CONSTANT-POWER POWER SUPPLIES FOR THE TESLA MODULATORS

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Abstract

For the TESLA Test Facility at DESY modulators, which generate high voltage, pulses of 130 kV with an electrical power of up to 16.8 MW are used. The pulses have a repetition rate of up to 10 Hz and a width of 1.7 ms. Since it is not possible to take the pulsed energy directly from the mains the required energy is stored in capacitor banks to be released during the pulse. Power supplies are needed to recharge the capacitor banks of the modulators without disturbing the mains. In particular the low repetition rate of the pulses has to be suppressed. To be independent from the repetition rate the power supplies have to operate in a constant power mode. The DC charging current into the capacitors decreases during the loading with the same factor with which the voltage increases. In this way the current taken from the three-phase mains is constant. Different types of power supplies have been investigated at DESY and are described here. These types are antiductors with secondary diode bridges, switched mode power supplies, diode bridges plus series switched mode supplies, diode bridges with SCR bridges in sequential phase control.

1 INTRODUCTION

TESLA Test Facility (TTF) is used to develop technical components for the future accelerator TESLA. One of these components are the modulators producing a pulsed high voltage for the klystrons. The power needed for the klystron is up to 16.8 MW for 1.7 ms. The repetition rate will be up to 10 Hz for TTF and 5 Hz for the future accelerator. In TESLA 650 of these modulators will be installed. In order not to disturb the mains with this pulsed power energy storage capacitors mounted inside the modulator. These have to be loaded with constant power. The stored energy is released during the pulse. To ensure the loading with constant power different types of power supplies are investigated at DESY.

2 DISTURBANCES TO THE MAINS

The amount of allowed disturbances is defined in the German norm VDE 0838 or the equivalent European norm IEC 38. No energy consumer is allowed to produce more distortions than 3% of the short circuit power of the mains. For low frequencies in the visual spectrum this value is even more restricted. The low frequencies are called flicker frequencies. The human eye is very sensitive to changes in light intensities in this frequency domain. For the 5 Hz repetition rate of TESLA the allowed distortions are reduced to 0.5 % of the short circuit power.

TESLA will have a distributed power system with a voltage of 20 kV. Each service hall in which the modulators are installed will have a short circuit power of app. 200MVA.. In these service halls up to 100 modulators are installed having an average real power consumption of up to 15 MW.

$$d = \frac{\Delta S}{Ssc} \leq 0.5\%$$

ΔS is less than 1 MVA

with

d= factor of allowed distortions
ΔS = variation in apparent power
Ssc = short circuit power

The power variation for a single modulator results to 6.5% of the nominal power. Changes in the reactive power have to be included.

In order not to disturb other consumers in TESLA like DC power supplies or beam diagnostics one should not even go to this limit.

3 TYPES OF POWER SUPPLIES

3.1 Antiductor

In TTF three modulators are installed with antiductors at the 400 V level with transformer and secondary diode bridge. The original one loop voltage regulation was replaced by a constant current regulation to decrease the mains distortions. Even with this improvement the disturbance to the grid is so high that the switching of the modulators can be seen in the current of DC magnet power supplies. Calculations have shown that even with a constant power regulation the variation in power is still up to 20% of the nominal power. Therefore another topology has to be found.

3.2 Switched mode power supply

Switched mode power supplies combine a few advantages. With the primary diode rectifier nearly no reactive power is generated. With proper grouping of the vector groups of the transformers of each power supply 12-pulse behavior in the halls can be achieved. Due to the high switching frequency and the low filter time constants the regulation dynamic is very high. Nevertheless at the beginning of the investigation capacitor charging power supplies in that power range had not been available on the market for reasonable prices. Therefore DESY investigated different topologies of switched mode power supplies with a constant power regulation. The resulting power supply is shown in Fig.1

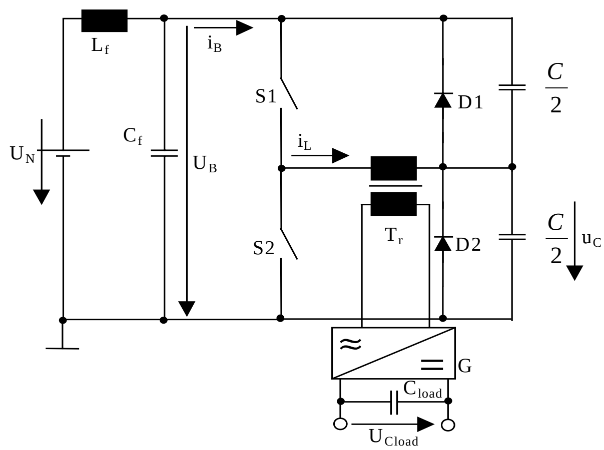

Fig 1. Switched mode power supply with P = f(fswitch)

The advantage of this topology is that the power transmitted to the storage capacitor is independent of the secondary capacitor voltage. When keeping the switching frequency constant the input power from the mains stays constant. P = (f_{switch}).

A high power module with 75 kW was built as a prototype and commissioned at DESY. A 300 kW power supply consisting 4 of these modules is in construction. The regulation fulfilled the demands of constant power loading as well.

3.3 Hybrid power supply

Switched mode power supplies are still expensive. The price per Watt is still around 1 DEM. ≈ 0.5 $. Further investigations had to be done. When looking at the curve form of the modulator capacitor the signal can be split into a DC part and an AC part (Fig.2). The DC voltage never decreases below the minimum value U_{Cmin}. This can be produced by a cheap diode rectifier. Only the varying AC voltage is produced by a switched mode power supply. The cost reduction can be up to 40% of the full switched mode solution.

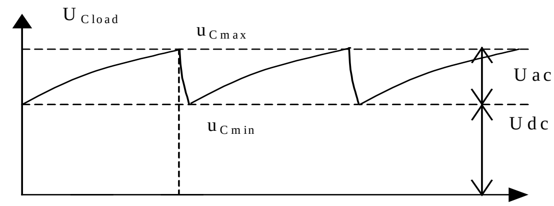

Fig. 2. Voltage over time of the modulator capacitor

3.4 Diode rectifier with SCR bridge

The basic idea of this topology is the one of the hybrid supply. A diode bridge produces the DC part. Instead of using a switched mode power supply the AC part is produced by a SCR bridge. Two different solutions have been found for this.

3.5 SCR bridge in sequential phase control

With the independent variation of the phase shift angle of the cathode and anode SCRs it is possible to change the reactive power without changing the resistive power. It is known that the reactive power decreases by a factor of 2 when exchanging either the cathode or the anode bridge to diodes. This is just a special case of the above mentioned topology with $\alpha 1$ = variable and $\alpha 2 = 0$. The disadvantage of the half bridge is that either the inverter or the rectifier region can be driven with this bridge. With SCRs both possibilities are available. In simulations it was found that this topology is leads to good results. The power variation can be cut down to less than 3%. Disadvantage is that the mathematics for the regulation is difficult and a lot of computation has to be done. This regulation is only valid in a rather small range.

3.6 SCR bridge with higher voltage

In simulation it was found that it is sufficient to use a SCR bridge with just one phase shift angle when the nominal voltage of the bridge is high. Due to the relatively small variation in the current the change of the reactive power is small enough to fulfill the specification. To cut the cost even more it is possible to use an antiductor with secondary diode rectifier.

Both solutions are having the disadvantage that the DC current has to be smoothed with a large choke. In the simulation the introduced choke was 3 H as in the actual running modulators. If the value of the choke was decreased the models got mathematical instabilities. The result of small power variation was not obtainable.

4 REGULATION

A crucial part of the constant power power supply is the regulation. It is a digital regulation with a self learning algorithm. The hardware is based on programmable ALTERA device. The regulation and hardware have been developed at DESY.

The capacitor of the modulator is charged corresponding to a voltage reference curve stored in a RAM. The reference curve is slowly adjusted until the input power is constant and the final voltage of the capacitor equals the nominal capacitor voltage. The adjustment takes several charging periods. Using this reference curve ensures that at the end of charging the capacitor voltage equals the nominal voltage and that the input power is constant.

The repetition accuracy for the voltage is better than 0.5 % of the nominal value. In tests with a small power model the variation on the mains voltage could be up to 50 % of the nominal voltage. The regulation corrected this without disturbing the output voltage. In reality sudden voltage steps of only 2 % coming from the transformer tab switch are foreseen. The regulation is able to handle this.

5 CONCLUSION

The low repetition rate of TESLA with the high pulsed power rise to hard specifications for the power supplies. Different types of power supplies have been investigated in terms of functionality and price. The result is that there are solutions. The most convenient type is the switched mode power supply but the price is still high. A good compromise is the hybrid power supply, a series connection of a diode bridge and a switched mode supply, since low price and good regulation abilities are combined. The third topology is the series connection of a diode bridge and a SCR rectifier. The drawback here is the large filter choke that has to be introduced to smooth the DC current. The regulation for this power supply could difficult. For the switched mode power supply one prototype is tested and power supplies can nowadays be bought from industry. For the two other solutions prototypes have to be developed and tested with a modulator in the TTF.

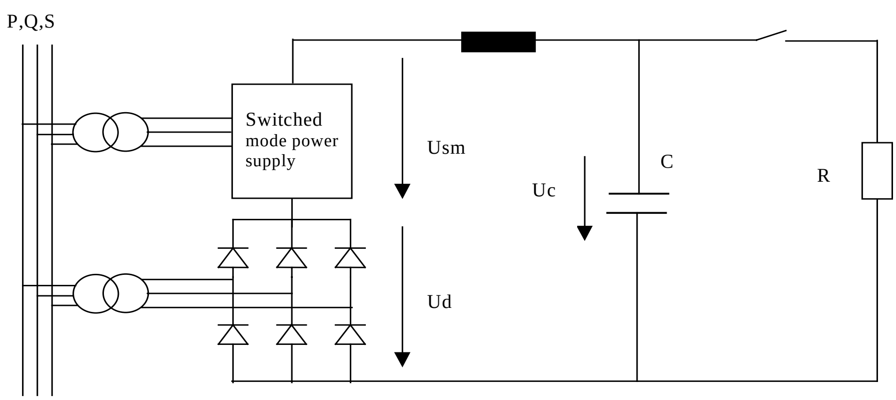

Figure 3: Diode bridge with switched mode power supply

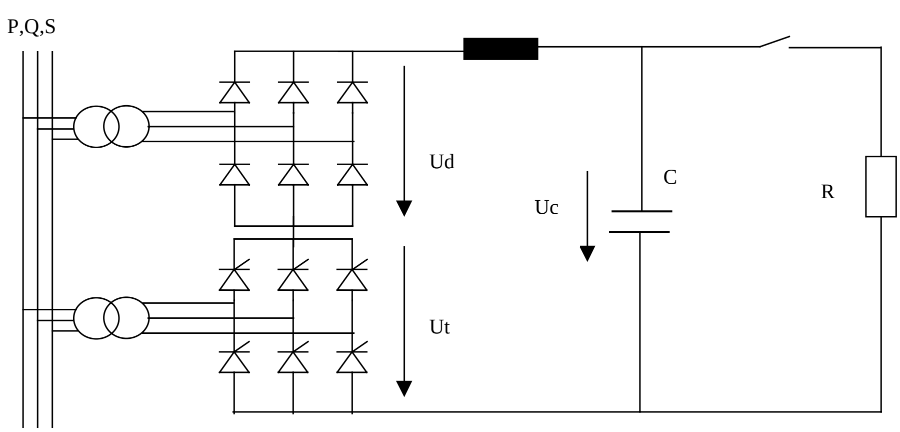

Figure 4: Diode bridge with SCR rectifier