**TELKOMNIKA Indonesian Journal of Electrical Engineering**
Vol. 13, No. 1, January 2015, pp. 20 ~ 25
DOI: 10.11591/telkomnika.v13i1.6724 

# A Decoupling Structure of Controllable Reactor of Transformer Type

**Yu He*, Huatai Chen**
Power Supply Company of Baiyin, Baiyin, 730900, China
*Corresponding author, e-mail: 469721978@qq.com

***Abstract***

*In order to make controllable reactor of transformer type (CRT) working of safety, reliable and compensation effect is obvious, the principle of "high impedance, weak coupling" must be satisfied in the design of CRT structure. The magnetic integration technology used in the design of the ontology of CRT in this paper, a decoupling integrated core structure is proposed. This paper also calculates the leakage reactance and current of decoupling structure.*

***Keywords:*** *controllable reactor of transformer type, magnetic integration, equivalent circuit*



## 1. Introduction

In the EHV transmission system, in order to solve the problem of reactive power balance, reactive power compensation device must be installed [1-3]. Controllable reactor of transformer type (CRT) is a new multi-winding reactive power compensation device; the working principle diagram of CRT is shown as Figure 1 [4-6].

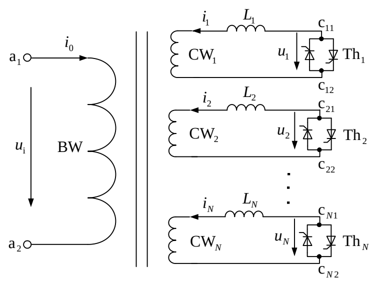


Figure 1. The working principle diagram of CRT

In Figure 1, the purpose of the reactive power capacity with continuous smooth adjustment of CRT can be achieved by adjusting the size of conduction angle of the anti-parallel thyristors series in control winding loop, and the current harmonic content is small of CRT [7, 8]. However, because it has multiple control windings, there is a magnetic coupling among the control windings, which leads to the subsequent control winding input will makes the control winding current utilization rate is decline of have been put into operated, in order to improve the control winding current utilization and make the CRT reliable work, reference [9] pointes out that the structural design of the CRT must follow the design principles of "high impedance and weak coupling".

In this paper, aiming at the problem of magnetic coupling among the control windings, the integrated magnetic structure of CRT which is based on the magnetic integration technology is proposed, this structure achieves the decoupling of the control windings by providing a low reluctance magnetic circuit [10-12]; Generally this structure also can be easily extended to the structure of the multiple control windings, provides a reference for the further application of magnetic integration technology.

*Received September 25, 2014; Revised November 4, 2014; Accepted December 12, 2014*

**2. A Decoupling Structure of CRT**

In magnetic integration technology, the decoupling integrated method which provides a low reluctance magnetic can achieve the decoupling of multi-windings [13]. this method is applied to the structural design of CRT, and a kind of integrated magnetic structure of CRT is proposed and shown as Figure 2.

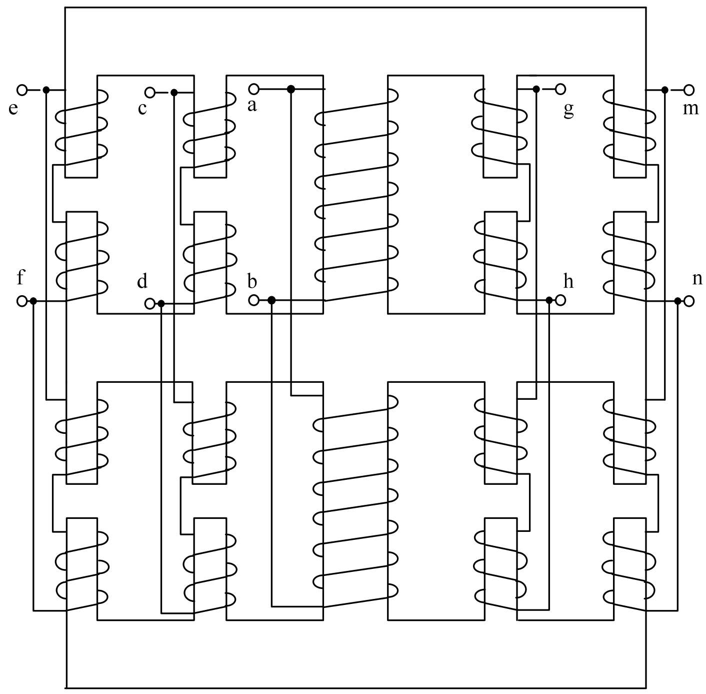


Figure 2. Decoupling Structure of CRT

In Figure 2, the center column and upper and lower yoke are low reluctance, each side of column opened the gap. The center column wound around the work winding and work winding is constituted by two windings of paralleled. Each control winding also constituted by two windings of paralleled and this two windings wound around in up and lower column respectively. Because have air gap in side of column of this decoupling structure, the magnetic flux generated by each control winding are closed through the center column and itself column and could not through columns wound around other control windings, so this structure meets the decoupling of control windings. This structure is symmetrical of up and lower sections, on its upper section is concerned, there are five columns, so the magnetic flux generated by work winding only have 1/4 cross-linked with each control winding, which meets the design principle "high impedance" of CRT. Also because work winding and control windings all constituted by two windings in parallel, thus, the effect of reactive power compensation is great of this decoupling structure.

**3. Calculation of Leakage Inductance**

Because of symmetry of decoupling structure, the follow analysis and calculations only for one small basic unit as shown in Figure 3.

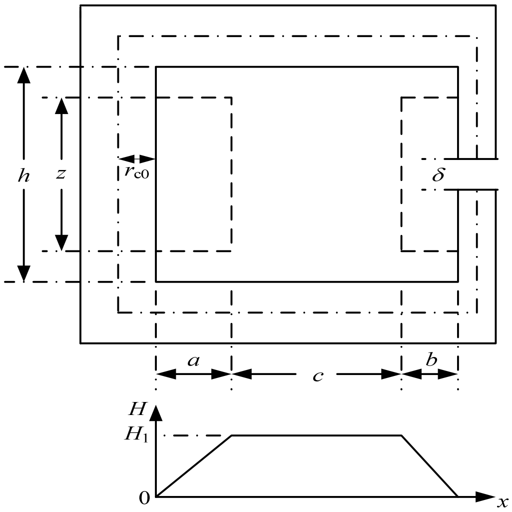


Figure 3. The distribution graph of magnetic field intensity

In Figure 3, h is height of iron core window, z is equivalent height of winding, $r_{co}$ is radius of center column, a is equivalent width of work winding, b is equivalent width of control winding, c is distance between two windings, $\delta$ is length of air gap.

Set $i_0$ is current of work winding, $i_1$ is current of control winding, make inside of center column to zero reference. Based on Ampere circuit law, in 0~*a* areas, the current increase linearly along *x* direction, the magnetic field intensity also increase linearly, formula of magnetic field intensity is follow:

$$H_{ax} = H_0 \frac{x}{a} = \frac{N_0 i_0}{za} x \tag{1}$$

In *a*~*a*+*c* areas, because there is no current increase, so magnetic field intensity remain unchanged, the formula is follow:

$$H_{cx} = H_m = \frac{N_0 i_0}{z} \tag{2}$$

In *a*+*c*~*a*+*b*+*c* areas, since the reverse current of control winding, the magnetic field intensity decrease linearly, so the formula if follow:

$$H_{bx} = H_m - \frac{N_1 i_1}{bz}\left[x - (a + c)\right] \tag{3}$$

According to the magnetic field intensity distribution of the magnetic field determines the magnetic energy, in 0~a areas, the formula of magnetic energy is follow:

$$W_a = \frac{\mu_0}{2}\int_0^a H_{ax}^2 dV = \frac{\mu_0}{2}\int_0^a \frac{N_0^2 i_0^2}{z^2 a^2} x^2 \cdot \pi x \cdot z dx = \frac{\mu_0 \pi a^2}{8z}(N_0 i_0)^2 \tag{4}$$

In a~a+c areas,

$$W_c = \frac{\mu_0}{2}\int_a^{a+c} \frac{N_0^2 i_0^2}{z^2} \cdot \pi x \cdot z dx = \frac{\mu_0 \pi (ac + \frac{1}{2}c^2)}{2z}(N_0 i_0)^2 \tag{5}$$

In a+c~a+b+c areas,

$$W_b = \frac{\mu_0}{2}\int_{a+c}^{a+b+c} H_{bx}^2 dV \tag{6}$$

Since exciting current is very small, so paper ignore it's effect, there is $N_1 i_1 = N_0 i_0$, formula (6) can rewrite as follow:

$$\begin{aligned} W_b = & \frac{\mu_0\pi[2b(a+c)+b^2]}{4z}(N_1 i_1)^2 + \frac{\mu_0\pi(a+c)[2b(a+c)+b^2]}{zb}(N_1 i_1)^2 \\ & - \frac{\mu_0\pi[(a+b+c)^3 - (a+c)^3]}{3zb}(N_1 i_1)^2 + \frac{\mu_0\pi[(a+b+c)^4 - (a+c)^4]}{8zb^2}(N_1 i_1)^2 \\ & - \frac{\mu_0\pi(a+c)[(a+b+c)^3 - (a+c)^3]}{3bz}(N_1 i_1)^2 + \frac{\mu_0\pi(a+c)^2[2b(a+c)+b^2]}{4zb^2}(N_1 i_1)^2 \end{aligned} \tag{7}$$

Magnetic energy of the whole area is follow:

$$W_a + W_b + W_c = \frac{1}{2}L_{\sigma 0} i_0^2 + \frac{1}{2}L_{\sigma 1} i_1^2 \tag{8}$$

Simultaneous formula 4, 5, 7 and 8, we can get follow:

$$L_{\sigma 0} = N_0^2\left[\frac{\mu_0\pi a^2}{8z} + \frac{\mu_0\pi(ac + \frac{1}{2}c^2)}{2z}\right] \tag{9}$$

$$\begin{aligned} L_{\sigma 1} = & N_1^2\frac{\mu_0\pi[2b(a+c)+b^2]}{4z} + N_1^2\frac{\mu_0\pi(a+c)[2b(a+c)+b^2]}{zb} \\ & - N_1^2\frac{\mu_0\pi[(a+b+c)^3 - (a+c)^3]}{3zb} + N_1^2\frac{\mu_0\pi[(a+b+c)^4 - (a+c)^4]}{8zb^2} \\ & - N_1^2\frac{\mu_0\pi(a+c)[(a+b+c)^3 - (a+c)^3]}{3bz} + N_1^2\frac{\mu_0\pi(a+c)^2[2b(a+c)+b^2]}{4zb^2} \end{aligned} \tag{10}$$

In formula (10), $L_{\sigma 0}$ and $L_{\sigma 1}$ is leakage inductance of work winding and control winding respectively.

## 4. The Equivalent Circuit of Basic Unit

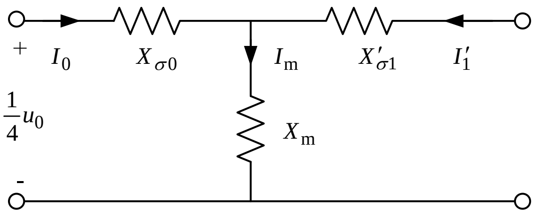


Figure 3. The equivalent circuit of basic unit

Figure 3 is equivalent circuit of T type, in Figure 3, we ignores the resistance of work winding, control winding and excitation resistance. In order to ensure the magnetic flux chain relationship remains the same, the voltage of the primary side is $u_0/4$ in equivalent circuit, all parameters of circuit are return to the side of work winding [14].

In Figure 3, $I_m$ is excitation current, $X'_{\sigma 1}$ is imputed value of leakage reactance of control winding, $I'_1$ is imputed value of current of control winding. According to the magnetic Ohm's law, we can get:

$$I_m = \frac{R_m u_0}{4N_0^2 \omega} \quad (11)$$

In formula (11), $R_m$ is magnetic resistance (including magnetic resistance of center column, iron yoke and side column).

According to equivalent circuit, we can get follow formula:

$$\left.\begin{aligned} & I_m = I_0 + I_1' \\ & \frac{1}{4}u_0 = I_0 Z_{\sigma 0} + I_m Z_m \\ & 0 = I_1' Z_{\sigma 1}' + I_m Z_m \end{aligned}\right\} \quad (12)$$

Based on formula (12), we can calculate:

$$I_1' = \frac{4I_m Z_{\sigma 0} - u_0}{4Z_{\sigma 0} + Z_{\sigma 1}'} \quad (13)$$

$$I_0 = I_m - I_1' \quad (14)$$

**5. Calculation for Example**

The parameters of iron core is showing as Table 1, turns of work winding is $N_0 = 1600$, turns of all control winding is 120.

Table 1. The parameters of iron core

| parameter | value(cm) | parameter | value(cm) |
|---|---|---|---|
| *a* | 23 | *h* | 125 |
| *b* | 1 | *z* | 110 |
| *c* | 16 | δ | 3mm |
| $r_{co}$ | 39.5 | $\mu_r$ | 2000 |

According to value of Table 1, we can calculate the currents of all windings are show as Table 2.

Table 2. Calculation values of current

| | no-load | CW1short circuit | CW1~CW2 short circuit | CW1~CW3 short circuit | CW1~CW4 short circuit |
|---|---|---|---|---|---|
| current of BW/A | 2.3219 | 36.3253 | 72.6505 | 108.9758 | 145.3011 |
| current of $1/2CW_1$ | 0 | 15.8407 | 15.8407 | 15.8407 | 15.8407 |
| current of $1/2CW_2$ | 0 | 0 | 15.8407 | 15.8407 | 15.8407 |
| current of $1/2CW_3$ | 0 | 0 | 0 | 15.8407 | 15.8407 |
| current of $1/2CW_4$ | 0 | 0 | 0 | 0 | 15.8407 |

We can be seen that this structure can not only realize the decoupling between the control winding, but also the compensation effect is very good according to the calculation results in Table 2.

## 6. Conclusion

In this article, the decoupling integrated magnetic technology is applied to the structure design of CRT, a CRT decoupling structure has been proposed. On the basis of the calculation of the leakage inductance of the windings and equivalent circuit is established, we get the following conclusions:

(1) The “weak coupling” design requirement among control windings of CRT can be realized by providing a low reluctance magnetic circuit.

(2) When the air gap of side column becomes bigger, the degree of coupling among control windings becomes smaller.

(3) The method of decoupling among control windings by adjusting the air gap of side column of magnetic integrated structure of CRT is effective.

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