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Operating Regime as Rectifier with Power Factor Correction of Two – Quadrant Converter with RNSIC

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Abstract: A new topology for a two-quadrant converter is presented. In the AC/DC transfer mode the converter works as a rectifier with near sinusoidal input currents (RNSIC), while in the DC/AC transfer mode it works as a square – wave pulse switching inverter. Some suggestions for the converter is characterized by smaller power losses, reduced EMI problems and higher reliability.This new converter topology could have numerous applications. For example, in adjustable speed drives with regenerative braking, wind energy conversion systems and small hydro interconnections with induction generators.

INTRODUCTION

A new converter for two – quadrant is presented in this paper; it is equipped with 6 transistors (e.g. IGBT) having square-wave pulse switching (that is not PWM) operation, as shown in Fig. (**1a**). When the energy is transferred from the AC side to DC side, the transistors are off and the converter works as a RNSIC (Rectifier with Near Sinusoidal Input Currents), as show in Fig. (**2**) [7-9]. When the energy is transferred from the DC side to the AC side, the transistors are controlled to conduct for θ angles (square-wave pulse switching) and the converter works as inverter, as show in Fig. (**1b**).

AC/DC OPERATION MODE

Which is a module of the two quadrant converter in Fig. (**1a**). The capacitors $C_1 – C_6$ have the same value C and they are DC capacitors. The inductors L_R, L_S and L_T have the same value, denoted by L_1, and they are connected on the AC side. L_1 and C fulfil the condition $0{,}05 \le L_1 C\omega^2 \le 0{,}10$ in order for the phase currents i_R, i_S, i_T to be practically sinusoidal (ω denotes the mains angular frequency), [7-9].

Considering that the currents i_R, i_S, i_T are practically sinusoidal and have the amplitude $I_{(1)}$, a function of the load

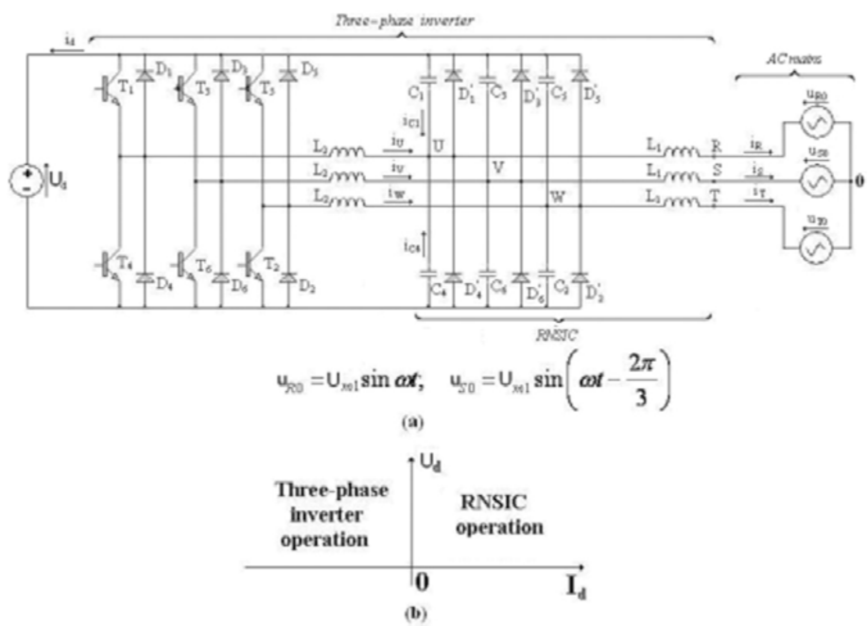

Fig. (1). Converter for two – quadrant with RNSIC; (**a**) Configuration; (**b**) Operations

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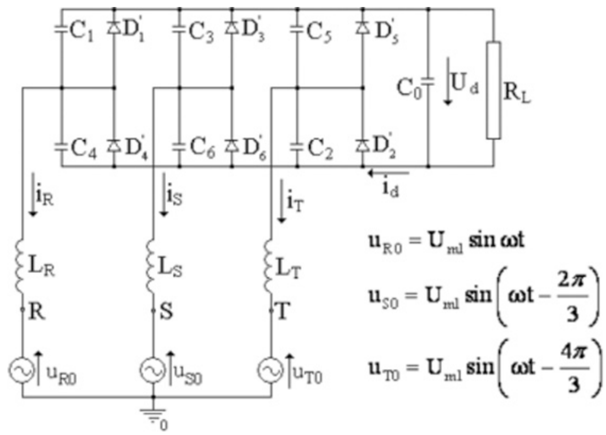

Fig. (2). Configuration of RNSIC converter.

resistor R_L, the current I_d of medium value can be calculated from the following relation:

$$I_d = \frac{3I_{(1)}}{2\pi}\left(1+\cos\omega t_1\right) \quad (1)$$

where ωt_1 is the angle of turning on for the diodes $D_1' - D_6'$.

There are two extreme case during RNSIC converter functioning. In the first case, if $R_L = 0$ (and so, $U_d = 0\, and\, \omega t_1 = 0$), the capacitors C_1 – C_6 are short – circuited and the angle $\varphi = +90^0$ is inductive. In this case, the phase currents are sinusoidal and have maximum amplitude, equal to I_{max}. In the second case, if the voltage U_d exceeds the value $\sqrt{3}U_{m1} / \left(1-2L_1C\omega^2\right)$, the diodes $D_1' - D_6'$ do not conduct any more and the angle $\varphi = -90^0$ is capacitive (and so $R_L = \infty\, and\, \omega t_1 = \pi$). For this latter case, the phase currents are also sinusoidal and the amplitude has a minimum value I_{min}, referred to as the holding current. The ratio I_{min}/I_{max} has the value:

$$\frac{I_{min}}{I_{max}} = \frac{2\,L_1C\omega^2}{1-2\,L_1C\omega^2} \quad (2)$$

The phase displacement angle between the phase voltage and the fundamental of the phase current, as a function of the mean rectified voltage U_d rated to the reference value $U_{ref} = \frac{3\sqrt{3}U_{m1}}{\pi}$ specific for the classical three – phase rectifier [1]. The voltage U_d can be established at a certain value by the load current.

The variations of the output voltage U_d rated to the reference value U_{ref} and the amplitude of the phase current $I_{(1)}$ rated to the reference value I_{max} as a function of the ratio R_L/R_{Lr} (R_{Lr} denotes the rated load resistor for $\varphi = 0^0$).

The rated operation of the RNSIC converter is defined for $\varphi = 0^0$ and $R_L/R_{Lr} = 1$. For this case, the variations of the rated angle $\left(\omega t_1\right)_r$, the angle corresponding to when diodes begin to conduct, and the ratio $R_{Lr}/L_1\omega$, as function of the parameter $L_1C\omega^2$. The interval between 45^0 and 60^0 for $\left(\omega t_1\right)_r$ ensures a reduced content of higher harmonics for the input currents.

DC/AC OPERATION MODE

In what follows we describe the operation of the converter in Fig. (**1a**) as an inverter. During the first stage, which starts at t_0, the transistor T_1 begins to conduct and the capacitor C_1, charged at initial voltage U_{in}, is discharged to final voltage, U_{end}, while capacitor C_4, initially charged at voltage $\left(U_d - U_{in}\right)$, is charged to $(U_d - U_{end})$ by the help of the oscillatory processes in which transistor T_1 and inductor L_2 take part. After the blocking of transistor T_1, made at t_1, the second stage begins, when the energy accumulated in inductor L_2 is rapidly transferred to DC and AC sources through diode D_4. Finally, in the third stage, which lasts between t_2 and t_3, the current i_U is zero, and the current i_R has a practically sinusoidal waveform, flowing through capacitors C_1 and C_4. At the end of this stage, capacitor C_4 is charged at voltage U_{in}, and C_1 at voltage $\left(U_d - U_{in}\right)$. Inductors L_2 have values two times smaller than L_1. For the case of operation in inverter mode, the voltage U_d is considered to be 15-25 % greater than for the case of rectifier system operation. Diodes $D_1' - D_6'$ are chosen according to the RNSIC component design specification, while the diodes D_1 – D_6 are rated for much smaller average currents.

The current i_R is given by :

$$i_R = \frac{u_{U0} - u_{R0}}{j\omega L_1} \quad (3)$$

while its active value, i_{Ra} , is given by :

$$i_{Ra} = \frac{U_{m2}}{\omega L_1}\left[\sin\left(\omega t + \alpha\right) - \frac{U_{m1}}{U_{m2}}\sin\omega t\right] \quad (4)$$

The active power transferred to the AC source is given by:

$$P = \frac{3}{2\pi}\int_0^{2\pi} i_{Ra}U_{m1}\cos\omega t\, d\omega t = \frac{3U_{m1}U_{m2}}{2\omega L_1}\sin\alpha \quad (5)$$

In order to obtain a unitary power factor at the AC source, it results from formula (4) that:

$$\cos\alpha = \frac{U_{m1}}{U_{m2}} \quad (6)$$

It results that the value of the power transmitted to the AC source could be varied by modifying the amplitude U_{m2} (thus the angle θ) and the angle α (thus the angle β).

The switch of the converter in Fig. (**1a**) from the inverter operation mode to the rectifier operation mode and reverse can be rapidly accomplished during a utility grid cycle $T = \frac{2\pi}{\omega}$.

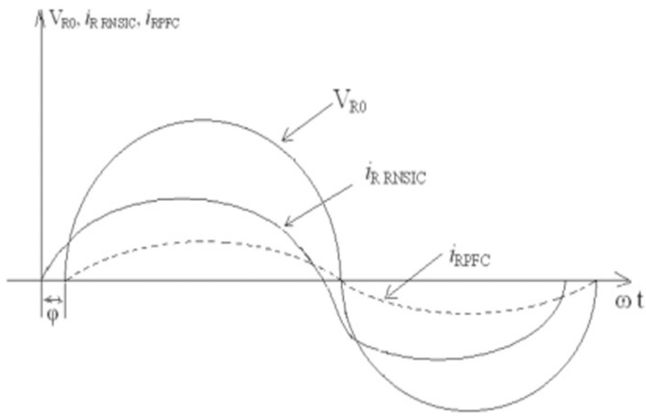

Fig. (3). Rectifier operation mode of the proposed converter (**a**) Waveforms of the phase current i_{RRNSIC} and the phase voltage v_{R0} in steady - state; (**b**) Waveforms of the phase current i_{RPFC}

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