

Virtual Current Source Method for Analyzing Flux Density of Shunt Units under Bucking and Boosting Modes

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In phase shifting transformers, power flow is regulated by adjusting the tap position, which also alters the phasor angles of the two excitations in the series unit. However, limited research has been conducted on the impact of two excitations phase angle on the magnetic field of the series unit. In fact, series units are particularly susceptible to operational hazards, especially saturation and thermal issues. In this paper, a virtual current source is put forward to simulate the tap position by changing current angle, and the effect of phasor difference of two excitation on magnetic field of series unit is studied. To demonstrate the efficacy of this approach, a series unit model is constructed and the magnetic field characteristics are analyzed under both bucking and boosting modes.

Index Terms—Bucking and boosting, equivalent circuit, field-circuit coupled model, phase shifting transformers, virtual current source

I. INTRODUCTION

PHASE SHIFTING TRANSFORMERS are crucial for controlling power flow within electric transmission networks [1]. When employed in high-voltage systems, phase shifting transformers typically consist of two units – a shunt unit and a series unit – to meet the appropriate lightning and switching impulse withstand requirements [2]. As depicted in Fig. 1, tap changers in the shunt units are utilized to regulate power flow within the system. By adjusting the tap positions, phase shifting transformers could operate in two modes: bucking mode, which restricts power flow, and boosting mode, which enhances power flow [3].

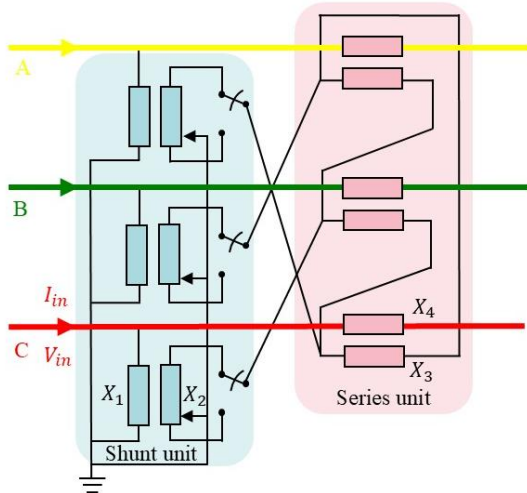


Fig. 1. Connection diagram of phase shifting transformers.

In phase shifting transformers, the series unit is subjected to two excitations [4]: voltage excitation from the shunt unit and current excitation from the power system. The phasor difference between the two excitations changes when the tap position is adjusted. By different phasor angle, the magnetic field of series unit face different situation, especially when the main flux, induced by the voltage excitation, and the leakage flux, induced by the current excitation, reach their maximum

values simultaneously, the magnetic field of series unit would face a challenge.

However, existing research on phase shifting transformers often overlooks the magnetic field behavior within the series unit, particularly the differences of the magnetic field under bucking and boosting mode.

II. VIRTUAL CURRENT SOURCE METHOD

A. Equivalent Circuit of Phase Shifting Transformers

To analyze the two excitations of the series unit, a simplified single-phase equivalent circuit [5] (*Phase C*) is presented in Fig. 2. X_1 and X_2 are the per-unit reactances of the two windings in the shunt unit, while X_3 and X_4 are the per-unit reactances of the two windings in the series unit, and n means the tap position equal to the cubic root of the product of the turn ratios of two transformers. It is noted that there is a star-delta connection between two units, so the across voltage V_b of Winding 3 has a 90-degree phase shift relative to line voltage V_a of Winding 2. That is the reason that the ratio is $1:jn$ in Fig.2.

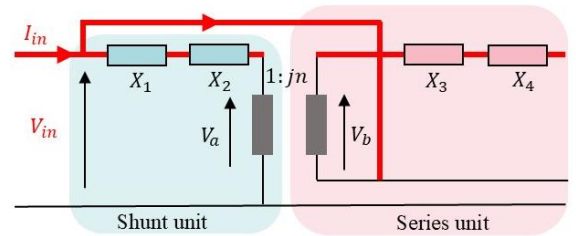


Fig. 2. Equivalent circuit of phase shifting transformers.

From Fig.1, it can be deduced that V_b and I_{out} are voltage excitation and current excitation of series unit. By applying Kirchhoff's Voltage Law and Kirchhoff's Current Law to this circuit, expressions for V_b and I_{out} are derived as given in (1) and (2).

$$V_b = jnV_{in} - (X_1 + X_2) \times \frac{n^2 I_{in}}{1 - jn} \quad (1)$$

$$I_{out} = \frac{I_{in}}{1 - jn} \quad (2)$$

Taking one per-unit phase shifting transformer model as example to study the phasor of two excitation, the base values of input voltage V_{in} and current I_{in} are normalized to 1 under nominal conditions and are aligned in the same direction. The reactance of the shunt unit is represented as j . Under most adjustment conditions, the tap position n varies within the range of -0.2 to 0.2. When $n = 0.2$, corresponding to boosting mode, it can be derived that the current excitation I_{out} lags the voltage excitation V_b nearly 90-degree. Conversely, in bucking mode, when $n = -0.2$, I_{out} leads voltage excitation V_b by approximately 90-degree[6]. This phase difference between the two excitation sources would result in distinct flux density distributions within the transformer's iron core.

B. Virtual Current Source Method for Boosting and Bucking

In a practical electric power system, the current I_{out} is determined by the characteristics of the connected load. In this paper, a virtual current source is introduced within the transformer model to simulate various load conditions by adjusting current phase angle. To investigate the influence of the phase difference between two excitation sources on the flux density within a series unit, the virtual current source is configured to be 90 degrees leading or lagging the voltage source. This approach mimics boosting and bucking modes of transformer operation, as illustrated in Fig. 3.

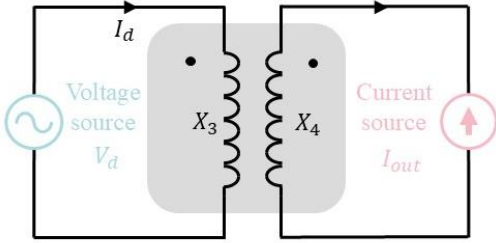


Fig. 3. Field-circuit coupled model with virtual current source.

III. RESULTS AND DISCUSSIONS

A. Boosting Mode

A series unit is constructed with the low-voltage (LV) winding positioned closer to the iron core inside and the high-voltage (HV) winding located outside. The HV winding is connected to a voltage source, while the LV winding is connected to a virtual current source. To simulate the magnetic field under boosting conditions, the current is phase-lagged by 90 degrees relative to the voltage (tap position $n = 0.2$). The system is modeled with $V_b = 107.5 \cos(100\pi t)$ kV and $I_{out} = -450 \sin(100\pi t)$ A.

In a series unit, the main flux, induced by the voltage source, and the leakage flux, generated by the current source, reach their maximum values at the same time. The presence of leakage flux significantly influences the distribution of flux density within the iron core.

Fig. 4 illustrates the flux density distribution at the three-quarter cycle. Focusing on the middle limb, the main flux and leakage flux exhibit a phase difference, resulting in cancellation of the main flux by the leakage flux within this region.

Conversely, in the side limbs, the main and leakage fluxes are in phase, leading to an amplified flux density. The values of middle leg and side leg are 1.48 T and 1.54 T.

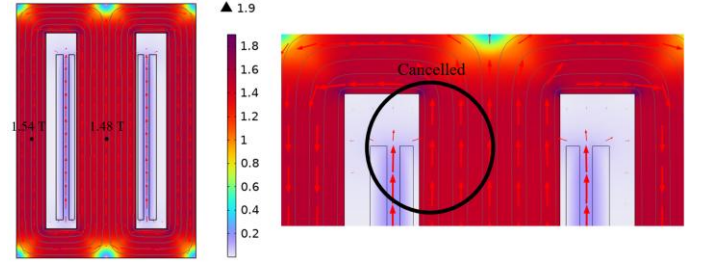


Fig. 4. Flux density distribution under boosting mode.

B. Bucking Mode

In bucking mode, the current leads the voltage by 90 degrees (tap position $n = -0.2$). Analyzing the flux distribution at the three-quarter cycle, the leakage flux aligns with the main flux in the middle limb, while it opposes the main flux in the side limbs. Consequently, the maximum flux density occurs in the middle limb, reaching a value of 1.59 T.

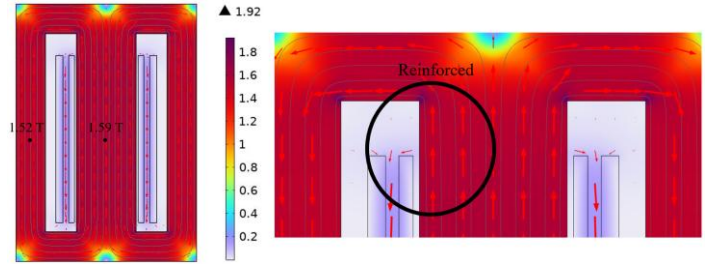


Fig. 5. Flux density distribution under bucking mode.

IV. CONCLUSION

In this paper, a virtual current source is introduced to simulate the excitation in the series unit, and the magnetic field characteristics of the series unit are investigated under both bucking and boosting modes. Besides, a series unit model is constructed as a case to analyze the direction of leakage flux and main flux.

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