Influence of Number Parallels Paths of a Winding on Overvoltage in the Asynchronous Motors Fed by PWM-converters
Belassel Mohand-Tahar

Abstract—This work is devoted to the calculation of the undulatory parameters and the study of the influence of the number parallel path of a winding on overvoltage compared to the frame and between turns (sections) in a multiturn random winding of an asynchronous motors supplied with PWM-converters.

Keywords—Asynchronous Motors, Parallel path, PWM-converters, Undulatory process, Undulatory parameters, Undulatory voltage

I. INTRODUCTION

The most common controllable ac drives are based on asynchronous motors (AM) and frequency converters (FC) with an element; the output voltages are formed by PWM, i.e., a series of rectangular pulses is created. Most modern FC employ (IGBT) with a switching frequency of 2-8 kHz. The length of the pulse front is determined by the type of converter switch and may be 0.2-1 (µsec).

As we know from the theory of transient processes, supplying rectangular pulses with rapid voltage increase to an AM winding induces wave processes (WP) in the winding. The wave processes constitute a complex set of physical phenomena accompanying the appearance propagation, and rapid change in the electromagnetic field of a circuit or system. The phenomena cause considerable voltage surge in the circuit (Fig. 1a). The calculation procedure of these constants of solving the problem and is based on the known equivalent circuit (Fig. 1b). The relation between the parameters of the two diagrams (Fig.1a and b) is given:

\[ L = L_s + \frac{R_s^2}{\omega^2 L_s} \]

\[ R = R_s + \frac{(\alpha L_s)^2}{R_s} \]

(1)

The voltage distribution in the given circuit is described by a hyperbolic partial differential equation [1-7]:

III. DETERMINATION OF THE UNDULATORY VOLTAGES

Analytic calculation of the voltage surges in the IM winding [1]-[7]-[8] entails the solution of the differential equation of the wave process (WP), which is written for the equivalent circuit in (Fig.1b).

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Here the x-coordinates vary continuously in the range \(0 \leq x \leq l\); \(l\) – is the length of the conductors in the parallel branch of the phase winding. Variation in \(x\) in the opposite direction to the incident wave motion, i.e., from the end of the winding \((x = 0)\) to its beginning \((x = l)\), is assumed to be positive.

All the parameters in the equation are referred to unit length. Therefore, the dimensions of the parameters are as follows:

- for the longitudinal branch:
  - the inductance \([L] = \text{H/m}\);
  - the resistance \([R] = \text{Ohm/m}\);
  - the longitudinal capacitance \([K] = \text{F/m}\).

- for the transverse branch:
  - the transversal capacitance \([C] = \text{F/m}\);
  - the conductivity \([G] = 1 / \text{Ohm-m}\).

The equation is solved by the Fourier method. To this end, the initial and boundary conditions determining the physical characteristics of the phenomena in the winding are preliminary specified. They are formulated as follows: a voltage wave characterized by the following equation is incident at the winding.

\[
u_\text{pul} = U(e^{-\alpha t} - e^{-\beta t}) \quad \text{when} \quad t > 0 \quad \text{(3)}
\]

where \(U = 10 \text{ (V)}\) – is the pulse amplitude; \(\alpha\) and \(\beta\) – are constants: \(\alpha = 1.2 \times 10^6 \text{ (sec}^{-1})\), \(\beta = 2 \times 10^8 \text{ (sec}^{-1})\).

Zero initial conditions are assumed. The state is characterized by the following equation.

\[
\frac{\partial^2 u(x,0)}{\partial x^2} = \gamma^2 \frac{\partial u(x,0)}{\partial t} \quad \text{(4)}
\]

where \(\gamma = \sqrt{C/K}\)

The ends of the winding are insulated, with following boundary conditions:

- for the ends of the winding \((x = 1)\): \(U(l,t) = u_\text{pul}(t)\)
- for the ends of the winding \((x=0)\).

\[
\frac{\partial u(0,t)}{\partial x} = 0
\]

It should noted that while solving the differential equation «(2)», by Fourier’s method, the dependency of the parameters of frequency, \(R\), \(L\), and \(G\) have been taken into account by using the iterative method discussed in [1] –[7] (see algorithm, Fig.2).

IV. COMPUTATION RESULTS OF THE UNDULATORY PARAMETERS AND OVERVOLTAGES

Computation results of the parameters \(C_i\) and \(K_i\) without considering their variation according to the frequency and \(G_i\), \(L_o\), \(R_o\) for a frequency of 200 kHz.

The numerical values of these parameters for the parallel paths numbers, \(a=1\) and \(a=2\) are given on the table I.
### Table I

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Number of parallel Paths of a Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_s$, pF</td>
<td>$a=1$</td>
</tr>
<tr>
<td>$K_s$, pF</td>
<td>$a=2$</td>
</tr>
<tr>
<td>$G_s$, $1/\Omega$</td>
<td>$3.25 \times 10^{-5}$</td>
</tr>
<tr>
<td>$R_s$, $\Omega$</td>
<td>$173.92$</td>
</tr>
<tr>
<td>$L_s$, $\mu$H</td>
<td>$1250$</td>
</tr>
</tbody>
</table>

The computational results of the undulatory voltage, assuming that the windings is supplied with a similar impulsion as for an impulsion generated by a PWM control equipped with IGBT transistors are shown in figures 3, 4 and 5, for various values number of parallel branches winding. Figure 3, represents the undulatory process on the neutral of winding. Figure 4, gives (WP) on the first and the last section of a winding and Fig.5, presents the voltage distribution for every six turns along the parallel path for two points in times: $t=3 \times 10^{-7}$ (sec) and $t=1.2 \times 10^{-6}$ (sec).
Fig. 5 Distribution of voltage through every six turns along the parallel paths of a winding for two points in times

- $t = 3 \times 10^{-7}$ s,
- $t = 1.2 \times 10^{-6}$ s

a) $a = 1; b) a = 2$

V. CONCLUSION

1) The arrival of a rectangular impulsion voltage similar to the one of a PWM variable frequency control in an asynchronous motor winding will trigger in the winding an undulatory process. By treating several cases, one notices that the overvoltage calculated with this method exceeds twice the voltage applied initially and the process at any point of the winding has a deadened oscillatory character (fig. 3).

2) Fig. 3 Shows that overvoltages compared to the frame fall with increase in the number of parallel path.

3) The results of simulation obtained show that the overvoltage between turns (sections) in a multiturn winding decreased considerably with the decrease of the number of the parallel path of a winding (fig. 4 and 5).

4) It can be seen from Fig. 5 that the voltage distribution at section and turns along the parallel path at the different points in time becomes more uniform with the increase in the time of the undulatory process.

5) The presented calculation procedure for wave-length constants and overvoltage’s in the pulls supply broadens

6) The possibilities of investigation and the design of an insulation system for variable-speed drives and allows the choice for much correct values for interturn test voltages.

REFERENCES


