EFFICIENCY OF THE THYRISTOR COMPENSATOR OF REACTIVE POWER IN THE NETWORK OF THE ELECTROTHERMAL PLANT

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Abstract

The article considers the efficiency of the thyristor static compensator of reactive power (TSC) in the network of the furnace-bucket technological installation. According to the results of the study, it was determined that during the operation of the TSC, the fluctuations of the supply voltage do not exceed 1% of the nominal voltage, and the power factor is within 0.98-1. The use of 3rd and 5th harmonic filters provides a non-sinusoidal voltage coefficient at the level of 2%-3%.

Keywords: reactive power compensator, power factor, harmonic filters, non-sinusoidal factor.

Introduction. The presence of sharply changing loads requires a careful approach to the selection of parameters of the power supply system and its elements. The main issues that arise during the operation of power supply systems with sharply changing loads are the determination of calculated active and reactive loads, the determination of the ranges of active and reactive power fluctuations and the associated voltage and frequency fluctuations, as well as the selection of the type and parameters of devices that improve quality electricity.

These are the questions that arose during the development of the power supply system of the "furnace-bucket" technological installation operating in the converter shop of the metallurgical plant. The general purpose of the thyristor static compensator installed at the power substation is to improve the power factor of the power supply system, limit harmonic distortions and reduce voltage fluctuations under the influence of a specific load. The set tasks are solved by the method of regulating the reactive power and filtering the harmonics of the consumed current.

Setting the problem. Determination of the efficiency of the static thyristor compensator with controlled reactors in the case of powering the furnace-bucket unit.

Article results. Indicators of phase-to-phase voltage deviation on 35 kV buses, the level of power factor increase and the voltage non-sinusoidal factor were calculated.

The workshop of the КУ-35 substation is powered by a deep-entry substation, which receives a voltage of 150 kV from the power system. The ТДНМ-63000/150/35 kV step-down transformer has a secondary voltage of 35 kV, which is transmitted via a cable to the closed switchgear of the КУ-35 substation.

According to the principle of operation, the "furnace-bucket" unit works like an ordinary arc furnace, but the specific power of the transformers is much smaller and is approximately 100-160 kVA/t. The reason is the absence of such an energy-consuming stage as melting the charge, the supplied energy is spent only on melting various additives and maintaining the proper temperature of the metal. The power of the furnace transformer is the main energy-technological parameter of the arc heating installation and determines the efficiency of its operation: the speed of heating the metal, as well as the quality of the technological process. The required nominal power of the transformer is selected taking into account the frequency and nature of the processing.

Closed switchgear 35 kV.

1. The complete switchgear 35 kV (РП-35 kV) is made of two sections, it consists of 14 cabinets of the КУ-35 kV series with gas-electric switches with E8N drives and microprocessor-based protection, automation and control devices of the КШ527, КБР541, КЕР543 type.

2.Two power step-down transformers of own needs ТМ-250/6/0.4 kV with U/Un-0 connection scheme, capacity of 250 kVA each.

3. Two three-phase damper reactors with a nominal voltage of 35 kV and an inductance of 0.4 mH.

4. Two single-phase double thyristor controlled reactors with a nominal capacity of 32 MVAr in each phase.

5.Two three-phase filters of the 3rd harmonic with a capacity of 20 MVAr with a three-phase capacitor block and three single-phase reactors in each phase.

6. Two three-phase filters of the 5th harmonic with a capacity of 9 MVAr with a three-phase capacitor block and three single-phase reactors in each phase.

7. The thyristor valves cooling system consists of a heat exchanger pumping station a control cabinet and pipelines.

The thyristor blocks control the power of the thyristor-reactor group, the change in power is carried out by changing the opening angle of the thyristors. The thyristor unit consists of serially connected thyristor pairs in which the thyristors are connected oppositely in parallel. Each pair has its own control electronics and optical fibers.

The principle of operation of the complex. Voltage fluctuations that occur in the case of sharply changing loads are practically proportional to reactive power fluctuations. Therefore to reduce voltage fluctuations, it is necessary to use compensating devices, the parameters of which must meet the following requirements: speed, compensation of the range of reactive power fluctuations and the rate of rise and fall of reactive power and in case of possible asymmetric load modes, perform phase-by-phase regulation of reactive power.

The presence of non-linear elements in arc furnace circuits is one of the reasons for the appearance of higher harmonics of currents and voltages in power networks. The non-linearity of the current-current characteristic of the arc causes distortion of the shape of the current curve and the generation of higher harmonics. Non-sinusoidal currents enter the power supply system through the furnace transformer, as a result of which the shape of the supply voltage curve is distorted. According to the conducted studies, it was determined that the average level of harmonics for the refining period (it corresponds to the "furnace-bucket" mode of operation) is: $\nu = 2$, U_ν=1,5%; $\nu = 3$, U_ν=2,2%; $\nu = 4$, U_ν=0,5%; $\nu = 5$, U_ν=1,7%; $\nu = 6$, U_ν=0,5%; $\nu = 7$, U_ν=0,8%.

Parameter	UA	UB	UC
Average value, kV	35,21	35,22	35,10
Mean square deviation, kV	0,20	0,22	0,25
Voltage fluctuation limits:			
upper limit, V	35410	35440	35350
lower limit, V	35010	35000	34850
Relative deviation U_A /uaver, %	0,57	0,62	0,71

	Input №1	УПК-1
current, A	I=543A	I=599A
active power, kVt	P=25359 кVt	P=24595 кVt
reactive power, kVar	Q=17386 кVAr	Q=15131 кVAr
power factor, *co*sφ	tgφ=0,68; cosφ=0,82	tgφ=0,61; cosφ=0,85

As you can see, in this mode, significant reactive power is consumed from the network.
Below are the indicators of the measuring devices (controlled reactors are turned on):

	Input №1	УПК-1	ТКР-1	Ф-3	Ф-5
current, A	478	451	293	327	151
active power, kVt	28640	28040	165	129	37
reactive power, kVar	1145	14520	15255	19634	9132
power factor, *co*sφ	0,99	0,88	0,02	-	-

Thus the compensating device must provide regulation of reactive power according to the arc furnace operating schedule as well as include filters of the 3rd and 5th higher harmonics.

The mode of operation of the compensator depends on the value of the system voltage. If the system voltage is less than or equal to the lower limit of the adjustment range of the compensator, then the maximum power of the capacitor bank of the compensator should enter the network, and the power of the reactor should be zero. As the network voltage increases, part of the capacity of the capacitors is consumed by the reactors. Static compensators of this type use thyristor-controlled reactors, magnetized reactors and core saturation reactors.

A static compensating device with reactors controlled by thyristor valves is installed at the KU-35 substation. Disadvantages of the scheme with controlled valves include the presence of higher harmonics in the current consumed by the reactor from the network. As a battery of capacitors, filter capacitors are used, which are configured with the help of series-on reactors to resonate the voltage of the corresponding harmonics.

Experimental studies of the efficiency of the thyristor static compensator device. In the course of research, it is necessary to determine the following points: the quality of voltage stabilization on the 35 kV buses, the level of power factor increase and suppression of higher harmonics.

1. *Voltage stabilization*. Due to the fact that the thyristor static compensator device allows the possibil-

ity of phase-to-phase voltage regulation, we will determine the quality of stabilization of each phase-to-phase voltage (table 1).

According to the standard, the permissible voltage fluctuation for arc furnaces should not exceed 1% of the nominal voltage, that is, the TSC complex meets the standard according to this parameter.

2. *Power factor.* The level of reactive power in the case of TSC operation can be determined by the indicators of active and reactive power meters, which are installed on all connections of each bus section: inputs, load feeders, controlled reactors and 3rd and 5th harmonic filters.

Indications of devices in case of disconnection of the thyristor-reactor group and disconnection of harmonic filters (according to the principle of operation of the control scheme, when the TSC is disconnected, the automation simultaneously turns off the filters as well):

Data analysis shows that switching on the compensator makes it possible to raise the power factor almost to unity (reactive power consumption from the network is only 1145 kVA).

3. *Suppression of higher harmonics.* Conventional arc furnaces operate in three modes: melting, oxidation and refining. Each of the modes is characterized by its composition of higher harmonics. Thus in the melting mode, the second and third harmonics prevail. During the period of oxidation and refining, the furnace arc burns steadily and calmly, the level of higher harmonics in the voltage and current decreases significantly, especially in the refining mode. The "furnace-bucket" technological installation works with liquid metal, that is, in a mode close to refining.

Earlier it was pointed out that the "furnace-bucket" installation cannot work without a thyristor reactor group and without filters, this situation occurs in case of tripping of protection against current imbalance (in the circuit of reactors or capacitor banks).

In this mode, there is no compensation of reactive power and suppression of higher harmonics, that is, we have the following composition and level of harmonics:

ν	2	3	4	5	6	7
U_ν,%	1,5	2,2	0,5	1,7	0,5	0,8
U_ν, V	303,4	445,1	101,1	343,9	101,1	161,8

Let's determine the average value of the non-sinusoidal voltage coefficient according to the expression

$$K_{HC} = 100 \cdot \sqrt{\frac{\sum_{\nu=2}^{\nu=7} U_\nu^2}{U_{\Phi_{nom}}}} = 100\sqrt{\frac{455012}{20231}} = 3,35\%.$$

In the case of operation of the reactor with filters, the level of higher harmonics is significantly reduced:

ν	2	3	4	5	6	7
U_ν,%	0,5	0,7	0,3	0,9	0,3	0,5
U_ν, V	101,1	141,6	54,6	182,1	54,6	101,1

In the case of operation of the reactor with filters, the level of higher harmonics is significantly reduced:

The coefficient of non-sinusoidal voltage is:

Thus the coefficient of non-sinusoidal voltage in both cases does not exceed the standard of 5%, the results indicate the effective operation of the smoothing filters.

$$K_{HC} = \cdot 100\sqrt{\frac{79801}{20231}} = 1,39\%.$$

4. *General conclusions from the analysis of the work of the TSC.* The main task of the compensating device is to limit the impact of a sharply changing load on the voltage regime of the power supply network and to increase the power factor of the furnace-bucket technological installation.

The analysis of the obtained indicators shows that the task has been accomplished: the phase-to-phase voltage fluctuation on the 35 kV buses of the substation does not exceed 1%, and the power factor is at the level of 0.95...1.0. Regarding the higher harmonics, the following can be said: the average value of the non-sinusoidal voltage coefficient does not exceed the normative value, but the maximum values are always 2-3 times higher than the average indicators. Therefore, the operation of the TSC device is unacceptable without power filters. In this case, the source of adjustable reactive power and devices for limiting higher harmonics is lost. The operation of the imbalance relay is most often caused by the failure of high-voltage capacitors.

The static compensator of this type is characterized by high speed, the possibility and a significant range of phase-to-phase voltage regulation. In our opinion, the following was not taken into account during the design. First of all, the "furnace-bucket" technological installation works only in refining mode, there are no significant power surges, so high speed is not required. There is also no need for phase-by-phase adjustment of the compensating device. Secondly, if we take into account the significant power factor in the range of 0.80-0.85, then a wide range of reactive power regulation will be superfluous.

Conclusions. Thus during the period of operation (almost 5 years) of the furnace-bucket technological installation, the system with a thyristor-controlled reactor showed its performance and efficiency, however, for technological installations of this type, it is advisable to use another type of reactive power regulation (for example, a reactor with a magnetized core), which would allow to significantly reduce the volume of the building and reduce the costs of electrical equipment.

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