

УДК 621.314.58

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OVERVOLTAGE PROTECTION FOR RESONANT CIRCUITS USED IN INDUCTION HEATERS

Induction heaters (IH) are successfully used in industry for metallurgy purposes (metal melting, metal hardening etc.). Working principle of IH is based on generating eddy currents inside the volume of metal part by external changing magnetic field. These currents, in turn, generate thermal losses inside work piece. Inductor (magnetic field source) and AC current source for inductor define magnetic field configuration, field strength and frequency, required per technological processes. Due to high power demands of IH used in industry, resonant inverters are mainly used to alleviate efficiency losses in such systems. Furthermore, resonant inverter helps to achieve high values of AC current inside inductor for more efficient usage of the discussed effect. However, this advantageous, on first glance, effect of resonant topologies is also its main drawback.

When no work piece is present inside or near inductor (no load condition), all input power is used to increase stored energy inside LC circuit of resonant inverter until parasitic power loss would equalize with input power. As per requirements, quality factor of such circuits has to be high to increase power efficiency. Because of this, voltage and current generated inside LC circuit in no load condition will be outside of safe operating area of used components, which leads to catastrophic failure of IH. The weakest point of such resonant inverter is capacitor bank in LC circuit, which fails due to overvoltage breakdown of capacitor's dielectric material.

Detuning operating frequency of resonant inverter outside of LC tank resonance region solves this problem. LC tank capacitor voltage can be used as an indication of such unwanted condition. By its measurement, inverter controller can shift its operating frequency according to measured value. Function of frequency shift vs. measured capacitor voltage can be obtained by IH calibration algorithm.

This function can be calculated numerically by solving equation (1) to find required operating frequencies to achieve predetermined capacitor voltage values during different load conditions:

$$U_c = U_m \cdot G_r(f_{sw}, Y), (1)$$

where U_c is a predetermined LC tank capacitor voltage; U_m is an input voltage; $G_r(f_{sw}, Y)$ is a transfer function of simplified resonant circuit, which value depends on operating frequency f_{sw} of inverter and predetermined ratio Y of LC tank capacitor impedance at LC tank resonant frequency Z_c and equivalent load resistance R_{eq} :

$$Y = Z_c / R_{eq} .$$

Usually, U_c during normal operation of IH is much lower than maximum allowed voltage of used capacitors. This allows implementing frequency shift only during unsafe operation conditions without affecting inverter work parameters during normal operation. Dimensionless parameter Y is included to omit measurement and calculation of R_{eq} during operation of inverter, which is non-trivial engineering task.

Equation (1) solutions for different load conditions and required U_c for these conditions can be put into look-up table (LUT). Implementing such LUT inside existing inverter controller based on digital microprocessor does not require substantial amount of additional computing resources. Creation of this table can be achieved during calibration sequence during system start-up. Simplified implementation of proposed system showed positive results. During no-load condition, inverter successfully avoids LC tank overload. Under normal work conditions overvoltage protection does not affect system performance.