A NEW THREE PHASE THRISTOR-INVERTER CIRCUIT WITH IMPROVED COMMUTATION CONDITIONS

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ABSTRACT
This paper presents an improved three phase, voltage-fed, phase-commutated thyristor-inverter with a new commutation circuit. The commutation circuit is designed to improve commutation conditions with the additional use of two low-power voltage sources and six low-power thyristors. The theoretical analysis of the developed inverter circuit and experimental results are given.

1. INTRODUCTION

Voltage-fed thyristor bridge inverters are classified in respect of the difference between the commutation circuits. According to the commutation conditions, the bridge inverter can be realized with phase commutation, sequential phase commutation and individual commutation. The phase commutation thyristor-inverter circuit is shown in Fig.1. In this topology a commutation circuit is used to turn off the thyristors that belongs to every phase so it is called as phase commutation inverter circuit. C_k capacitors are used for cutting off the upper and lower thyristors currents of which phases they are related. T_1....T_6 are main thyristors and T_{k1}...T_{k6} are auxiliary thyristors. T_1....T_6 thyristors are switched on for 120° or 180°. Inverter output waveforms depend on the conduction angle of the thyristors. In this topology some difficulties in the commutation occur when the dc link voltage U_d is adjusted. In thyristor-inverter topologies the charge voltage of the commutation capacitor C_k is proportional with the U_d voltage. When the dc link voltage is low, in order to commute full load current, commutation mechanism should be planned greater than the nominal condition. In this case, commutation elements are also forced with more currents. In this paper, a new thyristor-inverter with improved commutation that works properly over a wide range of U_d is proposed.

2. IMPROVED INVERTER CIRCUIT

Three phase, voltage-fed, thyristor-inverter with improved commutation conditions is shown in Fig.2. This circuit works in a wide input voltage range and it is not effected from load variations. The circuit can work with 120° or 180° conduction angle. In the improved inverter circuit, two low-power voltage sources, six low-power thyristors and six R_s resistances are used to charge the commutation capacitors with a proper polarity to U_{dk} value without being effected from inverter input voltage and load properties. The operation of the inverter circuit is as follows; when the thyristor T_1 is conducted T_{s1} is also triggered. If the voltage of C_{k1} capacitor is lower then U_{dk}, than it is charged through the T_1-C_{k1}-L_{k1}-R_{k1}-U_{dk}-T_{s1} loop to U_{dk} value with a polarity to turn off the thyristor. At time t_1, to turn of the thyristor carrying the I_y current, T_{k1} is triggered and through T_1-T_{k1}-R_{k1}-L_{k1}-C_{k1}-T_1 loop, L_{k1}-C_{k1} resonance circuit is formed.

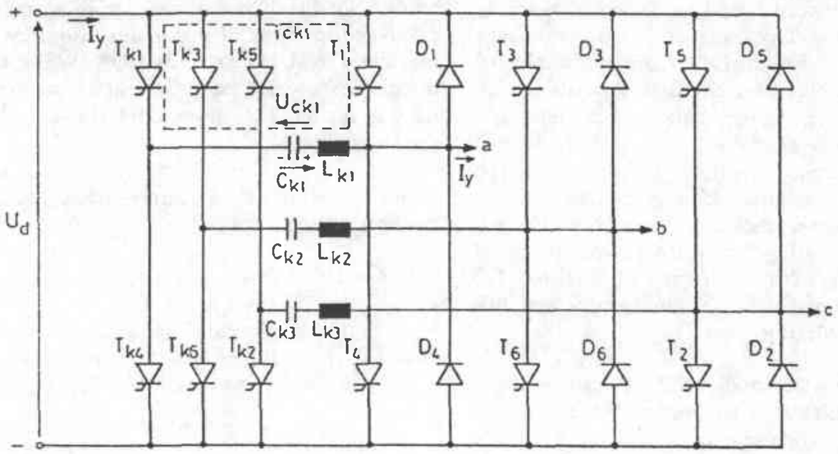

Fig.1. Three phase voltage-fed thyristor–inverter with phase commutation.

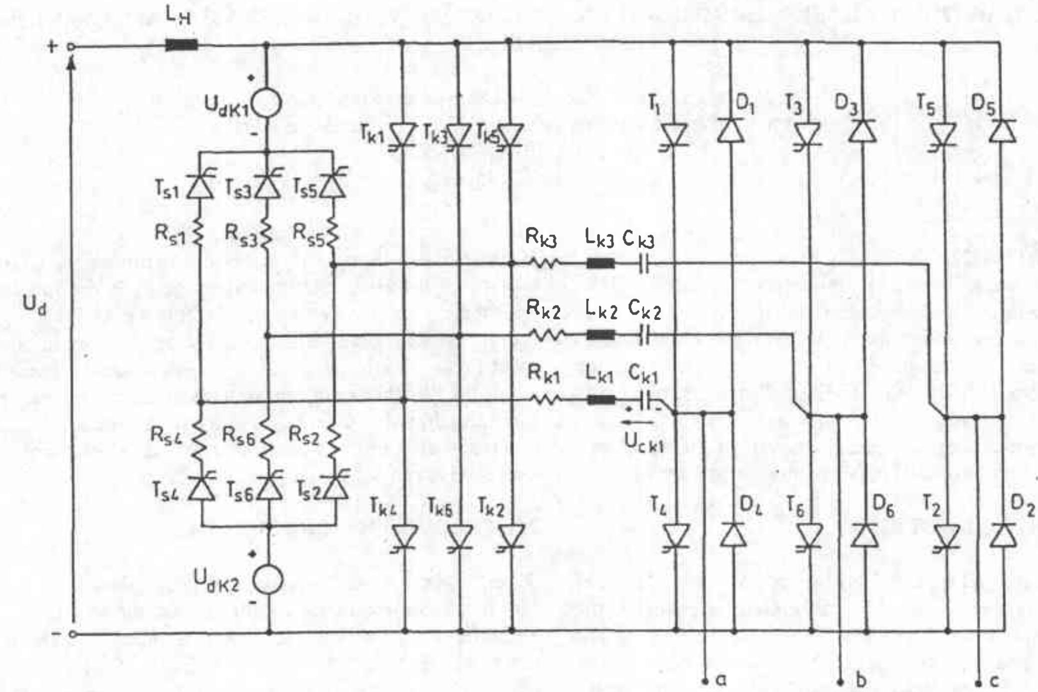

Fig.2. Proposed three phase, voltage-fed, thyristor-inverter with improved commutation.

At time t_2 when the resonance current reaches to I_y load current, the current in T_1 thyristor falls to zero and T_1 turns off. D_1 diode carries the resonance current excessive than I_y load current and resonance continues. At time t_4, resonance current falls below I_y so D_1 diode turns off. When D_1 turnes off, if the value of the reversed voltage on the C_{k1} capacitor is not enough to reduce the cathode voltage of D_4 diode below negative link voltage than this capacitor is charged linearly approximately to voltage U_d (between t_4 and t_5). Between t_5 and t_6, U_{ck1} capacitor voltage exceeds U_d source voltage until D_4 diode carries the I_y load current completely. At time t_6, the current in thyristor T_{k1} falls to zero and T_{k1} turns off. Commutation is completed and capacitor C_{k1} is charged to turn off T_4 with a voltage more than U_d. At time t_7, thyristors T_4 and T_{s4} triggered together. If the voltage of C_{k1} capacitor is lower then U_{dk}, than it is charged through the T_4-U_{dk2}-T_{s4}-R_{s4}-R_{k1}-L_{k1}-C_{k1}-T_1 to at least U_{dk} value. With triggering of thyristor T_{k4}, thyristor T_4 turns off in a similar way and this continues periodically.

The purpose of the small value inductance at the input of the circuit is to protect semiconductors against high rise rate of current and voltage. If this inductance is not used, for example, when T_1 is triggered, rise rate of voltage on T_4 becomes to high and T_4 switches on.

3. THEORETICAL ANALYSIS OF THE COMMUTATION

In commutation, when the thyristor turned off, negative voltage is applied to it as long as the diode that is anti-parallel with the thyristor is conducting. Thus, conducting time of the diode should be longer than the t_q turn-off time of the thyristor given in the catalog. Since commutation inductance L_k and capacitance C_k is selected once, the time of the negative voltage which is applied to the thyristor when it is turned off can be calculated in terms of maximum resonance current I_{cm}, maximum load current I_y and U_{co}. While commutation the elements which carry current are shown with thick lines in Fig.3a. The current and voltage waveforms are shown in Fig.3b-c.

After T_1 has turned off commutation capacitor current can be written as,

$$i_C = I_y + i_{D1} \tag{1}$$

where, i_{D1} is the current flows in D_1. From the simplified circuit shown in Fig.4 capacitor current is obtained as,

$$i_c(t) = \frac{U_{co}}{A} e^{-\frac{R_k}{2L_k}(t-t_1)} Sin\omega(t-t_1) \tag{2}$$

where,

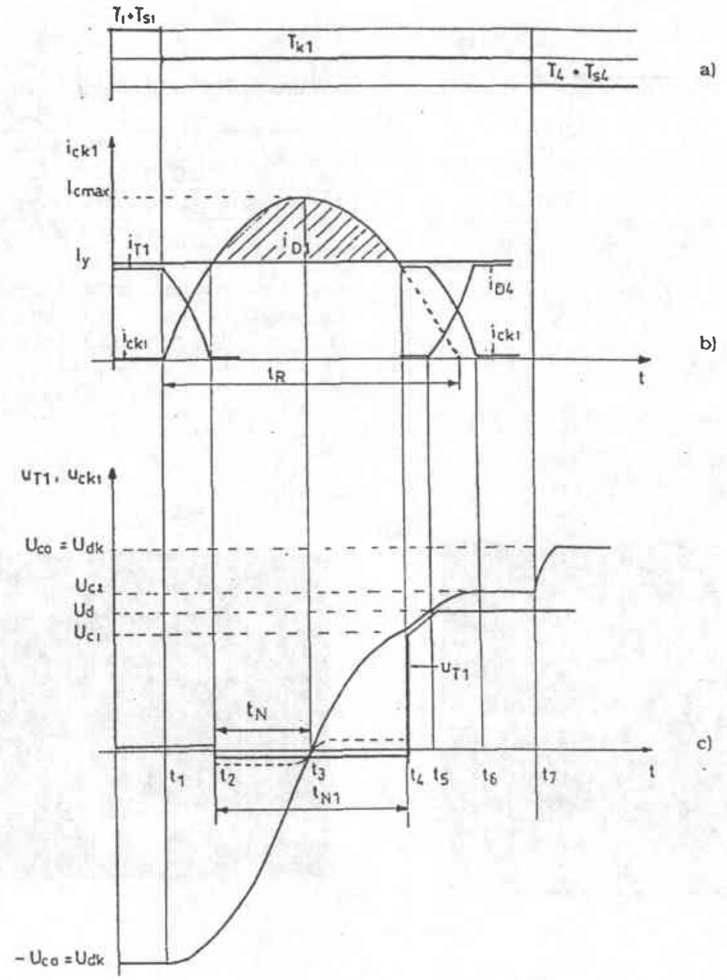

Fig.3. In commutation, a) the elements which carry current (shown with thick lines), b) current waveform and c) voltage waveform.

$$A=\sqrt{\frac{L_k}{C_k}-\frac{R_k^2}{4}} \qquad \omega=\sqrt{\frac{1}{L_kC_k}-\left(\frac{R_k}{2L_k}\right)^2}\,.$$

If the commutation resistance R_k is neglected, capacitor current is given as,

$$i_c(t)=U_{co}\sqrt{\frac{C_k}{L_k}}\,Sin\omega_0(t-t_1) \qquad (3)$$

where,

$$\omega_0=\frac{1}{\sqrt{L_kC_k}}$$

Maximum value of the capacitor current is given as,

$$I_{c\max}=\frac{U_{co}}{\sqrt{\frac{L_k}{C_k}}} \qquad (4)$$

To determine negative voltage application time t_N to thyristor T_1, anode voltage of thyristor should be analyzed after the thyristor current falls to zero. The voltage of the thyristor which turned off is equal to the voltage on D_1 diode and it is approximately 1 V. This is the time interval between t_2 and t_4 which the D_1 diode conducts. In practice, because of the inductance around D_1, the reverse voltage on T_1 is somewhat different. In some applications, the effect of the leakage inductance around D_1 diode to the reverse voltage of thyristor can be neglected. So the t_{N1} is obtained as,

$$\begin{aligned} t_{N1} &= t_4-t_2 \\ &= 2\sqrt{L_kC_k}\ arc\ \cos\left(\frac{\sqrt{\mathrm{L_k/C_k}}}{\mathrm{U_{co}}}\,I_y\right) \end{aligned} \qquad (5)$$

4. EXPERIMENTAL RESULTS

The improved inverter circuit given in Fig.2 is realized in the laboratory and it is used in the control of squirrel cage induction motor. The induction motor and commutation circuit element values are given in Table 1.

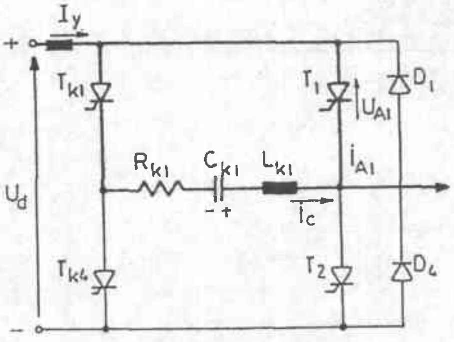

Fig.4. Simplified resonance circuit.

Table 1. The induction motor and commutation circuit element values.

Induction Motor			
1,5 kW	220 V(Δ),	1405 d/d	6.4 A(Δ)
Commutation circuit element values			
$R_K=1\Omega$	$L_k=134$ mH	$C_k=2.2\mu F$	

It is observed that inverter circuit has worked regularly for different input voltage, frequency and loads. Results from application circuit are given in Fig.5

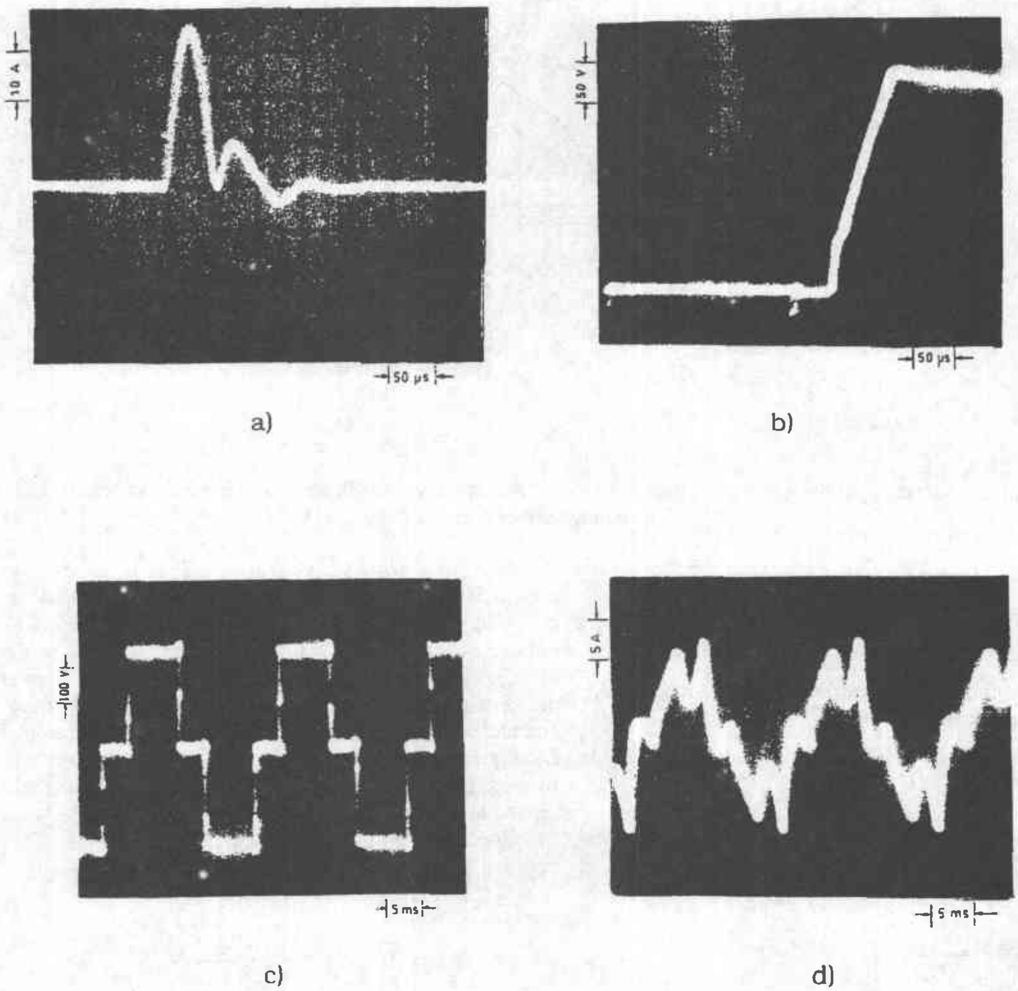

Fig.5. Variations from application circuit. **a)** Commutation capacitor current, **b)** main thyristor anode voltage, **c)** inverter output voltage, and **d)** induction motor phase current.

5. CONCLUSION

In the proposed commutation circuit, commutations are obtained with the additional use of two low-power voltage sources. By means of these sources commutation occurs at least with U_{dk} source voltage regardless of input voltage and load properties, therefore the commutation problems, which arises from the change of input voltage in a wide range has been removed. It has been observed that thyristor-inverter with the proposed commutation circuit has worked stable in a wide input voltage range.

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