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THE IMPORTANCE OF NON-ACTIVE POWER IN CHOOSING HIGH POWER ELECTRIC DRIVE

Slobodan Mirchevski
"Ss Cyril and Methodus" University, Skopje
Faculty of Electircal Engineering and Information Technologies
Skopje, RN of Macedonia
mirceslo@feit.ukim.edu.mk

Dragan Vidanovski
JSC "North Macedonian Power Plants", Skopje
REK Bitola
Bitola, RN of Macedonia
vidan.d@gmail.com

Mihail Digalovski
"Ss Cyril and Methodus" University, Skopje
Faculty of Electircal Engineering and Information Technologies
Skopje, RN of Macedonia
mihaild@feit.ukim.edu.mk

Goran Rafajlovski
"Ss Cyril and Methodus" University, Skopje
Faculty of Electircal Engineering and Information Technologies
Skopje, RN of Macedonia
goran@feit.ukim.edu.mk

***Abstract*—The paper examines the energy consumption in electric drive for transport of bucket wheel SRs 1050. For this type of electric drives in the past DC motor drives with AC/DC converter regulator were used. Now days it is usual to use three phase Variable Voltage Variable Frequency (VVVF) converters with DC link as energy converter. Energy consumption measurements of this type of drive is conducted and elaborated. Focus of inters of these paper is how non-active power reacts on induction motor (IM), or what type of IM we should chose if we have VVVF converter for electric drive. This type of variable speed drive works, in dynamic regime and we wanted to reduce electric looses, but in reality we measure very large quantities of reactive (Q) and distortion (D) power. Also with increasing of dynamics (regime S8, S9 and S10 defined in IEC 60034-1 standard [4]) produced harmonic and distortion power are increasing. The consumption of reactive, distortion and harmonics are evaluated. Non-active energy consumption question is presented through measurements with power analyzer.**

Keywords—electric drive, non-active power

I. Introduction

In electrical motor drives applied in mine machines like bucket wheel bagger is very important to have regulation with fast response in dynamic regimes such as S8, S9 and S10 and for this purpose DTC control is applied to the drive for transport [4]. Not only is good regulation purpose, so is the decrease of electrical loses and consumption of active and reactive power. With DTC control we have very high frequencies because of switching of the power transistors, significant amount of reactive and distortion power is consumed. There are two things where usage of power converter is problematic: the first is produce of reactive and distortion powers which fluctuate in power network, and produced reactive and distortion power in the inverter side (after DC link) has significant impact in parameter changes of IM (especially for resistances of stator and rotor) [12] [13]. Reactive and distortion power produced from rectifier unit of power converter make the harmonic power factor smaller than power factor for base frequency (f=50Hz) which means that we have high consumption and it costs money and causes greater pollution.

The mmeasurements presented in this paper are made according IEEE Std 1459/2010, IEEE Standard Definitions for the Measurement of Electric Power Quantities under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions, [17]. In these paper was investigated electric motor drive with these type of induction motor *2.RZKIT 355 Mk-6.*

II. Regulations in the Field of Electric Power

According IEC 60034-1 for Duty types S8, S9 and S10 regimes, using power converters high harmonics appears (because of using semiconductor switches). This voltage and current harmonics produces non-active power – power of distortion.

In the next figure representing power diagram according DIN 40110 [1]:

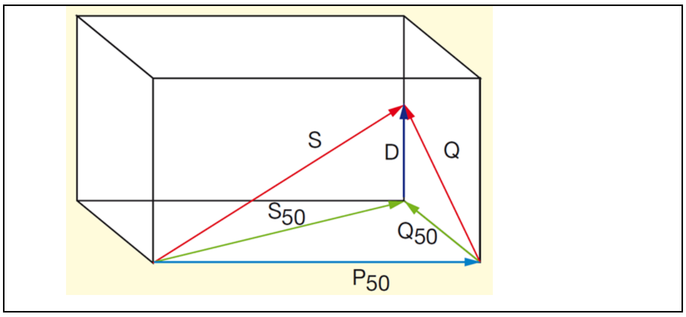

Fig. 1. Power Diagram according DIN 40110

The next equations represent the power of distortion:

$$D = \sqrt{Q^2 - Q_{50}^2} = \sqrt{S^2 - P^2 - Q_{50}^2} \quad (1)$$

where:

S-Apparent power VA

P-Active power W

Q-Reactive power VAr

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P50-Active power for 50 Hz

Q50-Reactive power for 50 Hz

like semiconductor devices (rectifiers and inverters) and other magnetic cores in saturation (transformers and motor cores, magnetic amplifiers). The current is non sinusoidal and according formula

$$D = U\sqrt{\sum_{\nu=2}^{\infty} I_{\nu}^{2}}. \tag{2}$$

Distortion power consists from current harmonics. The reactive power Q_{50} is reactive power which is store in the inductivities and capacitors in the consumer (induction motor - IM) and flow from network to consumer and backwards (vice versa). The geometrical sum of all current harmonics per current at 50 Hz is well known as total harmonic distortion factor - THD

$$THD_i = \frac{\sqrt{\sum_{\nu=2}^{40} I_{\nu}^{2}}}{I_1} \tag{3}$$

III. Measurement Methodology

Basic plate data of induction motor type 2.RZKIT-355-Mk-6 are 120 kW/742 min-1, 80-300V, 10-37.5Hz, η=88,5 – 94,7 %, $\cos\varphi$=0,855 – 0,860, 284A.

Energy measurement is conducted on electric drive for transport with DTC controlled converter using these instruments product of FLUKE: 1735 Power Data Logger, 105 B Scope-meter 100MHz, 41 B Power Harmonics Tester [3] and 345 PQ Clamp-meter. These power measurement instruments compiles with IEC 61000-4-3 Class A standard [5] which defines measurements methods and ensure reliable and precise results. From FLUKE data catalogue for Power Data Logger 1735 [2], sampling rate is 10,24 kHz and that means that the instrument can measure up 50 harmonics.

IV. Case Study

The following figures represent the measurement which is made with instruments:

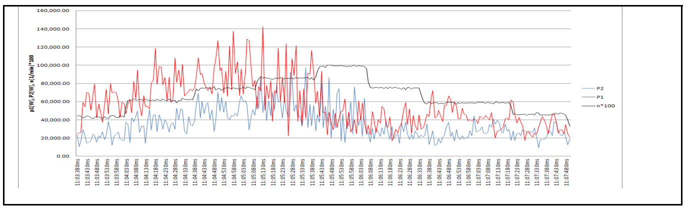

Fig. 2. Graphical representation of P_1, P_2 and speed

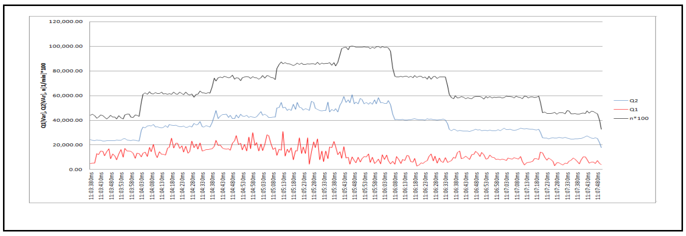

Fig. 3. Graphical *representation* of Q_1, Q_2 and speed

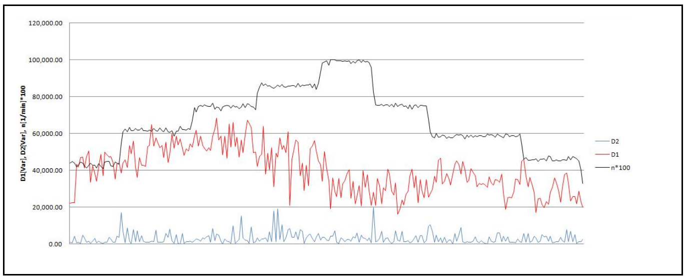

Fig. 4. Graphical representation of D_1, D_2 and speed

The results from measurements are given in figures 2 to 4. In figures are shown active power P_1, Q_1 and D_1 which is measured before the power converter, in the line side (with subscript 1-red color), and active power P_2, Q_2 and D_2 which is measured after the power converter, in the motor side (with subscript 2-blue color). For better representation the speed measurement is multiplied with coefficient 100.

As we see from figure 2 active power P_1 is significant greather than P_2 when IM is accelerating. On other case for reactive power, from figure 3 Q_1 is smaller than Q_2 and when speed change reactive power Q_2 foloves changes of speed. From figure 4 distortion power D_1 is signficant greather than D_2. These means that distortion power migrate in power network (400 V in the bucket wheel SRs 1050).

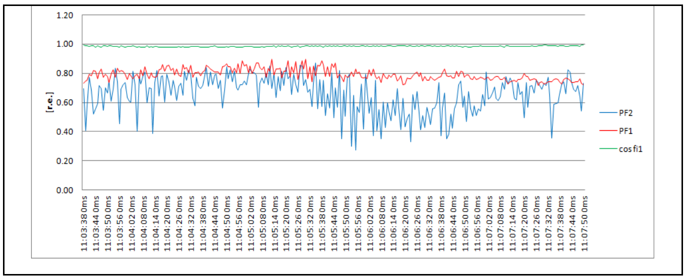

Fig. 5. Representations of power factor-PF and cosφ

As we can see from figure 5 the power factor *PF* contains harmonics, and it varies in range 0,74<*PF*<0,81. For fundamental frequency, the power factor varies in range 0,98<$\cos\varphi$<0,99. It is obviously that the manufacturer of power converter is correcting $\cos\varphi$, because the price of reactive power is much lower than price of active.

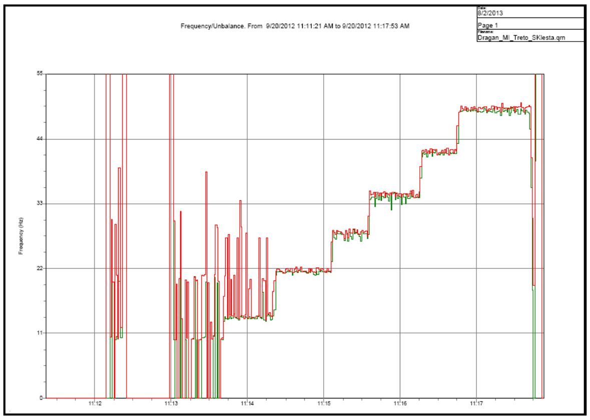

Fig. 6. Changes of freqencies-speed when IM accelerated

Changes of speed of the IM is in six steps when motor accelerated and from figure 6 these frequencies is 14, 20, 25, 32, 39.5 and 50 Hz. Harmonics which are producet from converter is presented in folowing figures. Measurement was made with osciloskope Fluke 105 B Scope Meter for 32 and 50 Hz.

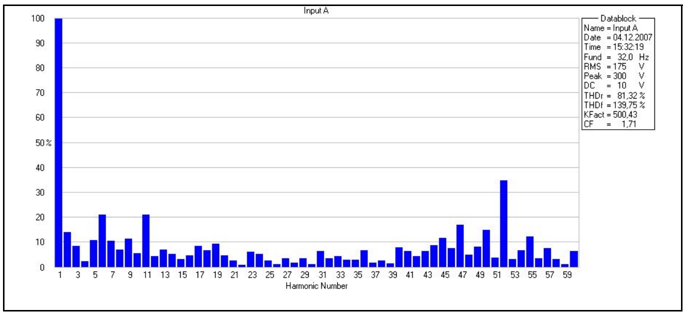

Fig. 7. Voltage harmonics at 32 Hz

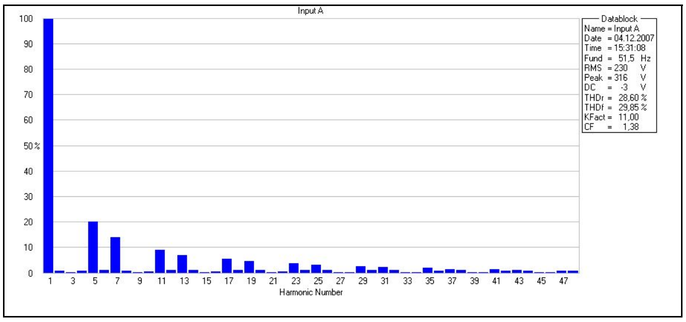

Fig. 8. Voltage harmonics at 51.5 Hz

Figures 7 and 8 represent harmonical specter at motor side (after converter). At smaller speed amount of harmonics is greater than when IM works with nominal speed.

Appearance of distortion power means that we have harmonics in the energy power system. On the line side measurement with Fluke 41 B Power Harmonic Tester [6] were made, and according to these measurements the graphical representation for base frequency f=20 Hz is:

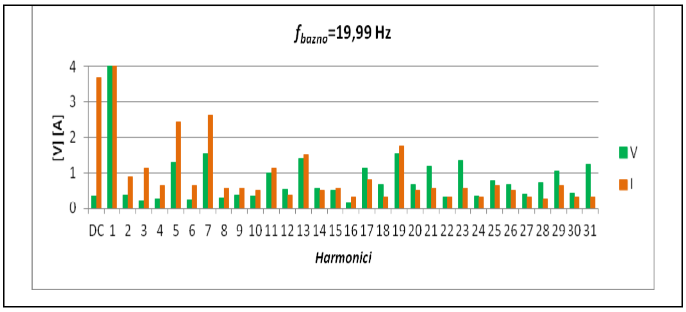

Fig. 9. Voltage and current harmonics for one phase for duration of one cycle

From figure 5, 7 and 8 we see that the induction motor is polluted with very high voltage and current harmonics. This fact means that the mathematical models of the induction motor must take in consideration the effect of harmonics influence on the parameters of the motor [10] and [14].

Also from figure 4 and 9, line side network is polluted with distortion power D_1 and high harmonics when IM works with small speed (f=20 Hz).

In the following table measurements at the line side of power converter are presented:

TABLE I. MEASUREMENTS AT THE LINE SIDE OF POWER CONVERTER

f Hz	I_1 A	PF_1	$\cos\varphi$	P_1 W	Q_1 VAr	D_1 VAr	S_1 VA
10,2	36,3	0,740	0,990	24871	4893	22469	33873
15,0	54,6	0,760	0,990	37480	7715	31536	49586
20,6	95,9	0,810	0,980	65087	14553	50068	83396
29,4	59,2	0,770	0,980	40208	8405	33000	52691
37,8	80,4	0,800	0,980	54604	11448	40600	69000
43,6	85,3	0,790	0,990	58493	12200	45208	74927
49,7	68,7	0,790	0,990	47139	15036	61023	78562

Table 1 represents the measurements for specific speeds of the induction motor. From the table it is obvious that the reactive power is smaller compared to the active ($\cos\varphi$ is constant and his value is high), but distortion power is in range with active power e.g. $0{,}77 \le \frac{P_1}{D_1} \le 1{,}34$. This means that the power converter produces high harmonics and high values of distortion power. This may cause problems in the power network, power converters, transformers, induction motors and power capacitor banks and will increase the production of green house gases CO_2, SO_2, N_2O and produce environmental pollution [8].

TABLE II. MEASUREMENTS AT THE MOTOR SIDE AFTER POWER CONVERTER

f Hz	U_2 *V*	I_2 *A*	PF_2	P_2 *W*	Q_2 *VAr*	D_2 *VAr*	S_2 *VA*
10,2	128,8	59,8	0,863	19601	11487	985	22698
15,0	129,8	612	0,844	20103	12785	946	23805
16,6	134,3	54,1	0,823	17473	12473	3322	21210
20,6	172,7	64,8	0,718	24134	23355	922	33597
22,5	187,2	64,9	0,722	25950	25102	3695	35915
29,4	204,5	60,8	0.655	31400	40223	3399	50914
30,8	252,8	87,4	0,820	51122	35621	931	62315
37,7	313,1	66,9	0,699	42991	43856	1562	61432
37,8	313,3	56,1	0,616	31400	40223	3399	50914
42,8	356,8	60,1	0,671	42627	47748	8249	63474
43,6	361,3	50,3	0,509	27507	46814	5735	53993
49,7	403,0	51,9	0,505	42627	47748	8249	63474

When the speed increases, by increasing the voltages on the motor clamps, the injection of reactive power Q_2 increases. Value of Q_2 directly depends on magnetic fluxes which appear into the motor and we can see that Q_2 is greater than P_2. Because of that reason power factor PF_2 decreases to values of 0,863 to 0,505. In cases of greater speeds, the power losses increase because of the increase of Q_2.

V. CONCLUSION

Influence of variable speed drives on reactive energy consumption and influence of variable speed drives on distortion energy consumption is considered. Reactive energy consumption and distortion is produced by nonlinearities from IM and from nonlinearities generated from power converter and type of control.

From measurements in examples, presented in this paper is obviously that the reactive power has great value, and distortion power we can't neglect.

When an engineer are planning and projecting new electric motor drives, knowledge of distribution of power in networks and in IM is useful. This article analyzes powers which appear when converter is used for speed control of electric motor drives. Also engineers should take care for energy efficiency and pollution problem using new technologies.

Energy efficiency is the powerful way for reducing the global pollution problem. Electric drives have great saving potential [14]. It is based on improving efficiency, with decreasing losses by use of power converters and increasing dimensions of electric machines and power factor (by using compensation and filtering methods).

However, the consumed total (for all harmonics) power according DIN 40110 must be paid. It is the best way to provide solid conditions for producing, transferring, distributing and using electricity. Reactive power including distortion power must be registered and paid. Better tariff models are always possible. It is time to use better measuring apparatus for electric power in industry and domestic applications. Consumption of reactive power is not negligible even for domestic use [9], due to increased use of smart electronics devices.

The appearance of high values of reactive and distortion power may manifest problems in:

- Distribution network, by overheating the lines, transformers,
- Induction motor, by overheating motor windings and magnetic core,
- Power converters, by overheating power switches components, DC capacitor, malfunctioning of microprocessor based equipment,
- Failure of power factor capacitors,
- In power station this reactive and distortion energy must be produced and transported, only a small part of non-active energy is pay from customer,
- Producing more energy, like reactive and apparent, is increasing production of green houses gases CO_2, SO_2, N_2O and more environmental pollution also.

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