Jakość i Użytkowanie Energii Elektrycznej
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POWER ELECTRONICS IN POWER PLANTS

Energoelektronika w elektrowniach systemowych

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Summary: **This paper presents an analysis of the influence of non-linear consumers in power plants on the voltage quality of service supply networks and describes a solution to improve the voltage quality of this network. Measuring and simulation results are presented.**

Streszczenie: **Artykuł przedstawia wybrane wyniki analizy wpływu odbiorców nieliniowych energii elektrycznej na jakość napięcia w sieci rozdzielczej niedużych elektrowni systemowych. Opisano rozwiązanie służące do podwyższenia jakości napięcia w tej sieci, potwierdzone przedstawionymi wynikami symulacji i pomiarów.**

Keywords: power quality, power plant, power electronics, active filters
Słowa kluczowe: jakość energii elektrycznej, elektrownie, energoelektronika, filtry aktywne

1. INTRODUCTION

Due to liberalisation of the energy sector all power station operators are forced to achieve highest cost efficiency. Hence in connection with optimisation of facilities, power electronic components are applied in increasing numbers.

The chronologically observation of new power plant projects in Europe shows us the trend in an increasing number of non-linear consumers with high power rating, for example electrical drives with frequency inverters.

The goal of this paper is twofold: *firstly*, to show that power electronics in power plants contribute to the degradation of the voltage quality of the service supply network, and *secondly*, to present a solution to improve the voltage quality of this network.

2. SERVICE SUPPLY NETWORKS OF OLDER BASE LOAD POWER PLANTS

Conventionally designed base load power stations are characterised by far-reaching redundancies. Sub-distributions and consumers are evenly partitioned on the bus bars. The aim is the even distribution of operation load. Another reason is in the reduction of voltage drops in case of switching or energising of large motors. Non-linear loads did not have any significance for design of station service supply network. They were only represented with irrelevant capacities. As an example for station service supply system concepts of this power station age group, the circuit design of the 500 MW power plant Jänschwalde is shown in Fig. 1.

Two boilers feed the 500 MW turbine. The 10kV station service supply network therefore splits up on four partial bus bars. In the course of the modernisation, each unit got a flue gas desulfurisation plant.

3. STATION SERVICE SUPPLY NETWORK OF NEW 800/900 MW UNITS OF VATTENFALL EUROPE GENERATION

To show the philosophy of the design of this power plant, a short conceptual overview is given.

3.1. Common conceptual foundations

The common conceptual basis is the so-called double unit with a mutual station service supply network reservation and separate 110kV supply from outside (see Fig. 2).

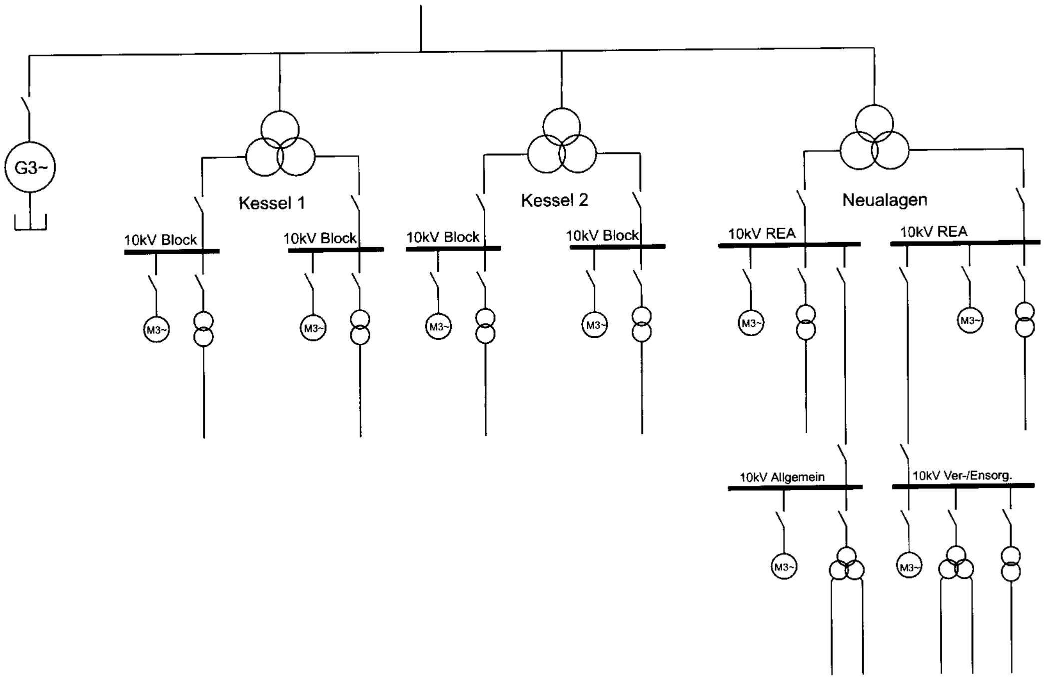


Fig. 1. Simplified single-line diagram of power plant Jänschwalde

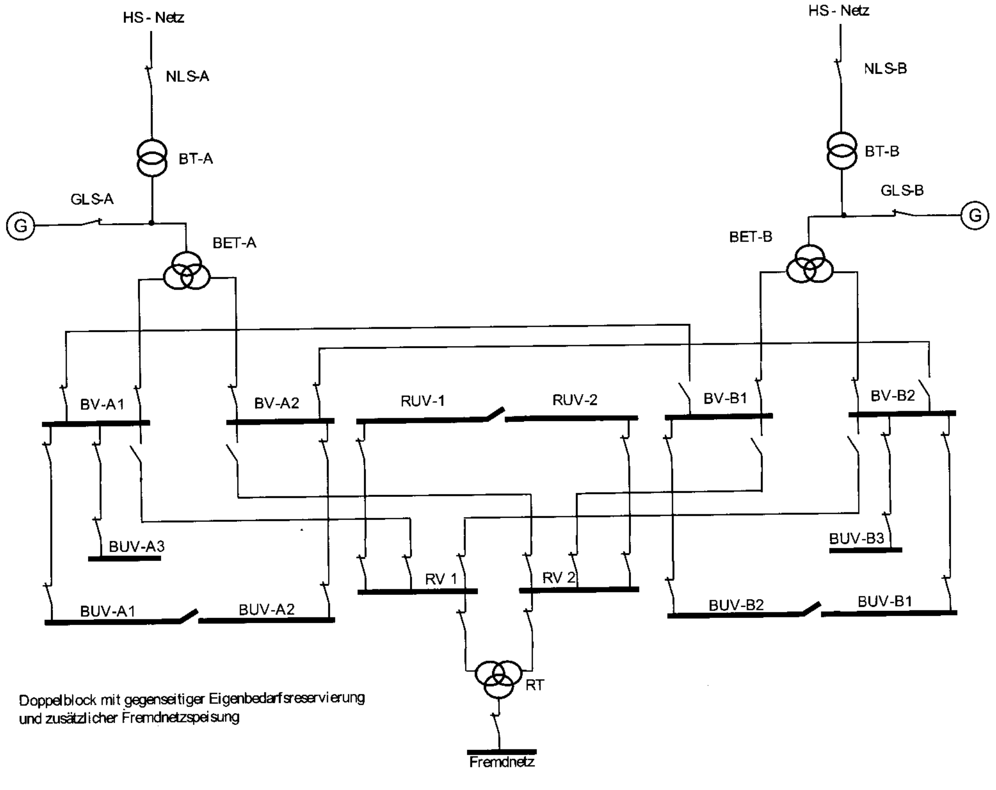


Fig. 2. Simplified single-line diagram of the power plant with a double unit

The basic concept of the design of this power plant is the same as it is described in item 2. It was applied without deviation in the 900 MW unit of the power plant Boxberg which was intended first. There are 10kV bus bars exclusively with „mixed" consumers. This means, one and the same 10kV bus bar supplies low voltage transformers, as well as 10kV motors, frequency converter- fed drives and 10kV sub-distribution networks.

The general points of auxiliary supply structure are briefly described on example of the power plant Schwarze Pumpe (see Fig. 4). Main items of the station service supply network are both 10kV bus bars. These supply all post-connected units and general switchgears. The incoming supply is respectively carried out via two service transformers. The connection of these transformers with the generator main current lead is realised without circuit breaker(see Fig. 4).

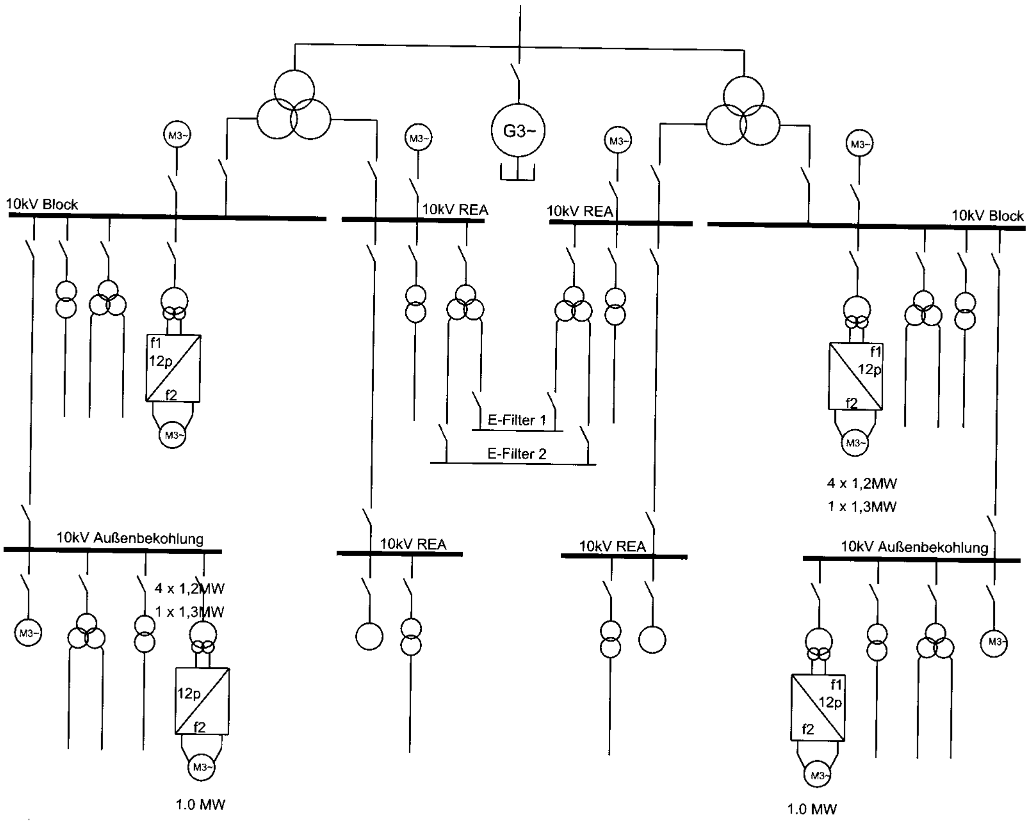


Fig. 3. Simplified single-line diagram of the power plant Boxberg

With the respective generator in operation, the station service supply system energy is provided by this turbine-generator directly. The required capacity is fed via machine transformer from the 400kV network in case of unit outage and opened generator circuit breaker. The service transformers are designed with three windings. Respectively they feed the above mentioned bus bar and a further bus bar for large motors.

As many operating states as possible are mastered for economic reasons without the external 110kV supply. Therefore, both units can be fed by only one station service supply system. If the supply of one unit stops, the accompanying 10kV bus bars are coupled automatically with those of the other unit. For this switchover altogether four fast-switching facilities are used per unit. These facilities are able to execute protection orders to switch over to the neighbouring unit. This can be an automatic or manual switchover initiated from the control room for example. This means that the switchover from unit-related to coupled station service supply is effected automatically, whereas switchbacks from coupled to unit-related service are stimulated manually.

In case of blackout of the 400kV voltage the coupling of the 10kV bus bars is activated by hand switchover to the 10kV bus bars Y0BCA and Y0BCB. These bars are fed from the 110kV supply. The 110kV net transformer provides supply during standstill of the two units and the complete supply for the auxiliary boilers including district heating station. Process steam and district heating supply are sustained in that way. The 110kV supply is not designed for operation, planned start-up and shut-down of the unit. The start of each unit is carried out via the 400kV network.

3.2. High power rating non-linear loads in the service supply network of new power plants

Due to optimisations in power plants, frequency converter-fed drives is used for coal mills. Conventionally such tasks were earlier realised by means of so-called governing clutches. As a result, non-linear loads became increasingly an important criterion for design of the station service supply networks.

3.2.1. Power plant Boxberg IV (1 x 900MW)

There are exclusively „mixed" bus bars in the 10kV level. This means, that one and the same 10kV bus bar feeds low voltage transformers as well as 10kV motors, frequency converter-fed drives and 10kV sub-distributions. Altogether there are 8 frequency converter-fed drives in operation. The power rating of each drive equals 2,300kW and they are now in operation for approx. 6 years. The speed range of these electrical drives equals 0-450 r.p.m. Every drive is fed by a 10kV switchgear via a transformer. The used three-phase current asynchronous motors are designed as 6-winding machines.

The drives of the three main condensate pumps have a power rating of each 1,400 kW. The fundamental arrangement corresponds with the concept described for the coal mills.

Simplified single-line diagram of the power plant Boxberg is shown in Figure 3.

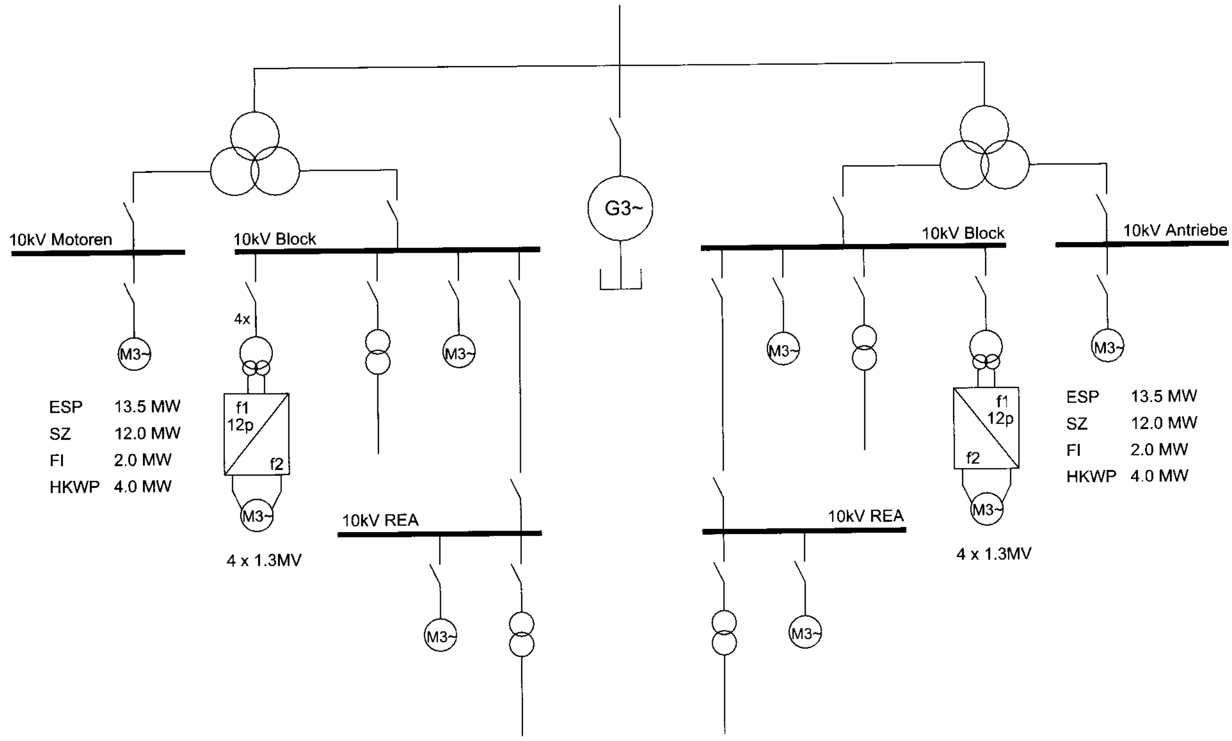


Fig. 4. Simplified single-line diagram of the power plant Schwarze Pumpe

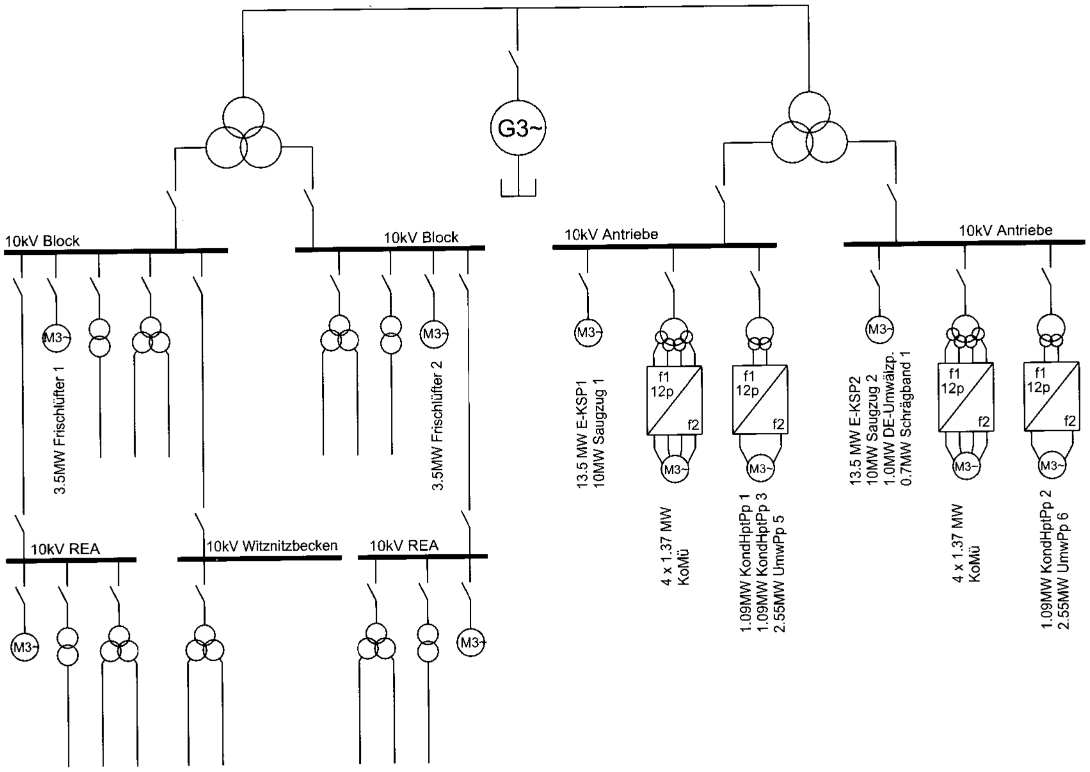


Fig. 5. Simplified single-line diagram of the power plant Lippendorf

3.2.2. Power plant Schwarze Pumpe (2 x 800 MW)

Here, so-called „motor bus bars" were defined. 10kV motors are exclusively fed by these bus bars (Figure 4). The frequency converter-fed drives are fed by bus bars together with the low voltage transformers. The eight frequency-controlled drives per unit for the coal mills are of the same design as at Boxberg.

3.2.3. Power plant Lippendorf (2 x 900 MW)

The frequency converter-fed drives with the 10-kV motors are fed from a common bus bar (Figure 5). The low voltage transformers are fed in separately. In addition to the speed control of the coal mills and the main condensate pumps, the boiler circulating pumps are also controlled via frequency converters at this station.

Altogether it becomes clear that the share of non-linear consumers in the station service supply network grows steadily. This does not only apply to drives with a relatively large power rating. It applies to units with a smaller power rating in the same degree.

3.3. Comparison of the station service supply networks concerning harmonics

An ever-increasing number of non-linear consumers spreads out on virtually all voltage levels in the station service supply systems. This leads more and more to impressing current harmonics which distort the grid voltage. Voltage drops are also a consequence of commutation. There is a principle danger to arrive at resonance areas of the complete station service supply network, albeit the respective capacities of the cable system play here a decisive role.

Despite these disadvantages frequency converter-fed drives will have to take on more and more tasks in future in the power station process in order to haul existing plant optimisation potentials. Hence it is essential to take negative consequences into account already in the design phase. According to our experiences, the supply structure of the linear and non-linear consumers to the switchgears is of decisive importance. In order to prove this and due to some disturbances of 400V motors and switched mode power supplies it was decided to measure and analyse the harmonics in the station service supply network of the new power plants. The objective was to check whether the thresholds in the complete station service supply system, which are summarised in the following table, adhere to the class 3 of DIN EN 61000-2-4 standard (industrial network). Later, it has proved advantageous to take the consumer structure in the 400V level into account and to strive for class 2 limits of DIN EN 61000-2-4 standard (public network).

3.3.1. Carrying out of measurements

Net analysers of DEWETRON port 2000 type were used for the execution of the measuring. A harmonic analyser is constituent in the net analysers. It works pursuant to DIN EN 61000-4-7 to the 50. harmonic. A voltage analyser according to DIN EN 50160 is also integrated. For recording of harmonic levels up to the 80. harmonic, additional 8-channel transient measuring cards with a channel sampling rate of max. 1.25 MHz were used.

Before starting a measuring in the power plant service supply network, a measuring program was initially prepared in co-operation with the operator. The program contained the facilities to be measured and the measurement procedures. During the measuring the units should be operated in normal mode (unit full load). Two measurement procedures were applied.

Short-term measurement: during the short time measurement the measuring signals for current and voltage with 100 kHz over the period of 5 seconds were recorded. The acquired time signal was then analysed over a time window of 5 periods with an analysis software up to the 80. harmonic one and finally noted down as amplitude spectrum.

Long-term measurement: The long-term measurement includes harmonics of voltage and current up to the 50. harmonic one. During the measuring an eight periods data block was analysed. The computation duration for the analysis is less than 160 ms, so that an all-embracing recording was possible. The results of this analysis were recorded as mean average value of one minute time intervals. The long time measurement was carried out for more than at least six hours.

3.3.2. Measuring results

As explained in the previous sections, the station service supply networks of the power plants are differently arranged. A direct comparison of single bus bars is therefore not possible. The measurement results of the single measuring are summarised as follows:

Power plant Jänschwalde: At 108 bus bars the measuring of harmonics had been carried out. Overshoots of the limit values (class 2, DIN EN 61000-2-4) were found mainly at bus bars of auxiliary facilities and electrostatic precipitators.

Power plant Boxberg: Measuring of harmonics were carried out at 71 bus bars. Overshoots of the limit values were recognised also here (class 2, DIN EN 61000-2-4). Beyond that, it was also found regarding class 3 in all voltage levels.

Power plant Schwarze Pumpe: The 10kV bus bars correspond to class 3 of DIN EN 61000-2-4. Overshoots were proved only at the low voltage bus bars for the coal conveyor belts and feeders.

Power plant Lippendorf: It was tested on 16 10- kV bus bars as well 110 bus bars. Short time and long time measurements were carried out at the bus bars for coal mills. No overruns of the class 2 limit values could be stated during the measuring. The limit values of class 2 were exceeded on four 690V bus bars supplying the water-steam cycle. The 690V frequency converter drives for the coal conveyor belts and feeder drives are reason for this. Insignificant transgressions of the class 2 appeared at the 400V inverter bus bars.

3.4. Summary of the measurement results

The following Fig.6 represents the distribution of the measurement results for each power plant.

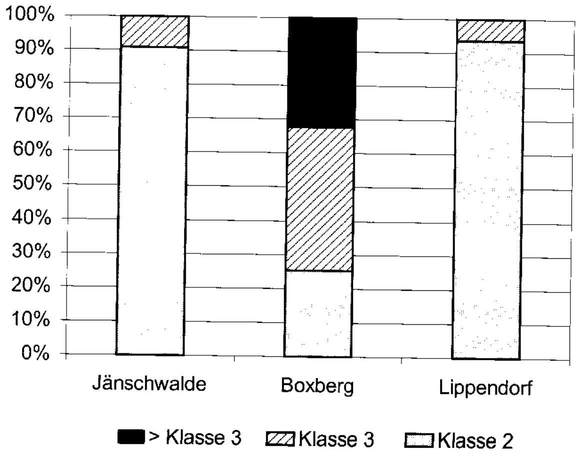
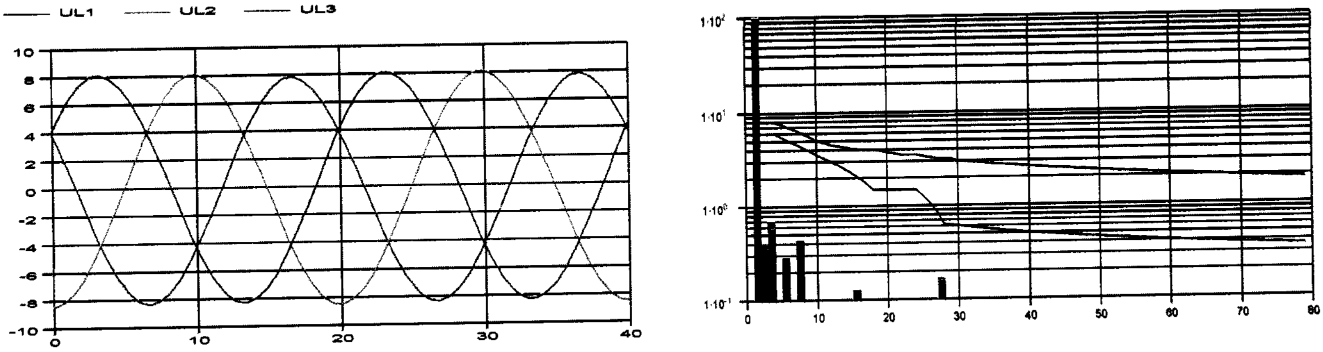
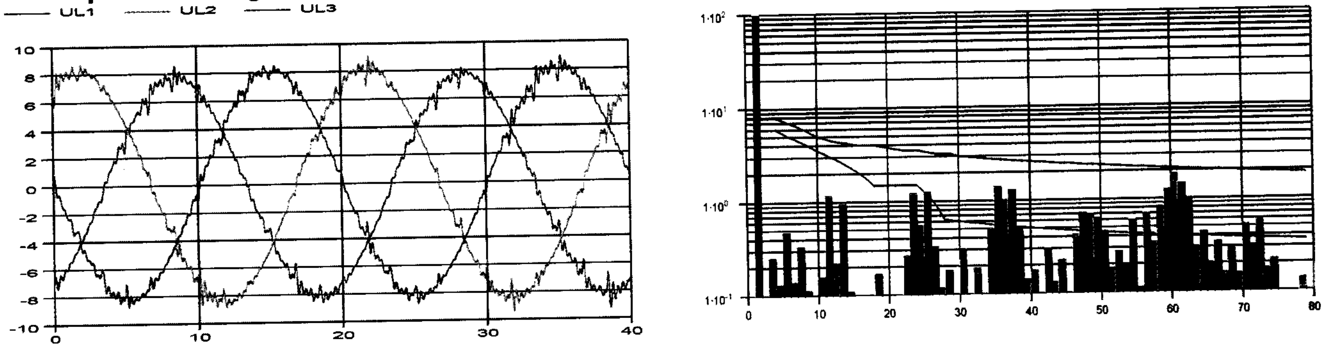
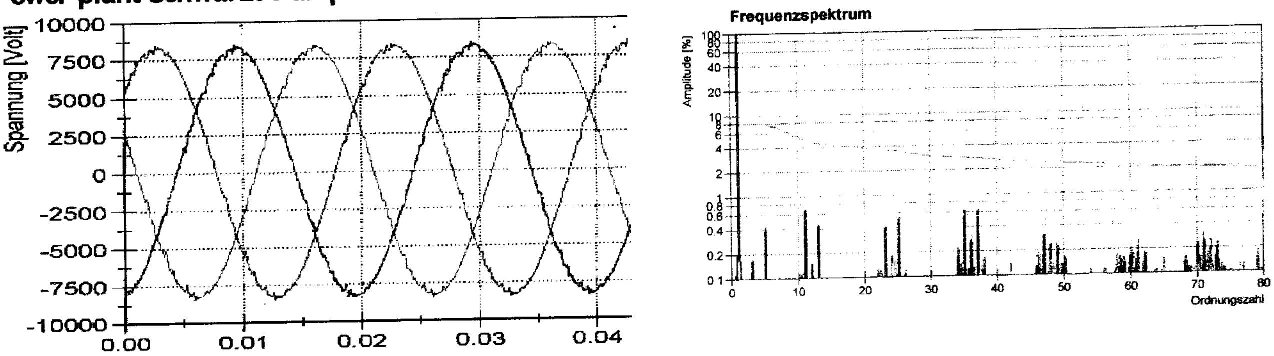


Fig. 6. Distribution of measuring results (according. to DIN EN 61000-2-4)


Power plant Jänschwalde E2BBB


Power plant Boxberg Q0BBB


Power plant Schwarze Pumpe A0BBB

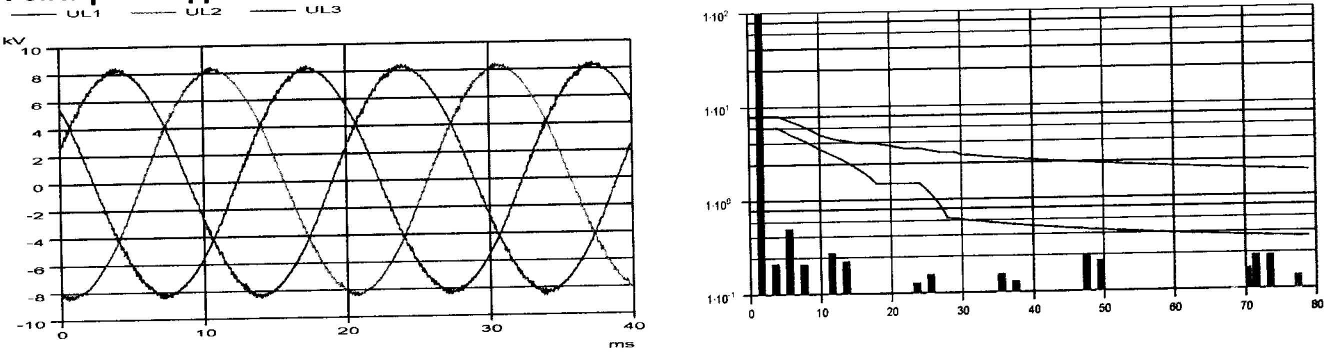

Power plant Lippendorf S0BBD

Fig. 7. Comparable 10KV bus bars of the power plants

About 32% of the bus bars of the power plant Boxberg are outside class 3 of the DIN EN 61000-2-4. We found overshoots above the 50-th harmonic ones.

Fig. 7 shows the voltage wave forms together with harmonic spectra diagrams for roughly comparable 10 kV bus bars of the power plants. The most favourable design variant concerning frequency converter technology and non-linear load was realised at Lippendorf power plant. At the time of the design phase of this station it was already apparent that non-linear consumers had to be considered particularly. Therefore frequency converter drives are connected with the 10kV motors to common bus bars. The low voltage transformers are supplied separately.

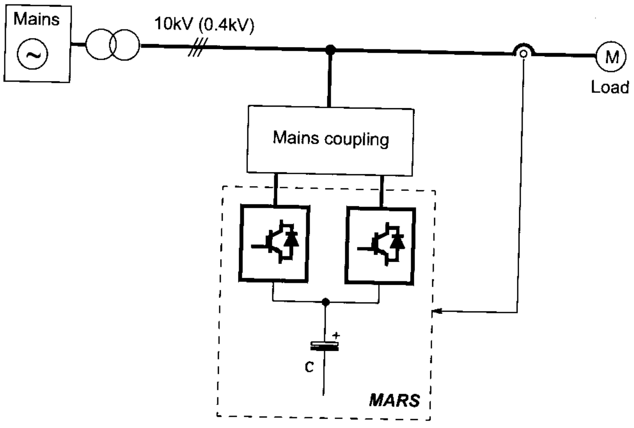


Fig. 8. Block diagram of the MASR restoring system

4. CANCELLATION OF HARMONICS BY USING OF FILTERS

In service supply networks of the power plants, the passive filters can be used to absorb harmonics generated by the non-linear load, primarily due to their low cost. However, they have the following drawbacks:

- the mains impedance strongly influences the compensation characteristics of the filter;
- they result in new resonances and therefore magnify the levels of the other harmonics;
- they can not be rated only for the loads being compensated. They are affected by harmonic currents from other non-linear loads or by harmonics from the power system.

Compared with the passive filter, the active filters can be used to reduce harmonics in the mains without worrying about all the problems associated with applying passive filters [1].

Active filters can not be overloaded by harmonics from the power system. Due to the fact that active filters use the same IGBT-inverter technology that is used in adjustable speed drives, their cost is not high.

Moreover, the active filter can be easily adjusted to specific applications by simply modifying the software or control parameters.

4.1. Mains Active Restoring System (MARS)

The principle of the operation of the restoring system MARS is based on active filters. The restoring system MARS uses the same IGBT-inverter technology as the active filters.

Figure 8 shows the block diagram of the MARS system for 10kV mains with a non-linear load.

There are two three-phase voltage source inverters, which are linked through a common voltage dc rail and they are connected in parallel by a coupling circuit (see Fig.8) to the mains. This connection of the voltage source inverters makes it possible not only to increase the power rating of the system, but also to reduce the high-frequency switching-ripple current in the mains. The last one is reached by using a special control of both these voltage source inverters.

Figure 9 shows a block diagram of the control unit of the MARS.

The control scheme is based on a cascade control with a current control in the inner loop without mains voltage sensors. The current controller sets the output voltage of the voltage source inverters for each sampling period of the control system so that the line current has a reference value. The voltage controller allows the dc voltage to have an almost constant value. The output signal of the dc-link voltage controller determines the value of the active current of the mains non-linear load [2,3].

Figure10 shows an aplication of the mains active restoring system MARS at Boxberg power plant. There are two MARS units which are connected to two 10kV bus bars with non-linear loads.

The MARS system is used to achieve the cancellation of harmonics of adjustable speed drives (the sum power rating about 10 MW) and the damping of cable oscillations in the network. To reduce the resonance frequency of the cable oscillations in the network the PFC capacitor is used. This

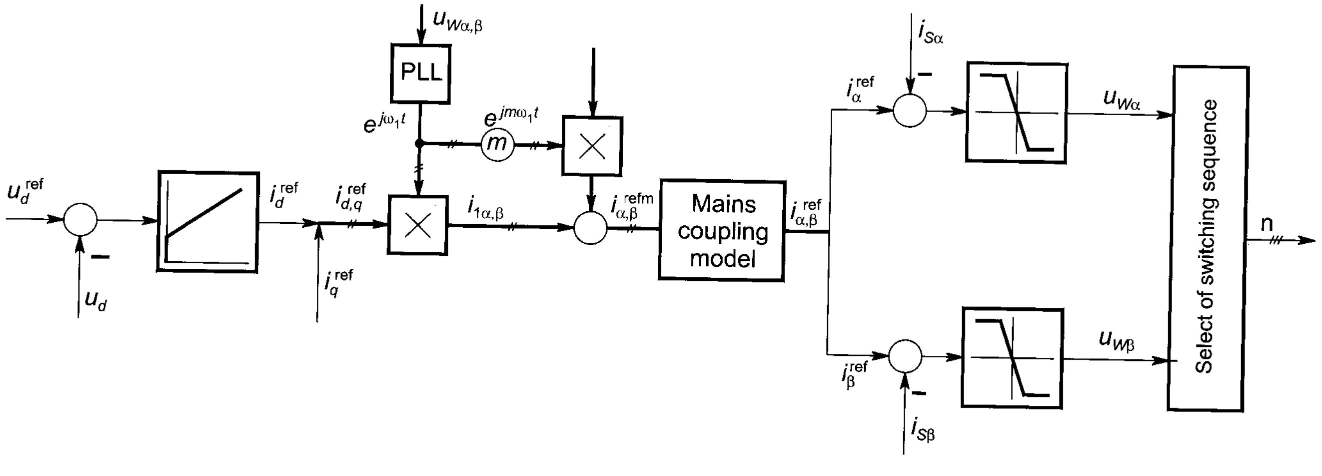


Fig. 9. Block diagram of the control unit

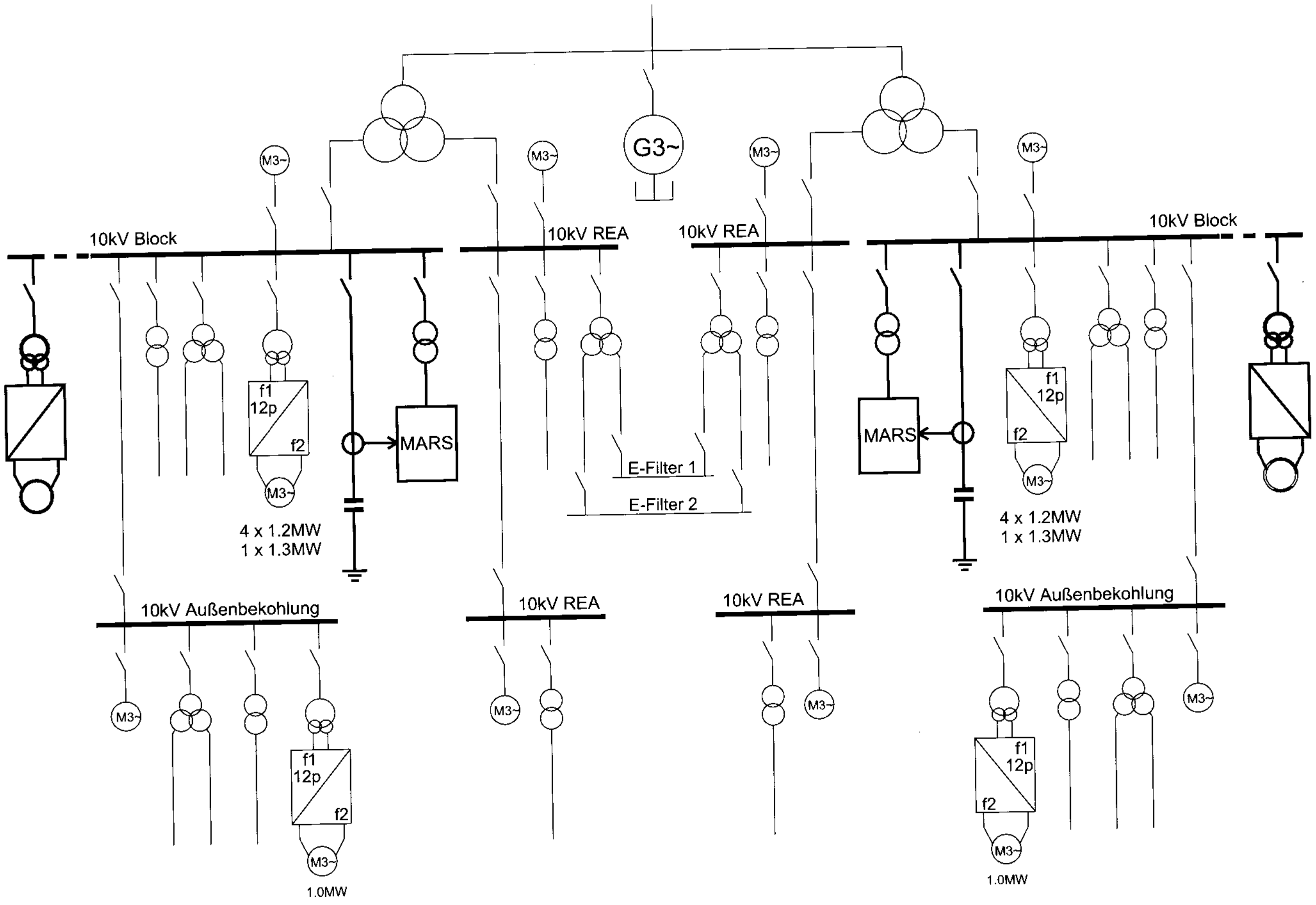


Fig. 10. Application of the restoring system MARS at Boxberg power plant

capacitor is connected in parallel to the MARS system. The control system of the MARS uses the current of the PFC capacitor to protect it (see Fig.10).

To adjust the nominal value of the ac voltage of the MARS unit to the voltage of the service supply network a step-down transformer is used.

4.2. Simulation results

The optimal power rating and the best compensation strategy of the MARS system was defined by using of simulation tools.

The Modelica library called PQLib (**P**ower **Q**uality **Libra**ry) was used for power quality analysis in the network using simulation tools written in Modelica. The PQLib is based on the package concept. The package concept was introduced into Modelica to help organise definitions of models, connectors, etc.

The simulation results with and without MARS system are shown in Fig. 11 and Fig. 12.

The voltages of the 10 kV service supply network of the power plants in three phases without MARS system are presented in Fig.11. From this figure it is seen that the voltages of the 10 kV bus bar are very distorted due to the cable oscillations in the network.

To improve the power quality of the service supply networks the MARS system is activated. Fig.12 shows the voltages of the 10 kV bus bar in three phases with MARS system. The cable oscillations in the network in this case are practically eliminated as you can see from the wave form of voltages in Fig.12.

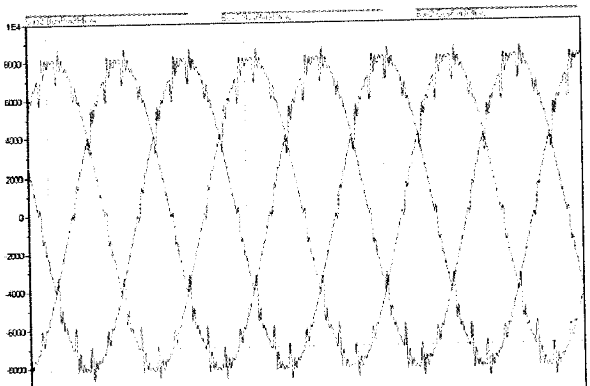


Fig. 11. Simulation results: service supply network volt-ages without MARS system

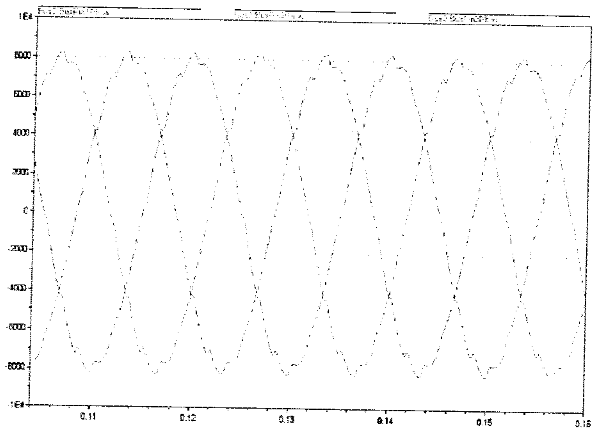


Fig. 12. Simulation results: service supply network voltages without MARS system

5. CONCLUSION

The non-linear loads such as electrical drives with frequency inverters contribute to the degradation of the supply quality of the service supply networks in power plants. To achieve the cancellation of harmonics of non-linear consumers and the damping of cable oscillations in service supply networks the active filters can be sucsesfully used.

6. REFERENCES

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