PAM GTO inverter with quasi resonant dc link

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Contents  This paper presents a technique for realizing PAM capability in the case of a resonant dc link three phase inverter equipped with GTO thyristors. A new quasi resonant dc link circuit together with a sinusoidal PAM for an inverter fed drive are proposed in order to reduce the power losses in the machine and in the inverter. An improved dynamic behavior is also discussed in the paper. The harmonic analysis of the output voltage is presented for different operation modes.

1 Introduction
In the last years, a considerable research effort has been made in the development of the resonant dc link converters since these show many advantages in comparison with the conventional dc link inverters.

Conventional dc link inverters use so called hard or stressed switching; i.e., the devices turn on and turn off at full dc voltage, causing large switching losses. In resonant dc link inverters, a resonant circuit is added to the inverter input to convert fixed dc into the form of pulsating dc. The resonant frequency may be in the tens of kHz range so that the inverter output fundamental voltage can be formed at a desirable precision integrating these discrete pulses. The purpose is to turn on and turn off the inverter devices during the zero voltage interval [1–5]. The main drawback of the resonant dc link PWM inverters consists in the complexity of the controller since their resonant circuits are permanently working and, thus, the conduction durations of GTO thyristors have to be a multiple of the resonant period [5–7]. For this reason, a resonant circuit is proposed in this paper to release the voltage swing only when the GTO thyristors switchings are necessary. A static frequency converter operating on this principle has the following advantages:

- the devices switching loss at both turn on and turn off disappears, thus giving high inverter efficiency;
- the device heating is low due to conduction loss only; therefore, heat sinking or cooling requirement is low;
- the inverter can be operated without snubbers;
- all the above factors make the inverter size small at reduced cost. Lower size and smaller heat dissipation open up the possibility of inverter integration at higher power levels;
- the device reliability is improved because there is no stress due to excursion in the active area;
- the EMI problem is less severe because resonant voltage pulses have lower \( \frac{dv}{dt} \) than those of a stress-switched inverter;
- for motor drive systems, the acoustic noise will be very small.

The goal of this paper is to combine the advantages of minimum switching losses delivered by resonance in the dc link circuit of a three phase inverter with low power losses in the induction machine obtained by PAM technique.

2 Inverter operation mode
Figure 1 shows a static frequency converter composed of a diode rectifier, an intermediate dc voltage circuit equipped with a filter \((L_f - C_f)\), a resonant circuit \((L_r - C_r)\) and a clamping circuit – and a three phase PAM inverter. The inverter is composed of six GTO thyristors \((T_1 - T_6)\) and six bypass diodes \((D_1 - D_6)\).

In what follows, the inverter operation based on the sinusoidal Pulse Amplitude Modulation [8–10] is described. This inverter allows the modification of the amplitude of the output voltage fundamental \(V_{1L}\) for different output frequencies \(f_i\) less than the maximum frequency \(f_{max}\) \((f_{max} \text{ can be 50 or } 60 \text{ Hz})\). For frequencies higher than \(f_{max}\) the inverter keeps the output voltage to a constant value.

For \(f_i < f_{max}\) the variation of both output voltage and frequency is obtained by the modification of the inverter
pulse frequency $f_p$. The frequencies $f_p$ and $f_i$ are in a fixed ratio denoted with $m$. It is not necessary to extend the output frequency range down to 0.5 Hz for an induction machine inverter-fed drive since the rotor does not rotate under this frequency. While the output frequency varies between about 0.5 and $f_{i,\text{max}}$, $m$ is maintained constant inside certain limits of frequency $f_i$ as shown in Fig. 2a. The limits of each frequency domain are chosen so as to keep the higher harmonics content of the load current less than a maximum allowable value. For instance, Fig. 2b shows the load rms current $I_{\text{rms}}$ dependence on both $f_i$ and $m$ for a certain induction machine working with a constant load torque at variable speed. For this case, the rms of the fundamental of load current is maintained constant.

The ratio $m$ can have the following optimum values:

$$m = 12, 24, 48, 72, 120, \text{ and } 192$$

Such an inverter operation, as shown in Fig. 2a, leads to minimum power losses in the machine (because of the higher current harmonics) and in the inverter (because of the zero-voltage power device switching) [11–13].

The waveforms of the output voltages $V_{Us}$, $V_{Vs}$, $V_{W}$ together with the waveforms of the fundamentals of the stator currents are presented in Figs. 3a, b, c for the case of $m = 12$ pulses, while Fig. 3d shows the $T_1$-$T_6$ GTO thyristors command sequences for an output voltage period.

Analogously, Figs. 4 correspond to the case of 24 pulses. In order to reduce the content in low harmonics of