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Study Quality of Voltage on Single Track AC Railway Traction Electrification

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ABSTRACT

Quality of voltage is one of important parameter for power quality in electrification parameter. The voltage parameter is said to be good if the voltage level does not exceed or less than the standard voltage. In the operation of electric trains, several conditions can cause over and under voltage. Like when a train accelerates or decelerates it will affect the system voltage. This research study about quality of voltage on single track AC railway electrification. The method used in this study is to simulate a model of railway electrification such as traction substations, overhead electrification and rail infrastructure. System modeling is done using open power net software. The results of this simulation show the condition of voltage fluctuations on the bus, overhead wire and pantograph sides

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1. INTRODUCTION

Electrification in the railway sector is one of the important factors that must be ensured in good condition before operating the train. Among the parameters that become the standard for power quality in electrification systems are voltage, current, power factor and harmonics. In railway electrification systems there are those that use AC electrification or DC electrification [1]–[4]. AC electrification is more widely used for long-distance train travel operators. While DC electrification is more widely used for short distance train operators. Of course, there are advantages and disadvantages of each system. In this study, AC electrification was used as study material for further research.

In previous research, it has been examined about power quality on railway electrification system [2] such as about voltage regulation [5], harmonic on traction substation [6], energy feedback in railway electrification [7], and so on. This research will focus on looking at the voltage parameters on the AC railway electrification system. A research has been discussed about On-line simulation of voltage regulation in autotransformer-fed AC electric railroad traction [8]. Unilateral power supply and bilateral power supply has been studied before [9].

To find out and predict the power quality of AC railway traction, dynamic simulation-based research has been carried out using Mathlab software with several scenarios [10]. In previous research has been done with study analysis about traction system unbalance problem [11] which states that As the demand for power requirements for traction systems is increasing significantly, it is important to carry out an impact analysis of using special loads to estimate the Negative-Sequence currents of each generator. Considering the structure of a three-winding connected transformer in particular, the V-V junction scheme has the disadvantage of an inherently unbalanced structure, and is substantially the least effective in reducing unbalanced currents caused by unequal loads on the two-phase sides and in the transformation [12]. A comparative analysis of different transformer configurations - conventional cyclic phase tapping at adjacent substations on Indian Railways has been carried out. in this case also pay attention to the connection and configuration of Scott taking advantage of the hot standby currently in service [13] [14].

This research is a basic research to determine the quality of the voltage that occurs in the overhead catenary system (OCS) which is formed from a transformer with a configuration of 2 secondary windings to supply the right and left routes of the traction substation. The case study of this research is single track with AC railway electrification. The voltage parameter is seen every time and along the route that is used as the research model.

2. RESEARCH METHOD

2.1 Modelling of AC Railway Traction Electrification

In this study, AC railway traction electrification is studied through testing of electrification models starting from traction substations, overhead catenary system, conductors to infrastructure rails. the infrastructure track that will be studied is a single track with a length of 85,400 m. There are 3 stations on this track, namely station A, station B and station C. On this track there is the addition of a second track at kilometers 9,750 to 10,250 which is at the location of station B. The position of the placement of conductors such as earth wire, messenger wire, contact wire as well as right rail and left rail shown in figure 2. In this model, to provide electricity supply along the route, 2 traction substations are placed at positions 5 km and 80 km with the technical specifications shown in table 3.

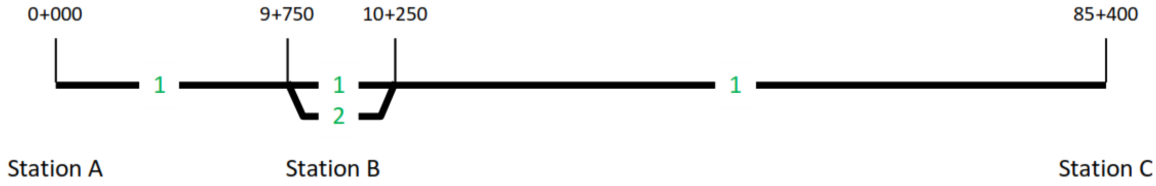

Figure. 1. Track Infrastructure studied.

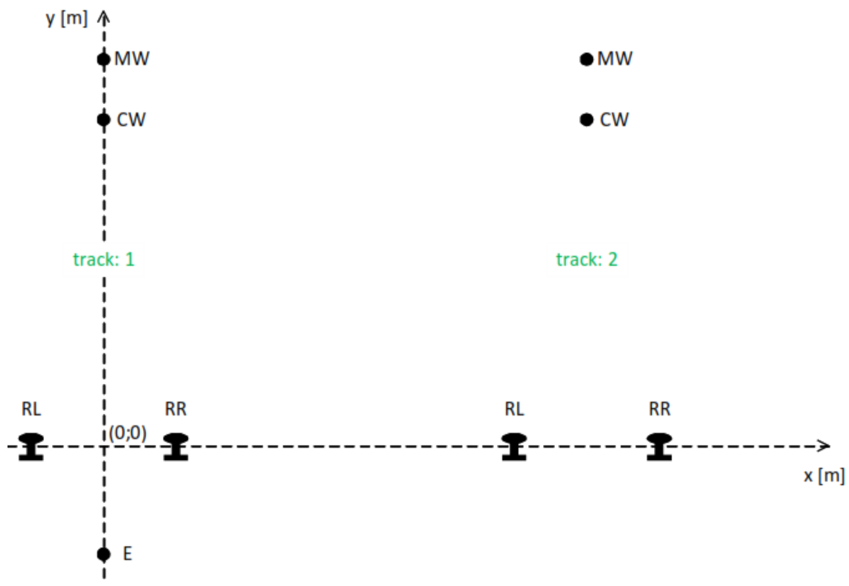

Figure. 2. Conductors position design studied.

AC railway electrification design analyzed using the conductor design parameters as shown in table 1. The parameters entered include the position of the track placement on the X and Y axes, resistance of conductors, equivalent radius, temperature coefficient and conductor cross-sectional area.

Table 1. Conductor Design Parameters

No	**Track**	**Name**	**X [m]**	**Y [m]**	**R20 [Ohm/km]**	**r_eq [mm]**	**Temp. coeff.**	**T [°C]**
1	1	E	0	-465	0.0494	465000	-	-
2	1	MW	0	6.9	messenger wire: 150 mm² Cu rope			60
3	1	CW	0	5.3	grooved contact wire 150 mm² Cu			80
4	1	RL	-0.75	0	0.21	41	-	-
5	1	RR	0.75	0	0.21	41	-	-
6	2	MW	10	6.9	messenger wire: 150 mm² Cu rope			60
7	2	CW	10	5.3	grooved contact wire 150 mm² Cu			80
8	2	RL	9.25	0	0.21	41	-	-
9	2	RR	10.75	0	0.21	41	-	-

Table 2. Connect track 1 and 2 using Network/Connectors parameters

No	**From line/track/km/condName**	**To line/track/km/condName**
	beginning of track 2 at 9+750	
1	A/1/9.750/MW	A/2/9.750/MW
2	A/1/9.750/CW	A/2/9.750/CW
3	A/1/9.750/RL	A/2/9.750/RL
4	A/1/9.750/RR	A/2/9.750/RR
	end of track 2 at 10+250	
5	A/1/10.250/MW	A/2/10.250/MW
6	A/1/10.250/CW	A/2/10.250/CW
7	A/1/10.250/RL	A/2/10.250/RL
8	A/1/10.250/RR	A/2/10.250/RR

Table 3. Define propulsion, power supply and auxiliary parameters

No	**Parameters**	**value**
1	Power Supply	AC 1ϕ, 25kV, 50Hz
2	Traction max Power	5560 kW
3	Traction max Effort	250 kN
4	Traction mean Efficiency	90 %
5	Brake max Power	5560 kW
6	Brake max Effort	250 kN

No	Parameters	value
7	Brake mean Efficiency	90 %
8	Max Recovery Voltage	29 kV
9	Auxiliary constant power	100 kW

Table 4. Define Substation TSS 05 and TSS 80 parameters

No	Parameters	value
1	Power Capacity	16 MVA
2	Primary/Secondary Voltage of Two Winding Transformer	70 kW
3	Load Losses at nominal power	15 kW
4	Relative Short Circuit Voltage	9.6%
5	No Load Current	0.31 A
6	Z impedance real	0.001 Ohm
7	OCS and Return Rails specification	1/0.6kV, 1x150Cu / 50Cu (Brugg, 53378)
8	Z imaginer and Z real of conductors	0.097 Ohm/Km and 0.1253 Ohm/Km

2.2 Compare with standard voltage

According to the Irish version of the European Standard Document EN 50163:2004, about Railway Application – Supply voltage of traction systems, the standard parameters is shown in table 1.

Table 5. Supply voltage of traction systems standard parameters (EN 50163)

Electrification system	Lowest nonpermanent voltage	Lowest permanent voltage	Nominal voltage	Highest nonpermanent voltage	Highest permanent voltage
15 kV AC 16,7 Hz	11 kV AC	12 kV AC	15 kV AC	17.25 kV AC	18 kV AC
25 kV AC 50 Hz	17.5 kV AC	19 kV AC	25 kV AC	27.5 kV AC	29 kV AC

3. RESULTS AND DISCUSSION

Analysis of the electrical parameters in this model was carried out using open power net software (OPN). The analysis was carried out under normal circumstances in the time range 01:00:00 – 01:49:08. The analysis is carried out by comparing the measured parameters with applicable standards or regulations. In this study the parameters measured were busbar power, conductor voltage, pantograph voltage, rail – earth potential. Busbar Power operated in this study is shown in fig. 3. This power is supplied by substation 5 and substation 80. This study was conducted for 109.08 minutes at 01:00:00 – 01:49:08. From the figure 3 apparent power of TSS 05 and TSS 80 is presented. From the figure it can be seen the pattern of increasing and decreasing power of each TSS. When the power of TSS 05 has increased, at the same time there is a simultaneous decrease in TSS 80. Conversely, when the power of TSS 05 has decreased, at the same time there has been a simultaneous increase in TSS 80. From the data, the sum of apparent power shows that there are 2 activities from the train that passes during 01:00:00 to 01:49:08.

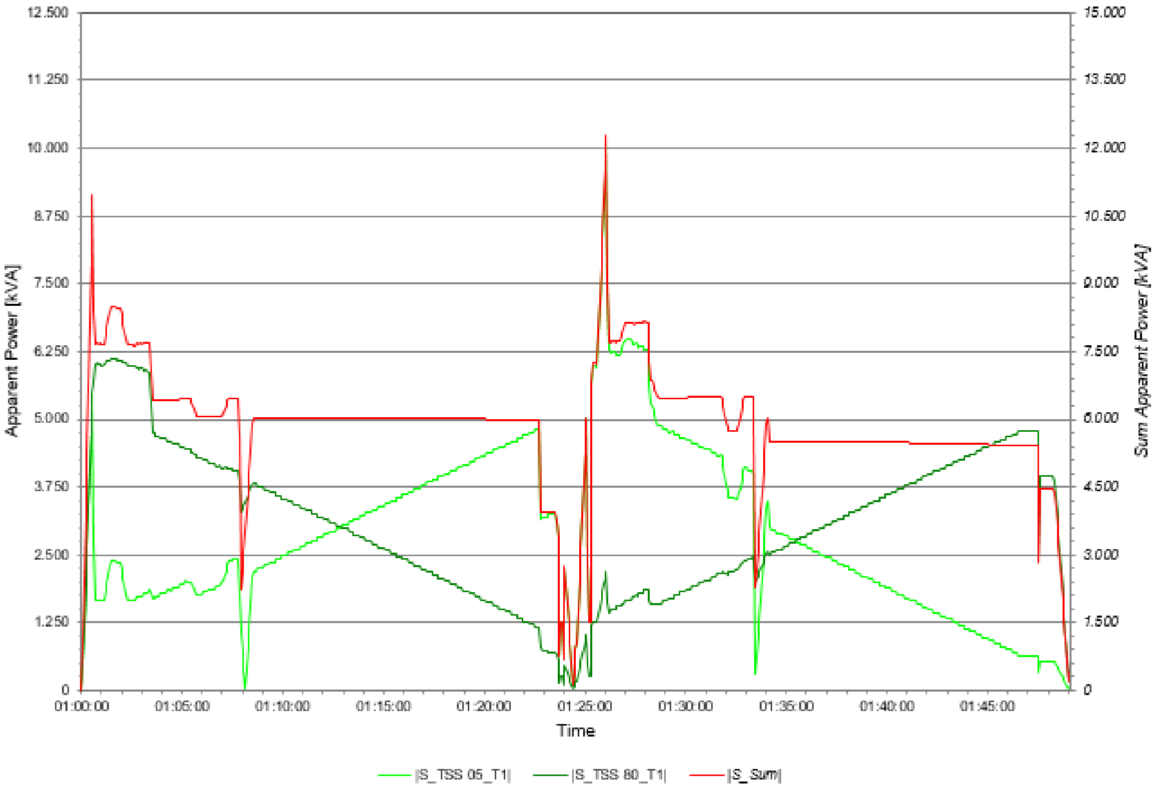

Figure. 3. Busbar Power in normal operation network AC, Aggregation two winding transformer.

Table 6. Current and Loss of Energy in conductors

Substation	Item	Type	$\|I\|_{max}$ A	I_{rms} A	I_{rms15} A	E_{loss} kWh
TSS 05	**ocs**	**Busbar**	**370**	**119**	**173**	**-**
TSS 05	T1	Two Winding Transformer	370	119	173	-
TSS 05	*A/1/CW/5.000*	*Feeder*	*370*	*119*	*173*	*0,1*
TSS 05	**return**	**Busbar**	**370**	**119**	**173**	**-**
TSS 05	T1	Two Winding Transformer	370	119	173	-
TSS 05	*A/1/RL/5.000*	*Feeder*	*185*	*59*	*86*	*0,0*
TSS 05	*A/1/RR/5.000*	*Feeder*	*185*	*59*	*86*	*0,0*
TSS 80	**ocs**	**Busbar**	**223**	**121**	**155**	**-**
TSS 80	T1	Two Winding Transformer	223	121	155	-
TSS 80	*A/1/CW/80.000*	*Feeder*	*223*	*121*	*155*	*0,1*
TSS 80	**return**	**Busbar**	**223**	**121**	**155**	**-**
TSS 80	T1	Two Winding Transformer	223	121	155	-
TSS 80	*A/1/RL/80.000*	*Feeder*	*112*	*60*	*78*	*0,0*
TSS 80	*A/1/RR/80.000*	*Feeder*	*112*	*60*	*78*	*0,0*

Table 7. Current and Power parameter of two winding transformer

Sub station	**Signal**	**$\|I\|_{max}$ A**	**I_{rms} A**	**I_{rms15} A**	**$\|S\|_{max}$ kVA**	**$\|P\|_{max}$ kW**	**P_{rms} kW**	**P_{rms15} kW**	**$\|Q\|_{max}$ kvar**	**E kWh**	**E_{loss} kWh**
TSS 05	total	370	119	173	10.088	10.076	3.251	4.727	486	2.184	14,7
TSS 05	out	370	117	170	-	10.076	3.217	4.653	486	2.256	13,8
TSS 05	in	118	17	30	-	3.252	470	834	105	72	0,8
TSS 80	total	223	121	155	6.124	6.122	3.317	4.252	244	2.292	14,8
TSS 80	out	223	119	155	-	6.122	3.266	4.252	244	2.382	13,9
TSS 80	in	144	21	38	-	3.952	581	1.035	68	90	0,8

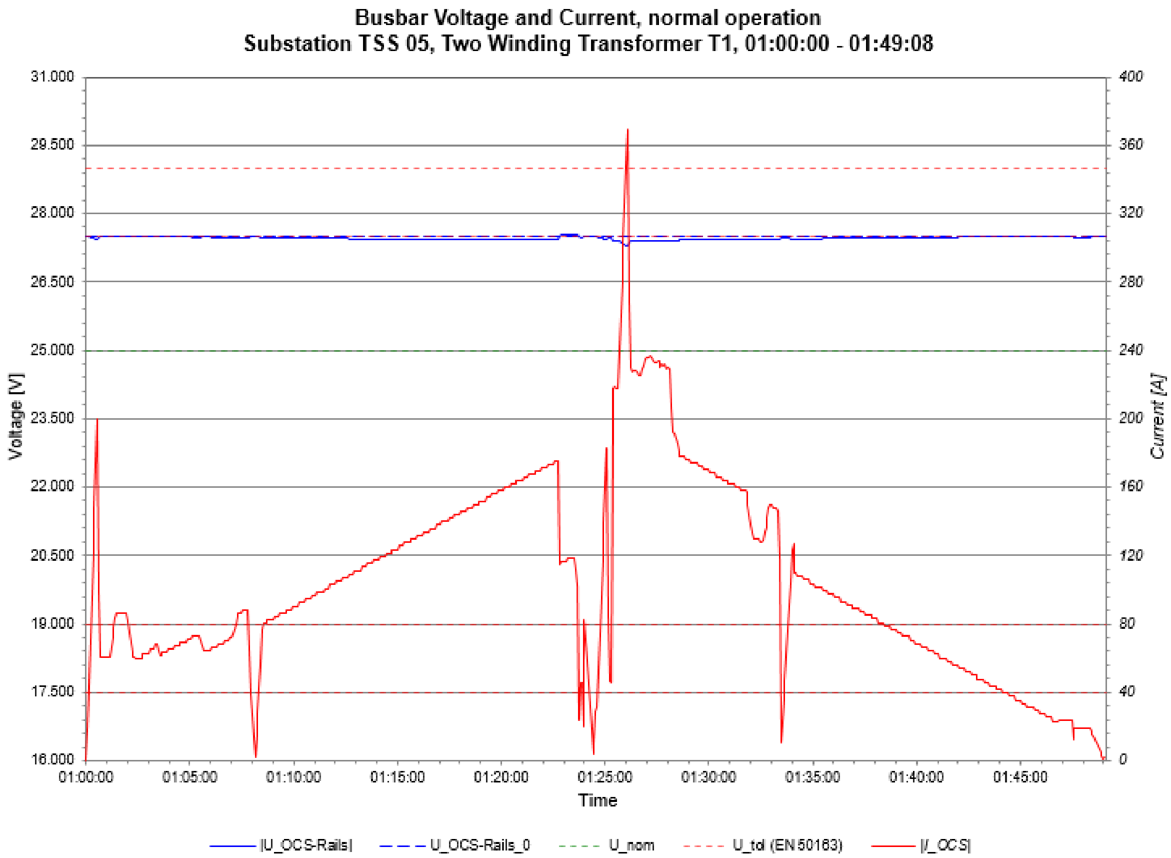

Figure. 4. Conductor voltage fluctuation in normal operation.

Busbar voltage and current of Substation TSS 05 in normal operation is shown in fig. 4. The fluctuation of voltage in line A especially at km 42+000 is around 26.950 V to 27.580 V. To see the conductor voltage curve clearly, it's shown in fig. 5. Pada gambar diatas bisa diketahui bahwa tegangan konduktor

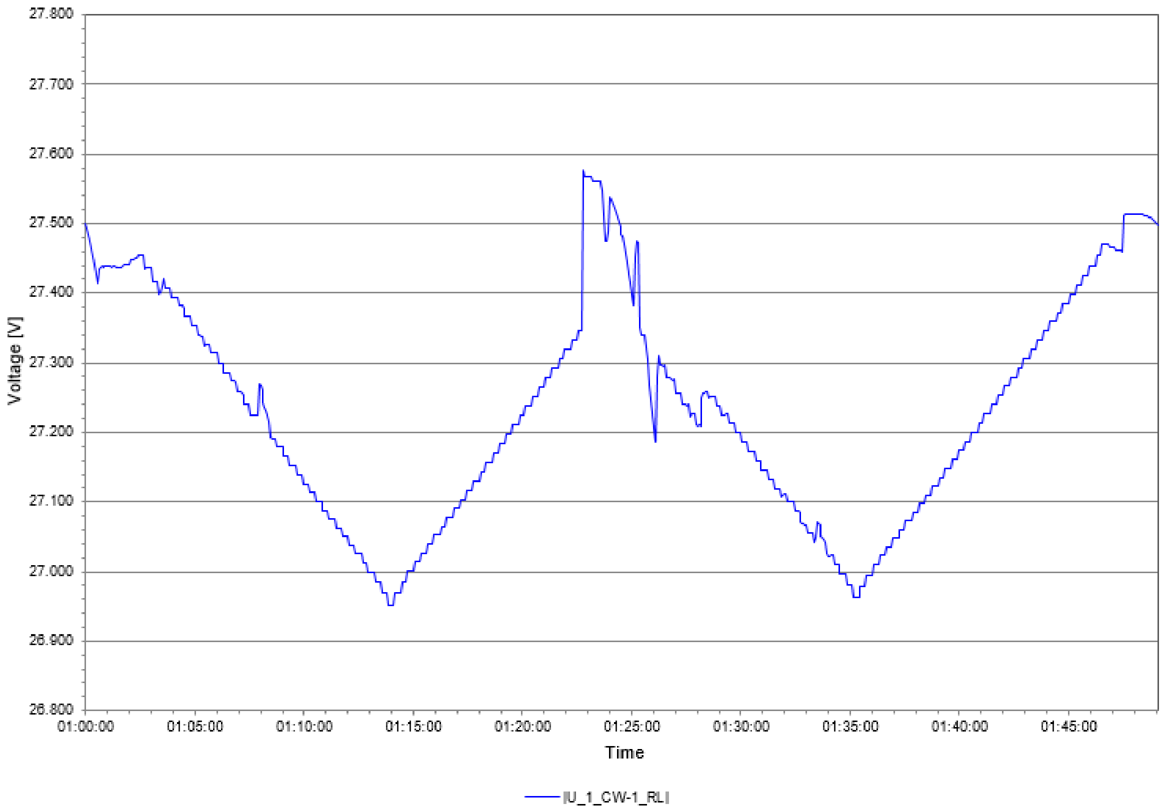

Figure. 5. Conductor voltage fluctuation in normal operation.

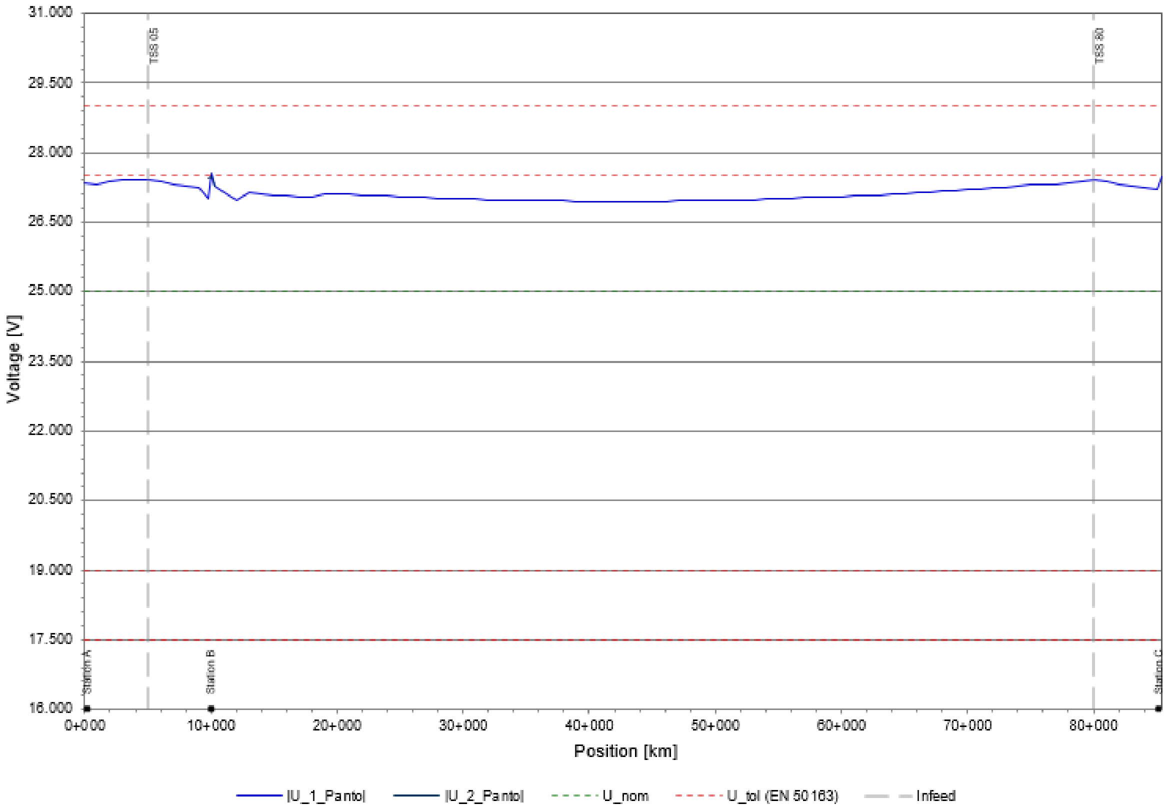

Figure. 6. Pantograph voltage fluctuation in normal operation.

Pantograph voltage condition in normal operation is shown in fig. 6. The fluctuation of voltage in line A at km 0 to 85+400 is around 27.000 V to 27.500 V. hal ini dapat dikatakan masih sesuai dengan standard Supply voltage of traction systems standard parameters (EN 50163)**.** For 25 kV AC 50 Hz system, the Highest nonpermanent voltage is around 27.5 kV AC, Lowest nonpermanent voltage is around 17.5 kV AC**.** From the pantograph voltage data in each km it can be concluded that the lowest voltage value is at the farthest point from the traction substation or at the midpoint of the route between the 2 traction substations. In km area of station B it can be seen that the pattern of increase and decrease in voltage is caused by acceleration and deceleration of train speed. When the train is decelerating, there is an increase in the voltage level, while when the train is accelerating, there is a decrease in the voltage level. This shows that the greater the use of power on the train, the greater the current it will absorb. This causes a voltage drop on the channel, because the greater the current, the losses on the channel also increase. Rail to earth conductor voltage condition in normal operation is shown in fig. 7. The fluctuation of voltage in line A at km 0 to 85+400 is presented around 10 V to 72 V.

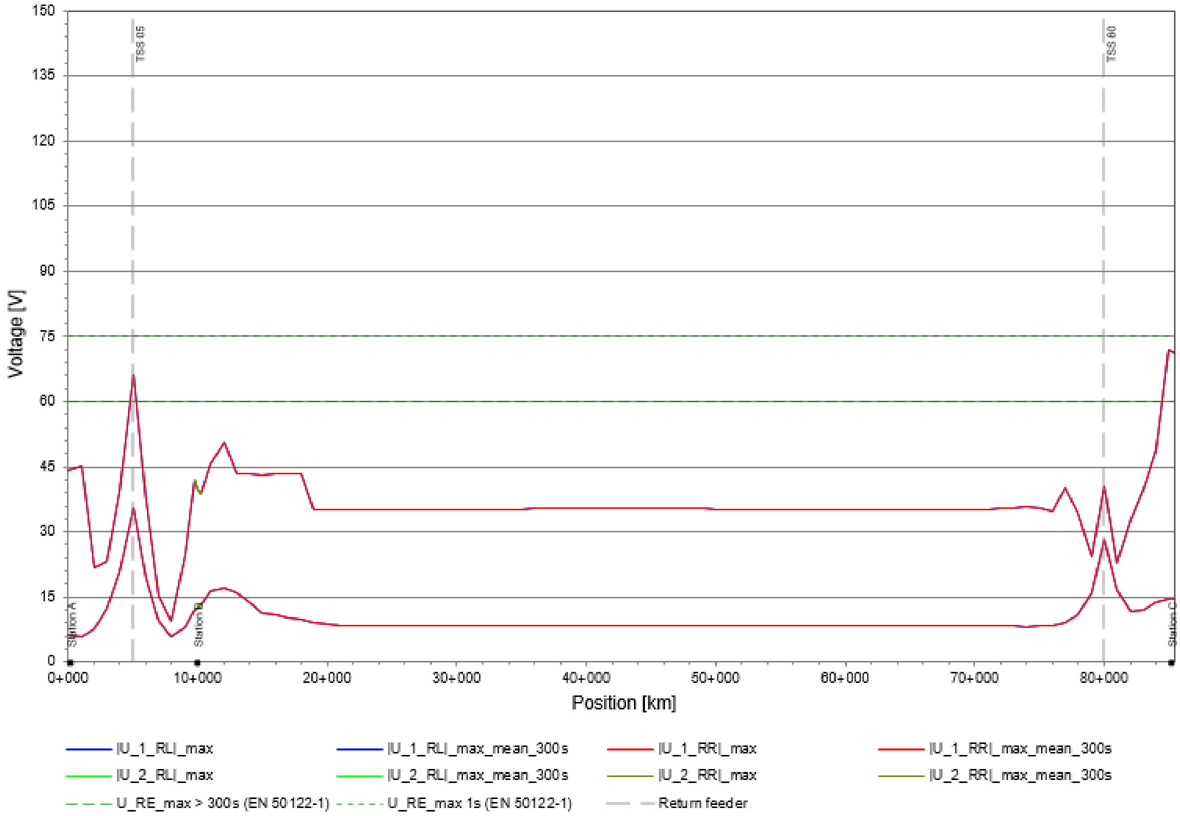

Figure. 7. Rail - Earth potential in normal operation.

4. CONCLUSION

Quality level of voltage in single track AC Railway traction can be seen from the results of running the simulation through the open power net software. From the results and discussion, voltage level of OCS is the same as the voltage level of pantograph. The voltage value is still appropriate standard Supply voltage of traction systems standard parameters (EN 50163)**.** For 25 kV AC 50 Hz system, the Highest nonpermanent voltage is around 27.5 kV AC, Lowest nonpermanent voltage is around 17.5 kV AC). besides that it can be seen that the OCS voltage level is also influenced by the amount of losses in the channel. Losses on the channel besides depending on the resistance value of the channel also depend on the train's power usage during acceleration and deceleration.

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