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DYNAMIC MODEL OF REVERSIBLE THYRISTOR TRANSDUCERS

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Abstract

Reversible thyristor transducers are used in reversible Direct Current electrical drives and are created from two non-reversible thyristor transducers installed in an opposite parallel manner, thus permitting to change the direction of load current.

Non-reversible thyristor transducers each have its own pulse phase control system: PPCS1 and PPCS2. Their control signals are formed by reversible transducer control system (RTCS). The latter can have various control principles and are divided into common and separated signals.

Key Words: Dynamic model, reversible thyristor transducers.

INTRODUCTION

High power consumption of the iron and steel production accompanied by continuous cost escalation of power resources stipulates primary importance of power saving for all its processing stages [1]. The main consumer of the electric power at the iron and steel facilities is an electric drive (ED). The total capacity of electric motors at the iron and steel facility amounts about 87% of power of all the equipment, while their power consumption makes up about 65% of the total[2,3]. Thus highest power savings may be obtained due to improved energy indexes of electric drives. In the first turn that of thyristor EDs of the rolling mills Energy indexes of thyristor EDs are mainly deteriorated due to the reactive power consumption caused by phase control of the rectified voltage (rectified EDV).

DC motors are widely used in industry because of its low cost, less complex control structure and wide range of speed and torque. There are many methods of speed control of DC drives namely field control, armature voltage control and armature resistance control method [2]. DC motors provide high torque which is required for traction appliances. In DC motor control over a large speed range, both below and above the rated speed can be achieved quite easily. DC motors have inherent disadvantages in that they need regular maintenance and are bulky in size. Also they are tailor-made and so difficult to replace. In general, armature voltage control method is widely used to control DC drives. In this method, a controlled rectifier or chopper is used but due involvement of power electronics elements, non-linear torque speed characteristics are observed which are undesirable for control performance [4].

Nowadays state-of-the-art speed control techniques of DC motor are available. Thyristor based DC drives with analogue and digital feedback are used. Phase locked loop control technique is also used for precise speed control and zero speed regulation. In the past, many researchers presented various new converter topologies on DC motor control for different appliances of industry [5],[6],[8] but at the basic level of all of them thyristor based AC-DC converters are used. MATLAB with its tool boxes like Simulink and SimPowerSystem are used for simulation [3],[7].

This paper provides a dynamic model of reversible thyristor transducer used in various industrial applications.

Reversible Thyristor Transducers With Common Control

Common control means that we simultaneously give control pulses in transducers Z_1 and Z_2 (figure1).

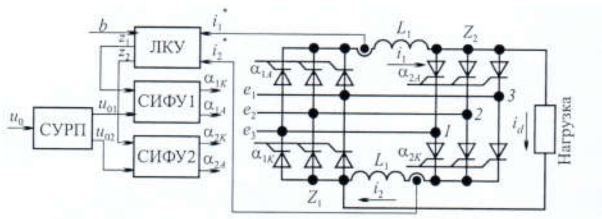

Figure 1 Circuit of Reversible Thyristor Transducer

One of the transducers works in rectifier regime and the other in inverter regime. We note the control angles of transducers Z_1 and Z_2 respectively by α_1 and α_2. To ensure that one transducer works in rectifier regime and the other in inverter regime.

We have $\alpha_1 + \alpha_2 \geq \pi$

We distinguish agreed and non-agreed control of transducers. For agreed control, the supply of transducers Z_1 and Z_2 is done from two sources that are not electrically related to each other.

Agreed common control is the one when medium electromotive force (emf) values of transducers Z_1 and Z_2 satisfies the relation:

$Ed_1 + Ed_2 = Ed_o \cdot [\cos(\alpha_1) + \cos(\alpha_2)] = 0$

Let us assume that $\alpha_1 = \alpha$ and $\alpha_2 = \pi - \alpha$,

In that case we have $Ed_1 = -Ed_2 = Ed_o\cos(\alpha) = E_d$ (1)

Instantaneous emf values of transducers Z_1 and Z_2 are different

$ed_1 = E_m \cdot [\cos(\tau_{1k} - \frac{\rho}{2} - \alpha) - \cos(\tau_{1A} - \frac{\rho}{2} - \alpha)]$;

$ed_2 = E_m \cdot [\cos(\tau_{2k} - \frac{\rho}{2} + \alpha) - \cos(\tau_{2A} - \frac{\rho}{2} + \alpha)]$;

where τ_{1k} and τ_{1A} are cyclic angle variables of cathode and anode groups of transducer Z_1

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τ_{2k} and τ_{2A} are cyclic angle variables of cathode and anode groups of transducer Z_2

Control signals u_{o1}, u_{o2} of transducers Z_1 and Z_2 are related with control angles α_1, α_2

$$\alpha = f(u_o) = \pi/2 \cdot (1 - u_o/u_B);\ \alpha = f(u_o) = \arccos(u_o/u_B) \quad (2)$$

In that case $u_o = u_{o1} = -u_{o2} \in [-u_B, u_B]$
Where u_B – basic value of control voltage

Non- agreed common control. It is the case where control angles α_1 and α_2 satisfy the condition:
$\alpha_1 + \alpha_2 = \pi + 2\sigma$, with $\sigma > 0$.
Assume that $\alpha_1 = \alpha + \sigma$ and $\alpha_2 = \pi - \alpha + \sigma$
With $\alpha_1, \alpha_2 \in [\gamma_{max}, \pi - \gamma_{max}]$
$\alpha \in [\gamma_{max} - \sigma, \pi + \sigma - \gamma_{max}]$;
γ_{max} – maximal value of commutation angle
σ – angle of disagreement
We have $u_{o1} = u_o - u_\sigma$;
$u_{o2} = -u_o - u_\sigma$;
where $u_o \in [-u_B - u\sigma + u_{max}, u_B + u\sigma - u_{max}]$;
$u_{o1}, u_{o2} \in [-u_B + u_{max}, u_B + u_{max}]$;
$u_\sigma = u_B \cdot 2\sigma/\pi$, $u_{max} = u_B \cdot 2\gamma_{max}/\pi$

In the case of non-agreed common control, regulatory characteristic of reversible thyristor transducer will have two branches (figure 2a)

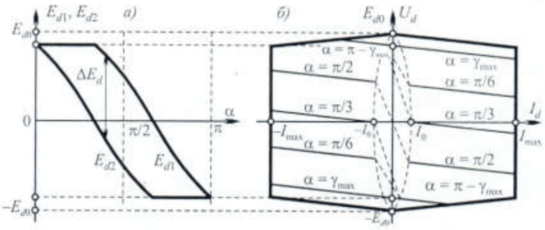

Figure 2 Characteristics of Reversible thyristor transducer with non-agreed common control

$(\gamma_{max} = \sigma = \frac{\lambda}{2} = \frac{\pi}{6})$

The first branch corresponds to positive direction of rectified current and functioning of transducer Z_1:

$$Ed_1 = Ed_o \cdot \begin{cases} \cos(\alpha+\sigma)\ for\ \gamma_{max} - \sigma < \alpha < \pi - \sigma - \gamma_{max} \\ \cos(\pi - \gamma_{max})\ for\ \pi - \sigma - \gamma_{max} < \alpha < \pi + \sigma - \gamma_{max} \end{cases}$$

The second branch corresponds to negative direction of rectified current and functioning of transducer Z_2:

$$Ed_2 = Ed_o \cdot \begin{cases} \cos(\gamma_{max})\ for\ \gamma_{max} - \sigma < \alpha < \sigma + \gamma_{max} \\ \cos(\alpha - \sigma)\ for\ \gamma_{max} + \sigma < \alpha < \pi + \sigma - \gamma_{max} \end{cases}$$

The load characteristics of thyristor transducers are limited by domain defined as follows:

$-[Ed_o - (R_{ph} + X_d)|I_d|] < U_d < [Ed_o - (R_{ph} + X_d)|I_d|]$;
$-I_{max} < I_d < I_{max}$
Where I_{max} is the maximal acceptable value of rectified current

In this case of common control between the transducers are circulating equalizing currents.The value of equalizing current I_{eq} depends on various factors and it is limited by special reactors with inductances $L_{12} = L_{21}$.

When the control angle increases, the equalizing current as a rule increases and reaches the maximal value at $\alpha = \pi/2$:

$$I_{eq} = \frac{2E\ d_{o*}\sin(\frac{\pi}{m} - \sigma)}{\omega * L_{12}\sin(\frac{\pi}{m})} * \left[1 - (\frac{\pi}{m} - \sigma) * ctg(\frac{\pi}{m} - \sigma)\right]$$

The expression of equalizing current depends on disagreement angle $\sigma = (\alpha_1 + \alpha_2 - \pi)/2$

If the value of σ increases, the equalizing current decreases. For $\sigma \geq \pi/m$, $I_{eq} = 0$ and in that case currents are conducted only by thyristors of one of the two transducers.

The advantage of non-agreed common control consists of the possibility of reducing the reactor inductance used for limiting the equalizing current. But in that case the privilege of agreed control and we need special control system to maintain $-I_{max} < I_d < I_{max}$.

The disadvantage of non-agreed common control is the presence of non-continuous current and the bounds in load characteristics when we cross from one square to the other.

Reversible Thyristor Transducers With Separate Control

Separate control of reversible transducers consists of sending pulses only in one of transducers Z_1 or Z_2. Thus thyristors of one of the transducers are opened while others are closed.

In the control system of reversible transducer with separate control (CSRT) must be included a logiccommutator installation(LCI), that permits to introduce one or the other transducer. Such a system as a rule is the control system of the electrical drive.

Output Boole signals of the logic installation are represented respectively z_1 and z_2. If $z_k = 1$, the control pulses in transducer Z_k are sent and if $Z_k = 0$, then control pulses of transducers are not sent (k=1, 2).

Logic installation that commutes control pulses of transducers Z_1 and Z_2 can be realized by captors in rectified current circuit of each transducer (figure 1).

Let us assume that currents of transducers Z_1 and Z_2 are respectively i_1 and i_2. We introduce functions $f_1 = 1(i_1)$ $f_2 = 1(i_2)$ and function f_o, that is equal to 1 if the signal in current b is positive, and 0 if it is negative with 1(x) being equal to unit function.

The signal b defines the transducer that will be operative in the next time interval and it is formed by control system of next hierarchy level.

We design Boole functions of logic installation that link input variables f_1, f_2 and f_o with output z_1 and z_2. For that purpose we present a truth table. From table 1:

Table 1

f_0	0	1	0	1	0	1	0	1
f_1	0	0	1	1	0	0	1	1
f_2	0	0	0	0	1	1	1	1
z_1	0	1	1	1	0	0	0	0
z_2	1	0	0	0	1	1	0	0

We have Boole functions:
$z_1 = \bar{f}_2 \cdot (f_1 \cup f_o)$;
$z_2 = \bar{f}_1 \cdot (f_2 \cup \bar{f}_o)$

To assure the reliability of current transit from one transducer to the other, we should exclude the cases of current interruption. The structural circuit of logic installation that makes the commutation of control pulses in transducers is shown on figure 3.

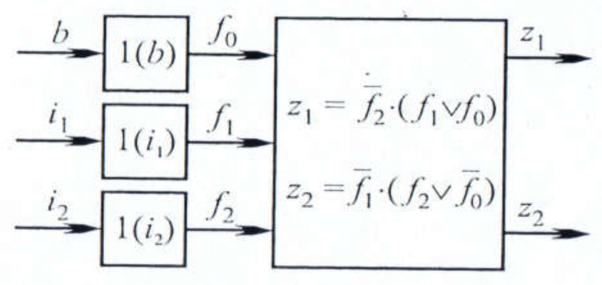

Figure 3 Structural Circuit of logic commutator installation

Input signals u_{o1} and u_{o2} of pulse phase control systems with separate control of transducers can be either agreed or non-agreed types. For separate agreed or non-agreed control respectively:

$u_o = u_{o1} = -u_{o2}$

$u_{o1} = u_o - u_\sigma$; $u_{o2} = -u_o - u_\sigma$

Structural circuit of forming input signals u_{o2} and u_{o2} for pulse phase control systems of thyristor transducers (PPCS1 and PPCS2) is shown in figure 4.

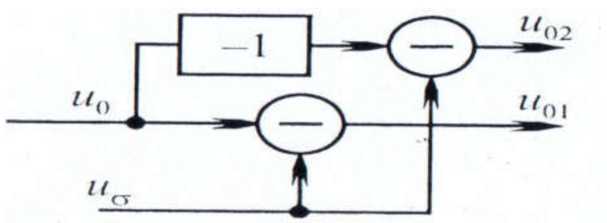

Figure 4 Structural Circuit of formation of input signals PPCS1 and PPCS2

Direct Frequency Transducers (DFT)

Direct frequency transducers are intended to change the frequency and amplitude of voltage u_d applied to the load and can be used for the control of electrical asynchronous motors. They transform three phase network voltages into one or three-phase network. They can be realized on the basis of reversible transducers.

The control system of direct frequency transducer (CS DFT) is a controlled generator of periodic voltage u_o that is sent to control system of reversible thyristor transducer. In that case the rectified voltage u_d will also be periodical.

Let us assume that the medium value of rectified e.m.f. E_d is a sinusoidal function with amplitude A and with angular frequency ω_2.

$$Ed = A\sin(\omega_2 t) \quad (3)$$

It is related with control voltage of reversible thyristor transducer u_o by:

$$Ed = F(u_o) = Edo.\sin\left(\frac{\pi}{2}, \frac{u_o}{u_B}\right) \quad (4)$$

Where $u_o \in [-u_B, u_B]$

Thus, from relations (3) and (4), for linear support voltage of PPCS;

$Ed = Ed_o \cdot \cos(\alpha) = Ed_o \sin(\pi \cdot u_o / 2 / u_B) = A\sin(\omega_2 t)$

Therefore to have sinusoidal middle value of rectifier voltage, it is necessary that CS DFT generates periodic signal

$U_o = U_B \cdot (1 - 2\alpha/\pi)$,

Where $\alpha = \arccos(\chi \cdot \sin(\omega_2 t))$; $\chi = A/E_{do}$ and ω_2 – control parameters allowing to change the amplitude and angle frequency of voltage in the poles of direct current of reversible thyristor transducer.

Instantaneous value of e.m.f. for direct frequency transducer:

$e_d = E_m \cos(\tau - \lambda/2 + \alpha)$;

$\tau = \lambda \cdot \mathrm{frac}(\omega \cdot t / \lambda)$; $\lambda = \pi/m$

ω – angular frequency of network voltage

The aspects of functions of control angle α depending on $\omega_2 t$ for various χ are shown on figure 5. The aspects of functions of e_d and E_d for e.m.f. values of frequency transducer depending on $\omega_2 t$ are shown on figure 6.

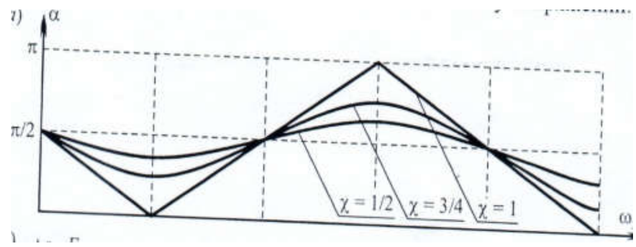

Figure 5 function, of control angle σ depending on angle $\omega_2 t$ for $\omega_2 = \omega/3$

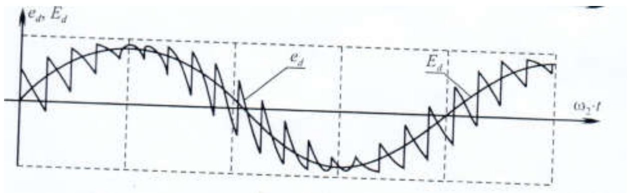

Figure 6 Instantaneous e_d and medium E_d of emf depending on angle $\omega_2 t$ for $\omega_2 = \omega/3$ and $\chi = 1$

Direct frequency transducers are used for the regulation of rotating speed of powerful special asynchronous electro-motors. As a rule electric synchronous rotating speed of powerful electromotor ω_2 does not exceed 10 – 12% of angular frequency for network voltage ω.

CONCLUSION

Reversible thryistor transducers are constructed from two non-reversible transducers and permit to change the current direction in the load.

The functioning of pulse phase control systems of two non-reversible transducers that constitute the reversible transducers can be either agreed or non-agreed. For agreed functioning, the change of rectified current sign occurs without discontinuity of the voltage while for non-agreed functioning there is sudden change of voltage in the load.

Control systems of reversible transducers are divided into common and separate. Systems of common and separate control have logic installation, which permits the functioning of only one of the non-reversible transducers.

For agreed common control, the reversible transducer always works in continuous current regime and between the transducers circulates an equalizing current. For non-agreed common control of reversible transducer, with small current values we will observe discontinuous current values regime and the expression of equalizing current will decrease. For disagreement angle $\sigma<\frac{\pi}{6}$, equalizing current disappears.

To assure the functioning of reversible transducers with separate or with non-agreed common control with disagreement angle $\sigma>\frac{\pi}{6}$, we need special control system of higher hierarchy level that will maintain the given voltage value in the load and satisfy the condition $-I_{max}<Id<I_{max}$.

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