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Study of the possibilities for optimization of reactive power according to the criterion "electric power quality" in the power supply system of a port complex

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GOAL OF THE STUDY

Based on the energy characteristic of the port and synthesized theoretical statement, in the conditions of asymmetric and non-sinusoidal load, to present an opportunity to minimize the reactive powers in the power supply system of the port complex.

METHODOLOGY OF THE INVESTIGATION

The total losses of active power ΔP in a system with asymmetric and non-sinusoidal currents are equal to:

$$\Delta P \approx \frac{1}{K_p^2} = \frac{1}{P^2}\left(P^2 + Q^2 + N^2 + (3n+1)\right)S_0^2 + D^2 \qquad (1)$$

Partial component of reactive power losses Q are equal to:

$$\Delta P_Q = \frac{Q^2}{P^2}.100 \quad [\%] \qquad (2)$$

Partial component of the pulsating power losses N are equal to:

$$\Delta P_N = \frac{N^2}{P^2}.100 \quad [\%] \qquad (3)$$

Partial part of the hidden power losses S_0 are equal to:

$$\Delta P_{S_0} = \frac{S_0^2}{P^2}.100 \quad [\%] \qquad (4)$$

Partial part of the losses from deformation power D are equal to:

$$\Delta P_D = \frac{D^2}{P^2}.100 \quad [\%] \qquad (5)$$

The individual partial parts of the powers can also be represented by the coefficients: ε_I, α_I, K_I and tgφ.

$$\left\{\begin{array}{l} \Delta P_Q = tg^2\varphi.100[\%] \;\; ; \;\; \Delta P_N = \dfrac{\varepsilon_i^2}{cos^2\varphi}.100[\%]; \\ . \\ \Delta P_{S_0} = \dfrac{(3n+1).\alpha_i^2}{cos^2\varphi}.100[\%] \\ \Delta P_D = \dfrac{1}{cos^2\varphi}.(1-\varepsilon_I^2)\dfrac{K_I^2}{1-K_I^2}.100[\%] \end{array}\right\} \qquad (6)$$

MAIN RESULTS FROM THE STUDY

Conventional active power losses in percentages are presented in table 1 and they are in the range (8.21 ÷ 8.95) % of the consumed power. The partial power losses from reactive flows and from asymmetric and non - sinusoidal modes (ΔP_Q, ΔP_N, ΔP_{S0}, ΔP_D) are presented in this table as %, which exceed the conventional losses. Their real value as a percentage of the consumed active power is presented in table 1.

In addition to the total active losses, the average values of P_{AV}, Q_{AV}, $tg\varphi_{AV}$ and K_R for each transformer station during the studied period are also given in table 2.

The analysis of the total losses of active power in the PSS of the port complex (table 1 and table 2) shows that their average value is $\Delta P\Sigma_{AV}$ = 18.86% of the consumed electrical energy. The average value of conventional losses ΔP_K that cannot be affected is $\Delta P_{K.AV}$ = 8.75%.

The difference between $\Delta P\Sigma_{AV}$ and $\Delta P_{K.AV}$ is the losses from inactive substances of power ΔP_N and their average value is $\Delta P_N = \Delta P\Sigma_{AV} - \Delta P_{K.AV}$ = 10.11%. Electrical energy savings can be achieved by impacting these losses.

Table 1. The partial power losses from reactive flows and from asymmetric and non-sinusoidal modes for different TS

TS	Input	ΔP_K [%]	ΔP_Q [%]	ΔP_N [%]	ΔP_{S_0} [%]	ΔP_D [%]	ΔP_Σ [%]
TS New mechanical workshop	1	8,21	5,68	1,51	6,42	3,62	25,44
TS Transformer Station	1	8,63	1,01	0,41	1,57	0,15	11,77
	2	8,82	6,08	1,55	6,90	3,39	26,74
	3	8,94	4,13	1,11	1,17	2,15	17,5
TS 11	1	8,86	6,95	0,17	0,63	7,66	24,24
TS 10	1	8,73	3,85	1,21	1,25	1,15	15,92
	2	8,83	2,57	0,11	0,47	1,85	13,83
TS 9	1	8,75	4,66	0,21	0,83	4,43	18,90
	2	8,66	0,94	0,11	0,39	0,18	10,28
	3	8,79	5,48	0,33	1,91	5,09	21,6
TS „Komi“	1	8,95	4,73	0,45	1,12	5,7	20,95
TS Terminal 4	1	8,69	3,71	1,18	4,55	1,1	19,23

Table 2. Average reduced energy indicators for different TS

TS	Input	P_{AV} [kW]	Q_{AV} [kVAr]	$tg\varphi_{AV}$	K_R
TS New mechanical workshop	1	81,6	98	1,2	0,66
ТП „Transformer Station“	1	33,4	8,2	0,41	0,92
	2	98	152	1,55	0,53
	3	157	98	0,62	0,79
TS 11	1	2,8	7,3	2,6	0,35
ТП 10	1	195	133	0,68	0,81
	2	13,2	8,2	0,62	0,83
TS 9	1	5,2	6,7	1,28	0,63
	2	280	90	0.35	0,93
	3	88	142	1,36	0,54
TS „Komi“	1	56	68	1,2	0,62
TS Terminal 4	1	15,1	11,4	0,76	0,72

The consumed electrical energy for one year (table 3) in the complex amounts to 10 182 327kWh (outputs New Port and Komi). The study covers about 75% of this consumption, i.e. the actual value of this electrical energy is W_D = 7,636,745 kWh. Electrical energy savings can be achieved by impacting of these 10.11% losses from inactive power substances. The absolute value of this economy is $W_I = W_D$. 10.11% = 847,679 kWh.

This is the maximum possible savings in the scope of the conducted research. In monetary equivalent, at an average price of CE = 0.2 BGN/kWh, BGN 169,535 is obtained. The real maximum savings due to the inability to achieve full compensation is about 20% lower, i.e. around 670,000 kWh/y or BGN 130,000 can be achieved at current electricity prices.

Table 3. Data on the electricity consumed by PORT BURGAS

During 2020		
	W [kWh]	
Month	Terminal East Output New Port	Terminal West Output Komi
January	791118,4	428015,2
February	711547,2	336544
March	657268	385972
April	496870	261513
May	430006	256687
June	396993	253562
July	504359	256374
August	447730	255595
September	463534	280238
October	429295,2	243408,8
November	530456,8	326563,2
December	649684,8	388993,6
Total for 2020	6508862,4	3673465,8
Total: 10182328,2		

In accordance with the existing negative phenomena - high levels of voltage fluctuations, current asymmetry and high level of pollution of the power system with high harmonics, it is necessary to introduce a system for compensation of reactive load, working on the criterion "direction and magnitude of inactive power".

The required capacitor power of the compensating system is determined using the formula:

$$Q_k = k.\mathrm{P_{AV}}(tg\varphi_{\mathrm{n}} - tg\varphi_{\mathrm{d}}) \tag{8}$$

The total compensating power is $Q_{K\Sigma}$ = 5120 [kVAr]. It's reduced value is $Q_{KR\Sigma}$ = 3430 [kVAr].

Table 3. Technical and economic analysis of the research process

TS (input)	$S_{нтр}$ [kVA]	$Q_{Kн}$ [kVAr]	P_{AV} [kW]	Q_c/Q_{kr} [kVAr]	K/K_r [bgn]	E/E_r [bgn]	T/T_r [г]
NMW	630	-	260	240	18 800	6 100	3,08
Tr. st. (1)	1250	10x25 (250)	510	600/350	44 000/26 000	15 640/13 800	2,81/1,88
Tr. st. (2)	1250	10x25 (250)	510	600/350	44 000/26 000	15 640/13 800	2,81/1,81
Tr. st. (3)	1250	10x25 (250)	510	540/290	39 300/21 550	14 500/11 600	2,71/1,85
PS11 (1)	1000	-	420	400	29 500	10 800	273
PS 10 (1)	1000	8x30 (240)	420	400/160	29 500/12 100	10 800/6 700	2,73/1,81
PS 10 (2)	1000	8x30 (240)	420	420/180	30 900/13 100	11 300/7 200	2,73/1,81
PS 9 (1)	1000	8x30 (240)	420	420/160	29 500/12 100	10 800/6 700	2,73/1,81
PS 9 (2)	1000	8x30 (240)	420	420/180	30 900/13 100	11 300/7 200	2,73/1,81
PS 9 (3)	1000	-	420	440	32 100	11 800	2,72
PS Komi	1000	-	420	400	29 500	10 800	2,73
PS Term 4	630	-	260	260	19 900	6 400	3,1
Total	$S_{n\Sigma}$ = 12 010	$Q_{cn\Sigma}$ = 730	P_{AV}= 416	5120/3430	376 100/251 950	135 880/112 900	2,76/2,23

CONCLUSIONS

The results of the study show that the absolute loss of active power due to losses of inactive energy substances (asymmetric and non-sinusoidal modes) is 10.11% and minimizing this value can lead to real savings of EE within a maximum of 6%.

The proposed high - tech regulator, allows to compensate the power losses from inactive substances of power. The technical and economic efficiency will provide savings of electricity within (3 - 9) % of the consumed in the site.

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