https://doi.org/10.1051/e3sconf/202340105007

Regulation of feeding part of complex of vibroacoustic diagnostics of rotary units of rolling stock

Murodilla Shadmonxodjayev*, and *Damir* Insapov

Tashkent State Transport University, Tashkent, Uzbekistan

Abstract. The article deals with the study of parameters of power supply control systems for the position of non-disassembly vibroacoustic diagnostics of rotary units of rolling stock. It is assumed that the power sources transmit constant electricity to bring the traction motors of electric locomotives and electric trains into rotation with the required frequency at the position of non-disassembly diagnostics of bearings. Experiments were performed following the MatLab/Simulink software. Analytical methods are used to determine the parameters of traction motors of electric rolling stock according to the program and the parameters of the controlled part as the power factor of various power supply options. The energy indicators of electric traction motors of electric rolling stock were determined in tabular and analytical forms, controlled parameters with different power coefficients of power sources. Based on the assessment of the energy indicators of various power supply options, it is concluded that it is advisable to use a circuit with a pulse converter in the position of vibroacoustic diagnostics of rotary assemblies. A variant of an energy–efficient power supply for non-disassembled vibroacoustic diagnostics is proposed, including an uncontrolled semiconductor rectifier and a pulse converter executed on an IGBT transistor. A radical way to increase the power factor of the power supply is using pulse voltage regulation.

1 Introduction

The power supply is designed to rotate the wheel-motor units of electric locomotives and electric trains at the position of non-disassembly diagnostics of bearings with the required frequency [1, 2].

The study aims to determine the power supply's adjustment parameters for the position of non-selective vibroacoustic diagnostics.

The power supply load is four series-connected traction motors of electric locomotives (VL80S, 3ES5K) and electric trains (ER9).

The article discusses the parameters of the control system and two possible options for power supplies [3, 4]:

- controlled three-phase bridge rectification circuit with step-down transformer;
- a pulse converter receiving power from the mains via an uncontrolled three-phase bridge rectifier.

---

*Corresponding author: smurodilla@gmail.com

In both cases, the power sources are assumed to receive electricity from the 380/220 V, 50 Hz network.

Determination of control angles and power coefficients for a power source operating in the position of vibroacoustic diagnostics when using a circuit with a step-down transformer and a controlled rectifier [5].

The parameters of traction motors are given in Table 1.

Table 1. Parameters of traction motors of electric rolling stock

№	Indicators		Characteristics of type engines		
			RT-51D	NB-418K6	NB-514
1	Collector voltages	U_{load}, V	825	950	980
2	Rated power	P_{load}, kW	200	790	835
3	Armature current	I_{load}, A	266	880	905
4	Rotation speed	n_{load}, rpm	1140	890	905
5	Resistance of armature windings	R_a, ohm	0.0556	0.011	0.0112
6	Resistance of the windings of the main poles	R_{mp}, ohm	0.132	0.0079	0.0071
7	Resistance of additional pole windings	R_{ap}, ohm	0.0252	0.0119	0.0132
8	Compensation winding resistance	R_{cp}, ohm	-		
9	Wheel diameter	D_w, mm	1050	1250	1250
10	Gear ratio of the gearbox	μ	3.17	4.19	4.19

To solve this problem, the load current I_{nom} of the traction motor is initially determined for the rotation modes of the wheel pairs 120; 150; 180; 240; 280; 300; 657 rpm. By the method of mathematical modeling in the MatLab/Simulink environment. The pictogram of the TED image in the MatLab environment, shown in Fig. 1., is located in the program library database at Simulink/SimPower System/Block Library/Machines [6-8].

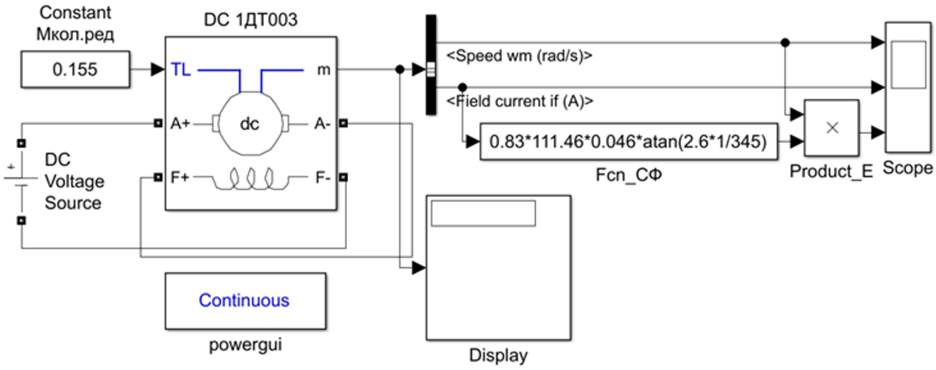


Fig. 1. Model in MatLab/Simulink for determining load current and EMF at given wheelset speed

2 Objects, results, and methods of research

Model ports A+ and A are the terminals of the armature winding of the machine, and ports F+ and F are the terminals of the excitation winding. The TL port (Fig. 1) is designed to supply the moment of resistance to movement. Using MatLab/Simulink, we will write in the Constant block (Fig. 1) and connect it to the TL port.

- nominal resistance torque (for TL port, see Table 2) [9, 10]:

$$M_r = \frac{D_w}{2\mu} = \frac{1.05}{2\cdot 3.4} = 0.155 \ \ \text{Nm} \tag{1}$$

where M_r is the torque of the driving wheel, energy losses in the gearbox on the motor shaft can be neglected. Here D_w is the diameter of the wheel of the wheelset, μ is the gear ratio of the gearbox;

Before using the TED model in the simulated switching scheme, it is necessary to set its parameters. The TED parameters window is shown in Fig. 2.

Using the data from Table 1, the sequential excitation TED input parameters are calculated, which are necessary for modeling in the MatLab environment, and entered in Table 2.

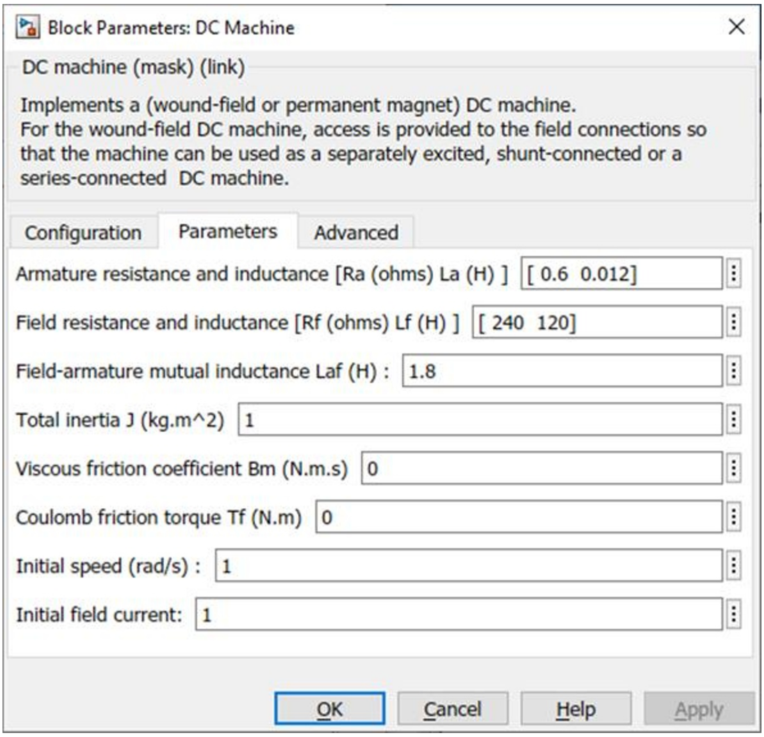
Preliminary calculations of parameters:

The necessary parameters of a DC machine with a permanent connection can be determined based on its passport data using the following ratios:

- nominal moment of resistance:

$$M_{load} = \frac{P_{load}}{\omega_{load}} = \frac{235}{130.83} = 1.796, \text{Nm} \tag{2}$$

where P_{load} is the rated power of the engine; ω_{load} is $(2\pi n_{load})/ 60$, (1/s) the nominal angular velocity of the armature rotation. Here n_{load} is the nominal speed of the armature rotation (rpm).



Block Parameters: DC Machine

DC machine (mask) (link)

Implements a (wound-field or permanent magnet) DC machine.
For the wound-field DC machine, access is provided to the field connections so that the machine can be used as a separately excited, shunt-connected or a series-connected DC machine.

Parameters

Armature resistance and inductance [Ra (ohms) La (H)] [0.6 0.012]
Field resistance and inductance [Rf (ohms) Lf (H)] [240 120]
Field-armature mutual inductance Laf (H) : 1.8
Total inertia J (kg.m^2) 1
Viscous friction coefficient Bm (N.m.s) 0
Coulomb friction torque Tf (N.m) 0
Initial speed (rad/s) : 1
Initial field current: 1

Fig. 2. Window for setting parameters of simulation modes of DC motors

- mutual inductance between the armature circuit and the motor excitation circuit

$$L_{af} = \frac{M_{load}}{I_a} = \frac{235}{345} = 0.0052 \quad \text{Gn}; \qquad (3)$$

where I_a=I_{load}, And is the rated current of the armature winding.

- inductance of the excitation winding:

$$L_f \geq (2-5)\frac{L_a R_f}{R_a} = 2.5\frac{0.0052 \cdot 0.151}{0.0715} = 0.028, \text{Gn}; \qquad (4)$$

where $L_a = c\frac{U_a}{I_a n_{nom} p} = 6\frac{750}{345 \cdot 1250 \cdot 2} = 0.0052$, Gn is the inductance of the anchor circuit. U_a=U_{load} is rated motor voltage; p is number of pole pairs; c=(1÷2.5) for machines with compensation winding (a large value refers to slow-speed motors), c=6 for uncompensated machines; R_a is active resistance of the armature winding; R_e= R_{mp} + R_{ap} =0.13+0.021=0.151 is the active resistance of the excitation winding, R_{mp}, and R_{ap} are the active resistance of the winding of the main and additional pole; for electric locomotive engines, the active resistance of the compensation R_{cp} winding is added.

- the moment of inertia of the electric motor:

$$J \geq (2-10)\frac{L_a P_{load}^2}{R_a^2 \omega_{load}^2 I_{load}^2} = 2.5\frac{0.0052 \cdot 235^2 \cdot 10^3}{0.0052^2 \cdot 130.83^2 \cdot 345^2} = 0.069, \ \text{kg} \cdot \text{m}^2 \qquad (5)$$

- mechanical losses of the electric motor:

$$P_{mech} = (0.005 - 0.02)\% \cdot P_{load} = 1.25 \cdot 235 = 293.75, \ \text{W} \qquad (6)$$

Table 2. The window of parameters of traction motors in the program library database at Simulink/SimPowerSystem/Block Library/Machines

	RT-51D	NB-418K6	NB-514	
M_r	0.166	0.149	0.1492	Nm
Ω_{nom}	119.32	93.153	94.723	1/s
M_{load}	1.676	8.481	8.8151	Nm
L_{af}	0.0063	0.0096	0.0097	Gn
c	6	1.75	1.75	
p	2	2	2	
L_a	0.0082	0.0011	0.001	Gn
R_e	0.1572	0.0198	0.0203	omh
L_e	0.081	0.0048	0.0047	Gn
J	0.944	4.073	3.9594	kg·m^2
P_{mech}	250	987.5	1043.8	W
T_f	1.048	5.3	5.5095	Nm
B_m	0.0088	0.0569	0.0582	Nms
I_{oh}	465.5	1320	1357.5	A

- reactive moment of resistance:

$$T_f \cong \frac{\Pi_{mech}}{2\omega_{load}} = \frac{293.75}{2 \cdot 130.83} = 1.123, \ \text{Nm} \qquad (7)$$

- coefficient of viscous friction:

$$B_m \cong \frac{\Pi_{mech}}{2\omega_{load}^2} = \frac{293.75}{2 \cdot 130.83^2} = 0.0086, \ \text{Nms} \qquad (8)$$

Values of the initial current field of the motor

$$I_f = (1.5 \ldots 2.5) I_a = 1.5 \cdot 345 = 517.5 \text{ A} \qquad (9)$$

The load current I_{nom} is determined using the Scope block (Fig.1.4 in):

$$I_{nom} = 34.79 \text{ A}$$

Next, the EMF of the rotation of the armature is determined.
The rotation frequency of the motor shaft n is determined by the rotation frequency of the driving wheels of the locomotive n_w and the gear ratio of the gearbox µ .

$$n = \mu n_w = 3.4 \cdot 150 = 510 \text{ rpm} \qquad (10)$$

According to the formula, we will find the RPM of electric motors, then using MatLab /Simulink in the DC Voltage Source block (Fig.1), increasing the input voltage U_{inp} to 50 V, we will stop when the RPM of the electric motor (n) reaches the desired values, note the load current Inom, EMF (E_{nom}) and write all values in tables 3; 4.

Table 3. Design characteristics of traction motors of electric rolling stock

	RT-51D	NB-418K6	NB-514	
n_w	120	120	120	rpm
	150	150	150	
	180	180	180	
	240	240	240	
	280	280	280	
	300	300	300	
	657	657	657	
n	380.4	502.8	502.8	rpm
	475.5	628.5	628.5	
	570.6	754.2	754.2	
	760.8	1005.6	1005.6	
	887.6	1173.2	1173.2	
	951	1257	1257	
	2082.69	2752.83	2752.83	
F_{nom}	0.043	0.077	0.0725	Wb
N	940	805	870	
C	149.68	128.18	138.54	
c_{nom}	15.67	13.417	14.5	1/(rpm)s

The EMF of rotation (E_{nom}) is determined as follows:
1. A vector signal consisting of four elements is formed in port m: speed, armature current, excitation current, and electromagnetic torque of the machine. Through the Bus Selector unit, the RPM elements and the excitation current are connected to the Scope unit (Fig. 1);
2. In MatLab/Simulink, the value of E_{nom} is determined using the Product block (see Table.1.4):

$$E_{nom} = CFn_{load} = 16.36 \qquad (11)$$

where *CF* is the magnetic flux of the motor:

$$CF = 0.83 \cdot CF_{nom} \cdot arctg \frac{2.6 \cdot I_{load}}{I_{load}} \qquad (12)$$

where F is the magnetic flux, Wb;

C_l; C_ω is structural constants of the engine:

$C_l = C_\omega = (pN)/(2\pi a)$; $C_e = C_n = pN/(60a)$.

We will write down certain values in the universal computing block F_{cn}, where a calculated expression is entered as a tuning parameter, the argument of which is the input signal specified by its transfer function.

The load resistance R_{nom} is defined as the sum of the resistances of the armature winding Ra, the winding of the main poles of the R_{mp}, the winding of the additional poles R_{ap} (for electric locomotive engines, the resistance of the compensation winding R_c is added).

The resistance of a circuit consisting of four traction motors is $4R_{nom}$ [4, 5, 11].

Determination of load voltage:

- per engine

$$U_{nom} = I_{nom} \cdot R_{nom} + E_{nom} = 34.79 \cdot 0.2225 + 16.36 = 24.1 \text{ V} \quad (13)$$

- for four traction engines

$$U_{nom} = I_{nom} \cdot 4R_{nom} + 4E_{nom} = (34.76 \cdot 4 \cdot 0.2225) + (4 \cdot 16.36) = 96.4 \text{ V} \quad (14)$$

Determination of the P_{load} load power:

- per engine

$$P_{load} = I_{nom} \cdot U_{nom} = 34.79 \cdot 24.1 = 838.47 \text{ W} \quad (15)$$

- for four traction engines

$$4P_{load} = I_{nom} \cdot U_{nom} = 4 \cdot 34.79 \cdot 96.4 = 3353.86 \text{ W} \quad (16)$$

The calculation results are summarized in Table 4.

Table 4. Parameters of electrical energy losses of studied electric motors during simulation in Simulink program

	RT-51D	NB-418K6	NB-514	
n_w	120			rpm
	There is one engine in the load			
n	380.4	502.8	502.8	rpm
U_{inp}	130	360	365	V
E_{nom}	19.86	12.17	12.04	V
I_{nom}	49.87	74.11	74.35	A
R_{nom}	0.2128	0.0308	0.0777	omh
U_{nom}	30.47	14.45	17.82	V
P_{load}	1519.66	1071.08	1324.69	W
	There are four engines in the load			
$4R_{nom}$	0.8512	0.1232	0.3108	omh
U_{nom}	121.89	57.81	71.27	V
P_{load}	6078.62	4284.33	5298.77	W
	PT-51D	HB-418K6	HB-514	
n_w	150			rpm

Continuation of table № 4.

	There is one engine in the load			
n	475.5	628.5	628.5	rpm
U_{inp}	180	480	480	V
E_{nom}	24.83	15.21	15.05	V
I_{nom}	56.15	79.15	78.33	A
R_{nom}	0.2128	0.0308	0.0777	omh
U_{nom}	36.78	17.65	21.14	V
P_{load}	2065.13	1396.83	1655.61	W
	There are four engines in the load			
$4R_{nom}$	0.8512	0.1232	0.3108	omh
U_{nom}	147.12	70.59	84.55	V
P_{load}	8260.5	5587.2998	6622.41	W
	RT-51D	NB-418K6	NB-514	
n_w	180			rpm
	There is one engine in the load			
n	570.6	754.2	754.2	rpm
U_{inp}	220	580	590	V
E_{nom}	29.8	18.25	18.06	V
I_{nom}	57.81	79.78	80.3	A
R_{nom}	0.2128	0.0308	0.0777	omh
U_{nom}	42.1	20.71	24.299	V
P_{load}	2433.92	1652.02	1951.24	W
	There are four engines in the load			
$4R_{nom}$	0.8512	0.1232	0.3108	omh
U_{nom}	168.41	82.83	97.197	V
P_{load}	9735.66	6608.09	7804.94	W
	PT-51D	HB-418K6	HB-514	
n_w	240			rpm
	There is one engine in the load			
n	760.8	1005.6	1005.6	rpm
U_{inp}	320	810	825	V
E_{nom}	39.72	24.32	24.06	V
I_{nom}	63.95	83.71	84.38	A
R_{nom}	0.2128	0.0308	0.0777	omh
U_{nom}	53.33	26.90	30.62	V
P_{load}	3410.36	2251.65	2583.41	W
	There are four engines in the load			
$4R_{nom}$	0.8512	0.1232	0.3108	omh
U_{nom}	213.31	107.59	122.47	V
P_{load}	13641.45	9006.62	10333.62	W
	PT-51D	HB-418K6	HB-514	
n_w	280			rpm
	There is one engine in the load			
n	887.6	1173.2	1173.2	rpm
U_{inp}	400	950	980	V
E_{nom}	46.35	28.38	28.09	V
I_{nom}	68.94	84.16	85.91	A
R_{nom}	0.2128	0.0308	0.0777	omh
U_{nom}	61.02	30.97	34.77	V
P_{load}	4206.75	2606.61	2986.68	W

Continuation of table № 4.

	There are four engines in the load			
$4R_{nom}$	0.8512	0.1232	0.3108	omh
U_{nom}	244.082	123.89	139.06	V
P_{load}	16826.99	10426.46	11946.72	W
	PT-51D	HB-418K6	HB-514	
n_w	300			rpm
	There is one engine in the load			
n	951	1257	1257	rpm
U_{inp}	440	1020	1050	V
E_{nom}	49.65	30.42	30.1	V
I_{nom}	70.95	84.33	85.9	A
R_{nom}	0.2128	0.0308	0.0777	omh
U_{nom}	64.75	33.02	36.77	V
P_{load}	4593.88	2784.35	3158.92	W
	There are four engines in the load			
$4R_{nom}$	0.8512	0.1232	0.3108	omh
U_{nom}	258.99	132.07	147.10	V
P_{load}	18375.53	11137.42	12635.69	W
	PT-51D	HB-418K6	HB-514	
n_w	657			rpm
	There is one engine in the load			
n	2082.69	2752.83	2752.8	rpm
U_{inp}	1150	2400	2410	V
E_{nom}	108.7	66.62	65.91	V
I_{nom}	86.3	90.73	90.17	A
R_{nom}	0.2128	0.0308	0.0777	omh
U_{nom}	127.07	69.42	72.92	V
P_{load}	10965.68	6297.98	6574.86	W
	There are four engines in the load			
$4R_{nom}$	0.8512	0.1232	0.3108	omh
U_{nom}	508.26	277.66	291.67	V
P_{load}	43862.71	25191.91	26299.42	W
	RT-51D	NB-418K6	NB-514	

Determination of the angle of regulation α for the bridge rectification circuit

$$\alpha = \arccos\left(U_{nom}/(K_{\text{sch}}\cdot E_2)\right) = \arccos(34.79/(2{,}34\cdot 110)) = 1.477\ \text{rad} \qquad (17)$$

in degrees

$$\alpha\cdot(180/\pi) = 1.477\cdot 57.2956 = 84.67^0 \qquad (18)$$

where K_{sch} - is the coefficient of the scheme, $K_{\text{sch}} = 2.34$;

E_2 - the effective value of the phase EMF of the secondary winding of the transformer (E_2 = 110; 73.33; 55; 44 V). The following transformation coefficient k= 2; 3; 4; 5 is used for calculations.

The results of the calculations are summarized in Table 5.

The analysis of the results shows:

- that in all cases, we have significant values of the control angles, and for electric locomotive engines, these values approach the value of π/2, which means the probability of switching the circuit to the inverter mode;
- increasing the transformation coefficient of the step-down transformer allows you to

reduce the adjustment angle.

Table 5. Indicators of angle of regulation α for model of bridge rectification scheme

	n_w	120 rpm		
	transformation coefficient	RT-51D	NB-418K6	NB-514
There is one engine in the load				
α	$k = 2$	83.24	86.83	86.07
	$k = 3$	79.81	85.21	84.08
	$k = 4$	76.34	83.59	82.08
	$k = 5$	72.82	81.97	80.08
There are four engines in the load				
α	$k = 2$	61.767	77.060	73.964
	$k = 3$	44.762	70.348	65.494
	$k = 4$	18.733	63.341	56.404
	$k = 5$	-	55.870	46.220
	n_w	150 rpm		
	transformation coefficient	RT-51D	NB-418K6	NB-514
There is one engine in the load				
α	$k = 2$	81.83	86.11	85.33
	$k = 3$	77.66	84.14	82.97
	$k = 4$	73.43	82.16	80.59
	$k = 5$	69.11	80.17	78.19
There are four engines in the load				
α	$k = 2$	55.17	74.12	70.86
	$k = 3$	30.9995	65.75	60.51
	$k = 4$	-	56.77	48.96
	$k = 5$	-	46.74	34.82
	n_w	180 rpm		
	transformation coefficient	RT-51D	NB-418K6	NB-514
There is one engine in the load				
α	$k = 2$	80.63	85.42	84.63
	$k = 3$	75.84	83.11	81.9
	$k = 4$	70.94	80.78	79.16
	$k = 5$	65.897	78.44	76.39
		There are four engines in the load		
α	$k = 2$	49.16	71.27	67.85
	$k = 3$	11.07	61.17	55.53
	$k = 4$	-	49.97	40.98
	$k = 5$	-	36.46	19.27
	n_w	240 rpm		
	transformation coefficient	RT-51D	NB-418K6	NB-514
There is one engine in the load				
α	$k = 2$	78.082	84.044	83.211
	$k = 3$	71.931	81.023	79.763
	$k = 4$	65.554	77.976	76.277
	$k = 5$	58.835	74.894	72.738

Continuation of table № 5.

There are four engines in the load				
α	$k = 2$	34.049	65.325	61.621
	$k = 3$	-	51.197	44.488
	$k = 4$	-	33.297	17.916
	$k = 5$	-	-	-
	n_w	280 rpm		
	transformation coefficient	RT-51D	NB-418K6	NB-514
There is one engine in the load				
α	$k = 2$	76.33	83.13	82.28
	$k = 3$	69.21	79.64	78.35
	$k = 4$	61.73	76.11	74.37
	$k = 5$	53.68	72.53	70.3
There are four engines in the load				
α	$k = 2$	18.52	61.26	57.33
	$k = 3$	-	43.81	35.89
	$k = 4$	-	15.72	-
	$k = 5$	-	-	-
	n_w	300 rpm		
	transformation coefficient	RT-51D	NB-418K6	NB-514
There is one engine in the load				
α	$k = 2$	75.469	82.672	81.828
	$k = 3$	67.867	78.947	77.665
	$k = 4$	59.825	75.173	73.434
	$k = 5$	51.059	71.332	69.108
	n_w	657 rpm		
	transformation coefficient	RT-51D	NB-418K6	NB-514
There is one engine in the load				
α	$k = 2$	60.45	74.39	73.58
	$k = 3$	42.25	66.17	64.89
	$k = 4$	9.15	57.39	55.52
	$k = 5$	-	47.63	44.93

3 Results and their discussion

Separately, let's consider the case of using a three-phase bridge-controlled transformer-free rectifier. The calculation results are summarized in Table 6.

Table 6. Power factor of bridge rectifier when adjusting switching angle γ

		RT-51D	NB-418K6	NB-514
There is one engine in the load				
n_w=120				
α		86.65	88.44	88.06
K_{pf}	γ =0	0.057	0.027	0.033
	γ =2	0.04	0.01	0.02
	γ =4	0.02	-0.01	0.00
	γ =6	0.01	-0.02	-0.02

Continuation of table № 6.

n_w=150				
α		85.95	88.08	87.69
K_{pf}	γ =0	0.068	0.033	0.039
	γ =2	0.05	0.02	0.02
	γ =4	0.03	0.00	0.01
	γ =6	0.02	-0.02	-0.01
n_w=180				
α		85.35	87.74	87.34
K_{pf}	γ =0	0.078	0.038	0.045
	γ =2	0.06	0.02	0.03
	γ =4	0.04	0.00	0.01
	γ =6	0.03	-0.01	-0.01
n_w=240				
α		84.10	87.05	86.63
K_{pf}	γ =0	0.099	0.050	0.057
	γ =2	0.08	0.03	0.04
	γ =4	0.07	0.02	0.02
	γ =6	0.05	0.00	0.01
n_w=280				
α		83.23	86.59	86.17
K_{pf}	γ =0	0.113	0.057	0.064
	γ =2	0.10	0.04	0.05
	γ =4	0.08	0.02	0.03
	γ =6	0.06	0.01	0.01
n_w=300				
α		82.82	86.37	85.95
$\text{K}_{\text{м}}$	γ =0	0.120	0.061	0.068
	γ =2	0.10	0.04	0.05
	γ =4	0.09	0.03	0.03
	γ =6	0.07	0.01	0.02
n_w=657				
α		75.75	82.29	81.90
K_{pf}	γ =0	0.236	0.129	0.135
	γ =2	0.22	0.11	0.12
	γ =4	0.20	0.09	0.10
	γ =6	0.19	0.08	0.08
There are four engines in the load				
n_w=120				
α		76.34	83.59	82.08
K_{pf}	γ =0	0.226	0.107	0.132
	γ =2	0.21	0.09	0.11
	γ =4	0.19	0.07	0.10
	γ =6	0.18	0.06	0.08
n_w=150				
α		73.43	82.16	80.59
K_{pf}	γ =0	0.273	0.131	0.157
	γ =2	0.26	0.11	0.14
	γ =4	0.24	0.10	0.12
	γ =6	0.22	0.08	0.11

Continuation of table № 6.

n_w=180				
α		70.94	80.78	79.16
K_{pf}	γ =0	0.312	0.154	0.180
	γ =2	0.30	0.14	0.16
	γ =4	0.28	0.12	0.15
	γ =6	0.26	0.10	0.13
n_w=240				
α		65.55	77.98	76.28
K_{pf}	γ =0	0.396	0.2	0.227
	γ =2	0.38	0.18	0.21
	γ =4	0.36	0.17	0.19
	γ =6	0.35	0.15	0.18
n_w=280				
α		61.73	76.11	74.37
K_{pf}	γ =0	0.453	0.230	0.258
	γ =2	0.44	0.21	0.24
	γ =4	0.42	0.20	0.23
	γ =6	0.41	0.18	0.21
n_w=300				
α		59.83	75.17	73.43
K_{pf}	γ =0	0.480	0.245	0.273
	γ =2	0.47	0.23	0.26
	γ =4	0.45	0.21	0.24
	γ =6	0.44	0.20	0.22
n_w=657				
α		39.15	57.39	55.52
K_{pf}	γ =0	0.38	0.515	0.541
	γ =2	0.37	0.50	0.53
	γ =4	0.35	0.49	0.51
	γ =6	0.34	0.47	0.50
		RT-51D	NB-418K6	NB-514

The results obtained show the inexpediency of using a transformer-free three-phase bridge-controlled rectifier.

A radical way to increase the power factor of the power supply is using pulse voltage regulation.

The mathematical model of such a source is shown in Fig. 3.

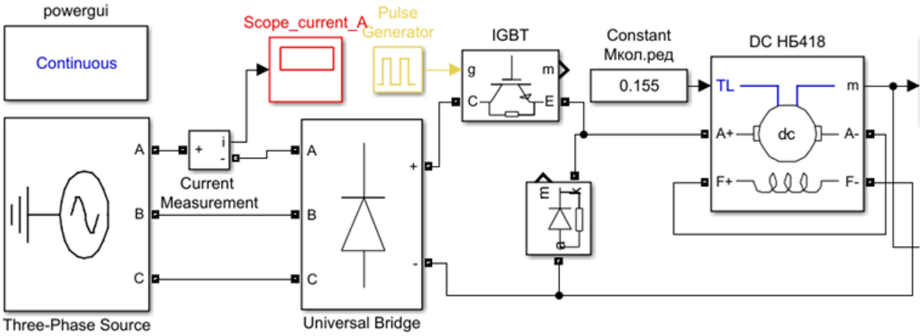


Fig. 3. Transformer-free three-phase rectifier with pulse converter

Table 1.7 shows the results of calculations of the filling factor λ of a pulse voltage converter at different speeds of the TED and operating modes of the installation: for one motor and four motors.

Below is an example of calculating the fill factor [4, 12, 13]:

$$\lambda \cdot U_d = I_{nom} \cdot R_{nom} + E = U_{nom} \qquad (19)$$

where λ is the fill factor of the power supply:

$$\lambda = \frac{I_{nom} \cdot R_{nom} + E}{U_d} = \frac{U_{nom}}{U_d} = \frac{24.09}{514,8} = 0.040 \qquad (20)$$

where U_d is the output voltage of the uncontrolled rectifier:

$$U_d = K_{sch} \cdot U_{ph} = 2.34 \cdot 220 = 514.8V \qquad (21)$$

where U_{ph} is the input voltage of the uncontrolled rectifier from the mains, it is 220V.

In addition to the values of the fill factor λ, the requirements for the harmonic composition of the current at the input of the rectifier are regulated by GOST 30804.3.12-2013; it is also advisable to determine the distortion factor of the input current $K_{df}$and the power factor χ depending on the PWM frequency, where 2400 Hz of the second stage of the power supply at the load of the electric motor NB-418K6:

$$K_{df} = \frac{I_1}{\sqrt{I_1^2 + I_2^2 + \ldots + I_n^2}} = 0.94 \qquad (23)$$

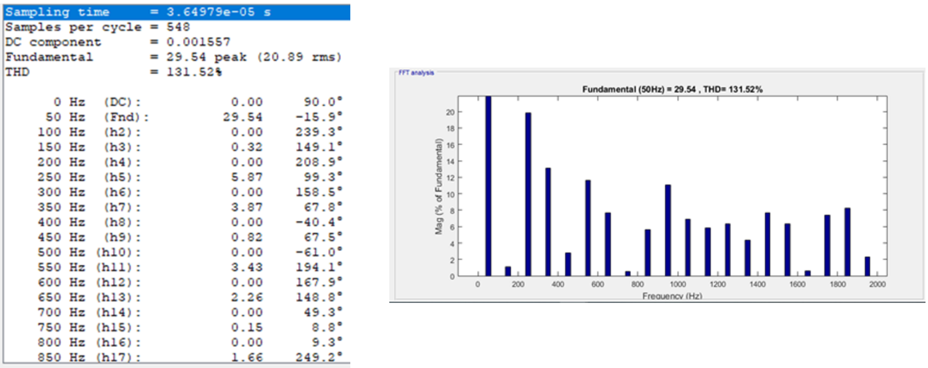
Table 7. Results of calculations of filling factor λ of pulse converter

At the revolutions of the pc wheelset	RT-51D	NB-418K6	NB-514
	There is one engine in the load		
	Fill factor λ		
120	0.059	0.028	0.035
150	0.071	0.034	0.041
180	0.082	0.040	0.047
240	0.104	0.052	0.059
280	0.119	0.060	0.068
300	0.126	0.064	0.071
657	0.247	0.135	0.142
	There are four engines in the load		
120	0.237	0.112	0.138
150	0.286	0.137	0.164
180	0.327	0.161	0.189
240	0.414	0.209	0.238
280	0.474	0.241	0.270
300	0.503	0.257	0.286
657	0.987	0.539	0.567

$$\chi = K_{df} \cos\varphi = 0.905 \qquad (24)$$

anywhere $\varphi = -15.9$ –of the phase shift between the vectors of the first harmonic of the current and the phase voltage. Then $\cos\varphi = 0.96$

The analysis was carried out using the Powergui FFT Analysis Tool (Fig. 4).



```
Sampling time      = 3.64979e-05 s
Samples per cycle = 548
DC component      = 0.001557
Fundamental       = 29.54 peak (20.89 rms)
THD               = 131.52%

     0 Hz   (DC):          0.00     90.0°
    50 Hz   (Fnd):        29.54    -15.9°
   100 Hz   (h2):          0.00    239.3°
   150 Hz   (h3):          0.32    149.1°
   200 Hz   (h4):          0.00    208.9°
   250 Hz   (h5):          5.87     99.3°
   300 Hz   (h6):          0.00    158.5°
   350 Hz   (h7):          3.87     67.8°
   400 Hz   (h8):          0.00    -40.4°
   450 Hz   (h9):          0.82     67.5°
   500 Hz  (h10):          0.00    -61.0°
   550 Hz  (h11):          3.43    194.1°
   600 Hz  (h12):          0.00    167.9°
   650 Hz  (h13):          2.26    148.8°
   700 Hz  (h14):          0.00     49.3°
   750 Hz  (h15):          0.15      8.8°
   800 Hz  (h16):          0.00      9.3°
   850 Hz  (h17):          1.66    249.2°
```

Fig. 4. Powergui FFT Analysis Tool Block

4 Conclusions

1. At the required loads, a controlled three-phase bridge rectification circuit with a step-down transformer has low power coefficients;
2. A pulse converter receiving power from the AC network through an uncontrolled rectifier at the same loads has a power factor equal to 0.9. It provides the required parameters for regulating currents and voltages.

References

1. Non-destructive testing: reference. V7t.T.7. In 2 books. Book 2. Vibroacoustic diagnostics / F.Ya. Balitsky. A.V. Barkov. N.A. Barkova and others: under the general ed. V.V. Klyuev. - M: Mechanical engineering. 2005. - 829 p.
2. Zelenchenko A.P. Diagnostic devices for traction motors of electric rolling stock. Textbook. M.: 2002, 37c.
3. Shadmonkhodjaev M. Sh. The position of vibroacoustic diagnostics of rolling bearings of electric rolling stock / M. Sh. Shadmonkhodjaev, A. P. Zelenchenko // Traction rolling stock. – 2019. – No. 210 – pp. 80-81.
4. Shadmonkhodzhaev M. Sh. Power supply for the position of non-disassembly diagnostics of bearings / A. P. Zelenchenko, A. A. Bogdan, M. Sh. Shadmonkhodzhaev / News of the St. Petersburg University of Railway Communications-St. Petersburg: PGUPS, 2021.-Vol. 18.-Issue 4.-S. 554-560.
5. Brovanov S.V., Dybko M.A. Method of calculating the currents of power switches of multilevel semiconductor converters. Reports of the Academy of Sciences of the Higher School of the Russian Federation. 2011. No. 1 (16). pp. 84-94.
6. Chernykh I.V. Modeling of electrical devices in MATLAB, SimPowerSystems and Simulink. - M.: DMK Press; St. Petersburg.: Peter, 2008. - 288 p.:
7. Shestakov A.A., Golechkov Yu.A. Mathematical modeling. // In 2 parts. Part 1. - M. MPS, VZIIT.1993,- 68s.//
8. Herman Galkin S. MATLAB SCHOOL Virtual laboratories of power electronics devices in the MATLAB-Simulink environment Lesson 14. Analysis, calculation and study of the power factor corrector / S. Herman Galkin // Power Electronics. - 2011. – Vol. 4. – No. 32. – pp. 90-96.

9. Rosenfeld V. E., Isaev I. P., Sidorov N. N. Theory of electric traction: Textbook for universities zh.-D. transp., – 2nd ed., reprint. and additional, – M.: Transport, 1983 – 328 p.
10. Alekseev A. E. Traction electric machines and converters. L., "Energy", 1977. 444 p. with il.
11. Slyshalov V. K., Shuin V. A., Kuvanov A.V., Vorobyova E. A., Filatova G. A. Methodology for determining inductances of three-phase power cables when calculating transients in 6-10 kV electrical networks // Bulletin of IGEU. 2015. No.6.
12. DC electric trains with pulse converters. Ed. Prof. Rosenfeld V.E. M., "Transport", 1976, 280s.
13. Gilardi, M. New horizons of technology of current sensors on the Hall effect / M. Gilardi // Power electronics. - 2015. – Vol. 3. – No. 54. – pp. 18-22.