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Study of Traction Transformer and Co-Phase Traction System

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L & T CONSTRUCTION
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Abstract—*The traction power supply system of electric railways has the following disadvantages of heavy unbalanced three phase, high content of harmonics in the current and large amount reactive power requirement, making the presence of neutral section insulator in every supply sector mandatory. These problems can be solved by implementing the Co-phase supply system. In this paper a Co-phase system and its properties have been studied. In this system, a new kind of transformer named YNvd transformer has been used. This paper also includes the comparison of Ynvd transformer with other transformers. Power flow in Co-phase system has also been studied and comparison of Co-phase system has been done with the traditional electric traction system. These results, conclusions, studies have been validated and verified under the environment of MATLAB/SIMULINK.*

1. INTRODUCTION

22kV Electric traction is considered one of the most preferred means of transportation in India because it is comfortable and economical. Electric traction fed by 25KV 50 Hz, single-phase AC supply obtained from 3-phase utility. The traction sub-stations that feed power to the contact wire are generally 30-40 km apart. They have an input voltage of 220/166/132/110 KV, which is step down to 25KV using traction transformers. The 25KV is fed to the locomotive through the pantograph fitted on the locomotive. The locomotive consists of a traction transformer that receives 25KV, and steps it down to 1000V to 1500V depends on the type of traction motor.

The single-phase load of electric railway will produce particularly poor power quality. These problems are mainly as follows: (1) which is due to use of very high single phase load which produced negative sequence current (NSC) in the three-phase grid. (2) Very high level of reactive power consumption due to use of DC-series motor and various drive in the traction system (3) the single-phase loads cause voltage unbalance disturbances to the three-phase sources. (4) Converter draws an AC current waveform in the form of narrow pulses, which is rich in harmonics and sub harmonics (**L**iu, 2005). As the amount of rail traffic increases, the issue of power quality distortion becomes more critical (Tan, 2005). This type of problems directly influences the three-phase industrial grid through traction substations

For encountering the problem of the NSC different type of traction transformer, such as impedance- matching balance transformer, Scott transformer, YNd11 transformer are used, but unfortunately, because the speed and load condition of the locomotives in the two-phase feeding system will change frequently, the feeding currents in a two-phase traction supply system are commonly unbalanced. The YNvd transformer one kind of novel three-phase to two phase balance transformer, can be used in electrified railway traction power supply system without phase exchange based on adjustable symmetrical compensations (Qunzhan,1996) also active power filters (APFs) are not widely employed in large scale in traction systems as well, because they are not able to compensate NSC effectively (Morrison,2001). For reactive power compensation and harmonic filtering compensator connected between two phases of balancing transformer (Matas, 2008).

An active power quality compensator with impedance-matching balance transformer and a Scott transformer is proposed in (Morimoto, 2002). Railway static power conditioners (RPC), which contain two converters connected back to back by a common dc capacitor, can compensate negative-sequence, harmonic, and reactive currents of the traction system (Uzuka, 2004). The compensation principle of RPC with Scott transformers is discussed in (Fujii, 2005).An RPC with Δ/Y transformers is proposed in (Matas, 2008).

In this paper, different kinds of traction transformers are evaluated (Fujita, 2009) and it is shown that YNvd transformer becomes more efficient and a preferable choice to work with co-phase system and then co-phase traction power supply system with YNvd transformer and active power compensator (APC) is proposed which is based on RPC system. YNvd transformer is used for power balancing and back-to-back converter with a DC link is used reactive power compensation and harmonic filtering. (Han,2010).

2. CIRCUIT ANALYSIS OFTRANSFORMERS

To evaluate the V-V, Scott, and Le Blanc-connected transformers, two assumptions are $k_1 = (N_1|N_2)$and$k_2 = (N_2|N_1)$ denote the turn ratios.

2.1. V/V Connection transformer

V/V traction transformer configuration is shown inFig.1. The Fig. shows twopower supply modes. The transformer draws three-phase currents from the primary side, and supplies two single-phase loads on the secondary side.

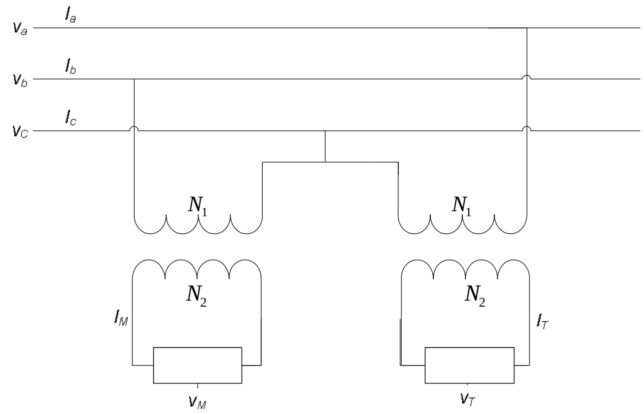

Fig. 1: V-V connection scheme.

Relationships between the primary and secondary-side phasor voltages and currents are, respectively, as follows

$$V_{ab} = V_a - V_a = k_1 V_T$$
$$V_{bc} = V_b - V_c = -k_1 V_M$$
$$V_{ca} = V_c - V_a = k_1 (V_M - V_T)$$
$$I_a = k_2 I_T$$
$$I_b = -(I_a - I_c) = k_2 (I_T - I_M)$$
$$I_c = k_2 I_M$$

2.2. Scott Connection transformer

The configuration of SCOTT traction transformer is shown in Fig2. Scott traction transformer consists of two single phase transformer M and T. The magnitude of the voltage at the secondary side is equal. The voltage angle of T transformer is 90° in lead of M.

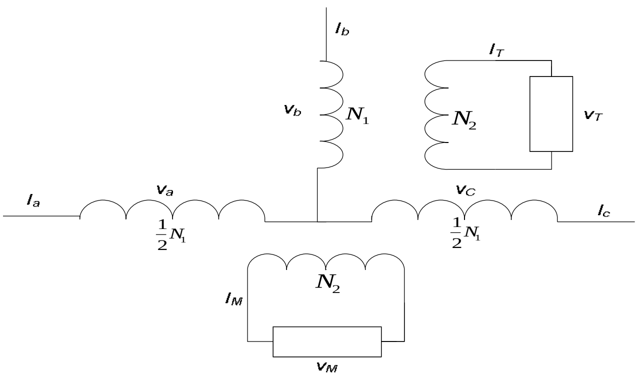

Fig. 2: Scott connection scheme.

The phasor voltages and current relationships are, respectively, as follows:

$$V_{ab} = V_a - V_a = \frac{k_1}{2}(\sqrt{3}V_T - V_M)$$
$$V_{bc} = V_b - V_c = -k_1 V_M$$
$$V_{ca} = V_c - V_a = -\frac{k_1}{2}(\sqrt{3}V_T + V_M)$$
$$I_a = \frac{2}{\sqrt{3}} k_2 I_T$$
$$I_b = k_2 (I_M - \frac{1}{\sqrt{3}} I_T)$$
$$I_b = -k_2 (I_M + \frac{1}{\sqrt{3}} I_T)$$

2.3. Impedance balancing transformer

The configuration of Impedance balancing traction transformer is shown in Fig.3. Primary windings are usually delta-connected to suppress the third harmonic currents from loads. It consistsfive special winding on the secondary side which separate into two phases.

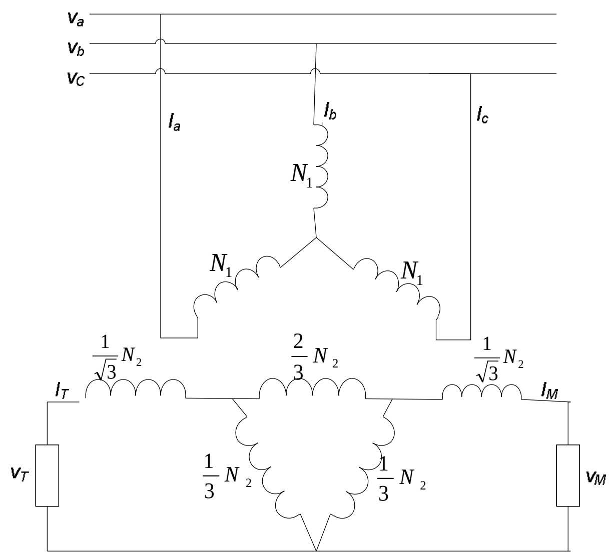

Fig. 3: Impedance balancing transformer scheme

The phasor voltages and currents relationships are, respectively, as follows

$$V_{ab} = V_a - V_a = -k_1\left(\frac{\sqrt{3}}{2}V_T + \frac{3}{4}V_M\right)$$
$$V_{bc} = V_b - V_c = \frac{3}{4}k_1 V_M$$
$$V_{ca} = V_c - V_a = k_1\left(\frac{\sqrt{3}}{2}V_T - \frac{3}{4}V_M\right)$$
$$I_a = -\frac{2}{\sqrt{3}} k_2 I_T$$

$$I_b = k_2\left(\frac{1}{\sqrt{3}} I_T + I_M\right)$$

$$I_c = k_2\left(\frac{1}{\sqrt{3}} I_T - I_M\right)$$

2.4. YNvdtransformer

YNvd traction transformer configuration is shown in Fig.4. The YNvd transformer one kind of novel three-phase to two phase balance transformer, can be used in electrified railway traction power supply system without phase exchange based on adjustable symmetricalcompensations.

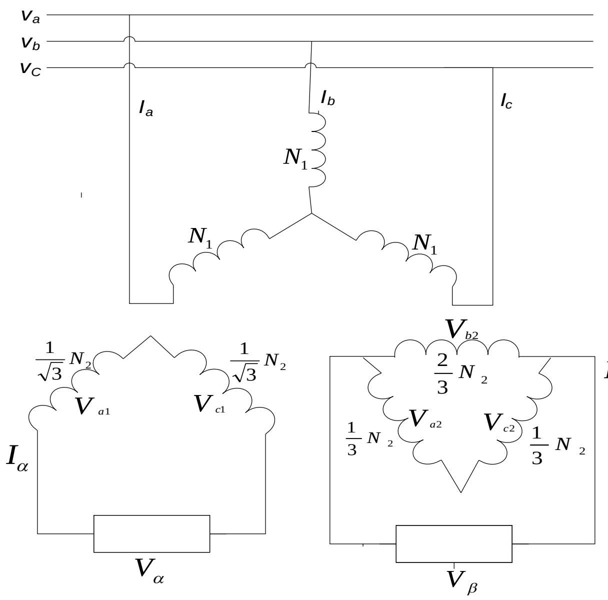

Fig. 4: YNvd Transformer scheme.

The primary side of Y connection, the secondary windings composes two groups, one is V-type connection called α-phase and the other is delta-type connection called β-phase. $V_\alpha$andV_βRepresent a two phase voltage system with a phase angle 90° between them. Mathematic modeling as follows

2.4.1 YNvdtransformer input voltages $V_aV_bV_c$And output voltages $V_\alpha V_\beta$Are:

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \frac{1}{K}\begin{bmatrix} 1/3 & 0 & -1/\sqrt{3} \\ -1/\sqrt{3} & 2/3 & -1/\sqrt{3} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

From (1)

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{1}{K}\begin{bmatrix} 1/3 & -1/\sqrt{3} \\ 0 & 2/3 \\ -1/\sqrt{3} & -1/\sqrt{3} \end{bmatrix} \quad (2)$$

2.4.2 Output-port voltage equations:

$$V_\alpha = V_{a1} - V_{c1}$$

$$V_\beta = V_{b2}$$

2.4.3 Output-port current equations:

$$I_\alpha = I_{c1} = -I_{a1}$$
$$I_\beta = I_{c2} - I_{b2}$$

It is found that there is no mutual impedance and electrical contacts between α and β-phases and α-phase is nominated as the leading phase, and β phase the lagging phase.

2.4.4 Condition for balancing:

$$|V_\alpha| = |V_\beta|$$

$$V_\alpha = jV_\beta$$

$$|I_\alpha| = |I_\beta|$$

$$I_\alpha = jI_\beta$$

3. CO-PHASE SYSTEM

A co-phase system transmits power from three phase grid utility for traction network using single-phase feeding wire. In a co-phase system the two adjacent SSs who adopt this system can supply in the same phase. The system configuration of the co-phase power supply system is given in Fig. 5, in which an YNvd transformer is selected owing to its low cost and simple connection. The YNvd transformer one kind of novel three-phase to two phase balance transformer One phase (α) supplies the traction loads, and another (β) is connected with an active compensator named APC.

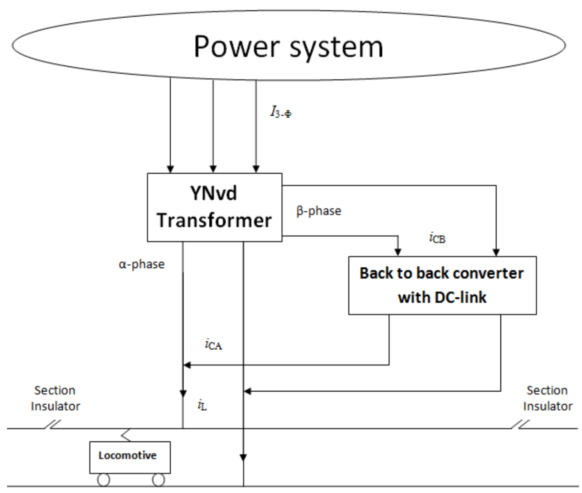

Fig. 5: Co-phase system model

The traction power system is separated into electrically isolated sections with length of 20– 30 km by neutral section (NS). The length of the NS varies from several hundred meters to more than 1 km. Because in co-phase system only one wire is fed into the system instead of two-phase feeding wires in a traditional scheme therefore number of neutral sections can be cut down by half than two-phase supply scheme. The adjacent SSs can supply power in same phase they have minor different value in terminal voltage. Therefore, the neutral section can be substituted by section insulator for safety between two co-phase supply sections. But the requirement of insulation is reduced than the traditional scheme. It reduced capital investment. Also in co-phase system, both two outputs of the YNvdtransformer supply the same section. As a result, the maximum rating of the locomotive on each section is doubled without increasing the capacity of the traction transformer.

3.1. Reactive Power Compensation And Harmonics Filtering

The back to back converter APC acts as a STATCOM for single-phase nonlinear load. One phase (phase α) supplies the traction loads, and another (phase β) is connected with an active compensator. The full-bridge converter (phase α side) rectifies the power from ac side to dc-link capacitor as a rectifier, or conversely converts the power from dc-link capacitor to ac side as an inverter (phase β side).Phase α absorbs entire reactive power of traction load, and the phase β only exchanges active power between grid and dc-link capacitor in order to control the dc voltage. The grid-side currents has been balance by active power transfer between α-phase and β -phase. The β-phase converter absorbs active power from the grid side. If the active power taken by the α-phase is smaller than that provided by the β-phase converter, the DC-link voltage increases and vice versa. Hence, the β-phase converter also works for DC-bus voltage control. The harmonic compensation is done by the α-phase converter.

3.2. Power Flow

The feeding wire is full-loaded the APC needs to transform only half of the load power from phase β

Winding to phase αwinding (Zeliang, 2011).Total load power P_L is as follows:

$$P_L = 2 \times P_f + Q_f + H$$

Where $P_f$active power isQ_f reactive power and H is representing harmonics. Reactive power can be generated by phase α converter only. In a similar way, harmonics can also be controlled and compensated by phase α converter therefor these are not flowing from β-phase.

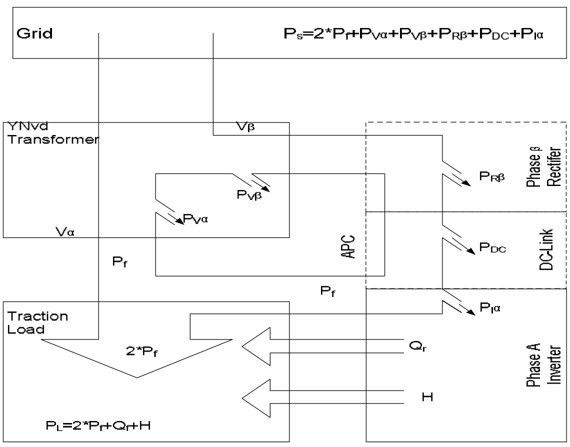

Fig. 6: Power flow diagram of co-phase traction power supply system.

Fig 6 shows the Power flow diagram of co-phase traction power supply system.

$$P = 2 \times P_f + P_{VA} + P_{VB} + P_{RB} + P_{DC} + P_{IA}$$

$P_{V\alpha}$ =Transformer losses of phases α

$P_{V\beta}$ =Transformer losses of phasesβ

$P_{R\beta}$ =Losses of phase β rectifier

P_{DC} =Losses of dc circuits

$P_{I\alpha}$ =Losses of phase α inverter.

4. SIMULATION & RESULT

An electrified traction system with two railway feeders is considered for this study. Grid side voltage is 132kv and traction load on each railway feeder is supplied by a 25 kV single phase via a distribution transformer. Then this voltage is again stepping down by locomotive transformer in a range of 1000 to 1500 according to the requirement of traction motor. Simulations of co-phase and traction load are done by using MATLAB/SIMULINK for verification of the feasibility of the system.

4.1 Simulation Result

Simulation result of output voltage in Fig. 7 shows that the magnitude is same and phase difference between two phases is 90°. Fig. 8 shows that balance primary current.

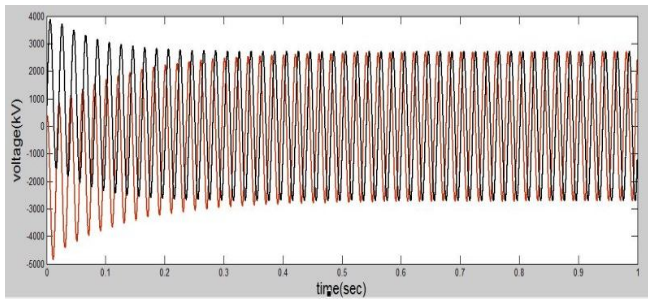

Fig. 7: Result of output voltage

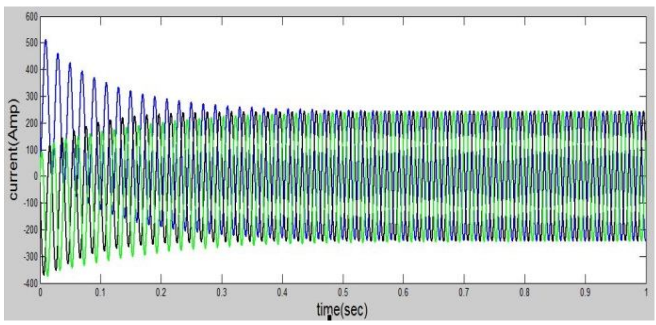

Fig. 8: Balance primary current.

5. CONCLUSIONS

Loading characteristics of a v/v transformer, Scotttransformer, impedance matching transformer andYNvd transformer for the electrified traction system has been studied.It provides useful guidance for the selection of reasonable traction transformer to meet the requirement of the power quality in the public grid.Then co-phase traction power supply system with YNvd transformer and APC is discussed. In a co-phase system only one wire is fed into the system instead of two-phase feeding wires in a traditional scheme therefore numbers of neutral sections can be cut down by half than two-phase supply scheme. It requires relatively small capital investment and also in this co-phase system section insulator is used in place of neutral section therefore losses of power are reduced and overall performance of traction system is improved. These studies have great significance on the design and application of new co-phase traction power supply system.

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