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REGENERATIVE BRAKING OF THE MULTISYSTEM LOCOMOTIVE "SIEMENS VECTRON X4-E-LOK-AB, A26"

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Key words: *Multisystem locomotive, asynchronous traction motor, Regenerative braking*

Abstract: *The paper presents the results of research on the parameters of electricity quality measured in the output 25 kV field of the Indjija electric traction substation in "Infrastructure of Serbian Ralways" when regenerative braking the locomotive "Siemens Vectron X4-E-LOK-AB, A26" on the section of railway from Golubinci station on the right track to the neutral section at Ruma Station (approx. 20 km long). The results of the measurements are significant for undertaking further activities in order to eliminate the observed irregularities.*

INTRODUCTION

Thanks to the modern technological development and to the rapid development of semiconductor technology, which led to the creation of powerful energy converter, nowadays the use of induction motors drives has increased, and this type of motor drive replaced DC motors drives in traction systems.

The AC motors have a high number of advantages [1, 2]:

- AC motors are lighter and more compact than DC motors;
- the absence of brushes and commutator makes the AC motors a cheaper option. In fact, it is well-known that the maintenance of commutators and brushes is very expensive, since the commutator plates wear out quickly due to the friction of brushes on commutator;
- with AC motors, it is possible to obtain a rotational reversing (transition from traction to braking and vice versa) without changing any connections;
- AC motors have a best attitude towards adhesion.

However, also the disadvantages are important and they are:

- when AC motors are operated below its full load capacity, the power factor drops to very low values;

- poor starting torque. When an induction motor is started, there is no resistance initially, thus, a high starting current (6 to 10 times full load current) flows through the rotor circuit and it may damage the circuit permanently.

The main circuit of the multisystem locomotive "Siemens Vectron X4-E-LOK-AB, A26" is realized with three-phase asynchronous motors and indirect vector speed control with the possibility of recuperative electrical braking (Figure 1) [3] .

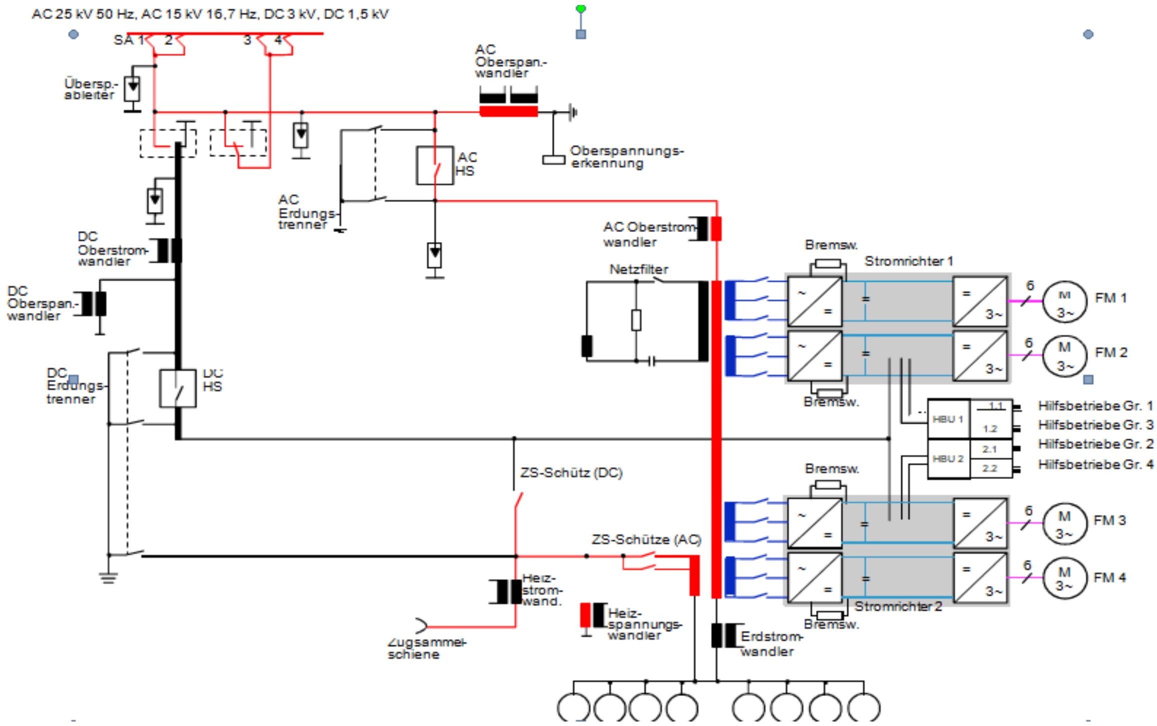

Figure 1: Main circuit of the "Siemens Vectron X4-E-LOK-AB, A26"

The technical characteristics of three-phase asynchronous traction motors of the "Siemens Vectron X4-E-LOK-AB, A26"are: U_n= 2675 V, U_{max}= 3353 V, I_n= 384 A, I_{max}= 570 A, P_n= 1480 , n_n=1810 1/min , n_{max}= 4300 1/min, f_n=60,8 Hz.

Structural diagram for regenerative braking of AC/AC system electric traction locomotive and speed–torque characteristics of asynchronous traction motor are given in Figure 2.

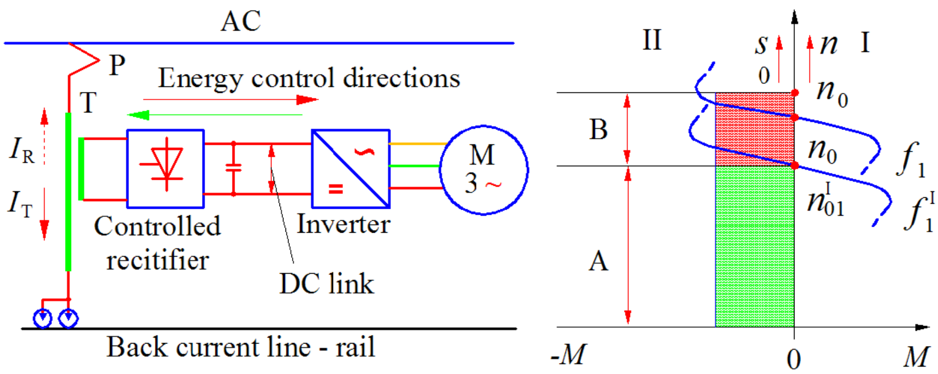

Figure 2: Structural diagram for regenerative braking of AC/AC system electric traction locomotive and speed–torque characteristics of asynchronous traction motor

The induction machine operates as a motor in traction and as a generator in braking.

The operating condition in traction mode is:

(1) $f > \frac{p \cdot n}{2}$

Thus, it follows that the frequency seen by the rotor is:

(2) $f_2 > 0$

Since:

(3) $f_2 = s \cdot f = \frac{\Delta n}{n_0} \cdot \frac{\Delta n \cdot p}{120} = \frac{\Delta n \cdot p}{120}$

It results that the slip is positive; thus, the rotational speed of the stator field is greater than the rotor speed:

(4) $s > 0$
$n_0 > n$

In such conditions both the active and the reactive power are positive:

(5) $P_1 = \sqrt{3} \cdot U \cdot I \cdot \cos\varphi > 0$
$Q_1 = \sqrt{3} \cdot U \cdot I \cdot \sin\varphi > 0$

Instead, the operating condition for which the induction machine behaves as generator is:

(6) $f < \frac{p \cdot n}{2}$

which results from the fact that, in braking mode, the rotor speed is greater than the speed of stator field $(n_0 < n)$, hence, the slip is negative $(s < 0)$. Therefore, the reactive power is absorbed (as in the traction mode) but the active power is negative:

(7) $P_1 = \sqrt{3} \cdot U \cdot I \cdot \cos\varphi < 0$
$Q_1 = \sqrt{3} \cdot U \cdot I \cdot \sin\varphi > 0$

The torque produced by an induction motor depends on the following three factors: firstly, the magnitude of rotor current I_2, secondly the flux Φ which interact with the rotor and it is responsible for the induced EMF in rotor E_2, lastly, the power factor cosϕ. Combining all these factors together we get the equation of torque as:

(8) $T \propto \Phi \cdot I_2 \cdot \cos\varphi$ (8)

The flux Φ produced by the stator is proportional to stator induced EMF E_1 ($\Phi \propto E_1$). Then we know that the transformation ratio K is defined as the ratio between the secondary voltage (rotor voltage) and the primary voltage (stator voltage).

(9) $K = \frac{E_2}{E_1}$
$K = \frac{E_2}{\Phi}$

Therefore:

(10) $E_2 \propto \Phi$

The expression of the rotor current I_2 is:

(11) $I_2 = \frac{s \cdot E_2}{\sqrt{R_2^2 + (s \cdot X_2)^2}}$

Finally, we know that the power factor is defined as the ratio between the resistance and the impedance:

(12) $$\cos\varphi = \frac{R_2}{Z} = \frac{R_2}{\sqrt{R_2^2 + (s \cdot X_2)^2}}$$

By substituting these values, we obtain:

(13) $$M \propto E_2 \cdot \frac{s \cdot E_2}{\sqrt{R_2^2 + (s \cdot X_2)^2}} \cdot \frac{R_2}{\sqrt{R_2^2 + (s \cdot X_2)^2}}$$

$$M \propto s \cdot E_2^2 \cdot \frac{R_2}{R_2^2 + (s \cdot X_2)^2}$$

By removing the proportionality:

(14) $$M = K \cdot s \cdot E_2^2 \cdot \frac{R_2}{R_2^2 + (s \cdot X_2)^2}$$

We can now plot the torque as a function of the slip: there are three regions of operation of the induction machine namely motoring $(0 < s < 1)$; generating $(s < 0)$ and braking ($1 < s < 2$).

The maximum Torque occurs when the slip is $s_{\max} = \frac{R_2}{X_2}$ and it results:

(15) $$M_{\max} = K \cdot \frac{E_2^2}{2 \cdot X_2} = K \cdot \frac{\Phi^2}{2 \cdot X_2}$$ (15)

Therefore, the maximum torque is directly proportional to square of flux, is independent of the rotor resistance and slip.

From the above diagram, it is possible to conclude that the stable region of operation is the one in the interval $0 < s < s_{\max}$ .In fact, in this region the torque developed by the motor is proportional to the slip. Therefore, the motor operation settles at a stable speed for given value of torque. However, if the slip increases beyond s_{max} due to high load torque, the torque developed by the motor reduces as the slip increases and this results in stalling of the motor.

In conclusion, the regenerative braking of induction motor takes place if the speed of the rotor is greater than synchronous speed $s < 0$, but with a reduction of the stator frequency regenerative braking can occur for speeds lower than synchronous speed. Therefore, the induction machine transfers its working point from the I to the IV quadrant and it switches its operation from motor to generator.

DESCRIPTION AND MEASUREMENT RESULTS

On 16.04.2019 at the time from 10:49h to 11:08h the locomotive "Siemens Vectron VECTRON X4-E-LOK-AB, A26" was tested, with serial number 91 80 6193 903-2 during movement on the section of railway from Golubinci station on the right track. to the neutral section at Ruma Station, approx. 20 km in length [4].

Measurement was performed by C.A 8352 power quality analyzer manufactured by Chauvin Arnoux. The recording device was connected to the secondary terminals of a voltage measuring transformer that measures voltage at 25 kV busbars in the ETS of Indjija and a current measuring transformer (measuring core) that measures the current at the circuit breaker that feeds the contact line on the right track of a section from the neutral section Indjija Selo (km 43 + 415) to the neutral section of Ruma (km 66 + 215). The observed locomotive was alone on the feeder arm, so that all measurements refer to the influence of this locomotive exclusively.

In the period when measurements were made, that is, by the time the locomotive passed the neutral section of Ruma (from 10:49 h to 11:08 h), slight variations in voltage were observed (Figure 3): U_{min} = 24,45 kV and U_{max} = 24.94 kV.

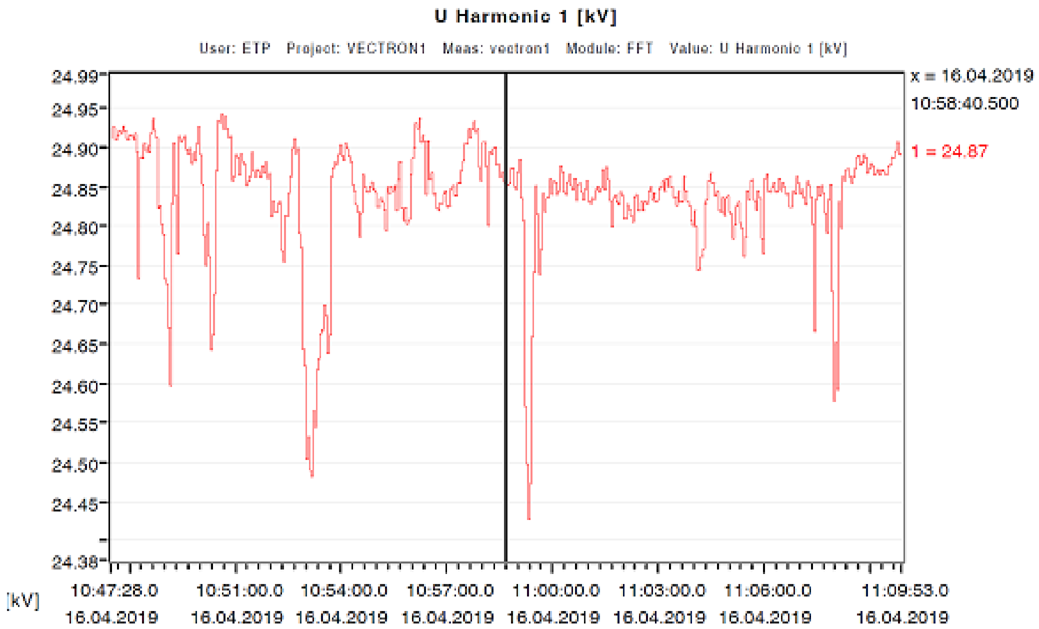

Figure 3: Measured voltage values

At 10:58:40 at maximum voltage U= 4.87 kV and acceleration of the locomotive, a maximum value of traction current of I_{maxu} = 123.2 A was registered.

When using recuperative braking at 10:53:09 the maximum braking current was measured: I_{maxk} = 73.6 A (Figure 4). No abnormal increase in the voltage on the contact network was observed during this brake.

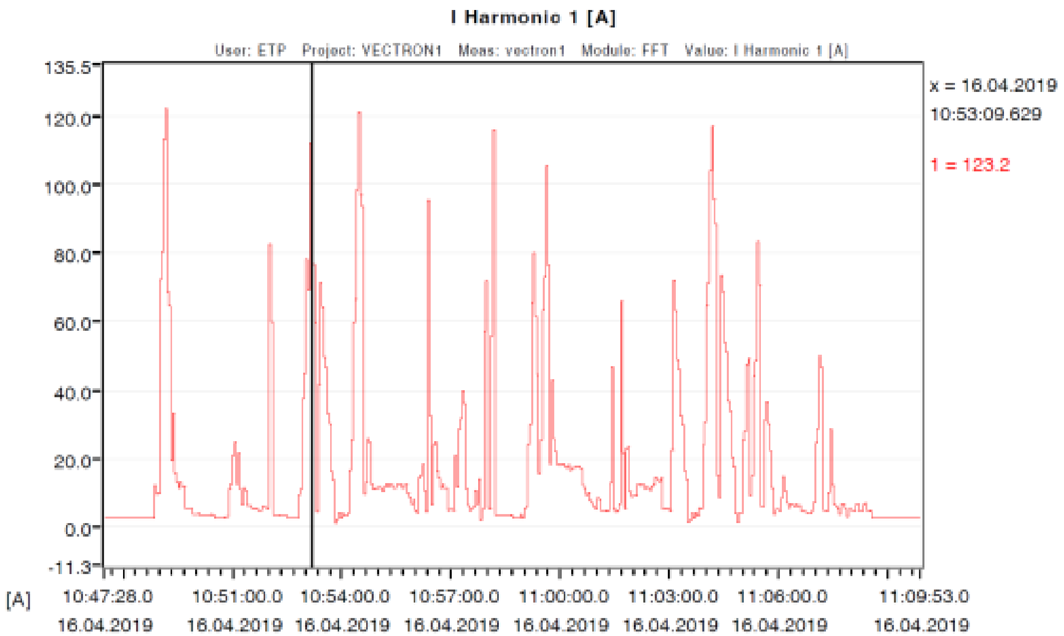

Figure 4: Measured value of current in recuperative braking

When accelerating the locomotive at the maximum traction current value of I_{maxu} = 123.2 A (10:58:40), the highest active power of P_{max} = 3,017 MW and reactive power Q_{max} = 0.215 MVAr were recorded, and at regenerative braking, the active power of: $P_{kočmax}$ = 1.825 MW.

The measured maximal values of total voltage and current distortion are: *THD U* = 6.395 % and *THD I* = 139.792%. *THD U* is below the permissible values (<8%) and THD I is not defined according to EN 50160. However, according to IEEE 1159-1995 *THD I* is limited to 5%.

CONCLUSION

Based on the performed measurements and analysis of the parameters of electricity quality on the 25 kV side of ETS Indjija when powering three-system locomotives "Simens Vectron X4-E-LOK-AB, A26" it is concluded:

- harmonic voltage distortion and corresponding THD are within the permissible limits;
- the change in voltage in the contact line during locomotive regenerative braking is insignificant;
- harmonic current distortions and corresponding THD are above the prescribed values;
- only odd higher harmonics with dominant first harmonics are present in the voltage and current waveform;
- harmonic current distortion and the corresponding *THD* should be reduced by incorporating appropriate active filters into the electric traction substation (ETS);
- the power factor is within the prescribed limits both in the electric traction mode and in the regenerative braking of the locomotive;
- the reactive power flows during traction and recuperative braking of the locomotive are considerable (Q_{max} = 215 kVAr)

REFERENCES

[1] Romero M., Pardo R., Gallego L., Developing a PQ Monitoring System for Assessing Power Quality and Critical Areas Detection, Revista Ingeniería e Investigación, Vol. 31, No. 2, pp. 102-109, (2011)

[2] Janda Ž., Review of Standards and Recommendations for the Control of Higher Harmonics in Power Grids, Proceedings, Electrical Engineering Institute "Nikola Tesla", (2004**)**

[3] https://press.siemens.com/global/en/feature/vectron-vehicle-concept

[4] Urošević P, M. Dražić M., Report on tests and measurements of electricity quality at the voltage level 25kV while driving and regenerative (recuperative) braking of the VECTRON X4-E-LOK-AB locomotive, variant A26, Serbian Railway Infrastructure, joint-stock company, Electrical Engineering Sector, (2019)

[5] Đurišić Ž., Đurić M., Description of measurement and acquisition system for control of electricity quality in the distribution system, 27th Consultation JUKO CIGRE, Zlatibor, May 29th - June 3rd 2005, (2005)

[6] Karimi-Ghartemani M, Iravani M., Measurement of harmonics/inter-harmonics of time-varying frequencies, IEEE Trans. Power Del., vol. 20, no. 1, pp. 23–31, January (2005)

[7] Giesbertz P., Petrov K., Quality of Supply in the Regulatory Control", BPC Proceedings, Belgrade, 19-21 June 2002, (2002)

РЕКУПЕРАТИВНО СПИРАНЕ НА МУЛТИСИСТЕМЕН ЛОКОМОТИВ "SIEMENS VECTRON X4-E-LOK-AB, A26"

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СЪРБИЯ

Ключови думи: *Мултисистемен локомотив, асинхронен тягов двигател, регенеративно спиране*

Резюме: *В статията са представени резултатите от изследванията на параметрите на качеството на електроенергията, измерени в изходното поле 25 kV на подстанцията за електрическа тяга в „Инфраструктура на сръбските релсови пътища“ при регенеративно спиране на локомотива „Siemens Vectron X4-E-LOK-AB, A26 "на участъка на железопътната линия от гара Голубинци по десния път до неутралния участък на гара Рума (дълъг около 20 км) Резултатите от измерванията са важни за предприемането на по-нататъшни дейности с цел отстраняване на наблюдаваните нередности.*