A STUDY OF INRUSH CURRENTS IN PWM CONVERTERS UNDER FREQUENTLY ELECTRICAL MAINS INTERRUPTIONS

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Abstract. For PWM converters operation the presence of the input capacitor termed “supporting capacitor” is always necessary. The capacitor has to meet special requirement and also special measures should be taken for limiting the high values of inrush currents. In the present work the limiting of the inrush currents is proposed to be via linear choke shunted with opposite connected diode. At higher supplied voltages this variant has the distinct advantage because all converters’ components operate under lower load voltages. The simulation of circuit behavior is performed through PSpice and the simulation results are represented.

Keywords: inrush current, linear choke, PWM converter, supporting capacitor.

INTRODUCTION

The converters with pulse width modulation (PWM) become practically the mass solution in a wide range of installed capacities taking the place of the classical conceptions [1], [2], [3]. For PWM converters’ operation the presence of input capacitor termed “supporting capacitor” is always necessary. The capacitor has to meet special requirements such as low impedance (i.e. low resistance in series and low inductance hum) as well as sufficient value of capacitance to implement its functional designation. The both of these special requirements are the cause for rather high values of the inrush currents at converters’ switching on to the power supply. Special measures should be taken for limiting these inrush currents because the operation of power supplies and the normal selection of protection equipment become more complicated. The normal conditions of EMC are also disturbed [3], [4], [5], [6].

The classical method to limit the inrush currents provides resistor connected in series shunted by a relay or a thyristor after converter’s switching on. The modern solutions with power factor correction (PFC block) overcome the problem without extra measures in case of a converter supplied by AC mains. But this modern decision is unfeasible if the converter is supplied by a DC source such as battery power supply or DC mains for electric transport vehicles. Under frequently electrical mains interruptions the classical method for limiting the inrush currents is impracticable because of highly loaded resistive component. This calls for a selection of resistor with greater designed power capacity, larger dimensions and increased risk of faulty operation.

In the present work the limiting of the inrush currents is proposed to be via inductive component (linear choke) shunted with opposite connected diode. This idea is a variant of previously discussed solution with nonlinear choke. The circuit variant with opposite connected diode at higher supplied voltages has the distinct advantage because converters' components operate under lower load voltages.

PRINCIPLE OF THE CIRCUIT OPERATION AND BASIC EQUATIONS

The inrush currents in DC/DC converter for an AC mains application such as electricity wiring, servo systems and etc. are investigated. The simulation and also the experimental results are confirmed for converter with power capacity not more than 3 kW. The circuit used in performing the investigation is presented in Fig. 1 and in Fig. 2.

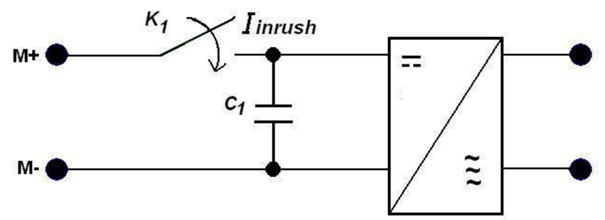

Figure 1. The circuit breaker K_1, the supporting capacitor C_1, the inrush current I_{inrush} and the PWM converter.

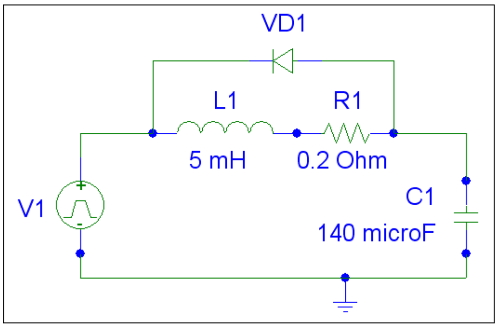

Figure 2. The circuit used in performing the investigation via software product PSpice.

The input capacitor C_1 charges at switching on of the PWM converter to the power supply source via the circuit breaker K_1 and through the linear choke L_1. The transient process could be characterized by the following equations if the electrical circuit resistance is neglected:

(1) $$i = \frac{U}{\rho} \cdot \sin \Omega t$$ (2) $$u_C = U_1.(1 - \cos \Omega t)$$

(3) $$u_{L_1} = U_1.\cos \Omega t$$

Where:

(4) $$\rho = \sqrt{\frac{L_1}{C_1}}$$ (5) $$\Omega = \frac{1}{\sqrt{L_1.C_1}}$$

These equations remain valid until the moment of switching on the diode VD_1. This moment corresponds to time (6) $t = \frac{\pi}{2\Omega}$, when the choke's (L_1) voltage turns its sign. The capacitor's (C_1) voltage is limited to the value that is equal to the value of the supplied voltage source (the voltage drop on diode VD_1 is neglected). The input alternating current is sinusoidal in accordance with equation (1) up to the moment when it reaches the value (7) $I_m = \frac{U}{\rho}$. After the diode's VD_1 switching on the choke's current begin to flow through the diode. The current alter according to the following equation:

(8) $$i_L = I_m.e^{-t/T_1}$$

Where:

(9) $$T = L_1 / r_1$$

r_1 – resistance of the choke's coil.

The simulation of the discussed process is performed through PSpice and the simulation results are represented in Fig.3.

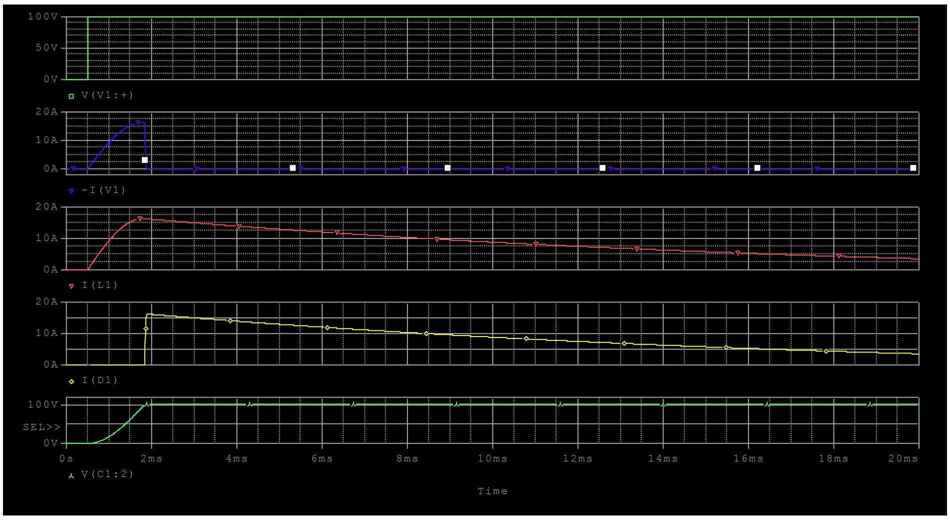

Figure 3. The voltage and current diagrams with PSpice simulation.

The transient process diagrams of supply voltage V(V1:+), the voltage drop on the capacitor C1 V(C1:2), the inrush current –I(V1), the current through the linear choke I(L1) and the current that flows through the opposite connected diode I(D1) are shown in the Fig.3. The magnitude of the investigated inrush currents is not more than 18A, as it was seen from the Fig.3. The rated current through the linear choke is about 6A up to 8 A.

The value of the supporting capacitor C_1, the value of the supplied voltage, the value of converter's current at main operational regime and the accepted admissible amplitude value of the inrush current I_m have to be taken into consideration for the selection and the design of linear choke L_1. The accepted admissible amplitude value of the inrush current I_m is determined in conformity with several requirements such as: - the admissible load of AC mains (supply voltage source); - the admissible interference level as a result of inrush current; - the admissible supporting capacitor's load C_1.

If the accepted admissible amplitude value of the inrush current is I_m then the value of the choke's inductance is determined by:

(10) $$L = \frac{C_1 . U_1^2}{I_m^2}$$

In similar applications the choke is designed with ferromagnetic core. The ferromagnetic core of the choke must not saturate itself during the transient process after converter's switching on and this limiting condition has to be taken into consideration for choke's dimensioning. The magnetic flux density alternation in ferromagnetic choke's core is defined by integral in the time of applied voltage and designing parameters. The following equations remain valid:

(11) $$U_{L_1} = \frac{d\Psi}{dt} = ws\frac{dB}{dt}$$

(12) $$\int_{B_0}^{B_p} dB = \Delta B = \frac{1}{ws}\int_0^{\pi/2\Omega} U_L.dt$$

(13) $$ws = \frac{U_1}{\Omega.\Delta B}$$

Where:

ΔB is the possible magnetic flux density alternation into choke's magnetic core up to the moment of saturation.

The magnitude of *ΔB* depends on the selected core material. For magneto-dielectric materials it is possible to select magnitude of *ΔB* equal to the material's saturation flux density. The common case is (14) $\Delta B = B_s - B_r$, where: B_s - is the saturation flux density B_r – is the remanence flux density of the material. The product in equation (13) - number of windings- "w" and the cross sectional area of the magnetic core material - "s" could be used for the design dimensioning of choke L_1 via one of well known methods.

Linear chokes may have various design structures as well. They can be realized either with a ferromagnetic core, or without such a core (so called "air chokes"). The chokes having a ferromagnetic core are most often designed with air-gaps that guarantee their linear characteristics. Introducing air-gaps not only creates design and technology problems for the manufacturing process, but also worsens the electromagnetic compatibility of these chokes due to increased emission of interference fields outside choke volume [7].

As a consequence of the facts disclosed so far, the linear chokes involving toroidal cores without air-gap become of special interest. The characteristics of such chokes are defined primary by the magnetic characteristics of the ferromagnetic material of the core. The basic requirement imposed on such materials is that the relationship between magnetic flux density and magnetic field strength should be linear (or near linear) in the work region of the core. In addition, for this region the relative permeability must be of approximately constant value. This material should meet also specific requirements guaranteeing that the choke inductance will not depend on the electric current passing through the choke. The designing procedure of such chokes features some specificity but they are very reliable and they answer the market requirements [7], [8].

General considerations concerning the designing procedure of linear chokes with toroidal strip-wound cores are given in [6] where is a proved fact that linear chokes involving cores without air-gaps requires materials with hysteresis loop of type “F”. Also the requirements to those materials are high permeability (almost constant) and low losses at high frequency [8].

In general, the choice of magnetic material for the linear choke core is the result of a trade-off between saturation flux density, energy loss, cost of the material and size for the complete device.

CONCLUSIONS

The suggested solution for limiting the inrush currents in PWM converters via linear choke shunted with opposite connected diode has good practical application in electric transport vehicles. The model is realized in trolleybuses and operates safety.

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