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Power Limit Control of a High Voltage-Frequency Transformer with Selective Harmonic Elimination at Unpredictable Load Variation

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Power transformers are crucial components in numerous applications requiring power transmission.However, they typically possess a bulky and heavyweight construction, featuring laminated magnetic cores and primarily operating at low frequencies, typically around 50 or 60 Hz [1]. Otherwise, equipment such high voltage source for ozone generation, pulsed laser, RF amplifiers, ballast for discharge lamps, have to deal with special requirements of volume [2], leading the transformers to high frequency operation.

The parasitic elements within a High-Frequency Power Transformer (HFPT) play a pivotal role in its [2]. These elements can be harnessed beneficially, as demonstrated in resonant converters [3], where parasitic elements can serve as the resonant tank, enabling zero-current commutation for the switches. However, in scenarios with variable loads, these resonances may be unintentionally triggered by harmonic components present in the power source, potentially leading to hazardous operating conditions [2]. To address this issue, a solution is to implement Selective Harmonic Elimination (SHE) at the power source, mitigating the risk of reach this resonance.

Figure 1 shows a voltage inverter feeding a HFPT transformer, here represented by its lumped model, that adequately represents the first series and parallel resonances, caused by the distributed inductance-capacitance of the windings.

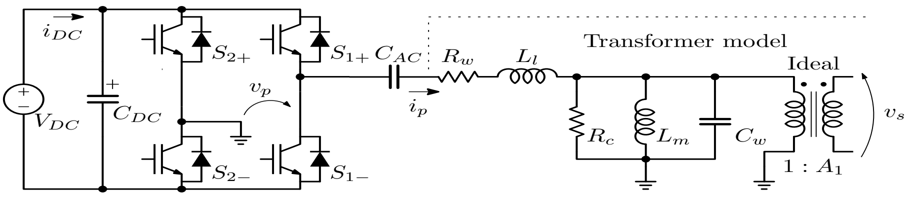

Figure 1: Transformer model and proposed control strategy.

The challenge of supplying a transformer with variable load (including the extreme conditions of open and short circuit) is to provide a power control, which drastically changes the system frequency response, as shown in Figure 2, simultaneously with the SHE.

Primary power flux control ($\bar{P}_p$) is accomplished through the introduction of an additional off-time c in the voltage waveform $vinv$ (Figure 3(a)), keeping the the 1/4 waveform symmetry at v_p to avoid the occurrence of even harmonics. $||V_p(t)||$ voltage is inferred by an observer, using $c(t)$, V_{DC} and $h(t)$ values. Additionally, considering the large value of R_c, the secondary power flux ($\bar{P}_s$) is approximated to be equal to $\bar{P}_p$.

$$\frac{d\bar{P}_p(s)}{dC(s)} = \frac{-V_{DC}^2}{\pi \cdot (s \cdot L_l + R_w)} \cdot LPF(s) = \frac{-311^2}{\pi \cdot (s \cdot 63.5 \cdot 10^{-6} + 0.329)} \cdot \frac{2 \cdot \pi \cdot 20 \cdot 10^3}{s + 2 \cdot \pi \cdot 20 \cdot 10^3} \quad (1)$$

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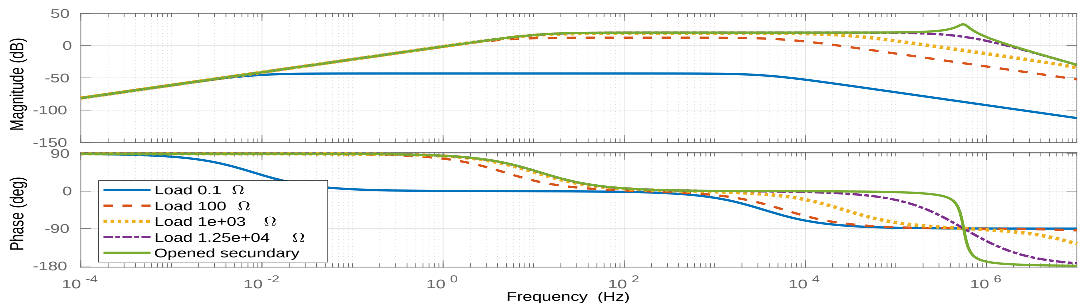
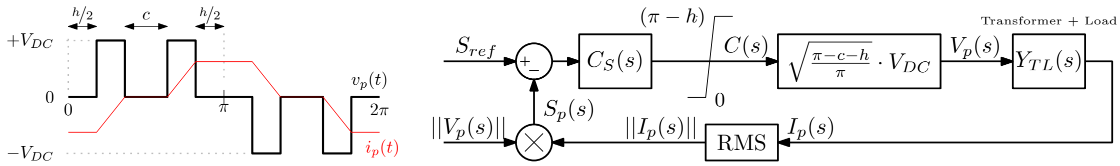


Figure 2: Frequency response of the admittance of a simulated transformer.



(a) Voltage waveform proposed.

(b) Power control proposed.

Figure 3: Voltage waveform and Power control proposed.

The control ($C_S(s)$) creates an interference on the SHE, given by (2). For a 311 V DC link, the 7[th] harmonic (n) could have the value of 40 V_{RMS}, when h is chosen as $^{180°}/_{n} = 25.71°$, for SHE at 100% voltage.

$$V_p^h(RMS) = \frac{1}{\sqrt{2}} \cdot \frac{4 \cdot V_{DC}}{n \cdot \pi} \cdot \left(-\sin\frac{n \cdot \pi}{2} \cdot \sin\frac{n \cdot c}{2} + \cos\frac{n \cdot h}{2} \right);\ n \ \exists \ odd \tag{2}$$

Making V_p^h equal do 0 in (2) is possible to modifies the h, controlling the power and achieving the SHE for all values of $c(t)$, which results in Figure 4.

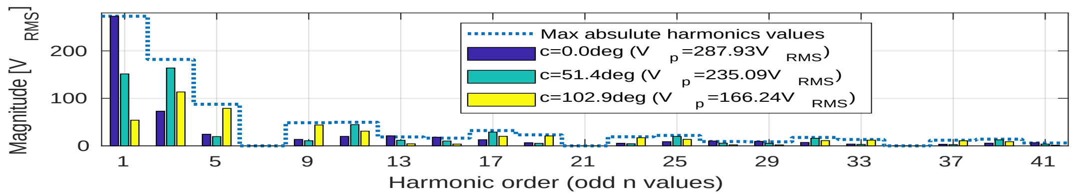


Figure 4: Harmonic values for different load situation and its maximum value reached.

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