EFFECT OF THE FEEDER CABLE AND TRANSFORMER IMPEDANCE ON THE MECHANICAL OUTPUT CHARACTERISTIC OF THE INDUCTION MOTOR

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ABSTRACT

The first part of this paper deals with the determination of the equivalent circuit parameters of the induction motor, cable and the transformer. The second part of this paper describes the effect of the feeder cable impedance on the mechanical output characteristic of the asynchronous motor. Calculation is performed for the six poles induction motor with the nominal output 20 kW, the feeding transformers with the rated capacity 50 kVA and 630 kVA. Calculation is performed by the MATLAB program.

KEYWORDS

Equivalent circuit, short circuit test, no-load test, mechanical output characteristic, operating conditions

1. INTRODUCTION

We propose suitable motors for different tipes mechanical equipment according to the mechanical characteristics of the asynchronous motor and its mechanical load. In modern applications motors are controlled by semiconductor converters but some applications with the biggest motors require higher reliability and efficiency. For these reasons semiconductor converters are not used for speed-torque controll and these motors are started by direct connection to the power network.

Mechanical output characteristics of these motors are dependend on the impedance of the supply transfomer and the supply cable. This paper presents an example with the asynchronous motor with the output 22 kW, the feeding transformer with the rated capability 50 kVA and the cable interconnection without the cable and with the cable 80 m and 180 m length.

2. CALCULATION OF THE EQUIVALENT CIRCUIT OF THE ASYNCHRONOUS MOTOR AND ITS FEEDING TRANSFORMER

2.1. Equivalent circuit of the asynchronous motor

If a motor has the balanced a magnetic circuit and windings and is supplied by a balanced three-phase voltage, we can describe it by the single-phase equivalent circuit.

Leakage inductances (X_{sta} and X_{rot}) represent the leak of the magnetic flux. The resistance of the stator winding is marked as Rsta in Figure 1. This resistance respects Joule losses in the stator winding. Magnetizing inductance $X_{\mu mo}$ and resistance R_{Femo} are connected in parallel. Inductance $X_{\mu mo}$ represents the main magnetizing flux that is in the magnetic circuit of the motor and resistance R_{FEmo} represents eddy-current losses.

The rotor resistance separation between the outgoing mechanical power and Joule losses in the rotor squirrel cage is a function of the slip. This dependence is described by the equation [1]:

$$\frac{R_{rot}}{s} = R_{rot} + \frac{1-s}{s} R_{rot} \tag{1}$$

The left side of this equation represents heat losses in the rotor squirrel cage. The resistance $\frac{1-s}{s} R_{rot}$ represents the mechanical power of the motor. The resistance $\frac{1-s}{s} R_{rot}$ is used for the calculation of the mechanical power which is:

$$P_{mech} = 3 \cdot R_{rot} \frac{1-s}{s} \left|\overline{I}\right|^2_{rot} \tag{2}$$

2.2. Determination of the equivalent circuit parameters by measurement

Elements of the asynchnous motor equivalent circuit can be determined by several measurements. The first measurement is the no-load test. This measurement determines the magnetizing inductance of the motor ($X_{\mu mo}$) and the resistance R_{Femo} represents eddy-current losses. During measuring the motor is not mechanically loaded. The second measurement is the blocked-rotor test. This measurement determines the resistance of stator and rotor windings (R_{sta} and R_{rot}) and leakage inductances of the stator and rotor (X_{sta} and X_{rot}). During this measuring the shaft of the motor is blocked. The third measurement is the stator resistance measurement. Ohm’s method or some of the resistance bridges can be used. This measurement is performed with the aid of direct current.

The measurement of the transformer is similar to the measurement of the asynchronous motor. The magnetizing inductance ($X_{\mu tr}$) and the resistance representing the eddy-current losses of the transformer magnetizing circuit (R_{Fetr}) are determined by the no-load test of the transformer. The transformer is supplied by nominal voltage and is not loaded. The next measurement is the short circuit test. The measured transformer has a short-circuited secondary winding and the reduced voltage supplies the primary winding. The reduced supply voltage is selected such that the nominal current passes through the transformer. The short-circuit voltage of the transformer is recounted into the percentual value.

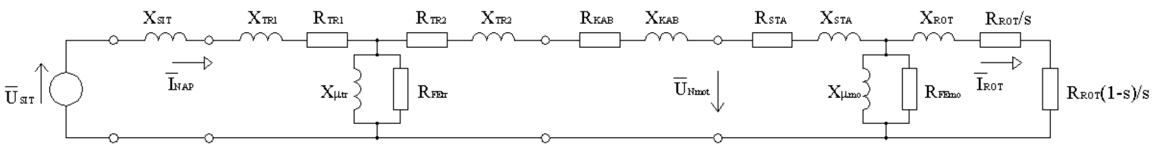

Figure 1 – The equivalent circuit of the modelled power system

2.3. The parameters of the component used in the modell

Asynchronous motor [1]:

Pout = 20 kW U_{mot} = 400 V U_{kmot} = 230 V I_{kmot} = 263 A $\cos\varphi_k$ = 0.44
U_{0mot} = 400 V I_{0mot} = 17,6 A $\cos\varphi_{0mot}$ = 0.1 R_{sta} = 0.192 Ω six poles

The first feeding transformer DOTN 50/20 used in the modell [2]:

S_{tr1} = 50 kVA U_{np1} = 22 kV U_{ns1} = 0.4 V u_{ktr1} = 3.9 % ΔP_{ktr1} = 1350 W
ΔP_{0tr1} = 175 W i_{01} = 0.04 I_{n1}

The second feeding transformer DOTN 630/20 used in the modell [2]:

S_{tr2} = 630 kVA U_{np2} = 22 kV U_{ns2} = 0.4 V u_{ktr2} = 4.1 % ΔP_{ktr2} = 8400 W
ΔP_{0tr1} = 1030 W i_{01} = 0.04 I_{n1}

Power network:
U_{ns} = 22 kV S_{knwk} = 80 MVA

Feeding cable:
R_{cab} = 3.59 Ω/km X_{cab} = 0.107 Ω/km U_{cab} = 400 V Length 80 m and 160 m

The speed – torque characteristic of the used fan:

$$M = 20 + 1.87 \cdot 10^{-4} n^2 \qquad (3)$$

2.4. Results of the analyse

Figure 2 shows the influence of the supply network, transformer and cable impedance on the speed-torque characteristic of the asynchronous motor and the operating point of the motor. The blue curves show the speed-torque characteristic of the motor that is supplied directly by the transformer (without the cable). The influence of the transformer and cables on the motor rated operating point is small. The rated operating point has same speed and torque in both cases. The rated capacity of the feeding transformer has the great influence on the torque maximum of the motor. This moment maximum is important on the electromechanical transient phenomena. The motor maximum torque increases from 593 Nm to 720 Nm by increase of the feeding transformer rated capacity from 50 kVA to 630 kVA. The rated capacity of the feedeng transformer has the influence on the starting torque of the motor. The motor has the starting-torque 278 Nm if it is supplied by the feeding transformer with the rated capacity 50 kVA. The motor has the starting-torque 370 Nm if it is supplied by the feeding transformer with the rated capacity 630 kVA. Cables with 80 m and 160 m length decline the starting-torque and the maximum torque of the motor. The high impedance (the small feeding transformer or the length feeding cable) in front of the motor may lead to the unstability of the motor starting. The torque generated by the motor is less than the load torque.

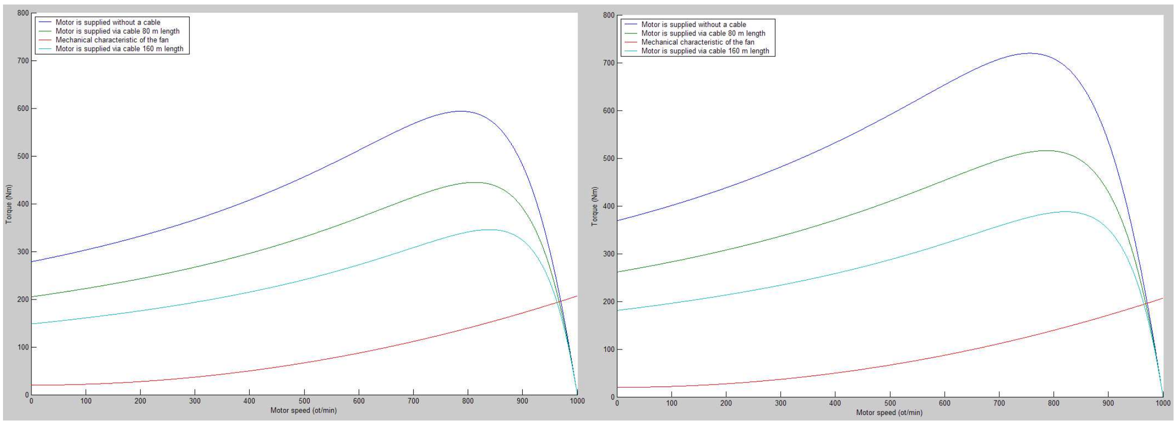

Figure 2 – Speed-Torque characteristics of the asynchronous motor (20 kW) that is powered by two transformers (50 kVA - left, 630 kVA - right)

The third figure shows a plot of the mechanical output versus the motor rotating speed during the starting of the motor. The rotating speed is equal to zero at the first time after the start of the motor (the slip of the motor equal to one) hence the outgoing mechanical power is zero. The value of the motor outgoing mechanical power designates the starting time of the motor. If the outgoing mechanical power has the greate value, the motor starting time is short. The power peak is reduced by the impedance of the feeding transformer and the cable. When the motor speed approaches the synchronous speed, the motor output mechanical power is zero because the motor has not any torque. In this case the stator input current passes through the magnetizing inductance. The input starting apperent power of the motor can be seven times higher than the input rated apperent power.

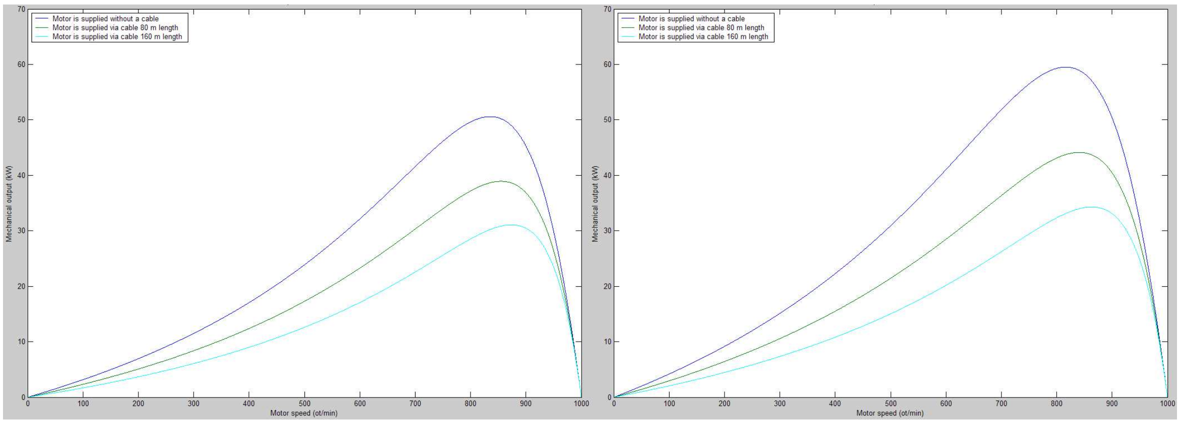

Figure 3 – Dependence of the mechanical power on the motor speed of the asynchronous motor (20 kW) that is powered by two transformers (50 kVA - left, 630 kVA - right)

An input current versus the motor speed is shown in figure four. This characteristic shows the influence of the feeding transformer rated capacity on the input starting current. The starting current value is important to setting up of the motor electrical protection and design of the feeding source rated capacity. If the used motor (20 kW) is supplied by the transformer (without the cable) with the rated capacity 50 kVA its starting current is 228 A. The motor has the strating current 263 A if the feeding transformer with the rated capacity 630 kVA is used. By the synchronous speed of the motor is passing current through the motor 17 A. This current passes through the magnetizing inductance and it is almost independent on the impedance in front of the motor.

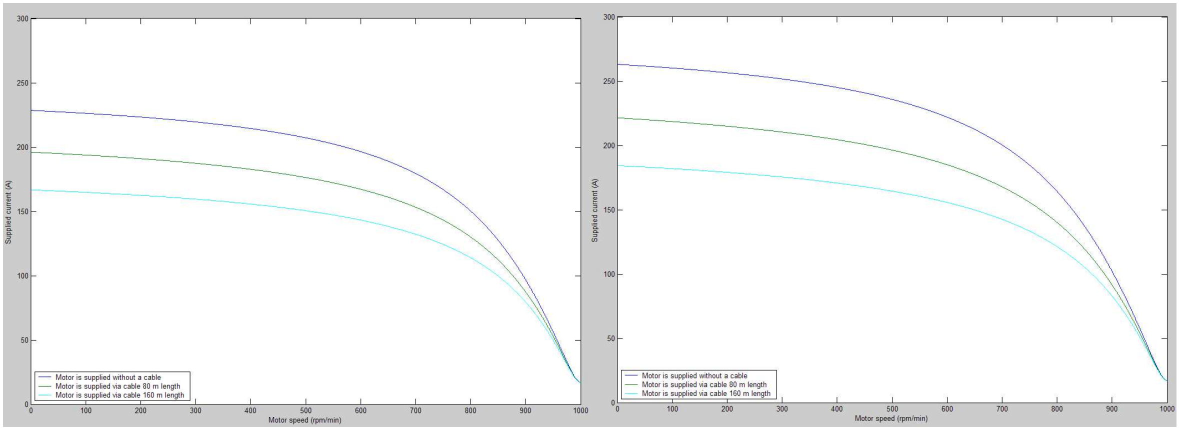

Figure 4 – Dependence of the supplied current on the motor speed of the asynchronous motor (20 kW) that is powered by two transformers (50 kVA - left, 630 kVA - right)

The value of the feedeing transformer rated capacity has the greate influence on the motor terminal voltage by the start of the motor. The terminal voltage of the motor is important to the determinating of the torque maximum of the speed-torque characteristic. The terminal voltage of the motor versus the motor speed is shown in figure five. If the transformer with the rated capacity 630 kVA supplies (without cable) the motor, its line – to – line terminal voltage by the start is 394 V. It is very small voltage reduction. If the motor is supplied by the transformer with the rared capacity 50 kVA, the line – to – line voltage reduction is 57 V by the start. This voltage reduction can adversely affect other equipment connected to the same transformer. The high value of the feeding transformer (or cables) impedence induces this large voltage reduce.

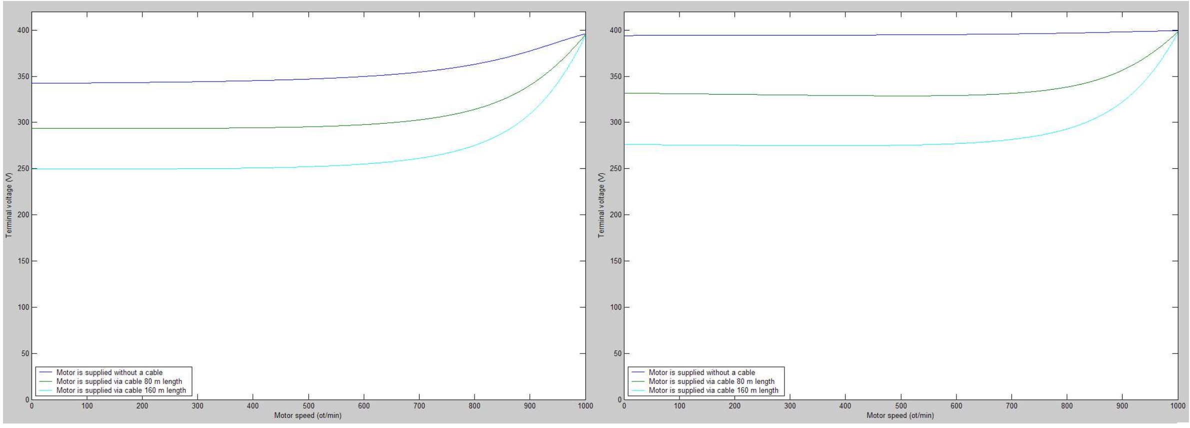

Figure 5 – Dependence of the terminal voltage on the motor speed of the asynchronous motor (20 kW) that is powered by two transformers (50 kVA - left, 630 kVA - right)

3. CONCLUSIONS

Above the results indicate influences the value of the impedance in front of the motor on the mechanical output power and the influences on the electrical unit (input current, input apparent power, terminal voltage). We can use these results for design of the motor and the transformer protection. The asynchrnous motors have other properties by the starting and other properties in nominal oparation. We have to design of the feeding source and the feeding line in the light of the transient phenomena of the motor. If the motor is supplied by the thansformer with the low rated capacity, the voltage reduction can be dangerous for other equipment. Above the characteristics can be used for the teaching.

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