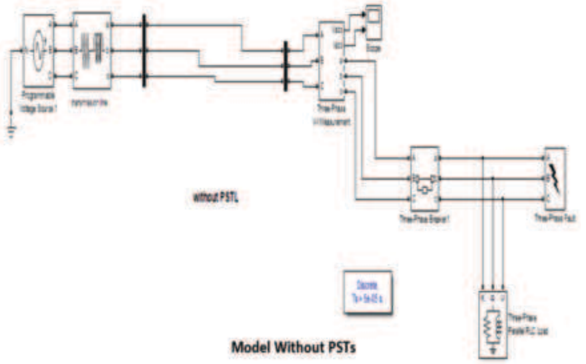
Matlab Simulation

The entire system is simulated using power system toolbox of MATLAB/Simulink. The circuit model for the 400 KV three phase transmission system with PSTs are developed using MATLAB Simulink. The model consist of 400 KV generation system , transmission line pi section of 140 km length , with PSTs or without PSTs . The transmission system employs three phase R-L-C load and connected through circuit breaker . ON load side a three phase fault is simulated . Uttar Pradesh zone of Indian power system identified an over loaded 400 kV line from UNNAO4 to PANKI4 data has been used to obtain simulation results .

Specificfations-

PST : 1000 MVA at 400 kV voltage level and ±30° regulation angle TL : Moose conductor , 140 ckt KM , Total R= 6.0852 OHM, Total L= 0.4323 H

Modelling



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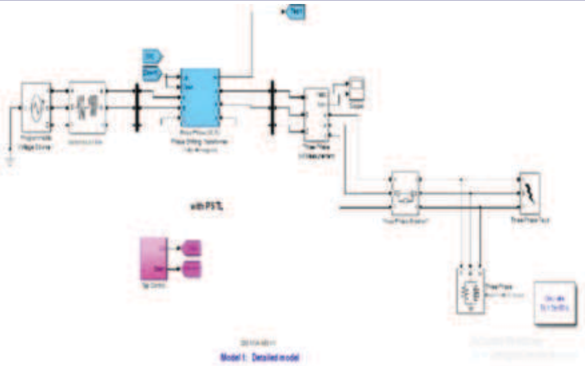
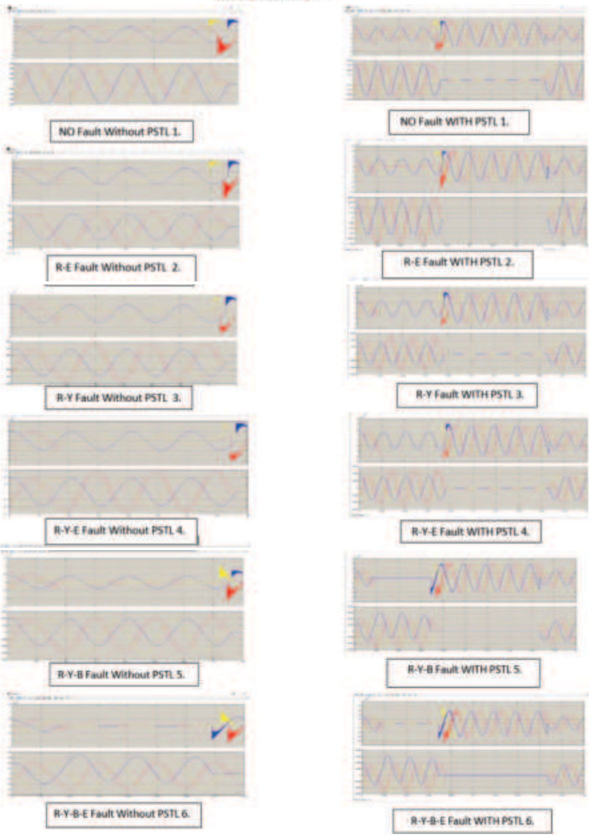


Model With PSTs



RESULT:-

WITH PHASE SHIFTING TRANSFOMER 30 DEG Phase shift						
CONDITIONS	VOLTAGE KV			CURRENT (A)		
	R	Y	B	R	Y	B
No fault	422	422	422	4230	4230	4230
R-E fault	0	422	423	3580	3300	3280
R-Y fault	0	0	422	5150	2670	3296
R-Y-E fault	0	0	422	3580	2975	3300
R-Y-B fault	0	0	0	3576	2972	6346
R-Y-B-E fault	0	0	0	3550	2950	6282

WITHOUT PHASE SHIFTING TRANSFOMER					
VOLTAGE KV			CURRENT (A)		
R	Y	B	R	Y	B
377	377	377	3766	3768	3773
0	376	375	4100	3772	3767
0	0	377	5890	3770	3500
0	0	377	4260	3400	3773
0	0	0	4100	3400	7280
0	0	0	4100	3400	7280

Power Flow

Without PSTL = 377 x 3766 /1000
= 1419 MVA

With PSTL 30 DEG phase shift = 422x 4230 = 1785 MVA % INCREASE = 25.79%

(IV) CONCLUSION

The research highlights the significant advantages of integrating Phase-Shifting Transformers (PSTs) in transmission networks. It demonstrates that PSTs enhance the system's voltage stability and boost power transfer capacity by more than 25% compared to systems operating without them. Simulation results further reveal that PSTs excel in regulating power flow while simultaneously reducing fault currents, which is a limitation of traditional transformers. Unlike conventional transformers that may amplify fault currents and increase line voltage under fault conditions, PSTs effectively mitigate these risks. By decreasing line voltage during faults, they protect network equipment, enhance operational safety, and contribute to overall system stability.

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