Міністерство освіти і науки України
Державний вищий навчальний заклад
НТУ "Дніпропетровська політехніка"

____Електро-технічний факультет___

Кафедра Електропривода
(повна назва)

ПОЯСНЮВАЛЬНА ЗАПИСКА
дипломного проекту (роботи)
__________бакалавра_________
(назва освітньо-кваліфікаційного рівня)

галузь знань____0507 Електротехніка та електромеханіка
(шифр і назва галузі знань)
напрям підготовки 050702 Електромеханіка
(код і назва напряму підготовки)
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(назва освітнього рівня)
кваліфікація_______фахівець у галузі електротехніки___________
(код і назва кваліфікації)
на тему: Розробка системи векторного керування асинхронним двигуном з функцією мінімізації втрат

Виконавець:
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____________ Берест О.С.
(підпис) **(прізвище та ініціали)**

Керівники	Прізвище, ініціали	Оцінка	Підпис
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Міністерство освіти і науки України
Державний вищий навчальний заклад
НТУ "Дніпропетровська політехніка"

ЗАТВЕРДЖЕНО:
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________________ Казачковський М.М.
(підпис) (прізвище, ініціали)

«20» січня 2018 року

ЗАВДАННЯ
на дипломний проект
бакалавра

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Тема дипломного проекту "Design of the Induction Motor Vector Control System with Loss Minimization Function"
затверджена наказом ректора ДВНЗ НТУ «Дніпропетровська політехніка» від __________________№_____

section	content	date
Copper losses	Copper losses optimization In Field Oriented Control of Induction motor	20.01.18 – 12.02.18
Core losses	Core losses optimization In Field Oriented Control of Induction motor	16.02.18 – 15.03.18
Occupational Safety and Health	Analysis of harmful and dangerous Production factors.	17.03.18 – 26.04.18
Economy	Establishing economic feasibility adopted technical decisions. Calculation capital and operating costs	29.04.18 – 30.05.18

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Термін подання дипломного проекту до ЕК 10.06.2018

РЕФЕРАТ

Пояснювальна записка 62 с., 20 рис., 2 табл., 7 джерел, 4 аркуша креслень.

Об’єкт детальної розробки: Асинхронний Електропривод

Мета роботи: модернізація системи векторного керування.

Технічний проект містить розрахунки, які підтверджують працездатність системи.

У розділі «Технологічна частина» вказані основні відомості про векторне керування та двигун.

У розділі «Автоматизований електропривод» виконаний аналіз, розробка та розрахунок стратегій по зменшенню втрат у системі векторного керування

У розділі «Охорона праці» виконано аналіз небезпечних та шкідливих виробничих чинників проектованого об’єкту. Проведені інженерно – технічні заходи з охорони праці, заходи щодо пожежної профілактики та ергономіки.

В економічній частині наведено розрахунки та витрати на електроенергію, експлуатацію. Витрати скорочені приблизно на 20% завдяки введення стратегій по зменшенню втрат електроенергії.

АСИНХРОННИЙ ДВИГУН, ВЕКТОРНЕ КЕРУВАННЯ, ЧАСТОТНЕ УПРАВЛІННЯ, МІНІМІЗАЦІЯ ВТРАТ, ВТРАТИ В МІДІ, ЕЛЕКТРИЧНІ ВТРАТИ, ВТРАТИ В СТАЛІ МАГНІТОПРОВОДА.

ABSTRACT

Explanatory note 62 p., 20 figures, 2 tables, 7 sources, 4 sheets of drawings.

The object of detailed development: Induction Motor

Purpose: Modernization of the vector control system.

The technical design contains calculations that prove the system's performance.

The "Technological part" section contains basic information about vector control and engine.

The section "Automated Electric Drive" analyzes develops and calculates loss reduction strategies in the vector control system.

In the section "Labor protection" an analysis of hazardous and harmful production factors of the projected object was performed. The engineering and technical measures on labor protection, measures for fire prevention and ergonomics have been carried out.

In the economic part, calculations and expenses for electricity, operation are presented. Losses are reduced by about 20% due to the introduction of strategies to reduce electricity losses.

INDUCTION MOTOR, FIELD ORIENTED CONTROL, FOC, VECTOR CONTROL, FREQUENCY CONTROL, REDUCES OF LOSSES, LOSS MINIMIZATION, COPPER LOSSES, CORE LOSSES.

РЕФЕРАТ

Пояснительная записка 62 с., 20 рис., 2 табл., 7 источников, 4 листа чертежей.

Объект детальной разработки: Асинхронный Электропривод

Цель работы: модернизация системы векторного управления.

Технический проект содержит расчеты, подтверждающие работоспособность системы.

В разделе «Технологическая часть» указаны основные сведения о векторное управление и двигатель.

В разделе «Автоматизированный электропривод» выполнен анализ, разработка и расчет стратегий по уменьшению потерь в системе векторного управления

В разделе «Охрана труда» выполнен анализ опасных и вредных производственных факторов проектируемого объекта. Проведенные инженерно - технические мероприятия по охране труда, мероприятия по пожарной профилактике и эргономики.

В экономической части приведены расчеты и расходы на электроэнергию, эксплуатацию. Расходы сокращены примерно на 20% благодаря введению стратегий по уменьшению потерь электроэнергии.

АСИНХРОННЫЙ ДВИГАТЕЛЬ, ВЕКТОРНОЕ УПРАВЛЕНИЕ, ЧАСТОТНОЕ УПРАВЛЕНИЕ, МИНИМИЗАЦИЯ ПОТЕРЬ, ПОТЕРИ МЕДИ, ПОТЕРИ В СТАЛИ МАГНИТОПРОВОДА.

Content

Introduction

The principle of vector control of electrical drives is based on the control of both the magnitude and the phase of each phase current and voltage. For as long as this type of control considers the three phase system as three independent systems the control will remain analog and thus present several drawbacks. Since high computational power silicon devices, from TI, came to market it has been possible to realize far more precise digital vector control algorithms. The most common of these accurate vector controls is presented in this document: the Field Orientated Control, a digital implementation which demonstrates the capability of performing direct torque control, of handling system limitations and of achieving higher power conversion efficiency.

During the last few years the field of controlled electrical drives has undergone rapid expansion due mainly to the advantages of semiconductors in both power and signal electronics and culminating in micro-electronic microprocessors. These technological improvements have enabled the development of really effective AC drive control with ever lower power dissipation hardware and ever more accurate control structures. The electrical drive controls become more accurate in the sense that not only are the DC current and voltage controlled but also the three phase currents and voltages are managed by so-called *vector controls*. This document describes the most efficient form of vector control scheme: the Field Orientated Control. It is based on three major points: the machine current and voltage space vectors, the transformation of a three phase speed and time dependent system into a two co-ordinate time invariant system and effective Pulse Width Modulation pattern generation. Thanks to these factors, the control of AC machine acquires every advantage of DC machine control and frees itself from the mechanical commutation drawbacks. Furthermore, this control structure, by achieving a very accurate steady state and transient control, leads to high dynamic performance in terms of response times and power conversion.

AC motor control structures generally apply three 120º spatially displaced sinusoidal voltages to the three stator phases. In most of the classic AC drives the generation of the three sine waves is based on motor electromechanical characteristics and on an equivalent model for the motor in its steady state. Furthermore, the control looks like three separate single phase system controls rather than one control of a three phase system. The machine models and characteristics used are valid only in steady state. This causes the control to allow high peak voltage and current transients. These damage not only the drive dynamic performance but also the power conversion efficiency. Additionally, the power components must be oversized to withstand the transient electrical spikes.

Great difficulty in controlling the variables with sinusoidal references: PI regulators cannot perform a sinusoidal regulation without damaging the sinusoidal reference, and hysteresis controllers introduce high bandwidth noise into the system that is hard to filter out.

No three phase system imbalance management. No consideration of the phase interactions.

Finally, the control structure must be dedicated according to motor type (asynchronous or synchronous).

The following chapters present the Field Orientated Control of AC drives. This control solution overcomes each of these drawbacks and thus improves the overall effectiveness of the AC drive. Detailed explanations and references to other helpful documents gives the reader a good understanding of the control structure and of the immediate benefits of such a solution.

1 Technological part

1.1 Field Orientated Control

The Field Orientated Control (FOC) consists of controlling the stator currents represented by a vector. This control is based on projections which transform a three- phase time and speed dependent system into a two co-ordinate (*d* and *q* co-ordinates) time invariant system. These projections lead to a structure similar to that of a DC machine control. Field orientated controlled machines need two constants as input references: the torque component (aligned with the *q* co-ordinate) and the flux component (aligned with *d* co-ordinate). As Field Orientated Control is simply based on projections the control structure handles instantaneous electrical quantities. This makes the control accurate in every working operation (steady state and transient) and independent of the limited bandwidth mathematical model.

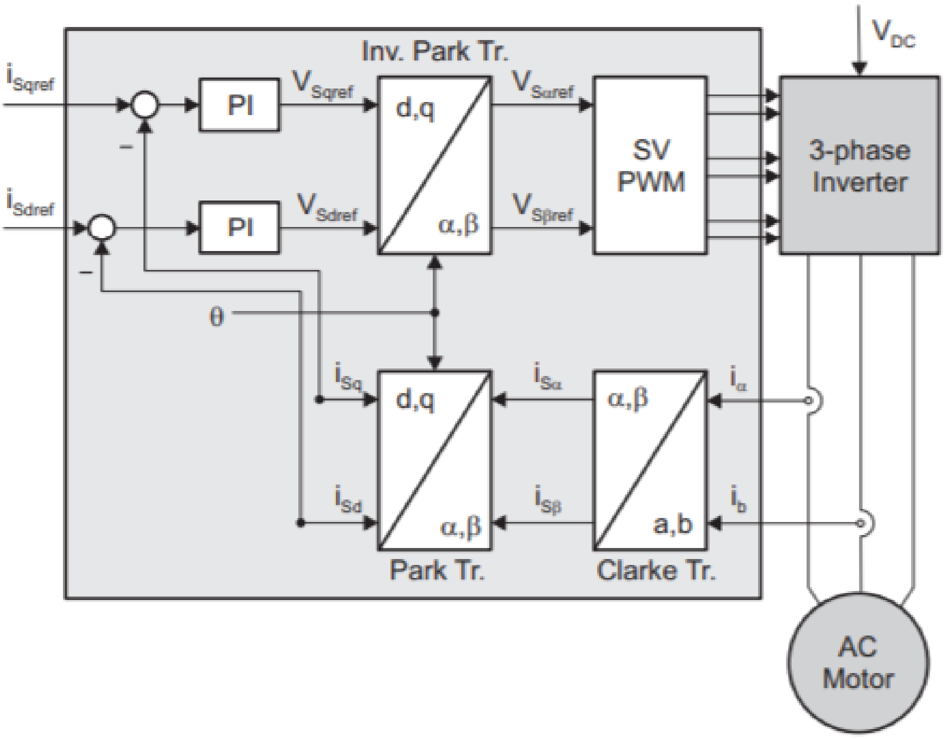
Thanks to FOC it becomes possible to control, directly and separately, the torque and flux of AC machines. Field Orientated Controlled AC machines thus obtain every DC machine advantage: instantaneous control of the separate quantities allowing accurate transient and steady state management. In addition to this advantage, Field Orientated Controlled AC machines solve the mechanical commutation problems inherent with DC machines. TMS320F240, by providing high CPU power and highly versatile motor control dedicated peripherals, makes the use of DC machines obsolete in terms of power conversion efficiency and system reliability, when compared with FOC AC machines.

Significant aspects of vector control application:

- Speed or position measurement or some sort of estimation is needed.
- Torque and flux can be changed reasonably fast, in less than 5-10 milliseconds, by changing the references.
- The step response has some overshoot if PI control is used.
- The switching frequency of the transistors is usually constant and set by the modulator.
- The accuracy of the torque depends on the accuracy of the motor parameters used in the control. Thus large errors due to for example rotor temperature changes often are encountered.
- Reasonable processor performance is required; typically the control algorithm is calculated every PWM cycle.

Although the vector control algorithm is more complicated than the Direct Torque Control (DTC), the algorithm need not be calculated as frequently as the DTC algorithm. Also the current sensors need not be the best in the market. Thus the cost of the processor and other control hardware is lower making it suitable for applications where the ultimate performance of DTC is not required.

1.2 The Basic Scheme for the FOC



Two motor phase currents are measured. These measurements feed the Clarke transformation module. The outputs of this projection are designated isα and $i_{s\beta}$. These two components of the current are the inputs of the Park transformation that provide the current in the d,q rotating reference frame. The i_{sd} and isq components are compared to the references: i_{sdref} (the flux reference) and isqref (the torque reference). At this point, this control structure shows an interesting advantage: it can be used to control either synchronous or induction machines by simply changing the flux reference and obtaining rotor flux position. As in the synchronous permanent magnet, a motor, the rotor flux is fixed determined by the magnets so there is no need to create one. Therefore, when controlling a PMSM, i_{sdref} should be set to zero. As induction motors need a rotor flux creation in order to operate, the flux reference must not be zero. This conveniently solves one of the major drawbacks of the “classic” control structures: the portability from asynchronous to synchronous drives. The torque command i_{sqref} could be the output of the speed regulator when you use a speed FOC. The outputs of the current regulators are V_{sdref} and V_{sqref}; they are applied to the inverse Park transformation. The outputs of this projection are $V_{s\alpha ref}$ and $V_{s\beta ref}$, which are the components of the stator vector voltage in the (α, β) stationary orthogonal reference frame. These are the inputs of the space vector pulse width modulation (PWM). The outputs of this block are the signals that drive the inverter. Note that both Park and inverse Park transformations need the rotor flux position. Obtaining this rotor flux position depends on the AC machine type (synchronous or asynchronous machine). The rotor flux position considerations are made in a following paragraph.

1.3 Motor rated parameters:

Motor.name	= 'K21R71G4';	
Motor.R1	= 29;	Ohm
Motor.R2	= 17.245;	Ohm
Motor.Lmu	= 1;	H
Motor.Lsigma	= 142.4e-3;	H
Motor.LS	= 1142.3e-3;	H
Motor.sigma	= 0.1246;	Einheitslos
Motor.T2	= 58e-3;	s
Motor.Zp	= 2;	Polpaare
Motor.UN	= 400;	V eff.
Motor.fN	= 50;	Hz
Motor.Imax	= 3.7;	A eff.
Motor.IqN	= 0.9;	A eff.
Motor.IdN	= 0.6;	A eff.
Motor.Psi1N	= 0.887;	Vs
Motor.MN	= 2.59;	Nm
Motor.Mmax	= 10;	Nm
Motor.PN	= 370;	W
Motor.J_M	= 4.9e-4;	kgm^2

2 Copper Losses optimization

2.1 Introduction to Copper Losses

Copper losses occur due to current flowing in stator and rotor windings. As the load changes, the current flowing in rotor and stator winding also changes and hence these losses also changes. Electro-magnetic torque of induction motor is approximately

$$T_{em} = \frac{3}{2} * Z_p * L_m * I_{1q} * I_{1d}$$

One can rewrite this expression in such way

$$T_{em} = K * I_m * I_r$$

So, take a look at this equation one can say that for a given load torque, the required electro-magnetic torque is obtainable by an infinite number of combinations of magnetizing current and torque producing rotor current. If I_m is large and I_r is small, then the core loss and the stator copper loss are large and the rotor copper loss is small. Contrarily if I_m gets smaller and I_r gets larger, then the core loss and the stator copper loss initially decrease and the rotor copper loss increases, but eventually the stator copper loss starts to increase also, so for a given load torque there is a ratio between the magnetizing current and the rotor current which generates a minimum of total losses. The motor is normally designed so that it operates with an optimum near rated load. But at low load there is an excess of magnetization, corresponding to a large I_m and a smallI_r. The total loss can then be reduced by reducing I_m and increasing I_r

In general case copper losses have view:

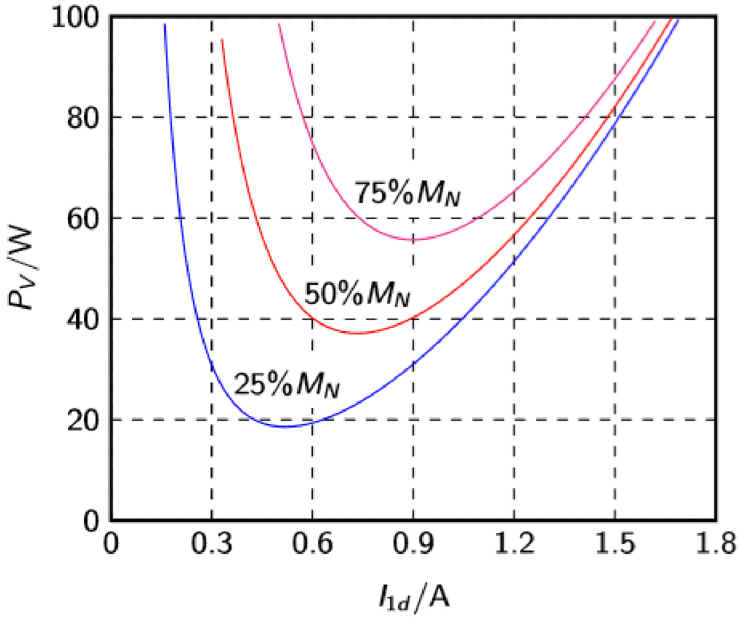
2.2 Calculations of Copper Losses Strategy

$$P_{losses,cu} = \frac{3}{2} R_1 I_{1d}^2 + \frac{3}{2} (R_1 + R_2) I_{1q}^2$$

Using general moment equation $T_{em} = Z_p * L_{\mu} * i_{sd} * i_{sq}$ and accept that load torque is constant one can obtain dependence copper losses of stator current’s direct component.

$$P_{losses,cu}(I_{1d}) = \frac{3}{2} R_1 I_{1d}^2 + \frac{2}{3} (R_1 + R_2) \frac{T_{em}^2}{Z_p^2 L_{\mu}^2 I_{1d}^2}$$

It has parabolic form



[3]

One can notice from the picture that there is only one extremum.

So, there is always such point of stator current which corresponds to the minimal copper losses. We can find expression for this point by finding extrema of this function.

This equation has parabolic form. That's why there is always one point (extrema) which corresponds to the minimal value of copper losses. Let us find this value

Using rules of Higher Math one can make:

1. Find the first derivative of copper losses equation
2. Set the derivative equal to zero and solve for I_{1d}
3. Obtained value of I_{1d} corresponds to a minimal value of copper losses

Let us make this

1)

$$\frac{d(P_{losses,cu})}{d(I_{1d})} = 3R_1 I_{1d} - \frac{4}{3}(R_1 + R_2)\frac{T_{em}^2}{Z_p^2 L_\mu^2 I_{1d}^3}$$

2)

$$3R_1 I_{1d} - \frac{4}{3}(R_1 + R_2)\frac{T_{em}^2}{Z_p^2 L_\mu^2 I_{1d}^3} = 0$$

$$R_1 I_{1d}^4 = \frac{4}{9}(R_1 + R_2)\frac{T_{em}^2}{Z_p^2 L_\mu^2}$$

$$I_{1d}^4 = \frac{4}{9}\frac{(R_1 + R_2)}{R_1}\frac{T_{em}^2}{Z_p^2 L_\mu^2}$$

$$I_{1d} = \sqrt{\frac{2}{3}}\sqrt[4]{\frac{(R_1 + R_2)}{R_1 * Z_p^2 L_\mu^2}} * \sqrt{T_{em}}$$

3) After all transformations there was obtained point for minimal I_{1d} for certain load torque

$$I_{1dmin} = \sqrt{\frac{2}{3}}\sqrt[4]{\frac{(R_1 + R_2)}{R_1 * Z_p^2 L_\mu^2}} * \sqrt{T_{em}}$$

Using this equation it is easy to find value of rotor flux ψ_{rd} which corresponds to the minimal copper losses

$$\psi_{rdopt} = I_{1dmin} * L_\mu = \sqrt{\frac{2}{3}}\sqrt[4]{\frac{(R_1+R_2)}{R_1 * Z_p^2 L_\mu^2}} * \sqrt{T_{em}} * L_\mu$$

Let us enter coefficient $k_{copper} = \sqrt{\frac{2}{3}}\sqrt[4]{\frac{(R_1+R_2)}{R_1 * Z_p^2 L_\mu^2}} * L_\mu$

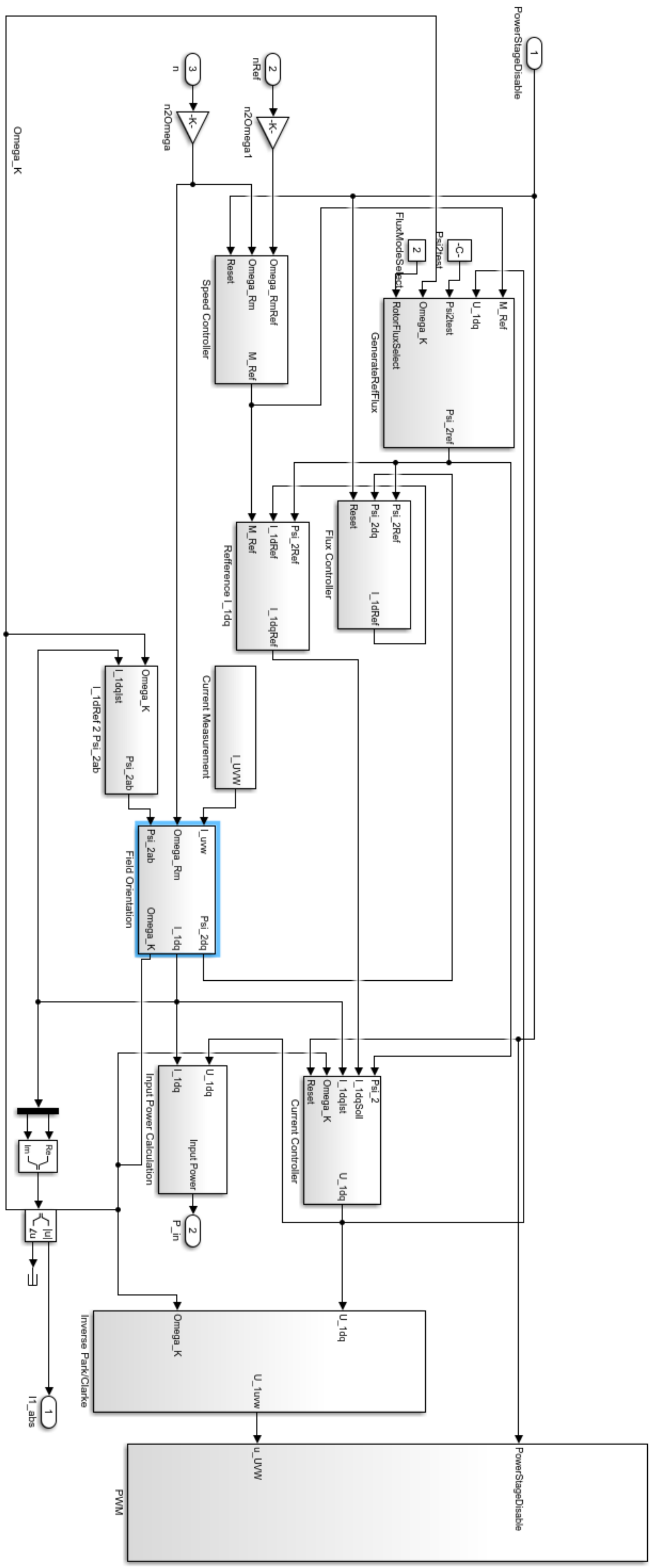
then $\psi_{rdopt} = k_{copper} * \sqrt{T_{em}}$

Using ψ_{rdopt} in Field orienting control FOC instead of constant value of ψ_{rd} one can significantly decrease copper losses.

I have been investigated induction motor DRS112M4

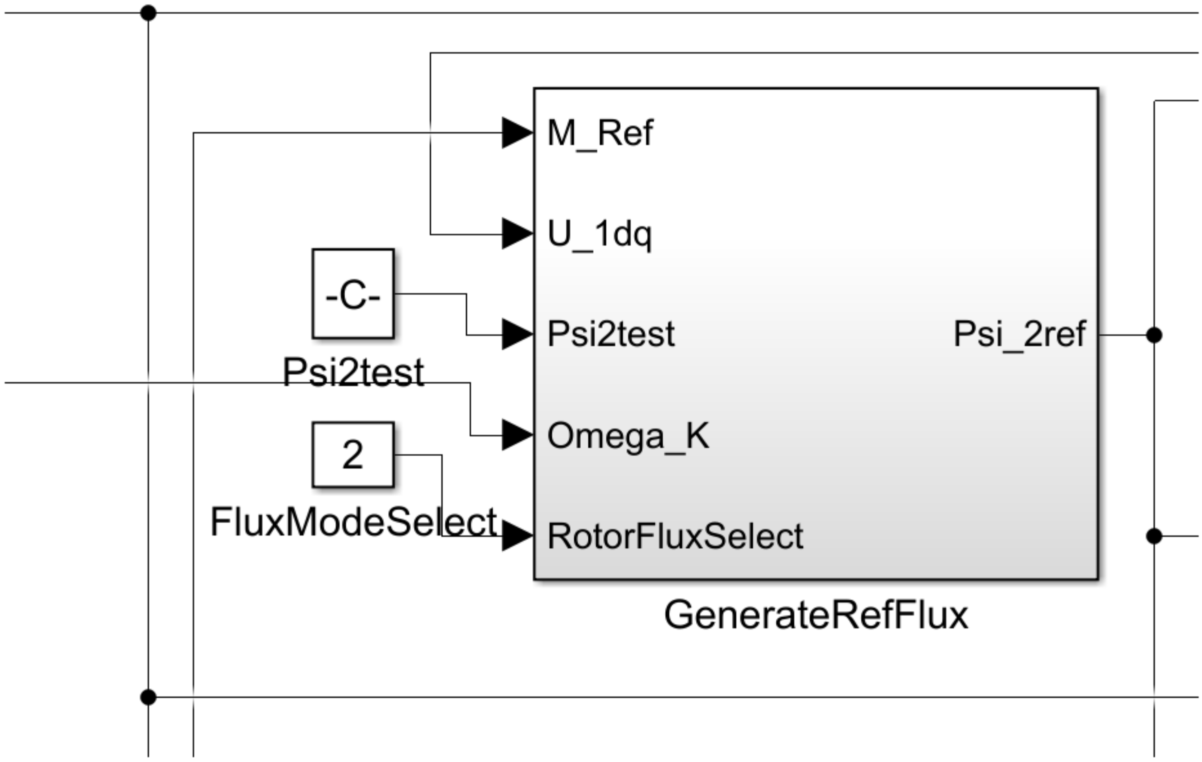
Rated data: P=370 W; w=1500 rpm; p=2

The scheme of the Field Oriented Control



Зм.	Арк.	№ докум.	Підпис	Дата	ЕП.18.15.5.ПЗ	Арк. 18

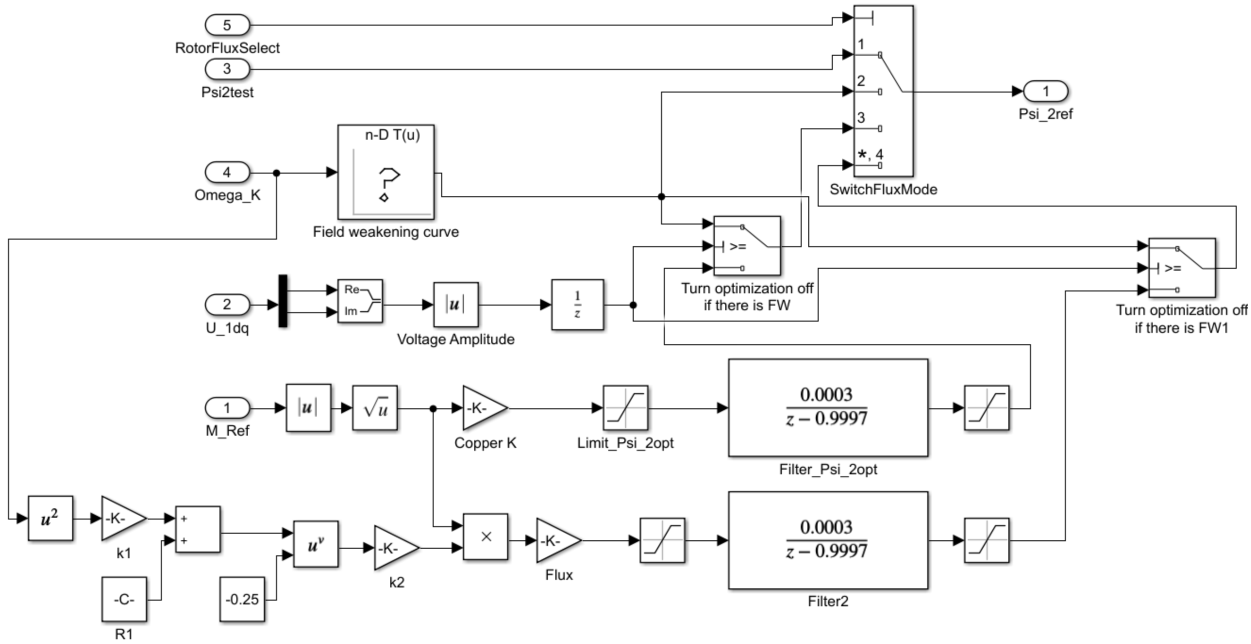
I have created bloc in Simulink model which calculates value of ψ_{rdopt}



And one can change desirable flux, using FluxModeSelect

1 - User flux
2 - standart flux
3 - Copper losses optimization
4 - Core losses optimization

This block contains :



This scheme calculates desirable flux where :

```
Editor - C:\Programs\initfoc.m
initfoc.m  init_foc.m  initfoc.m

    %Optimization of copper loses
    FaktcalcPsifromMmin = sqrt(sqrt(((Motor.R1+Motor.R2)*(2/3)*(2/3)/(Motor.R1*Motor.Zp*Motor.Zp*Motor.Lmu*Motor.Lmu))))*Motor.Lmu;


    %Optimization of core loses
    Rfe=2000; % core loss resistance
    PLossMinKoef1=(Motor.Lmu^2)/(Rfe)+(Motor.R1*Motor.Lmu^2)/(Rfe^2);
    PLossMinKoef2= sqrt(sqrt((Motor.R1+Motor.R2)))/sqrt(Motor.Zp*Motor.Lmu);
```

Filter_Psi_2opt and Filter2 were implemented to prevent instantaneous changing of the flux

Field Weakening curve protects drive from speed higher than rated one

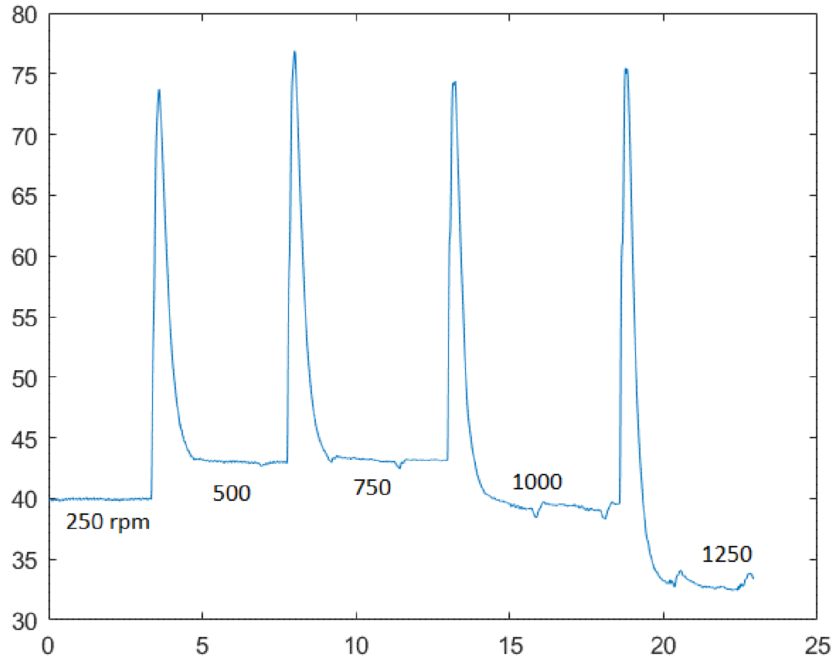
Turn optimization off if there is FW protects drive from voltage higher than rated and then it turns optimization off if there is field weakening mode

2.3 Copper losses Test

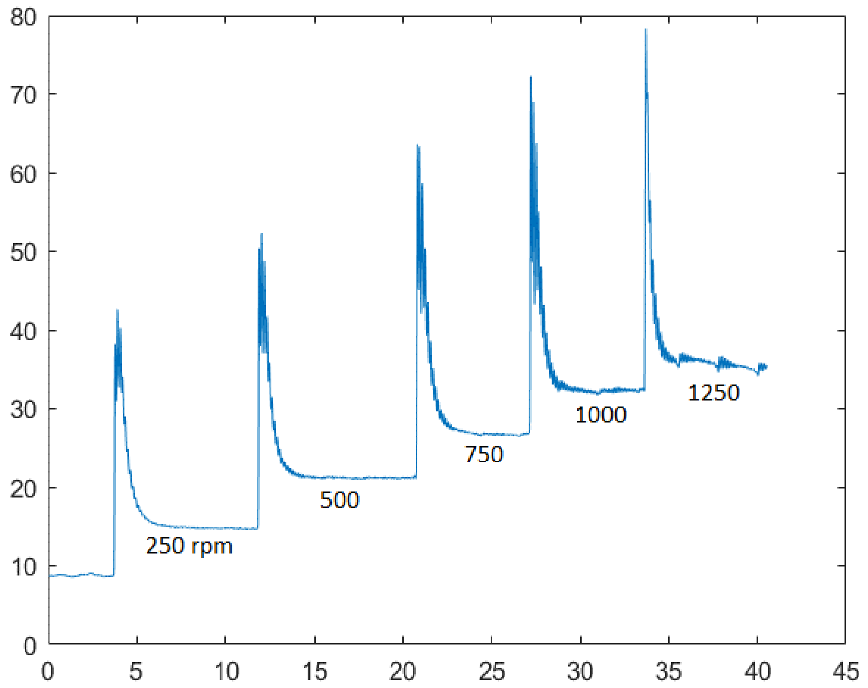
Let us compare Induction Motor operation with optimization and without it

For example, I was tasted Induction Motor at 250 till 1250 rpm

1. Consumed Power without optimization at No load mode



Consumed Power with copper optimization at No load mode



As we can see from the characteristics optimization gives very good result at small speed. Before 1200 there is much less consumption of the power sometimes even greater as 50%

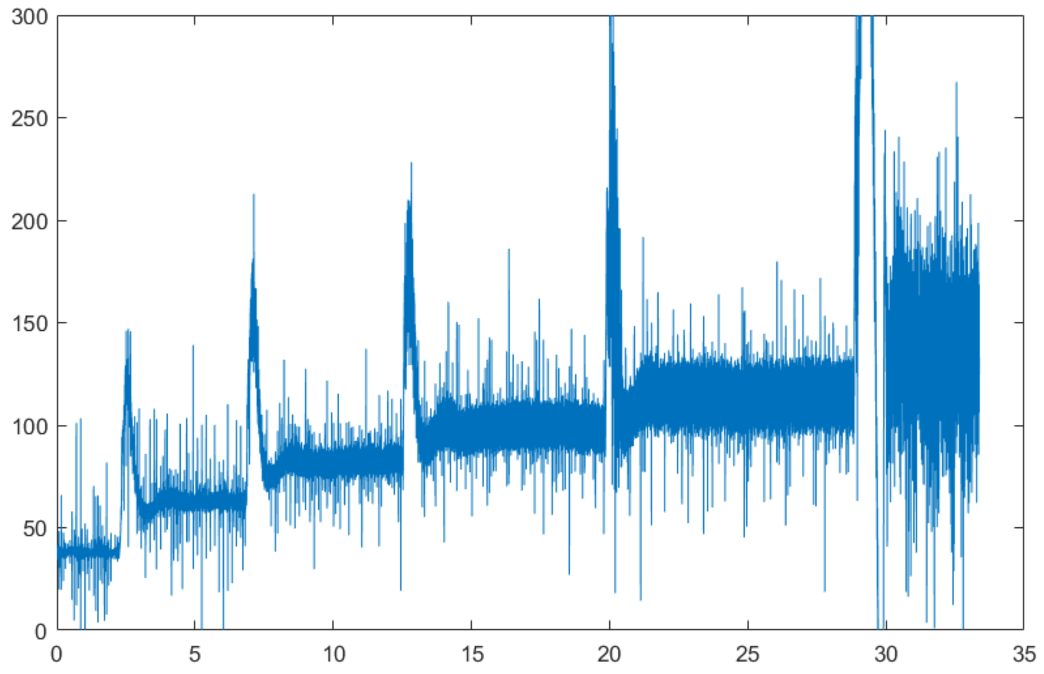
At 250 rpm with usual ψ_{rd} motor consumes something about 40 W

But with ψ_{rdopt} it consumes 16-17 W.

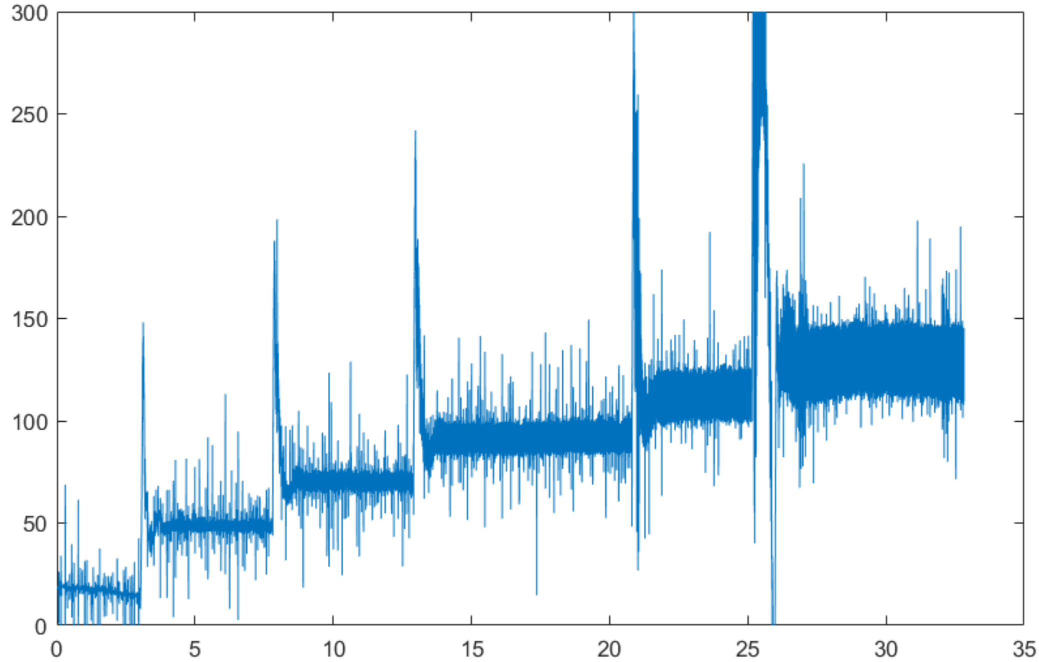
As speed gets higher stator coil resistance becomes greater and copper optimization gives worse results. For example at 1000 rpm power ratio is 38/31 W and at 1250 rpm and higher there is almost equal power consumption.

The same result we can see with operation under load

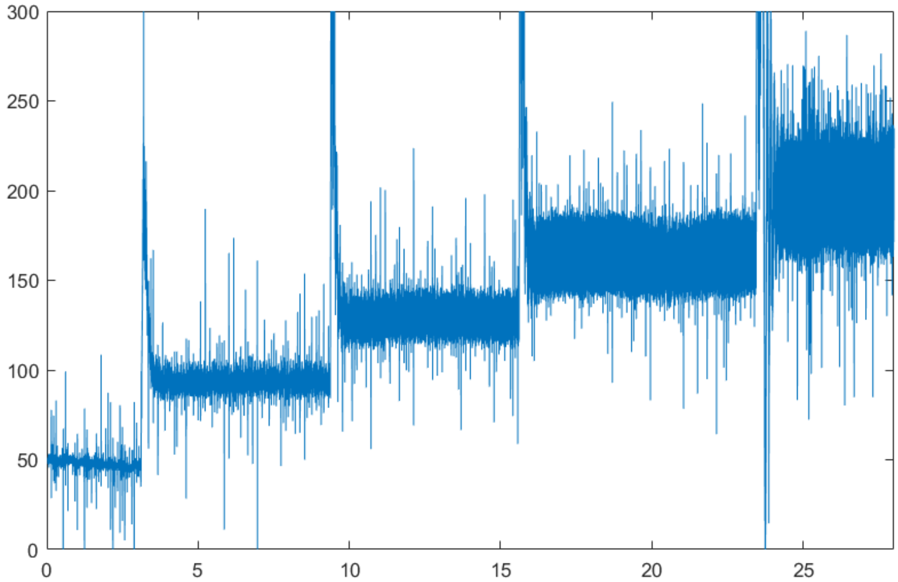
2. Consumed Power without optimization; Load 30 %



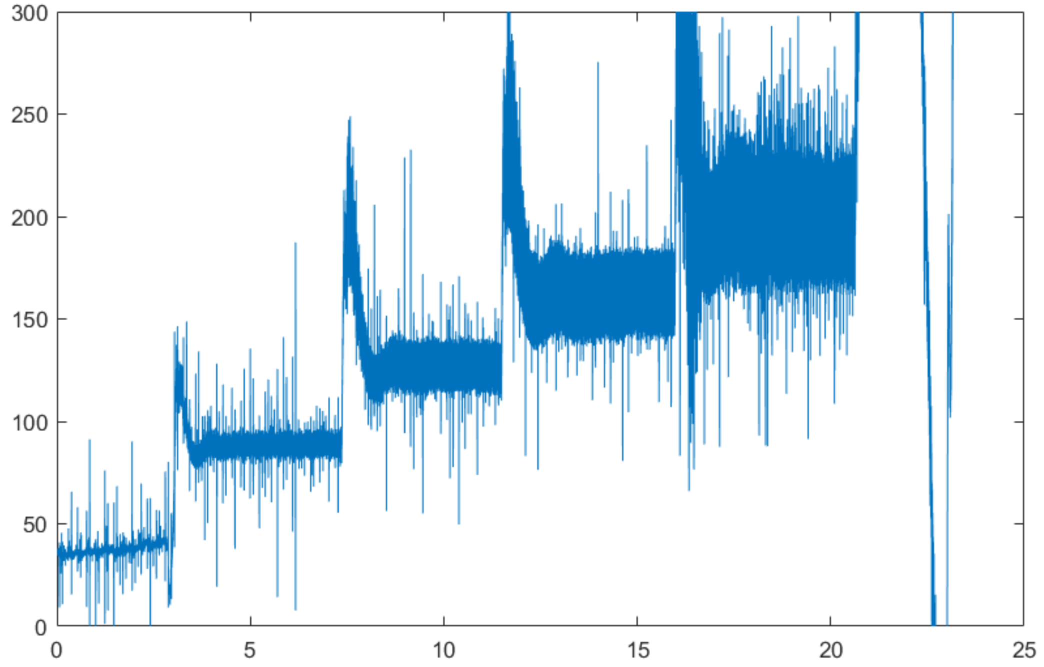
Consumed Power with copper optimization; Load 30 %



3. Consumed Power without optimization; Load 60 %



Consumed Power with copper optimization; Load 60 %



2.4 Conclusion of Copper losses strategy

When we increase Load Torque then Copper losses become grater and Copper optimization gives worse result.
An induction motors were developed to work at rated parameters, that is why they constructed in such a way to have minimal Copper loses at rated speed.

So, at range speed near the rated one Copper Optimization does not give any benefits.

3 Core losses optimization

3.1 Calculation of Core losses strategy

But at increasing speed Core losses become greater. So, Core lose optimization could reduce them.

Developed magnetic Torque is $T_{em} = Z_p * L_\mu * i_{sd} * i_{sq}$

Total losses are [1]

$$P_{loss} = P_{loss,d} + P_{loss,q} + P_{loss,dq}$$

$$P_{loss} = \frac{T_{em}}{Z_p * L_\mu} * ((\frac{(w_s * L_\mu)^2}{R_{Fe}} + R_s + (w_s * L_\mu)^2 \frac{R_s}{{R_{Fe}}^2}) * \frac{Z_p * L_\mu * {i_{sd}}^2}{T_{em}}) + (R_s + R_s) * \frac{T_{em}}{Z_p * L_\mu * {i_{sd}}^2} - 2w_s L_\mu \frac{R_s}{R_{Fe}})$$

If load torque is constant then for obtaining minimal lossess one can make the same transformation like with Copper losses. Let us asume that all motor paremetters does not depenf on i_{sd}

$$\frac{i_{sq}}{i_{sd}} = \frac{T_{em}}{Z_p * L_\mu * {i_{sd}}^2}$$

Let us enter coeeficient $k_1 = \frac{(L_\mu)^2}{R_{Fe}} + (L_\mu)^2 \frac{R_s}{{R_{Fe}}^2}$ for simplicity. Then

$$P_{loss} = \frac{T_{em}}{Z_p * L_\mu} * ({w_s}^2 * k_1 + R_s) * \frac{Z_p * L_\mu * {i_{sd}}^2}{T_{em}} + (R_s + R_s) * \frac{T_{em}}{Z_p * L_\mu * {i_{sd}}^2} - 2w_s L_\mu \frac{R_s}{R_{Fe}})$$

Foundation of minimal value of i_{sd}

$$\frac{d(P_{loss})}{d(i_{sd})} = 0$$

$$(w_s{}^2 * k_1 + R_s) * \frac{Z_p * L_\mu * 2 * i_{sd}}{T_{em}} + (R_s + R_s) * \frac{-2 * T_{em}}{Z_p * L_\mu * i_{sd}{}^3} = 0$$

$$(w_s{}^2 * k_1 + R_s) * (Z_p * L_\mu * 2 * i_{sd}{}^4) = (R_s + R_s) * \frac{T_{em}{}^2}{Z_p * L_\mu}$$

$$i_{sd}{}^4 = \frac{(R_s + R_s)}{(Z_p * L_\mu)^2} * \frac{T_{em}{}^2}{(w_s * k_1 + R_s)}$$

$$i_{sd} = \sqrt[4]{\frac{(R_s + R_s)}{(Z_p * L_\mu)^2}} * \sqrt[4]{\frac{1}{(w_s{}^2 * k_1 + R_s)}} * \sqrt{T_{em}}$$

Let us enter coeeficient $k_2 = \sqrt[4]{\frac{(R_s+R_s)}{(Z_p*L_\mu)^2}}$ for simplicity. Then

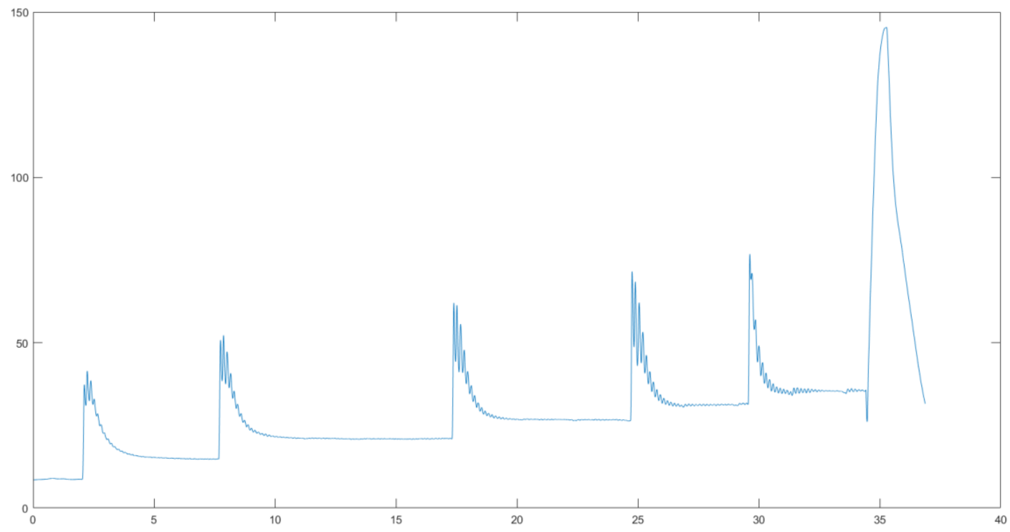
$$i_{sd} = k_2 * \sqrt[4]{\frac{1}{(w_s{}^2*k_1+R_s)}} * \sqrt{T_{em}} \text{ then}$$

$$\psi_{rdopt} = i_{sd} * L_\mu = k_2 * \sqrt[4]{\frac{1}{(w_s{}^2 * k_1 + R_s)}} * \sqrt{T_{em}}$$

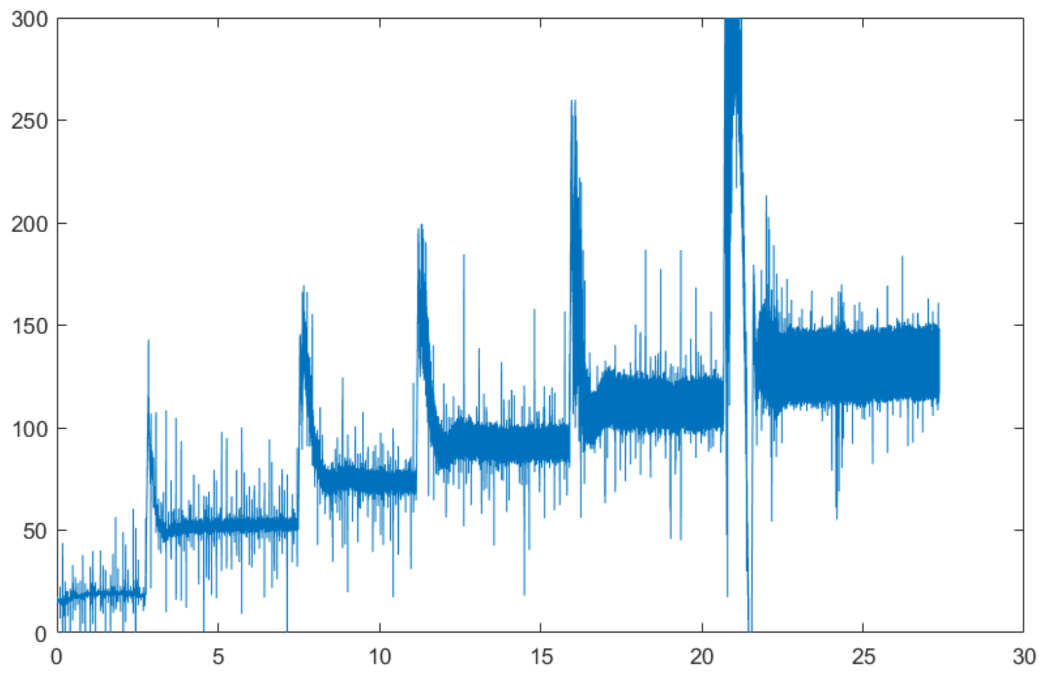
So, using this value of ψ_{rdopt} would give lower power consumption, cause this value accounts both copper and core losses

3.2 Core losses Test

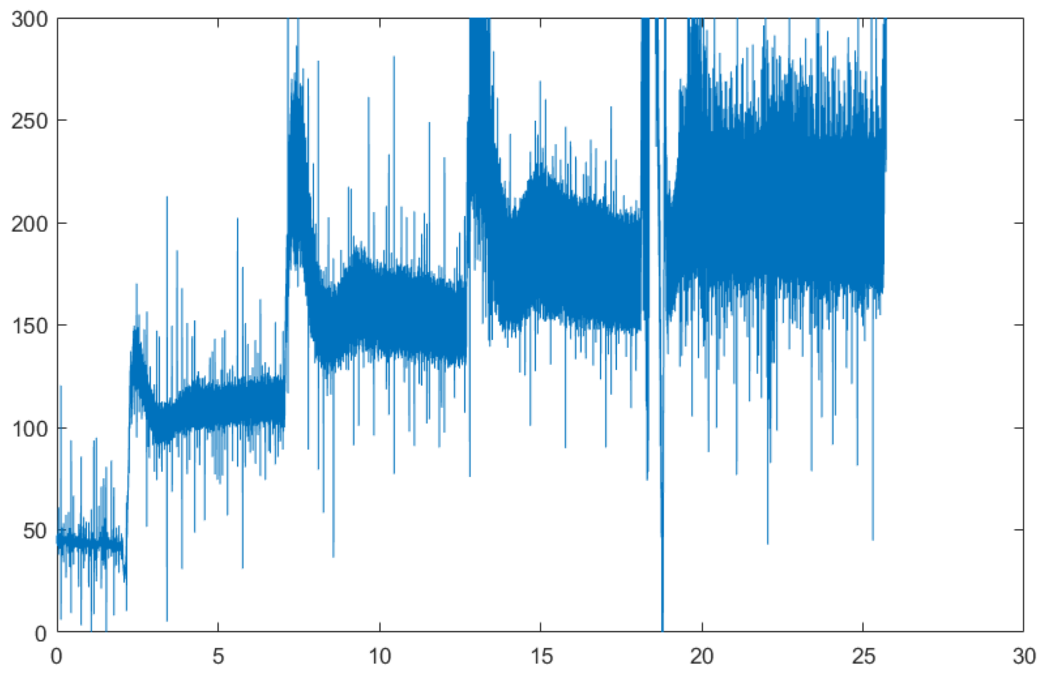
Consumed Power with core optimization; No load mode



Consumed Power with core optimization; Load 30 %



Consumed Power with core optimization; Load 60 %



Core losses optimization does not give any benefits at small speed. But at speed range near rated some energy benefits appeared.

3.3 Conclusion of both core and copper losses strategy

Here is the table that shows ψ_{rd} at different modes with load torque range 0..60% of rated and with speed range 0..1500 rpm

		T=0	T=20	T=40	T=60
ψ _core	w=250	0,42	0,48	0,58	0,84
ψ _copper		0,42	0,48	0,58	0, 84
ψ _core	w=500	0,42	0,5	0,68	0,83
ψ _copper		0,42	0,5	0,67	0,82
ψ _core	w=750	0,42	0,54	0,69	0,83
ψ _copper		0,42	0,53	0,68	0,84
ψ _core	w=1000	0,42	0,53	0,7	0,83
ψ _copper		0,42	0,53	0,69	0,83
ψ _core	w=1250	0,42	0,54	0,7	0,88
ψ _copper		0,42	0,55	0,72	0,89
ψ _core	w=1500	0,42	0,54	0,67	0,81
ψ _copper		0,42	0,53	0,74	0,87

As $T_{em} = \frac{3}{2} * Z_p * L_m * I_{1q} * I_{1d} = \frac{3}{2} * Z_p * I_{1q} * \psi_{rd}$

and $P = T_{em} * w = \frac{3}{2} * Z_p * I_{1q} * \psi_{rd} * w$ that is why if motor works at the same load torque and at the same speed, one can say that consumed power roughly proportional to the ψ_{rd}. That is why $\frac{P}{P_{opt}} = \frac{\psi_{rd}}{\psi_{rd,opt}}$ and using expression

$100 - \frac{\psi_{rd}}{\psi_{rd,opt}}$ *100 one can obtain expression for calculating value that shows saved energy during optimization.

Let us make this. Next table shows saved energy comparing with mode without optimization with load torque range 0..60% of rated and with speed range 0..1500 rpm

		T=0	T=20	T=40	T=60
ψ_core	w=250	51.724%	44.828%	33.333%	3.448%
ψ _copper		51.724%	44.828%	33.33%	3.448%
ψ_core	w=500	51.724%	42.529%	22.989%	5.747%
ψ _copper		51.724%	42.529%	22.989%	5.747%
ψ_core	w=750	51.724%	39.08%	22.989	3.448%
ψ _copper		51.724%	39.08%	22.989%	3.448%
ψ_core	w=1000	51.724%	39.08%	20.69%	4.598%
ψ _copper		51.724%	39.08%	20.69%	4.598%
ψ_core	w=1250	51.724%	36.782%	19.54%	1.149%
ψ _copper		51.724%	36.782%	17.241%	1.149%
ψ_core	w=1500	51.724%	39.08%	22.989%	6.897%
ψ _copper		51.724%	39.08%	14.943%	0%

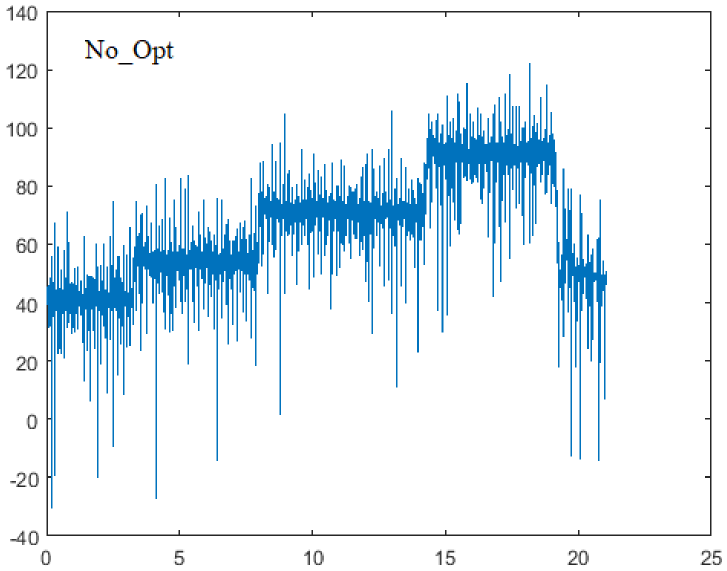
One can conclude that Copper optimization gives good result at small speeds and at small load torques, while Core optimization vice versa: does not work at small speeds and torques and begins to work at values close to rated parameters.

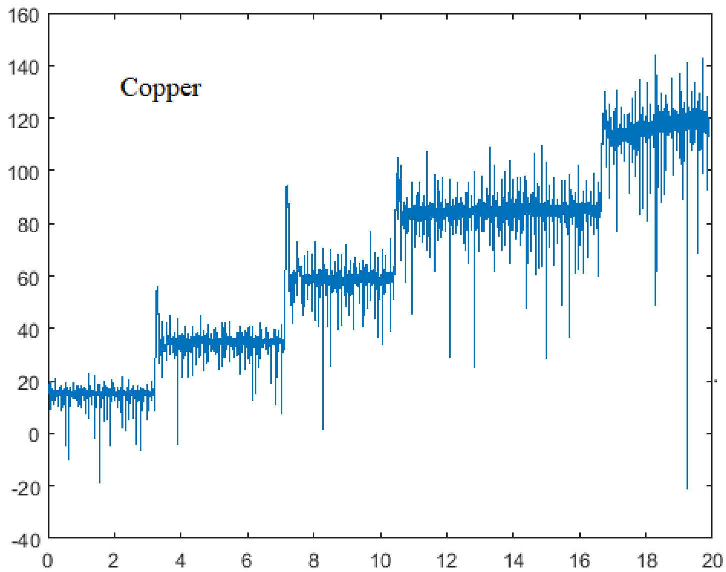
Stability

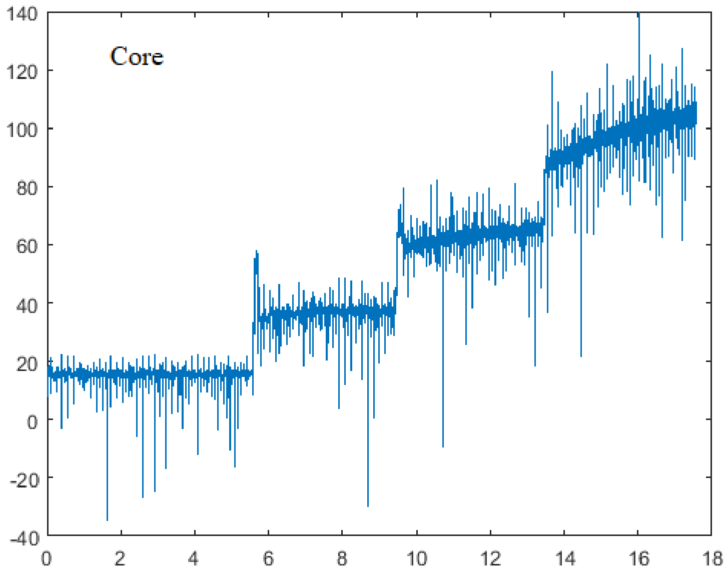
The field oriented control method operates with fast responses. So it satisfies the requirements of dynamic drives method to handle transients. The only disadvantage is its complexity. Both the VCIM and V/f control of induction motor uses PI controller, which is an excellent controller for linear systems. It reduces the steady state error and provides a smooth tracking with the command signal. But if the system is influenced by uncertainties, which usually composed of unpredictable variations in the machine parameters external load disturbances and modeled and non-linear dynamics, it is very hard or impossible to design the control structure based conventional PI controllers. To provide better control in the presence of such uncertainties. PI controller can be replaced by other robust control techniques, such as optimal control, Variable structure control, Adaptive, Fuzzy and neural control.

Let us see now behavior of induction motor at one speed with changing load torque. We will change load torque from 0 till 60% of rated with step = 20

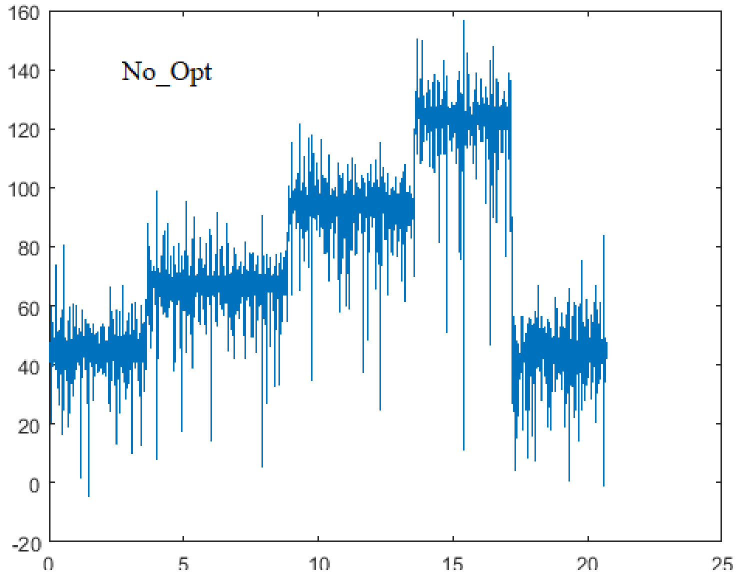
Speed = 250 rpm

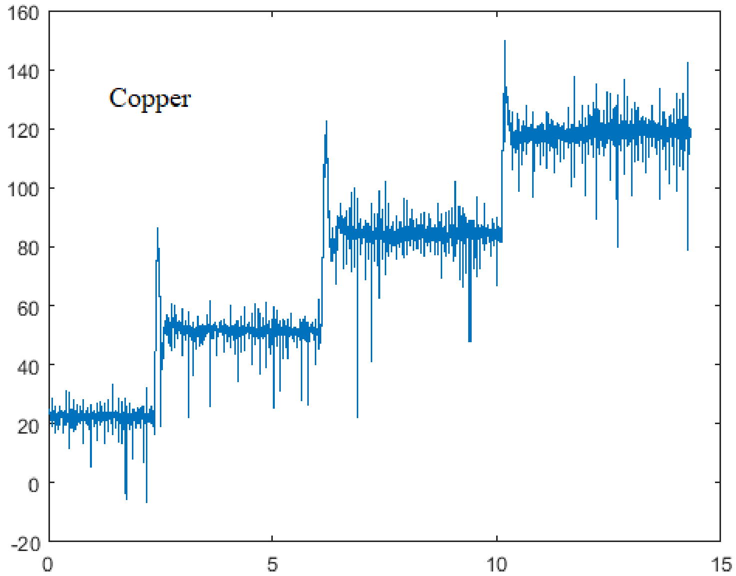


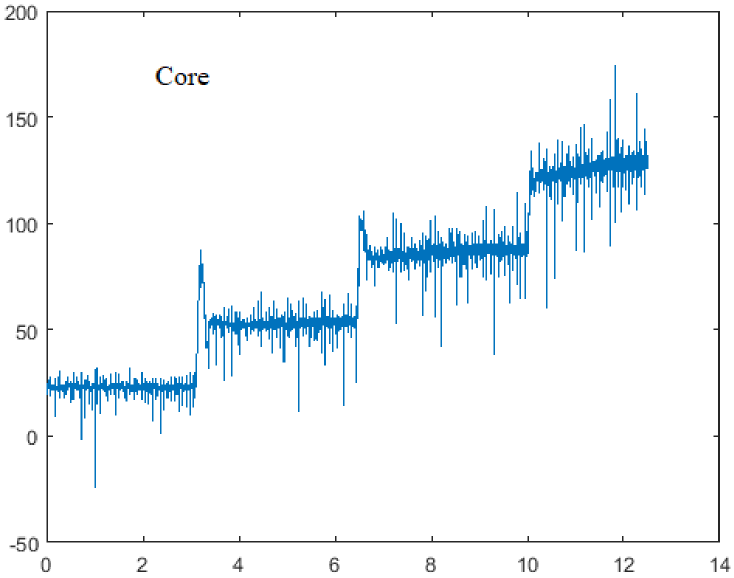




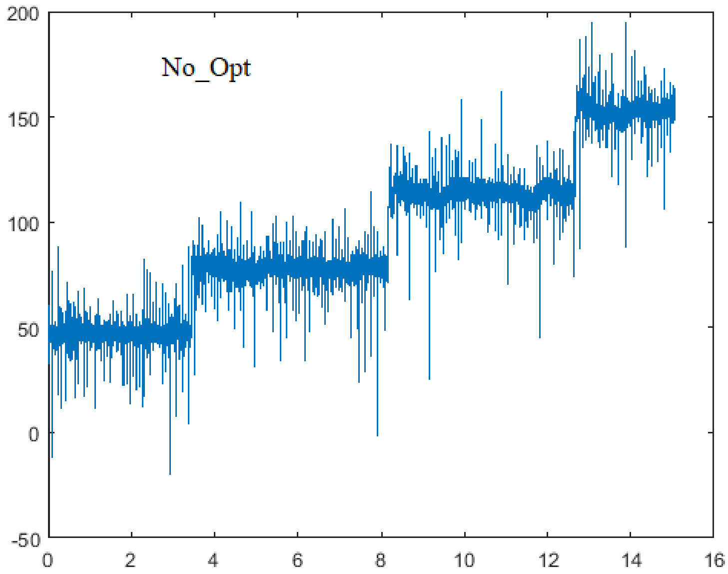
Speed = 500 rpm

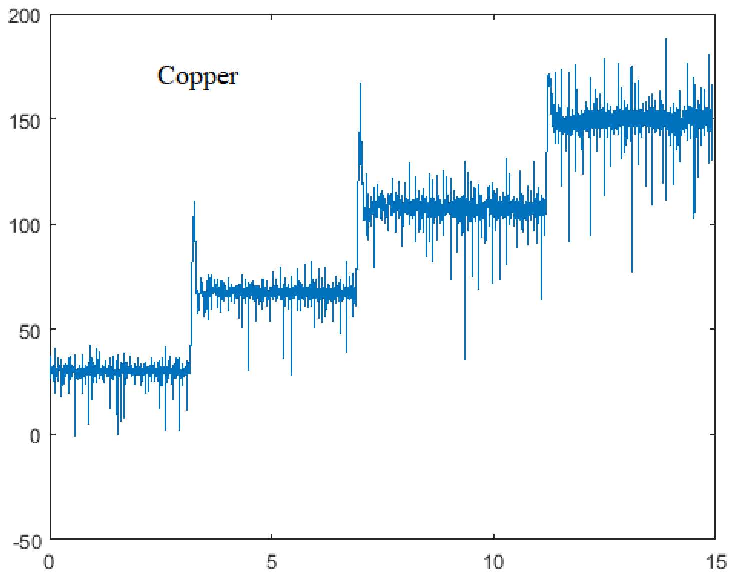


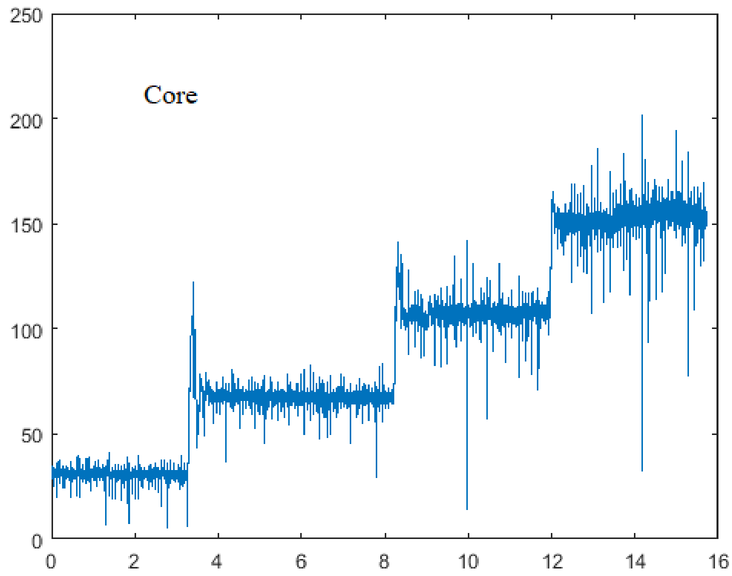




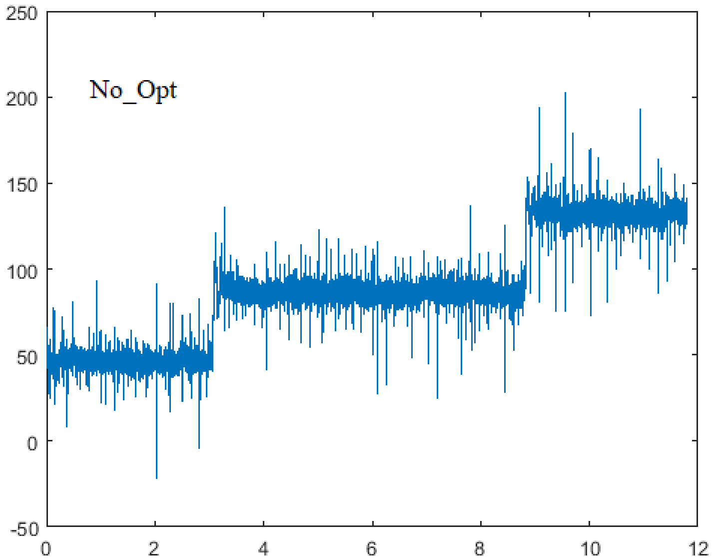
Speed = 750 rpm

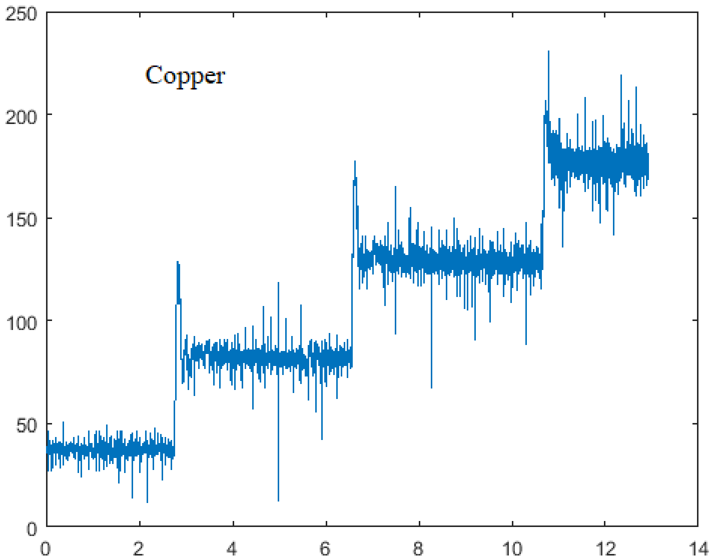


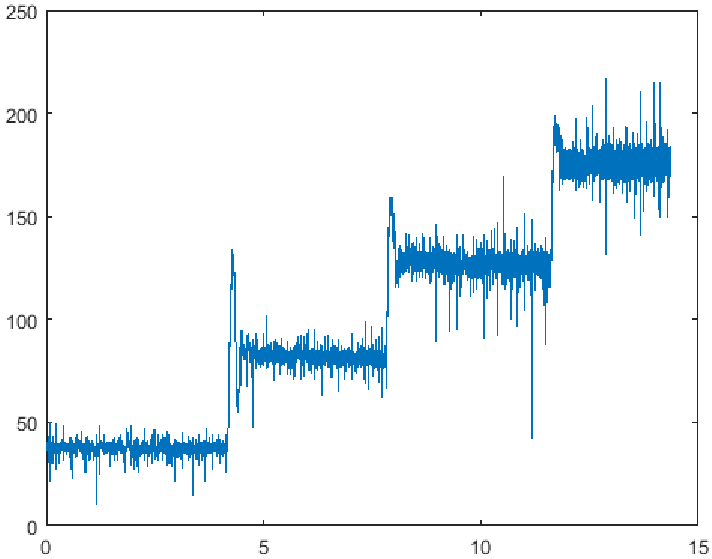




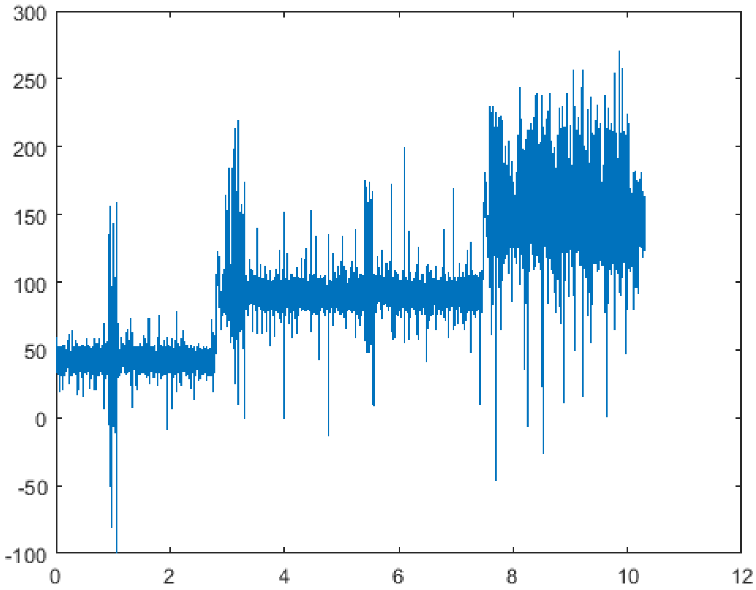
Speed = 1000 rpm

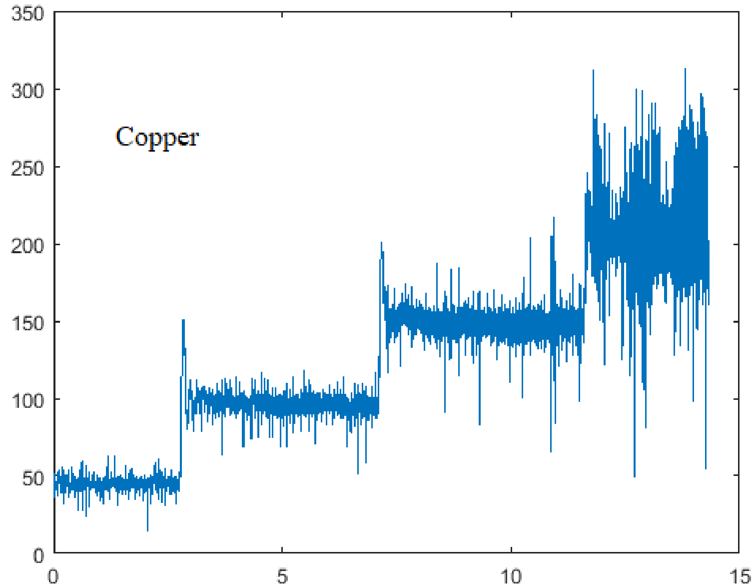


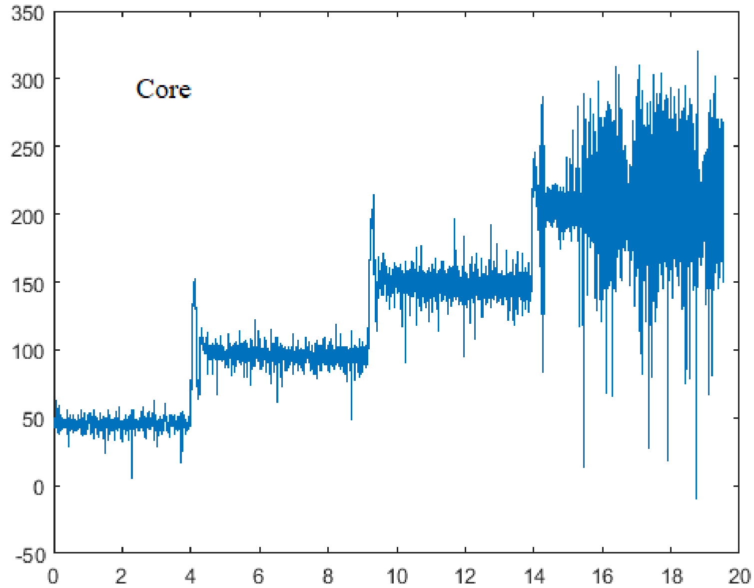




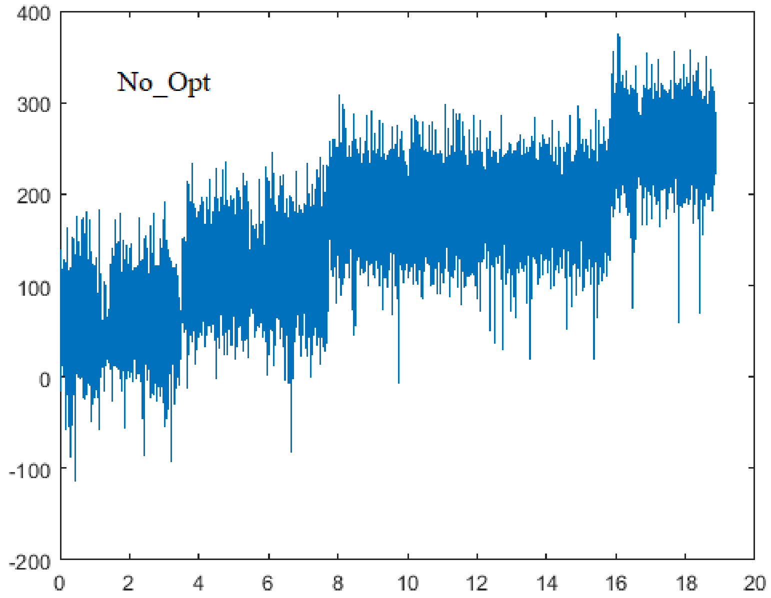
Speed = 1250 rpm

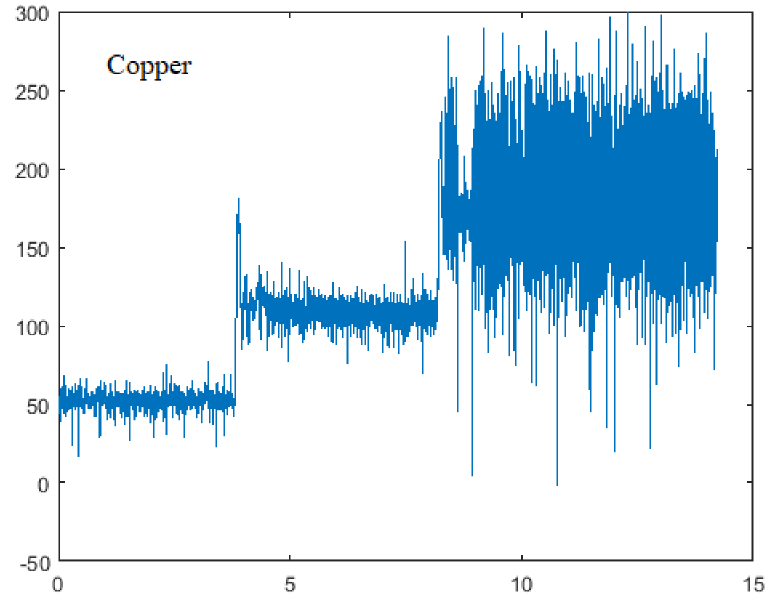


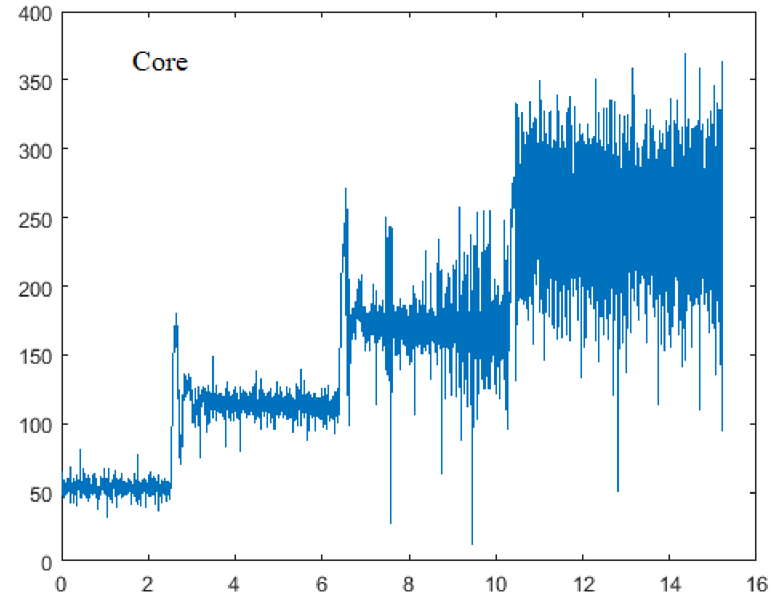




Speed = 1500rpm







One can see that motor is stable and gives the same results as were previously calculated.

3.4 Total Conclusion

Vector control is a complex and high price control technique. But in spite of that it is a high performance control technique. FOC use space vector representation which is valid in both steady and transient conditions. So, along with satisfactory steady state response FOC have excellent transient response. It operates with fast dynamic response. Its speed regulation is very good.

Copper optimization gives good result at small speeds and at small load torques, while Core optimization vice versa: does not work at small speeds and torques and begins to work at values close to rated parameters.

4 Occupational Safety and Health

4.1Analysis of harmful production factors of the projected process, object, system or device

Main Harmful Factors

Safety and environmental friendliness of the electric motor with a frequency converter during the introduction of new technological processes and equipment, the most acute problem is the occupational Safety and Health. The main task of the occupational Safety and Health is to reduce the number of occupational diseases and injuries in the workplace. Additional task is to provide safe and at the same time comfortable conditions with maximum work productivity. In the design, construction, manufacture, commissioning and operation of new facilities, measures for occupational safety should be envisaged and developed.

Occupational safety measures are carried out to protect the participants of the labor process from the impact of hazardous and harmful production factors arising in the course of its implementation. The paper considers an induction motor with a frequency controller. In this product there are the following dangerous production factors: increased voltage values in the electrical circuit, supplying the electrical equipment. Harmful factors are:

- increased noise level when running an induction motor (sound level up to 85 dB);

- Insufficient illumination of the working area. The following are hazardous and harmful production factors, depending on the types of work and operations.

Dangerous and harmful production factors types of work, equipment, technological operations:

1. Higher values of voltage in the electrical circuit (connection of electrical equipment and electrical devices).

2. Increased noise level (engine operation).

3. Insufficient illumination of the working area (taking readings from electrical measuring instruments).

Noise is a disorder combination of different in frequency sounds, has an adverse effect on the human body. It creates an acoustic discomfort. Noise creates stress on the nervous, cardiovascular and respiratory systems. Therefore, it is necessary to take measures to reduce noise in workrooms. Due to prolonged exposure, noise can cause occupational diseases such as depth and noise sickness. Insufficient illumination of the workplace or its absence, as well as too bright illumination, cause constant visual tension and, as a consequence, impaired your eyes.

The main harmful factors:

- Insufficient illumination of the working area.
- Noise and vibration;
- Deviation of microclimate indicators;

Insufficient illumination:

The illumination, that was created by natural daylight varies in extremely wide limits. These changes are caused by season and meteorological factors, in a short period of time the illumination of natural light can vary several times. Therefore, natural lighting of rooms cannot be characterized, and, therefore, normalized by the absolute value of the illumination. Rules and norms of artificial lighting are based on the laws that determine the performance of vision.

Noise and vibration:

Noise has a variety of effects on the human body. Sources of mechanical noise in the shops are gears, bearings, cams, crank mechanisms, chain drives, metal transportation processes, its deformation, cutting, vibration of machinery and equipment surfaces. Thermal noise occurs when the gas burners, heating devices, when burning various torches. Electromagnetic noise occurs when the transformers are noisy. The sound pressure level at workplaces in the shop is 90-120 dB, at a standard of 80 dB. The sources of vibration are: reciprocating driving systems: electric and pneumatic chisels, grinding machines.

Deviation of microclimate indicators:

In the production premises of the workshop, a microclimate is provided, which ensures normal conditions for the work of employers. Sources of thermal emissions are processed metal, heating devices, a mill, auxiliary equipment of a methodical furnace for heat treatment, finishing units. A large amount of heat is released when storing raw materials, finished products, cooling on refrigerators. In the rolling shops conditions must be created according to СанПиН 2.2.4.548-96 (Ukrainian norms). The optimum temperature is 16-25 ^{o}C, permissible 13-25 ^{o}C, when performing heavy physical work the maximum permissible temperature is 26 ^{o}C, and the relative humidity is not more than 75%.

The main dangerous factors:

- Movement of machines and mechanisms;
- Movement of the production material;
- The presence of high voltage.
- Electrical safety

Movement of machines and mechanisms:

The shop has various and auxiliary equipment. The driving parts of which represent a certain danger, as unintended contact with them can cause injuries to production personnel. These are rolling rolls, pulling, feeding and guiding rollers, tilters, pushers, collators, manipulators, roller tables, conveyors. Parts and assemblies of rolling machines (rolls, flywheels, connecting spindles, cogwheels, flying-shear drums, various couplings, bushings, cams, and eccentrics) perform rotational movements. Other parts and components (levers, elements of conveyors, pushers of manipulators and tilters) perform reciprocating motion. The danger of exposure is determined primarily by constructive problems. So, the danger increases if the rotating parts of the equipment contain protruding fasteners (bolts, studs, screws, nuts), and on their surface there are signs of uneven wear or defects (cracks, burrs, etc.).

Movement of the production material:

When performing metal cutting operations on scissors, the potential for personal injury can occur when the knives are replaced and the cutting edges of the welds are removed from the cutting surfaces, the shears and shears are removed from the scissors, the jamming of the shear is cut off in the scissors trough and on the conveyor, during the cutting and sampling. In the scrap space, the danger is possible when the carts are chopped-containers with cuts, as well as when the wagons are moved under the trimming, therefore, during the work, a periodic inspection of the equipment is carried out, in which personnel damage is also possible.

High voltage

Most of the electrical equipment in the shop operates at voltages up to 1000V. Electrical hazards are: electrical installations, electric motors, electrical equipment and power lines. In the shop there are sources of electromagnetic and electric fields, which are used for various purposes: heating working rolls, drying coatings applied to the surface of products, heating the initial products for hot rolling. The electromagnetic field is created by the operation of high-frequency and super-high-frequency installations. The norms for electromagnetic radiation according to СанПиН № 5802-91. (Ukrainian norms).

electrical safety

A significant danger is the possibility of continuing the operation of the electric drive with a dead ground fault. In order to avoid the danger of a ground fault, it is necessary to maintain a good insulation condition at all times.

First, it is necessary to perform acceptance tests during the commissioning of the electric drive. Such tests are carried out with an increased voltage at which insulation defects are detected due to a breakdown and subsequent burning of the insulation. After eliminating the detected effects, it is necessary to re-check.

Secondly, it is necessary to periodically check insulation - a periodic measurement of the insulation resistance of the drive within a specified time, or after the detection of defects. Measurements should be carried out with the unit disconnected for each phase relative to the ground and between phases in each section between two successive protection devices. The resistance of each section should exceed 500 kOhm per phase. Measurements are made by a mega-meter consisting of a DC generator with a manual drive, a logometer and additional resistors. The insulation resistance is nonlinear and depends on the applied voltage.

4.2 Engineering and technical measures of occupational Safety and Health

The installation of a converter is a potential hazard, since during installation and maintenance work a person can touch conductors that under the voltage. The factor determining the severity of the lesion is the magnitude of the electric current flowing through the human body. Power supply of the drive is carried out from a three-phase network with a zero wire frequency of 50 Hz, voltage 380 V.

From the analysis of cases of electro-injury, it follows that only organizational measures are insufficient, and technical measures are required, such as protective grounding and protective shutdown of the faulty stand. Since a three-phase alternating current network with a voltage of up to 1000 V is used, the personnel protection is carried out by protective grounding - a deliberate connection of metal parts of the stand, accessible to a person's touch with an external horizontal grounding electrode, which excludes human injury in case of a closure on the body. As a horizontal grounding electrode, strip steel with a cross-section of at least 4 * 12 mm or round steel with a diameter of at least 6 mm is used. According to the "Rules for the installation of electrical installations", the resistance of the grounding device in electrical installations with voltages up to 1000 V with isolated neutral should not be more than 4 Ohm. Of great importance for the prevention of electro-injury is the proper organization of maintenance of existing electrical installations, assembly, repair and maintenance work. Under the right organization, understand the precise implementation of the organizational and technical measures established by the existing "Interdepartmental rules on labor protection (Safety Rules for the Operation of Electrical Installations)," Rules for the Technical Operation of Consumer Electrical Installations ". When carrying out the work, the following organizational and technical measures must be observed: fencing located near the workplace and other live parts, which can be touched; work in dielectric gloves, standing on a dielectric mat; application of tools with insulating handles; performance of work by at least two employees. In accordance with ПОТ Р М-016-2001 РД 153-34.0-03.150-00 (Ukrainian), the maintenance personnel of electrical installations must meet the following requirements: persons under 18 years of age cannot be admitted to work in electrical installations; persons should not have injuries and diseases that interfere with production work; persons, after appropriate theoretical and practical training, must pass an exam and must have, for work in electrical installations, a certificate with an electrical safety group of at least the third

4.3 Calculation of lighting

In the workshop of the electricians, length = 25 m, width =19 m wide and altitude = 4.3 m at a height of 3.8 m from the floor, the special fluorescent lamps are suspended; They are to be installed in two rows, preferably solid. Illumination norm is 200 lux. Determine the coefficient of use of the luminous flux of lamps according to the formula:

$$i = \frac{A*B}{h*(A+B)} \tag{4.1}$$

where A and B – length and width, m;

h – distance, between flour and lamps, m.

$$i = \frac{28*16}{3,5*(28+16)} = 2,9$$

Let us find the utilization factor, i.e. the relative fraction of the flow of the lamp supplying the surface S; η=0,4.

We determine the required luminous flux of the lamp according to the formula:

$$F*N = \frac{E*k*S*Z}{\acute{\eta}} \tag{4.2}$$

E – lowest illumination, lux;

k - safety factor;

S – room space, m^2;

Z – coefficient for the transition from the lowest to the medium; (if Z=1,1 it gives more uniform illumination);

N – number of lamps.

$$F*N = \frac{200*1.5*112*1.1}{0.4} = 92400\ (lm)$$

Lamp tray ЛБ40 accept as 2480 lm, ЛБ-80 - 4320 lm.

Required number of lamps:

$$40\ Wt = \frac{92400}{2480} = 37\ ; \tag{4.3}$$

$$80\ Wt = \frac{92400}{4320} = 19; \tag{4.4}$$

Since the lamps are two-lamp and the number of rows is two, then in each row it is necessary:

$$40 \text{ Wt}= \frac{37}{4} \approx 9 \quad (4.5)$$

$$80 \text{ Wt} = \frac{19}{4} = 5 \quad (4.6)$$

Using 40W lamps, you can get solid rows, setting in each of them 10 lamps. The total length of the series will be about 12.5 m, that is, the rows will be at 0.75 not to reach the end walls.

4.4 Fire Safety

On the working site, a sign with the telephone number of the fire department and the fire controllers should be posted in a conspicuous place. The following standards should be established: the procedure for cleaning the room is established; determined the procedure for de-energizing the equipment in case of fire and at the end of the working day; established the procedure for firefighting, the actions of personnel in the detection of a fire; established the procedure and time limits for passing the fire safety briefing and classes on the fire-technical minimum, and those responsible for their timely conduct were appointed; a plan for the evacuation of people in the event of a fire should be developed and posted in a conspicuous place, and a system for warning people about the fire should be installed. Production workers are obliged: to comply with the fire safety requirements of standards, norms and rules approved in the established manner in the established order, and also to observe and maintain the firefighting mode; observe precautionary measures when using flammable liquids; in case of detection of a fire, notify the fire department and take measures to eliminate the fire and save people. Procedure for the fire: immediately inform the fire brigade by telephone; take as far as possible measures to evacuate people, extinguish the fire and preserve material values. The official who arrived at the site of the fire is obliged: to duplicate the report on the occurrence of a fire in the fire department and to message to in the higher management, the supervisor, the responsible duty officer on the object; in the event of a threat to the lives of people, immediately organize their rescue, using for this purpose all available forces and means; check the inclusion in operation of automatic fire extinguishing means; to switch off the electric power; stop all work in the building, except for works related to fire extinguishing activities; remove all workers outside the danger zone who do not take part in extinguishing the fire; implement general guidance on extinguishing a fire; organize evacuation and protection of material values; organize a meeting of fire departments and assist in choosing the shortest path for access to the fire. The working area should be equipped with the following: carbon dioxide fire extinguishers manual ОУ- 2, ОУ - 5, ОУ - 8 - 1 pc, foam, chemical, air-foam and liquid fire extinguishers – at one of them;

Measures to ensure the safety of people should be appointed depending on the fire hazard properties and quantities of substances and materials in accordance with ГОСТ 12.1.004—91 и ГОСТ 12.1.044—89 (Ukrainian).

Characteristics of substances and materials that are (circulating) indoors:

A (explosive and fire-hazardous) - Combustible gases, flammable liquids with a flash-point of not more than 28 ° C in such quantity that they can form explosive air-gas mixtures with the ignition of which an estimated overpressure of explosion in the room exceeds 5 kPa.

Substances and materials which are capable of exploding and burning when interacting with water, air oxygen or with each other in such quantity that the calculated excess pressure of the explosion in the room exceeds 5 kPa.

B (explosive and fire hazardous) - Flammable dust or fibers, flammable liquid with a flash point of more than 28 ° C, flammable liquids in such quantities that they can form explosive dust-air or steam-air mixtures, upon ignition of which the design overpressure of the explosion in the room exceeds 5 kPa.

B1-B4 (flammable) - Combustible and flammable liquids, solid combustible and difficult combustible substances and materials (including dust and fibers), substances and materials capable of interacting with water, oxygen or with each other only burn, provided that The premises in which they are available or circulated do not belong to categories A or B.

Г - Non-combustible substances and materials in a hot, hot or melted state, the processing of which is accompanied by the release of radiant heat, sparks and flames; flammable gases, liquids and solids that are burned or disposed of as fuel

Д - Non-combustible substances and materials in a cold state.

Of the above factors, the shop belongs to the category "G" .

The fire protection system provides the following activities:

1. The maximum possible use of non-flammable and difficult combustible substances and materials in production processes;
2. Limitation of the quantity of flammable substances and their proper placement;
3. Insulation of combustible medium;
4. Use of fire extinguishing media;
5. Application of structures of production facilities with a regulated boundary of their fire resistance and flammability;
6. The existence of a plan for the evacuation of people in the event of a fire;
7. Obligatory briefing on fire safety and non-admission of employees to work in the shop in the absence of briefing;
8. Use of fire alarm and fire alarm;
9. Organization of fire protection of the facility;
10. The use of collective and individual protection against fire.

Literature:

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5 Feasibility study

5.1 Introduction

A lot of counties use frequency controlled drive for a long time. It's about 35 years. During this time were found scientific and methodological fundamentals. Electrical devices, for controlling electric drives were updated. Technical equipment became better. Electrical engineers were trying to develop first efficiency increasing algorithms. Unfortunately, our country has different situation. Ukraine became to sell and develop frequency controlled electric drives with good quality and electric networks compatibility only few years ago. Also, due to economic situation in our country this type of electric drive is not cheap. Due to this reason a lot of enterprises are refused to use frequency controlled electric drives. That is why there are a lot of questions about saved energy benefits. Frequency controllers are consisted from expensive components that it is why their price is not small. Electric energy saving using frequency controlled drives and cash benefit are very important questions, especially in modern time. For example frequency controlled induction motor of pump.

At my project work I added frequency controller to induction motor. I have substituted usual unregulated 3-phase feeding for frequency controller feeding.

Economic benefits occur due to less energy consuming. At my calculations I did not account money spending for usual electric drive exploitation. They are the same as in case of unregulated electric drive.

At economic part I determine benefits from frequency controller entering at electric drive work and I also check advisability of this technology. For this reason I determine capital costs, operating costs, the cost of consumed energy and energy savings, I also determine the annual savings from the introduction of the frequency converter.

Data on electricity consumption by a working pumping station at enterprise "ION" in Kramatorsk.

5.2 Capital Costs Calculations

Determination of the value of project investments

$$\mathbf{К_{пр} = К_{об}\,\left(\sum_{i=1}^{к} Ц_i\right) + З_{тзс} + З_{м} + З_{н} + З_{пр}}$$

$$K_{pr} = K_{ob}\left(\sum_{i=1}^{k} C_i\right) + Z_{tzs} + Z_m + Z_n + Z_{pr}$$

K_{ob} - the cost of acquiring electrical equipment (automation, software, etc.) for the project or the total cost of the component elements of the type required for the implementation of the adopted technical solution;
K_{ob}=9429 UAH. Frequency converter VFC3610 (pricelist site Chastotnic.ua Kiev)

Z_{tzs} – Transport and storage and storage costs;
Z_{tzs} = 65 UAH (the cost of delivery by "Novaya Pochta");
Z_m- Installation costs;

Z_m = 0 (Installation works are carried out by the personnel of the Chief Power Engineer Department);

Z_n- expenses for adjustment works;

Z_n= 450 UAH (service for setting up frequency converters.) Price-list "Profdrive Ukraine"

Z_{pr}- other non-recurring investments of cash;

Z_{pr}=0 UAH

K_{pr}= 9429+65+450=9944 UAH.

5.3. Calculation of operating costs

- depreciation charges (C_a);
- work of service personnel (C_z);
- deductions to social activities from wages (C_c);
- costs for maintenance and current repair of equipment (C_m);
- the cost of electricity consumed by the design object (C_e);
- other operating costs (C_{pr}).

$$\boldsymbol{C = C_а + C_з + C_с + C_т + C_э + C_{пр}}$$

$$C = C_a + C_z + C_c + C_m + C_e + C_{pr}$$

5. 3.1. Calculation of depreciation charges

The minimum permissible useful life of machines and equipment

$\boldsymbol{T_p^{expect}}$= 5 years (established in item 145.1 NKU)

The annual amount of depreciation is determined by dividing the amortized cost by the useful life:

$$C_a=9944/5=1988,8 \text{ UAH}$$

5.3.2. Calculation of costs for maintenance of equipment C_m

On the maintenance of the frequency converter is a contract with STOV "Profdrive Ukraine" for service. The cost of the service is 600 UAH / year.

$$C_m = 600 \text{ UAH}$$

5.3.3 Calculation of operating costs excluding the cost of Electric Drive

Annual operating costs: $C = C_a + C_m$ = 1988.8 + 600 = 2588.8 UAH

5.4 Calculation of the cost of consumed electricity

5.4.1 Cost of electric power consumed by the pump unit for 1 year of operation in the case of an unregulated electric drive

$C_{прэп} = w_{cp} * k * t_{year} * c_e$

w_{cp} = 1,5 kW / h (Data on PE "ION")

k = 0.7 is the time efficiency of the electric drive

t_{year} - time in year (in hours) tgod = 24 * 365 = 8760

c_e -2.81 UAH / kW (date 01.05.18 Data on PE "ION" IE1 standard class of energy efficiency)

$$C_{nrep} = 1,5 * 0,7 * 8760 * 2,81 = 25,846.38 \text{ UAH}$$

5.4.2 The cost of electricity consumed by the pumping unit for 1 year of operation in the case of a regulated electric drive

Based on the developed optimization system, the power consumption of the regulated electric drive is on average 22% less than the unregulated drive, i.e. the engine will consume 78% of $\mathbf{C_{nrep}}$

The efficiency of the frequency converter is on the average 98%. Therefore, its introduction introduces additional losses of 2% of $\mathbf{C_{nrep}}$.

Total reduction factor of power consumption

$$\boldsymbol{k_{opt}} = 0.78+0.02=0.8$$

Hence the cost of electricity consumption with a frequency converter is equal to:

$$\boldsymbol{C_{rep}} = \boldsymbol{C_{нрэп}} * \boldsymbol{k_{opt}} = 25846{,}38 * 0.8 = 20677{,}104 \text{ UAH}$$

Calculation of energy savings Electricity consumption for 1 year

$\boldsymbol{Э_г} = \mathbf{C_{nrep}} - \mathbf{C_{rep}}$=25846,38 - 20677,104 =5169,276 UAH

Э **–** efficiency kW/hour per year

$\boldsymbol{Э} = \boldsymbol{Э_г}$ /2.81=1839.6 kW/hour per year

5.5 Determination of annual savings from the introduction of the design object

Total annual savings from the entering of a vector-controlled drive

$$Э_г^п = Э_г – С = 5169{,}276 - 2588{,}8 = 2580{,}476 \text{ UAH/year}$$

5.6 Determination and analysis of economic performance indicators

Coefficient of efficiency (profitability) of capital expenditures E_p shows how many UAH of additional profit (economy) brings one UAH of capital expenditures:

$$\mathbf{Ep} = Э_г^п/\mathbf{К}$$

where $Э_г^п$ - the total annual savings from the introduction of the project object ths. UAH.; ***K*** - capital costs for the option, which caused savings, ths. UAH.

$$\mathbf{E_p} = 2580.476 / 9944 = 0.26$$

The payback period of capital expenditures **Tp** shows how many years they will pay off due to the total savings from the implementation of the option: $\mathbf{Tp} = \mathbf{К}/Э_г^п$, years

Tp =9944/2580,476=3.8 years

№ p/p	Name	units	Project device	Alternative device	Changes, comparing with first one	
					UAH	%
1	2	3	4	5	6	7
1	Capital expenditures	UAH	0	9944	9944	0
2	Operating expenses, including: - depreciation deductions - work of staff - deductions for social events - technical maintenance and maintenance - The cost of electricity consumed - other expenses	UAH UAH	0 0 $C_{нрэп}$= 25846,38	C_a= 1988,8 C_m=600 $C_{рэп}$ = 20677,104	1988,8 600 5169,276	0 0 20
3	Total annual savings	Years	0	2580,476	2580,476	0
4	Estimated efficiency factor	-	0	0,26	0,26	0
5	Estimated payback period of capital investments	Years	0	3.8	3.8	0
6	Energy saving	kWt/hour	0	1839.6	1839.6	0

Conclusion

During the calculations in the economic part, the following data were obtained:

capital expenditures: $\boldsymbol{K_{np}}$ = 9944 UAH

operating costs: $\boldsymbol{C}$=2588,8 UAH

energy saving for 1 year: $\boldsymbol{Э_{г}}$=5169,276 UAH

total annual savings $Э_{г}^{п}$=2580,476 UAH per year

efficiency coefficient $\boldsymbol{E_{P}}$=0.26

Payback period of capital expenditures $\boldsymbol{T_{p}}$=3,8 years

According to the calculated data, it is evident that the efficiency coefficient is quite high and the payback period $\boldsymbol{T_{p}}$ = 3,8< $\boldsymbol{T_{p}^{ожид}}$ = 5 years. Therefore, the introduction of a frequency converter into an unregulated induction motor is an advantageous and expedient solution. Almost in 4 years, all invested funds go back and further profits will increase.

Total Conclusion

In my project work both copper and core losses strategies were developed and applied. Vector control is a complex and high price control technique. But in spite of that it is a high performance control technique. FOC use space vector representation which is valid in both steady and transient conditions. So, along with satisfactory steady state response FOC have excellent transient response. It operates with fast dynamic response. Its speed regulation is very good.

Copper losses optimization gives good result at small speeds and at small load torques, while Core losses optimization vice versa: does not work at small speeds and torques and begins to work at values close to rated parameters. The introduction of a frequency converter into an unregulated induction motor is an advantageous and expedient solution. Almost in 4 years, all invested funds go back and further profits will increase.

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