# Start-up and Reverse Analysis of Induction Motor Model in Pump Regime

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***Abstract*** **– This paper analyzes induction motor starting and reversing performances for pump drive. For theoretical analysis mathematical program MATLAB Simulink is used. Mathematical model of induction motor was improved with algorithm which consists of torque-slip function. Consequently, the results of modeling are accurate. At the end of transition process load torque circumstances of rotor speed was observed. During research obtained comparison of theoretical and practical measurements. In practical experiments was tested induction motor with wound rotor 0.3kW.**

***Keywords*** **– Electrical machine, induction motor, modeling, simulation .**

## I. INTRODUCTION

The pump with induction motor (IM) is one of the most used drives. Most part of generated energy is consumed by using pumps, for example, it is merchantable in several oil industries. It is necessary that pump performance depends on unbalanced voltage value. Net power quality makes influences on induction motor efficiency. This occurrence causes torque ripples. To make pump working more efficient, manufacturers decrease electrical machine loses and researchers improve new control methods and algorithms for drive control [1]-[2].

Nowadays pump drive systems are sometimes used as renewable energy sources. For example, produced energy from wind generator is supplied to pump. After that the pump transports water to reservoir that is located at high place. At the end the stored water is derived to hydro generator. In this case the cost of kilowatt per hour is lower. It means that this type of accumulated energy system will develop more in coming future [3].

One of the most interesting researches is made by professors from Bangladesh. Energy obtained from solar panels was converted and supplied to pump system pumping water to users. The objective of the paper was to develop converter that supplies three-phase induction motor [4].

It is necessary to take into account pump drive system vibrations. Shaft vibration is deviation from steady state mode. There are two kinds of vibrations; torsional and ·translational. The value of vibrations depends on rotor eccentricity and not less important is how singular motor and pump are centered [5].

As it is written the consumed power of pumps in one of China's provinces is 1,92MW. It means that electrical pump system must be efficient; therefore the authors develop control algorithm and converter device. Pump drive is designed for 155 kW doubly fed induction motor [6].

Induction motor is subjected for several overvoltage types. For example, it can be caused by lightening or different commutation of switches in nearby systems. In addition, insulation damages in relevant systems can also affect IM. So the problems can be solved in different ways; first, to limit the magnitude of the voltage spike that might be impressed on the system, second, to lower the rate of rise of the voltage surge to effectively distribute it across many turns of the motor winding [7].

## II. INDUCTION MOTOR MODEL

Nowadays one of the most efficient transition processes under research can be achieved using mathematical analysis. Many authors pointed out that not always mathematical model includes all system elements and load variations. Therefore authors with the help of voltage and frequency control methods can make IM performances more efficient. Slip optimization reduces power loses, stator current and consumed power [8].

Using program MATLAB Simulink a simple mathematical model was made. It consists of induction motor standard voltage equations and function of pump performance. The objective is to make function which can predict the efficiency of drive process. During the research, they developed a model that takes into account core losses and hysteresis losses. In mathematical model stator and rotor windings are symmetrical and distributed so that the magnetiomotive forces are sinusoidal. The effects of hysteresis and eddy currents are neglected. The motor parameters are independent on temperature. The advantage of this mathematical model is pump head and discharge function which overwrite mechanical characteristics [9].

### *A. Mathematical Model of Induction Motor*

Induction motor mathematical model is widely used for power system stability calculation [10]-[14].

Synchronous coordinate system is usually used to describe IM mathematical model in equations [15]-[16]:

$$\begin{aligned} V_{sd} &= R_s i_{sd} + \frac{d}{dt}\Psi_{sd} - \omega_s \Psi_{sq} \\ V_{sq} &= R_s i_{sq} + \frac{d}{dt}\Psi_{sq} + \omega_s \Psi_{sd} \end{aligned} . \tag{1}$$

$$V'_{rd} = 0 = R'_r i'_{rd} + \frac{d}{dt}\Psi'_{rd} - (\omega_s - \omega)\Psi'_{rq}$$
$$V'_{rq} = 0 = R'_r i'_{rq} + \frac{d}{dt}\Psi'_{rq} + (\omega_s - \omega)\Psi'_{rd} \qquad (2)$$

Flux of stator and rotor:

$$\begin{aligned} \Psi_{sd} &= L_s i_{sd} + L_m i'_{rd} \\ \Psi_{sq} &= L_s i_{sq} + L_m i'_{rq} \\ \Psi'_{rd} &= L'_r i'_{rd} + L_m i_{sd} \\ \Psi'_{rq} &= L'_r i'_{rq} + L_m i_{sq} \end{aligned} \qquad (3)$$

Total stator and rotor inductances equal to:

$$\begin{aligned} L_s &= L_{ls} + L_m \\ L'_r &= L'_{lr} + L_m \end{aligned} \qquad (4)$$

Electromagnetic torque as:

$$T_e = \frac{3}{2} p \left( \Psi_{sd} i_{sq} - \Psi_{sq} i_{sd} \right), \qquad (5)$$

Mechanical equation:

$$\begin{aligned} \frac{J}{p}\frac{d\omega_r}{dt} &= T_e - T_{load} \\ \frac{d\Theta_r}{dt} &= \omega_r \end{aligned} \qquad (6)$$

where

*Rs, Lls* – Stator resistance and leakage inductance,

*R'r, L'lr* – Rotor resistance and leakage inductance,

*Lm* – Magnetizing inductance,

*Ls, L'r* – Total stator and rotor inductances,

*Vsq, isq* – q axis stator voltage and current,

*V'rq, i'rq* – q axis rotor voltage and current,

*Vsd, isd* – d axis stator voltage and current,

*V'rd, i'rd* – d axis rotor voltage and current,

*Ψsd, Ψsd* – Stator q and d axis fluxes,

*Ψ'rq, Ψ'rd* – Rotor q and d axis fluxes,

*p* – Number of pole pairs,

$T_e$ – Electromagnetic torque,

$\omega_r$ - Angular velocity of the rotor,

$\Theta_r$ - Rotor angular position,

$\omega_s$ - Electrical angular velocity,

$T_{load}$ - Shaft mechanical torque,

*J* - Combined rotor and load inertia,

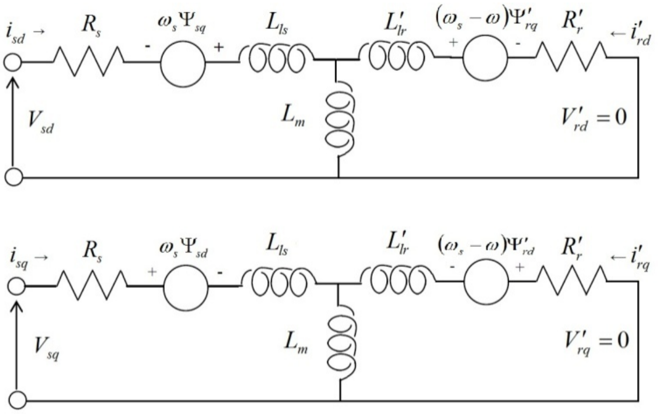

Fig. 1. d-axis and q-axis equivalent circuits of the dq-frame-based induction motor model.

All electrical parameters are referred to IM stator. Figure 1 demonstrates IM equivalent scheme for equations (1) and (2). Mathematical models exhibit inductances independently on rotor position. Easy incorporation of magnetic saturation and rotor skin effect are two additional assets of d–q models. The air gap flux density retains a sinusoidal distribution along the circumferential direction.

### *B. Mathematical Model in MATLAB*

So, modeling of transients is required for power-grid-fed (constant voltage and frequency) and for PWM converter-fed IM drives control [16].

From Figure 2 we can see that in several mathematical programs for pump accelerations process transitions use a squared function of torque-speed characteristic. But in real processes it can be otherwise.

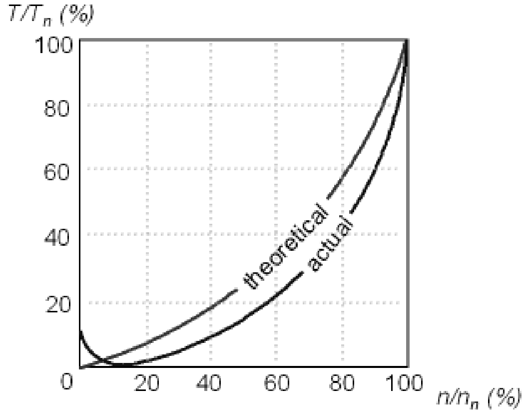

Fig. 2. Torque-speed characteristic of IM in pump performance.

During IM research there were chosen three kinds of pump characteristics in Figure 3. As it is seen at starting moment load torque value is small but after acceleration it increases till nominal. *T* – load torque, *Tn* – nominal load torque, *n* – rotor speed, *nn* – nominal rotor speed of IM.

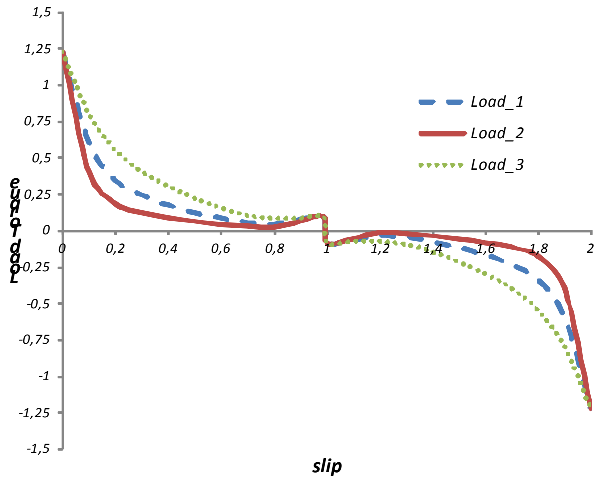

Fig. 3. Function of torque-speed characteristic for IM .

As Pump is started and after 0.5 seconds reversed then slip in function needs to be changed from zero till two. In MATLAB torque-slip function is operated with approximate one-dimensional function.

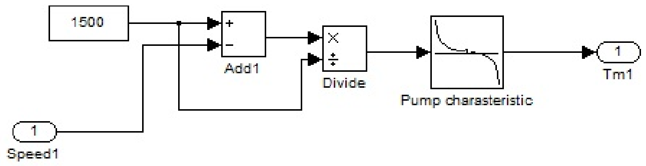

Fig. 4. Torque-speed characteristic in MATLAB.

At first the developed algorithm is calculating slip. After calculations load torque (PU units) value in block output depends on IM slip. In MATLAB Simulink LOOKUP TABLE block is using acceleration function from Figure 3. After simulations for IM mathematical model can chose soft or solid torque-slip characteristics.

## III. EXPERIMENTAL STAND

For the research the induction motor test workbench from company LEROY SOMMER was used (5. figure). It consists of researched motor, torque sensor (SCAIME), powder break and tachogenerator. IM rated data: $Pn=0.3kW$, $Un=400V$, $In=1.33A$, $fn=50Hz$, $Tn=2Nm$, IM is connected in parallel to powder break. Powder break characteristic is able to provide constant torque for all speed ranges. Rotor rotational speed is measured from the DC tachogenerator. Torque meter is placed between IM and powder brake. Its operating principle is based on tenzometrical sensor operation. Sensor input is connected to 12V DC supply voltage. It is supplied to strain gauges bridge, which consists of four sensitive tenzometrical metal pellicles. Output signal is transported to MODMECA meter and then strengthened and filtered. The moment of inertia is determined from the speed characteristic when IM is connected directly to the network. Friction coefficient is calculated from motor mechanical losses at no-load figures and justified. One line figure captions has to be centered.

Fig. 5. Test stand for IM characteristics.

Induction motor equivalent scheme parameters in Table 1 are calculated by means of LVS standard [18].

TABLE I

INDUCTION MOTOR EQUIVALENT SCHEME PARAMETER

| Parameters | PU units | SI units |
|---|---|---|
| $R_S$ | 0.127 | 25.4 |
| $X_S$ | 0.108 | 0.069 |
| $X_M$ | 1.021 | 0.65 |
| $X'_R$ | 0.108 | 0.069 |
| $R'_R$ | 0.124 | 24.8 |
| $J$ | $0.035 kgm^2$ | |

Moment of inertia is solved from deceleration oscillogram. Solved moment of inertia was calculated when IM was connected with powder brake. Friction coefficient was calculated from mechanical losses.

## IV. RESULTS OF SIMULATION

From used equations it is seen that induction motor model can be used in two modes; motor and generator. If load torque value is positive then IM model is working in motor regime, but if it is negative then in generator mode. Reactive static load torque was chosen for IM model. It means, in motor mode reactive torque is opposing rotor motion. This process does not depend on rotor motive direction. Therefore, after stator windings are switched to contrary side it is required to change load torque value. Otherwise motor starts to work in generator regime. For correctly IM mathematical model transition process measurements the time moment when switch turned stator windings to contrary side is chosen from practical stator oscillogram. The time at this switching pause is 0.1ms.

Figure 6 represents that the comparison between mathematical model and experimentally obtained data has quite well coincidence. Figure 7 mismatches between electromagnetic torque are observed only at the beginning of start-up process. Mentioned mismatches appear because of powder brake construction, it means that in start-up process when slip value is less powder brake load torque is smaller than nominal. This powder brake performance results in small electromagnetic torque fluctuations.

From Figures 8 and 9 we concluded that modeling IM transition process it is not necessary to take into account only constant load values. Start-up process can take longer time for acceleration if load torque remains constant. IM electromagnetic torque ripples in start-up process can be even 10 times more than nominal.

## V. CONCLUSIONS

Created IM mathematical model is very practical in treating the transients and control of symmetrical IMs fed from symmetrical voltage power grids or from PWM converters. In working process algorithm or in other words approximation for torque-slip characteristics was developed. Created mathematical function can be applied as a supplement for IM model in MATLAB. Summing up this developed function can be used to describe ventilator and pump transition processes and to get more accurate simulation results as well. Created IM torque-slip function can be changed for the required load. MATLAB program simulations also include contrariwise calculations from free acceleration torque-speed oscillogram to get steady-state characteristics.

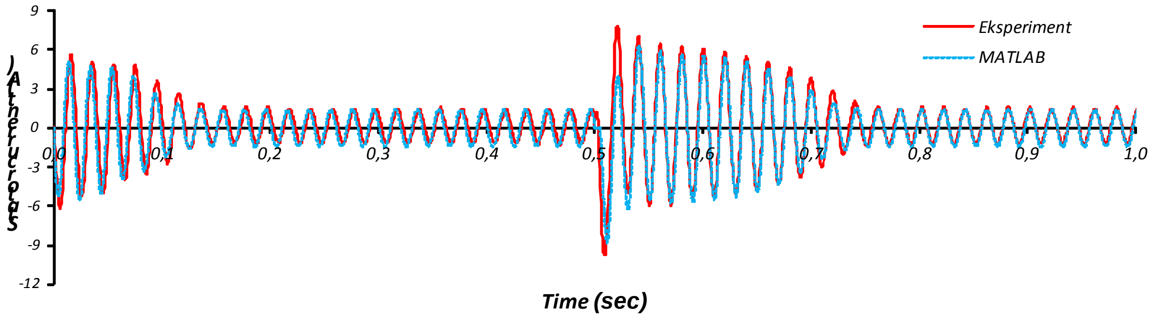

Fig. 6. Stator current in start-up and reverse transition process.

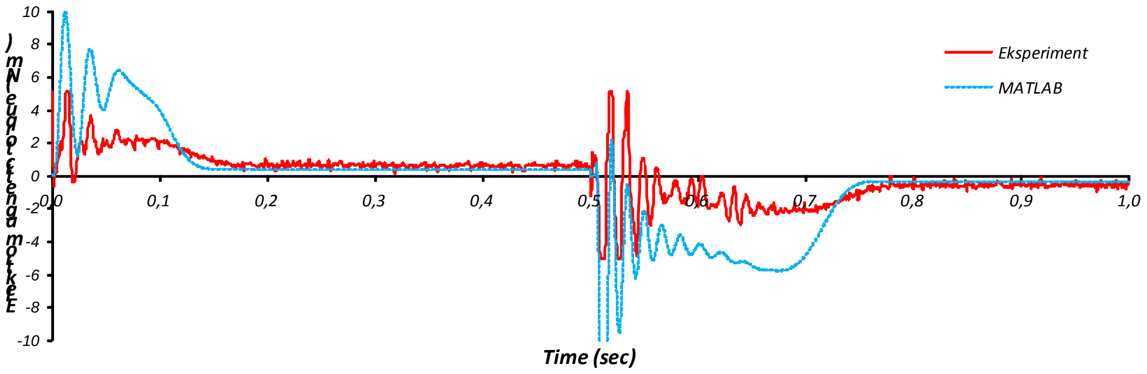

Fig. 7. Comparison between Electromagnetic torque in start-up and reverse transition process.

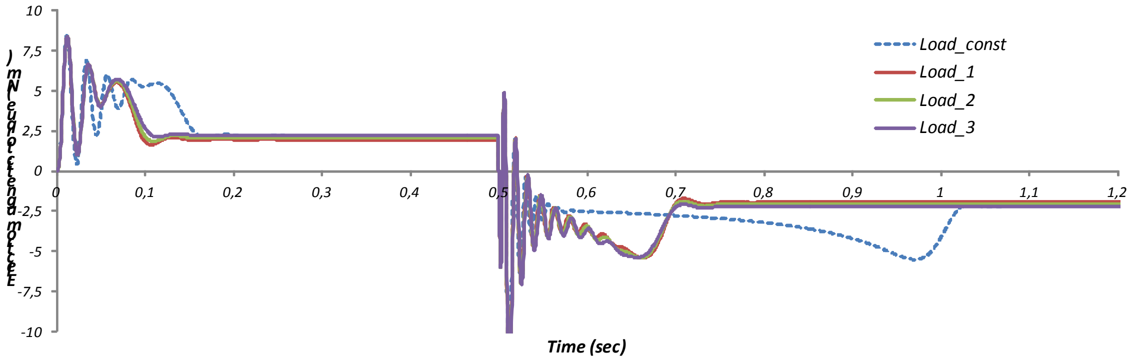

Fig. 8. Electromagnetic torque in start-up and reverse transition process.

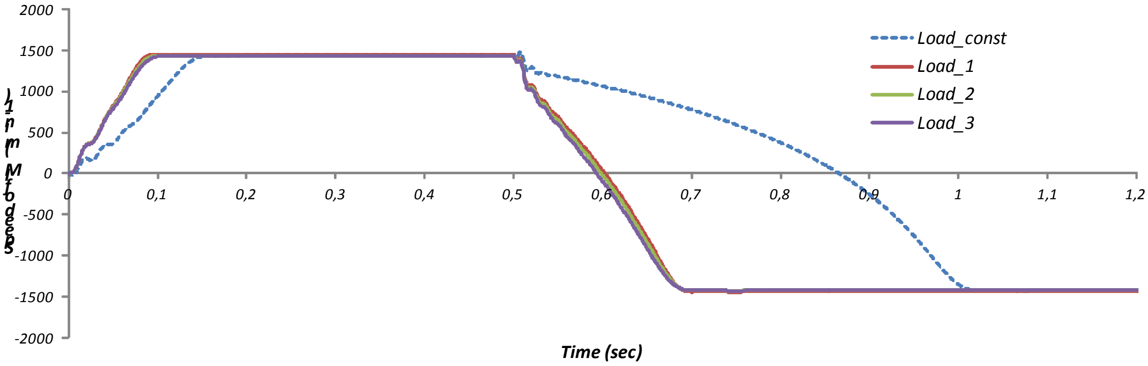

Fig. 9. Speed of IM in start-up and reverse transition process.

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**Guntis Orlovskis, Kārlis Ketners. Palaišanas un reversēšanas process asinhronā dzinēja modelim darbojoties sūkņa režīmā**
Rakstā ir aprakstīta Sūkņu piedziņas sistēmas mūsdienās pielietošana ari kā atjaunojamās enerģijas avotus. Tā piemēram, ar vēja ģeneratoru saražoto enerģiju piedzen sūkni, kas uzpumpē ūdeni tvertnē, tā atrodas lielā augstumā. Pēc tam ar uzkrāto ūdeni piedzen hidroģeneratoru. Šinī gadījumā uzkrātās enerģijas cena ir ļoti zema, tas lieci par to, ka nākotnē šādi enerģijas uzkrāšanas veidi parādīsies ar vien biežāk. Tiek izveidoti matemātiskie modeļi, kad ADz ar centrbēdzes sūkni darbojas stabilā režīmā. Optimizējot slīdi samazina jaudas zudumus, statora strāvu un patērēto jaudu**.** Izmantojot programmu MATLAB Simulink ir izveidots vienkāršs matemātisks modelis. Matemātiskais modelis sastāv no asinhronā dzinēja standarta sprieguma vienādojumiem un funkcijas, kas apraksta sūkņa darbību. Šī darba mērķis ir izveidot funkciju, kas uzlabos piedziņas efektivitāti. Tā kā sūknis tiek palaists un tikai pēc tam mainīts rotora griešanās virziens, tad momenta funkcijā no slīdes mainās no 0 līdz 2. Praktisko pētījumu darbā tiek izmantots asinhronā dzinēja testēšanas stends no kompānijas LEROY SOMMER. Tas sastāv no pētāmā motora, momenta devēja, (SCAIME), pulverbremzes un tahoģeneratora. Asinhronā dzinēja nominālie dati ir: $P_n=0.3kW$, $U_n=400V$, $I_n=1.33A$, $f_n=50Hz$, $T_n=2Nm$. Darba gaitā ir izveidots algoritms jeb momenta un slīdes raksturlīknes aproksimācija. Ar šo izveidoto matemātisko funkciju var papildināt asinhronā dzinēja modeli MATLAB Simulink programmā. Līdz ar to pētot pārejas procesus ventilatoriem vai sūkņiem var panākt lielāku precizitāti mehāniskajiem lielumiem.

**Гунтис Орловскис, Карлис Кетнерс. Процесс пуска и реверса для модели асинхронного двигателя, работающего в режиме насоса**
В данной статье анализируется процесс пуска асинхронного двигателя для реверсивного привода насоса, который использует энергию ветрогенератора. Насос наполняет водой бак, находящийся на большой высоте. Впоследствии набранная вода используется гидрогенератором. В этом случае стоимость накопленной энергии мала, что позволит в будущем широко применять подобные способы накопления энергии. Для теоретического анализа используется математический аппарат программы MATLAB Simulink. Математическая модель асинхронного двигателя была усовершенствована с помощью алгоритма, который определяет нагрузочный момент в зависимости от скольжения в диапазоне от 0 до 2.
Для экспериментального подтверждения модели асинхронного двигателя работающего с нагрузкой (центробежным насосом) были осуществлены исследования на опытном стенде компании LEROY SOMMER . В ходе исследования проведено сравнение теоретических и практических измерений. В практических экспериментов была протестирована асинхронных двигателей с фазным ротором 0.3 кВт.
В ссостав установки входят: исследуемый асинхронный двигатель, порошковый тормоз и тахогенератор. Асинхронный двигатель с номинальными данными: $P_n =0.3kW$, $U_n=400V$, $I_n=1,33A$, $f_n=50Hz$, $T_n=2Nm$.
В данной статье рассмотрено влияние скольжения в диапазоне от 0 до 2 для учета влияния статического реактивного момента нагрузки (центробежного насоса). Сформирован алгоритм, позволяющий аппроксимировать характеристику зависимости момента нагрузки от скольжения. Предложенной математической функцией можно дополнить в программе MATLAB Simulink модели асинхронного двигателя. В результате чего при исследовании переходных процессов асинхронного двигателя с вентиляторной нагрузкой можно получать более точные механические параметры.