THE USE OF SWITCH-MODE POWER CONVERTERS FOR THE LEP MAIN RING POWER CONVERTER SYSTEM

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Abstract

By the beginning of the 1980's it was evident that dc power converters working with high internal switching frequencies could offer substantial advantages in the accelerator environment. Reduced volume, high efficiency and excellent dynamic performance were among the attractions. But just how much power could be obtained and at what price was not clear. The search for suitable topologies which could not only cover the sub-kilowatt range but also the higher power levels was thus launched. This paper describes the work that has been carried out on switch-mode techniques at CERN and their application to a majority of power converters for LEP. The range of Switch-Mode Power Converters for LEP will vary from 340 W up to 40 kW and from 2.5 A to 2'000 A dc output. The paper will show how they have become an important part of the power converter system of LEP, allowing substantial savings in building size and cooling while offering much improved dynamic qualities.

Introduction

The LEP main ring magnet system requires about 760 individual power converters, which amongst other things must be able to grow with the machine. By the beginning of the 1980's Switch-Mode-Power-Supplies (SMPS) had been making a large impact on the European market and the Power Conversion profession was making predictions of ever-increasing power ratings and performance in general. CERN could not ignore this and launched a serious study on SMPS [1] in order that they would be used wherever practical in the LEP machine. What then are the advantages ?

Possible Advantages

Wherever switch-mode technology could be used then considerable reductions in the size of the equipment could result. The temptations thus offered in reduced building size and transport costs were difficult to resist. The possible reductions depended on the ratings and type of power converter, but in general a figure of three could be hoped for. A similar figure was expected for the weight.

With high internal switching frequencies, good dynamic performance could be expected which would greatly improve network transient response, and the harmonic ripple of conventional equipment could be eliminated without the need for active filters.

More efficient power converters give savings in energy consumption and in cooling requirements. It was clear that switch-mode technology could offer such power converters particularly for the smaller units. A well designed SMPS would also work at near unity power factor throughout its output range thus reducing reactive power consumption.

While these advantages seemed very attractive, as always they had to be weighed and evaluated against the disadvantages.

Possible Disadvantages

SMPS technology, at anything over a few watts, was the big unknown and experience had to be gained in order to make a worthwhile evaluation.

This was a specialist world and the number of potential suppliers were low. That coupled with high development costs might make switch-mode converters too expensive.

While conventional thyristor converters were well understood, there were many technical problems to be solved for switch-mode. Not only did topologies have to be found that worked, they had to be reliable. Problems of Radio Frequency Interference (RFI) had to be solved and such effects as negative input impedances controlled.

However these problems did not seem too daunting and the studies were started.

The Bipolar Power Converter for the Correction Magnets (± 5 A, ± 135 V and ± 2.5 A, ± 135 V)

CERN required over 500 bipolar power converters for the correction magnets and in such quantities price, volume and ease of production were important factors. Studies revealed that no commercial products were available in the required power range (340 W - 675 W). Only two types of bipolar converter seemed able to meet the LEP specification, namely a thyristor dual-converter or a linear solution. Both these were really two unipolar converters put together which meant high component counts and a 50 % utilization factor.

Initial design studies and switch-mode prototype work showed that :
- weights of switch-mode prototypes were 15 kg compared to 45 kg for the linear approach;
- dynamic performance was better than or equal to the linear approach and far exceeded the thyristor dual converter. Small signal bandwidth in excess of 5 kHz was easily achieved giving 10 times reduction of all mains-related outputs and practically no measurable output disturbance to 2% mains steps;
- all-inclusive efficiency was better than 80%, compared with 45% for the linear approach.

The work involved the testing of 3 commercial designs and the construction of 2 full-scale switch-mode prototypes. The studies of power limitations were undertaken using the first generation of POWER MOSFETS and revealed a figure of greater than 1 kW for a reliable design with single devices working at about 50 kHz. Although several switch-mode topologies were investigated nothing better or equal to the "H" bridge was found. The chosen design is shown in figure 1.

A performance specification to European industry was written in 1985. Close collaboration with the successful bidder has resulted in the first deliveries fully meeting the required specification. The same converter covers both the 2.5 A and 5 A requirements and two are installed per 19-inch rack.

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PAC 1987

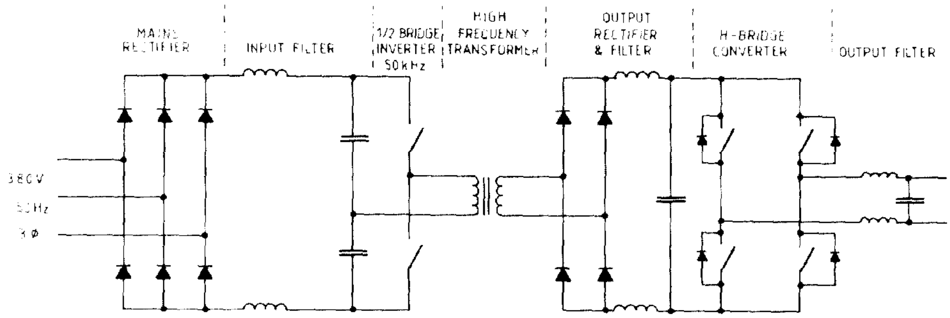

Figure 1: BIPOLAR POWER CONVERTER

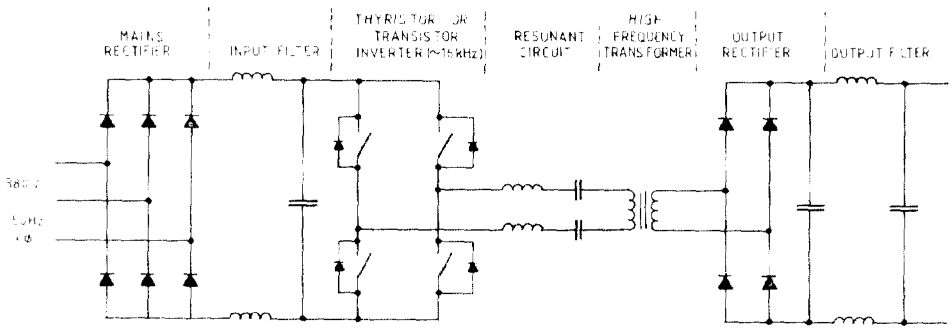

Figure 2: TYPICAL SERIES RESONANT POWER CONVERTER

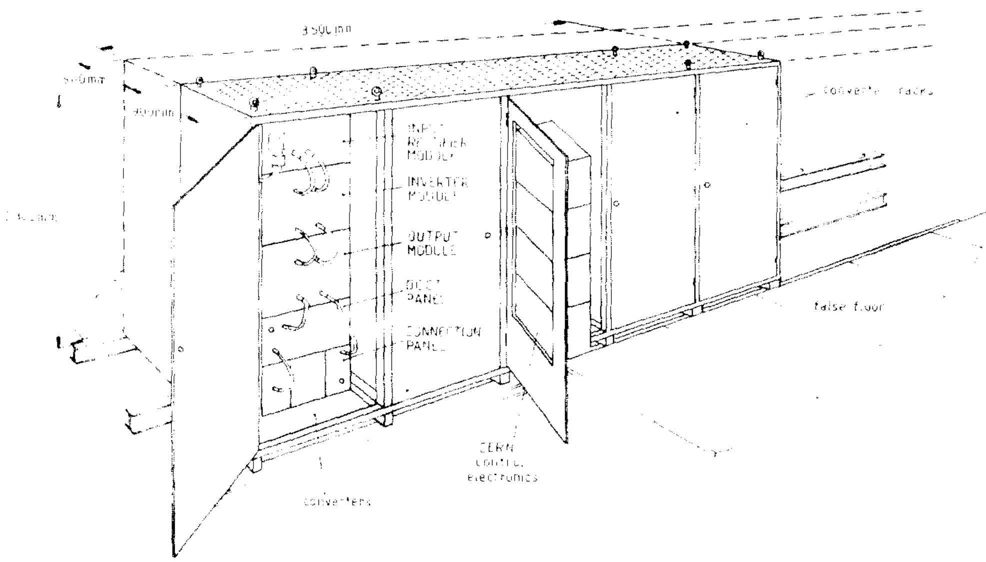

Figure 3. MECHANICAL LAYOUT OF FOUR 37.5 kW SMPS IN A CUBICLE

The basic price is 10% cheaper than a 'conventional' solution and, while it is difficult to be precise, the overall cost is probably in the region of 20 to 30% cheaper. The final version is very simple and compact, and requires no water or auxiliary cooling equipment. The output performance is excellent and capable of working to a precision of a few parts per million.

Power Converters for the Superconducting Low-β Quadrupoles of LEP

The Superconducting Low-β Quadrupoles of LEP require 2'000 A maximum. If conventional power converters were used then, because of their volume, they would have to be installed on the surface. This would require heavy current cabling needing a voltage output from the converter of 30 V. Following the work being done with industry and the successes being achieved with the Bipolar project, it seemed that a compact switching converter might be able to be used which could be installed underground close to the magnets. The savings in the power cabling amounted to 380 kSF and the power converter could be rated at 10 V giving a power reduction from 60 kW to 20 kW.

After investigations, a series-resonant converter was chosen working at 20 kHz. The quasi-sine wave inverter, which functions as a current source, had ideal characteristics to drive an adaption transformer needed to obtain the high output current. A prototype 'Schwartz' converter was built (figure 2) which showed the feasibility of such a design and that the entire power part could be installed in one 19-inch rack. The decision was therefore taken to approach industry for the construction of ten such converters and this is now underway.

The converters will be installed in a technical gallery close to the intersection point thanks to their low volume and small heat dissipation. The total savings amount to about 40%.

Power Converters for The Lower Power Auxiliary Magnets

Impetus had thus been given to the switch-mode approach and other fields of application were studied. There existed over 100 other circuits which it was thought could be powered by SMPS. In particular they needed a modular type of approach so that changes and uprating for higher energies of the machine could take place easily.

At the time of starting studies the circuits needed about 300 V dc. It seemed feasible to rectify directly the mains 380 V network and feed this through simple 'choppers' using large but fast bipolar transistor switches. Prototype 75 A, 300 V modules were constructed using current-mode control with a repetition rate of 16 kHz. Four such modules could be operated in parallel and located in one 19-inch rack, giving 90 kW per rack. While the system itself performed extremely well, the RFI problems were considerable and the final parameters for the magnets had reduced and differing voltages, meaning that an isolation/adaption transformer would be needed.

The decision was therefore taken to employ once again the series resonant converter. Three types were needed all rated at 37.5 kW but having outputs of 300 A - 125 V, 150 A - 250 V and 200 A - 188 V. The input rectifier and inverter are common to all types and only the output transformer and rectifier are different for the various types. Each converter is housed in one rack, and a cubicle made up of five racks contains four converters and their associated control electronics (figure 3).

An efficiency of 92% has been achieved and the building surface for these converters has been reduced from 626 m^2 to 240 m^2. After tendering, the basic converters were found to be 15% cheaper and taking into account building and electricity costs the total savings amounted to 33%. Coupled to this the power converters show the previously mentioned performance improvements.

Conclusions

About 82% of the power converters used on the LEP Main ring magnet system use switch-mode technology. Their total installed power is nearly 6 MW which accounts for 45% of the power taken from the 3-phase 380 V LEP network. Taking into account both direct and indirect savings they have reduced expenditure by about 33%.

Prototype work has shown that the advantages mentioned previously can certainly be realized and that the disadvantages can be overcome. RFI can be mastered and, although reliability will have to be monitored during machine operations, the indications are good. Throughout prototype work, Switch-Mode Power Converters have shown themselves to have excellent dynamic performance which is particularly suited to the accelerator environment. Invaluable experience has been gained in the field.

Acknowledgements

The above describes the work of many members of the LEP-PC Group to whom all thanks are due. The authors would also like to thank the many contributions made by the European Converter Industry without whom this work would have been all the more difficult.

References

(1) P. Proudlock, "The medium power auxiliary magnet power supplies for LEP. Can Switch-Mode meet the challenge ?", in Proceedings of the 5th Power Conversion International Conference, Geneva, Sept. 1982, pp. 297 - 309.