THE ASSESSMENT OF WORKING CONDITIONS OF TRACTION SUBSTATION FOR POWER AND REACTIVE ENERGY

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Summary: In this paper, problems concerning the management of reactive power of DC traction substation have been discussed. The structure of traction system and its main elements has been sketched. Reactive power issue with respect to rectifier sets has been presented. The case of generating reactive power of capacitive character in the traction supplying system and taken precautions has been also described.

1. INTRODUCTION

Reactive power and relevant phenomena as well as methods of its reduction are important elements of theory of power and electric energy [1], [2]. For the sake of equivalence of inductive reactive power consumption to capacitive reactive power generation, reactive power compensation method is the basis method of power management. Thanks to it, the cost of consumed electric power can be reduced and the improvement of working conditions of the system can also be achieved. Of course, this process is profitable only in case of recipients having devices, which need reactive power of inductive character. Inductive furnaces, motors, chokers, transformers and rectifier devices constitute such group of devices. Among the last devices, DC traction substations merging public power net with traction DC system play a big role.

At the time of persisting economic changes and leverage on financial results of enterprises, it is justified to consider every factor having the influence on their financial results. One of them is economic effectiveness of reactive power compensation for objects of DC substation.

2. DC SUBSTATIONS

In domestic traction supplying system, the substation with 6-pulses diode converter (PK17/3,3), 12-pulses (PD12/3,3, PD16/3,3, PD10/3,3 i PD7,5/3,3) and substation with one stage voltage transformation 110 kVAC/3kVDC work [2], [3].

6-pulses rectifier sets are fitted with rectifying transformer of YD11 connection and three-phase Diode Bridge. Transformers of non-traction and own needs work parallel with rectifying transformer. 12-pulses converters are fitted with three-winding three-phase transformer and twelve-phase diode set. Due to nominal power of converters, twelve-phase sets occur both in the smaller version (PD-12/3,3) and larger version (PD-16/3,3). Additionally, for the sake of overcurrent class III and VIb occurring at different nominal currents, two different notations for each converter are used (PD-7,5/3,3 (VIb) and PD-10/3,3 (VIb)).

In traction substation, smoothing devices consisting of cathode chokers, resonance filters and aperiodic elements are installed. Cathode chokers diminishes the slew rate of short-circuit currents and cooperates with the smoothing device.

Domestic traction supplying system can be divided into two groups, the group of 6-pulses rectifier sets about 75% and the group of 12-pulses rectifier sets. Devices with one stage voltage transformation AC/DC are in minority and they are installed in lines designed for high power trains.

Traction substations are supplied either from PPS (Points of Power System) 15[kV] or 110[kV] with the intermediate substation or directly from power system 110[kV]. In two first cases of cooperation with power system, the value of supplying voltage of the substation is dependent of assumed at given area typical voltage value. Mostly, its value is equal to U_n=15[kV] and constitutes the voltage for about 70% of traction substations. Short-circuit power of power system at the substation input depends on the configuration and parameters of supplying system. In supplying systems, short-circuit power on rails of transformer's stations 110/15 [kV/kV] for net of U_n=15[kV] and net of U_n=110[kV] is usually equal to S_{kQ}=150÷200[MV·A] and S_{kQ}=1000÷5000[MV·A] respectively.

Electric traction belongs with respect to the confidence of providing energy to the first class receivers requiring 100% reserve of electric power. Because of this, substations are supplied from two different energy sources or at least by two independent lines. Due to much higher reliability, substations are supplied from 110[kV] net by two independent supplying lines.

Power cables supplying traction substations are usually overhead lines. Cable lines in overhead lines do not exceed 15% of the length of all supplying lines. The length of lines supplying traction substations varies from several tens of meters to several kilometers.

3. DESCRIPTION OF THE CASE

For the sake of construction (rectifier transformer and diode set), traction substation is the reactive power receiver of inductive character. Fig.1 presents current and voltage waveforms of rectifier sets obtained through simulation [3]. The phase shift between obtained waveforms results from the presence of induction and commutation occurring in the rectifier.

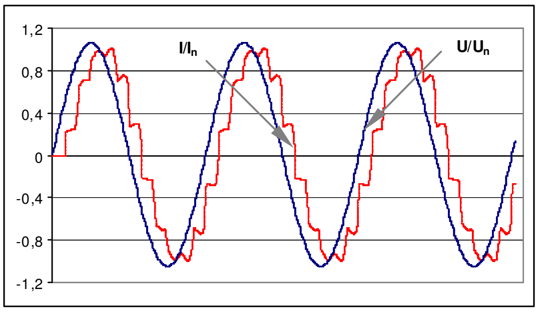

Fig. 1. Current and voltage charts of 12-pulses set

The estimation of theoretical considerations is also confirmed in practice. Measurements performed in substations [4] show inductive character of reactive power fed by substations. Because of this, in spite of high power coefficient- Fig.2, it is reasonable to consider described problem concerning such objects.

Particular case constitutes the work of substations placed in the urban area, where objects are supplied from power cables. In this case substations with supply cables can generate reactive power of capacitive character. Further, such a case will be described along with the manner of its elimination through the proper exploitation actions.

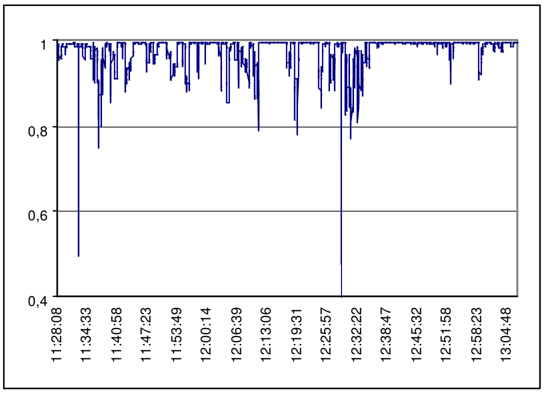

Fig. 2. Chart of power coefficient variability for the substation (value per quarter-hour)

In presented case the substation are placed in the urban area and whole net in the object is cabled. The substation (belonging to I category) is supplied by two lines of 15[kV], one of them is the main line and the second is the spare line. The first supplying point (PPS1) is generator of thermal-electric power station and the second point (PPS2) is public power system. In thermal-electric power station, due to some reasons, the synchronization of generators is lost and the break in supplying the energy from the main line happened. In this case, the substation is supplied from the spare line. However the spare line has the limitation resulting from ordered power (3MW). Taking into account the power of whole substation (PD 12/3,3), the power provided from the spare line is too low to supply railway traction line at its normal working condition. In this case the circuit supplying traction lines are disconnected while non-traction receivers remain intact. However, at night, cable's circuits cause that power character turns into capacitive. This fact has the reflection in charges bearing through Railway Lines for Distribution Company and the operation of net's devices.

At working main supplying system and for idle running the substation, power indicating by measuring circuits remains on average level of 200[kvar]. Devices of inductive character existing in the circuit completely compensate the power. However, capacitive power increases to about 250[kvar] during the supply from the spare line at disconnected traction net – Fig.3. This phenomenon is particularly apparent at night, when additional compensation coming from other devices does not exist.

Compensation of power difference was achieved through turning on idle running rectifier sets of traction substation. It was the consequence of lack of compensating chokers in the net. Inductive reactive power needing by each of sets is equal to 8[kvar]. Detailed data for idle running the set is shown in Tab. 1. Transformer 15/0,4 [kV/kV] working in the system compensated the influence of other power cables.

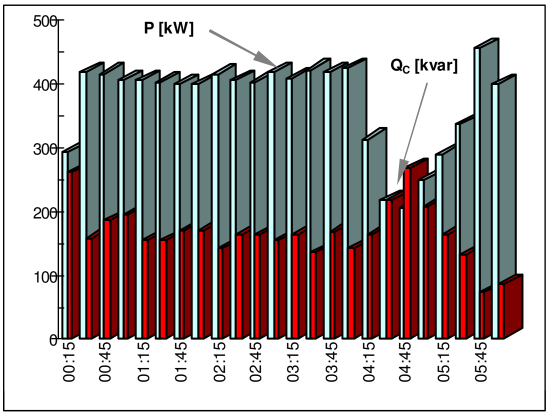

Fig. 3. Fragment of active and reactive power profile for the discussed case

However, after turning on two sets PD 12/3,3 (about 16[kvar] – 30% of need) higher current harmonics generated by rectifier sets begin playing role.

	L1	L2	L3
U/U_n [%]	103,3	104	103,3
I/I_n [%]	0,82	0,57	0,55
P/S_n [%]	0,27	0,18	0,14
Q/S_n [%]	0,045	0,038	0,102
S/S_n [%]	0,29	0,20	0,19
cos φ	0,99	0,98	0,7

Tab. 1. Data of rectifier set PD 12/3,3, at idle running

After turning on the third set, at idle running, contents of harmonics in the current was significant (TDD about 60%). Of course, 11th harmonic (12-pulses converter) was the most significant. Despite to idle running so that the current fed by sets was low, the influence of harmonics was significant. Such situation influenced on malfunction of many devices, short-circuit earth relays in particular. Disruptions were sensed by individual recipients in distance of many kilometers away from the substation.

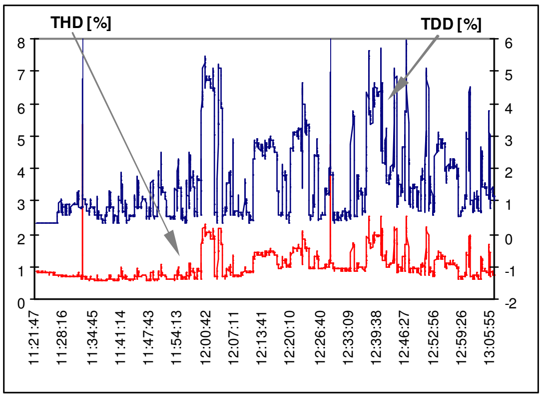

Fig. 4. Chart of the change of TDD (current) and THD (voltage) coefficients for the traction substation in normal conditions of work

Fig. 4 presents for comparison the chart of the change of TDD (Totaltotal Demand Distortion) and THD (Total Harmonic Distortion) coefficients for the traction substation working at normal load.

4. CONCLUSION

The right management of reactive power is very important economical and technical element of functional of modern enterprises. Application of this solution depends on thorough financial and technical analysis. Development of techniques of reactive power compensation and charges bearing through Railway Lines for Distribution Companies make the authorities apply this solution. In traction system at large number of substation's objects and low need for reactive power, the compensation is not necessary. In particular cases, it is necessary to thoroughly analyze the profit of its installation. Compensation used in described case did not require any investment, however it entailed negative consequences. The most important doubts were malfunction of devices protecting the system and computer devices. Deterioration of quality of voltage for non-traction recipients decreasing plausibility of the provider poses also the problem. At the analysis, the issue concerning amount of active power spending for the compensation of reactive power should also be taken into account.

Everybody can answer questions for particular case after performing many measurements and theoretical analysis.

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