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INDIA

Technical Report: Power Electronics and Motor Drives *

Prepared for the Government of India
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of J. Holtz
Expert in Power Electronics

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United Nations Industrial Development Organization
Vienna

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Abstract

The Power Electronics Group at CEERI Pilani have proved their expertise and ability to develop equipment for static power conversion for a variety of practical applications.

Consultancy was given under the UNDP program with respect to the current development projects of CEERI, introducing among others the novel technology of snubberless high-power transistor inverter design and the technique of a local high-frequency bus in a power electronic system as a common source of supply for base drive circuits and other electronic control.

This report includes proposals for future projects and recommendations for further improvement of the productivity of the group.

CONTENT

1. Duration of Consignment

The consignment was scheduled from 3rd December, 1987, until 2nd January, 1988, including 2 days for briefing and de-briefing in New Delhi, and 2 days for travelling.

2. Persons with whom technical matters were discussed

- Dr. G. N. Acharya, Director, CEERI Pilani
- U. Madhav Rao, Head, Power Electronics Group
- S. D. Perlekar
- Rahul Varma
- V. N. Waliwadekar

3. Lectures

The following lectures were given in Pilani:

1. Vector Control of AC Machines and On-Line PWM Optimization Using Signalprocessors.
2. Three-State Inverter for Very High Power PWM Drives Systems.
3. Regenerative Snubbers for GTOs in Voltage Source Inverters.
4. A Direct Three-Phase AC-to-AC PWM Converter for Unity Power Factor Operation of a Vector Controlled Induction Motor Drive.
5. A Redundant 80 kW Uninterruptable Power Supply System.
6. Single-Chip Microprocessor Control of an Ultrasonic MOSFET Centrifugal Drive.

The lectures were attended by the staff of the Power Electronics Group. Intensive discussions were triggered on the subjects treated in the lectures and on related actual development projects of CEERI.

4. Current Projects at CEERI

4.1 Transistor PWM Inverter for Traction Applications

A transistor inverter had been fabricated in the CEERI laboratory using 100 Amp. darlington modules. Commissioning of this unit had proved to be difficult and many devices had been spoilt in the process. In addition, it was considered unsatisfactory that high overvoltages were appearing across the semiconductor switches having 2.6 times the supply voltage magnitude. Owing to these, operation of the inverter is only possible at reduced supply voltage.

Another transistor inverter with increased capacity using 300 Amp. darlington modules had also been fabricated. The author was asked to participate in the commissioning of this system.

While examining the inverter, severe shortcomings were found which were estimated likely to produce problems during the operation similar to those of the first inverter.

It was then decided to abandon the 300 Amp. inverter and start with a different design strategy based on the expertise in this field developed recently at the University of Wuppertal. The new design comprises of

1. a novel arrangement of the electrical connections in the power circuit using multilayer conductor sheets instead of conventional wiring, making use of the extreme low stray inductance of multilayer arrangements,

2. elimination of the snubber circuits which was made possible by the use of the multilayer conductors,

3. abolishment of collector-emitter voltage sensing of the individual power transistors for short circuit protection. Instead, protection against short circuit in the load by monitoring the dc link current,

4. implementation of circuits for sensing the on-state duration of each power device, including the turn-off time, and feeding the sensed signal to a common interlock logic,

5. elimination of the anti-saturation circuits in the individual base drive units,

6. replacement of the opto-couplers for signal transmission between the control circuit and of the base drive units by high frequency switched magnetic cores,

7. elimination of individual 50 Hz power transformers for the respective base drive units and for the electronic control circuit. Instead, construction of a 50 kHz, 100 Watt switched mode power supply feeding a common high frequency bus for the potential separated supply of the base drive units, the current sensing circuit, the logic interlock circuit, the PWM modulator and the drive control system,

8. construction of a 300 Amp shunt resistor having extreme low inductance to be inclosed in the dc link circuit and connected to a comparator as an overcurrent detector, operated on the dc link potential,

9. abolishing the multi-pin connector plug-in PC boards. Instead, use of one common PC board for all base drive units, and only one more PC board for the electronic control.

During one month, the CEERI Power Electronics Group completed the design and construction of a new transistor inverter achieving the following improvements:

- considerable increase of power output owing to higher voltage utilization of the power transistors and owing to a more precise sensing of the current limit,
- reduction of the volume of the inverter to less than one third,
- reduction of weight owing to the local high-frequency power supply system,
- reduction of fabricating cost and reliability owing to the compact construction and the absence of plug-in cards.

4.2 40 kW Thyristor PWM Inverter for Mining Locomotives

A 40 kW thyristor PWM inverter for a mining locomotive drive was fabricated recently by CEERI and tested in the field. A study of the commutation circuit of this inverter revealed that the efficiency and the utilization of the components can be improved by a different design of the commutation circuit.

It is common practice to operate the McMurray type PWM inverter at a commutation capacitor voltage level that is only little higher than the supply voltage. This concept was also followed here. The capacitor voltage was kept at a low level by introducing a long delay time of the gate firing pulse of the main thyristors.

It was found that under the prevailing operating conditions, i.e. supply voltage 120 V, maximum inverter current 500 A, the capacitor voltage should be boosted to about two times the supply voltage. This can be achieved by simply advancing the gate firing pulse of the main thyristors.

The new concept will stabilize the capacitor voltage to be independent of the load current variations and will reduce the size of the commutation elements.

4.3 AC Drive Systems for Battery Powered Vehicles

The expertise acquired in fabricating a mining locomotive drive is proposed to be expanded employing transistor inverters as mentioned under 4.1 above. It is recommended to extend the investigations to an appropriate design of the drive motor, especially with a view to weight reduction.

4.4 Microprocessor-Based PWM Modulator

A microprocessor-based PWM modulator is developed at CEERI employing on-line computed pulse patterns. The algorithm averages the sampled voltage reference values over equidistant sampling intervals. The results are temporarily stored in memory locations. From here they are transferred to counters which generate the firing sequences. In order to reduce the time delay required for performing the algorithm it is intended to fabricate a dedicated microchip.

It is recommended, instead, to reduce the complexity of the PWM generation logic using the method presented in lecture 6. This method requires less hardware and exhibits better dynamic performance.

4.5 Power Factor Control in Variable Speed AC Drives

A concept of controlling a PWM inverter drive at minimum reactive power is being investigated at CEERI. The control system will reduce the power consumption of the ac drive. The continuation of this work is encouraged.

4.6 Sensorless Speed Measurement Based on Rotor Slot Harmonics

Filtering techniques are used to detect the frequency of the rotor currents of an induction motor from the measured stator currents. The application of this scheme aims at eliminating the tachogenerator for direct speed measurement.

4.7 Solid-State Three-Phase Short Circuit Protection for Motor Load

The proposal of installing active turn-off semiconductor power switches such as GTO thyristors for the protection against overload and short circuit of three-phase ac loads was discussed with respect to design, performance, and cost. It was agreed that such system would not compete with the present technology of mechanically operated circuit breakers with respect to cost and reliability.

4.8 Vector Control of AC Drives without Tachogenerator

Although research in this field can be considered challenging, it is not recommended to pursue the objective in depth. The amount of work involved and the complexity of the problem may not be sufficiently matched by the available equipment and staff, while the applicability of the expected results is difficult to assess.

5. Recommendations

5.1 Future Projects
5.1.1 General Considerations

Induction motor drives fed by PWM controlled transistor inverters are presently taking an increasing share of the market of speed variable drives in the power range up to about 50 kW in western countries. The maximum blocking voltage of power transistors is presently 1200 - 1400 Volts which is a good match to a three-phase supply of about 400 Volts. The high voltage fluctuations in the public power supply systems in India, however, do not permit a transfer of this attractive technology since the devices cannot withstand the frequently occurring overvoltages.

The prevailing conditions of Indian utilities call for a semiconductor device with high blocking capability at a low price. This is the converter grade thyristor, and a matching ac drive system is the current source inverter drive. Converter grade thyristors are manufactured in India. The concept of the current source inverter leaves the option of using inverter grade thyristors with inherently limited blocking capability in the machine side converter. Here, the overvoltage problem does not exist since the line overvoltages are suppressed by the preceding link inductor and the current controller.

It is recommended for the above reasons to embark on the design of current source inverter drive systems for industrial applications in a power range up to several 100 kW. Simple single-chip microprocessors as mentioned under 5.1.4 can be employed for the electronic control of such systems. An optimal efficiency control scheme may be implemented for current source inverter drives in extension of the work under progress mentioned in chapter 4.5.

GTO based PWM inverters may be included in the development program at a later stage, when the work is extended to cover high power inverters for industrial drives and electric locomotives.

Power transistors can be used only with non-fluctuating voltage sources like batteries and solar cells. This confines the field of application of power transistors in India to uninterruptable power supplies (UPS) and solar power converters.

5.1.2 Uninterruptable Power Supply Systems

The technology of the snubberless transistor inverter and the philosophy of an internal high-frequency supply bus that were introduced to CEERI in the frame of this consultancy can be made the basis of developing a family of UPS systems at a power range from 0.5 to 50 kW. Higher power ratings can be included depending on a market analysis. Among the problems to be solved are:

- redesign of the cooling system for power transistors
- anti-saturation control of the output transformer
- control of the instantaneous value of the output voltage for high dynamic performance
- control of operation under steady-state short circuit condition
- design of a static by-pass switch including the associated control
- design of a battery charging system using the UPS inverter in the regenerative mode
- monitoring system for self-test
- redundant parallel operation of two or more UPS inverters (at a later stage)

5.1.3 Autoadaptive Switched Mode Power Supply for Personal Computers

The increasing use of personal computers in various fields commerce, management and research makes it desirable to become more independent from the wide-range voltage fluctuation of the public power supply. It is suggested to develop an auto-adaptive switched mode power supply to be incorporated in the PC which permits a safe operation over a range of input voltages from about 120 to 300 Volts without using voltage stabilizers.

5.1.4 Introduction of an 8 bit Single-Chip Microprocessor for General Application

The lecture mentioned under 3.6 above reported on a very compact ac drive system (power density 1 kVA/litre) using only one 8 bit single-chip microprocessor with memory for the implementation of entire control system including the PWM modulator, the overcurrent protection, and the drive control. In a similar application an 8 bit single-chip microprocessor was used to control a current source inverter. Such single-chip microprocessors are available either with integrated program EPROM, or in a piggy-back version, or mask programmable. Some of them are equipped with a serial data interface and an on-board analog-to-digital converter. It is suggested to select a suitable processor which can be generally used for any electronic control system with a view to reduce cost, space and power consumption, and to increase flexibility.

5.1.5 Soft Starter for Induction Motors

High power induction motors are used for a wide range of industrial applications where constant speed is required. The starting currents of these machines are inherently high which necessitates the implementation of a soft starting scheme in order to avoid transient overcurrents in the supply system.

Soft starters use phase-angle controlled back-to-back connected thyristors to implement a closed loop current control scheme in the stator circuit of the motor. This facilitates an automated starting process during which the motor currents are limited to a permitted value. The CEERI group already developed a soft starter for a 25 kW motor with the above method. With the expertise they have high power soft starters can be developed.

5.1.6 Stand-By Power Supply for Ice-Lined Vaccine Refrigerators

Portable refrigerators equipped with ice lining for an extended cooling duration of up to six hours without external power supply are demanded for transport and storage of vaccines in rural areas in India. The refrigerators are to be supplied by back-up power systems in cases of longer power failures in the mains.

It was originally intended to use a full bridge single-phase MOSFET square wave inverter with transformer and a battery charger for a 48 Volt lead-acid battery. After some discussions a revised design was proposed:

1. to use a PWM inverter half bridge with a centre tapped transformer in order to increase the efficiency,

2. reduce the operating frequency to 5 Hz at no load and start a frequency sweep up to 50 Hz when a load appears at the output of the inverter. This eliminates the starting current of the compressor motor and reduces the required current rating of the semiconductor switches by about 75 %.

3. eliminate the battery charger and replace it by an appropriate control of the inverter in the regenerative mode.

5.1.7 Vaccine Refrigerator Using Peltier Elements

It is suggested to study the scope of introducing peltier elements in a novel ice-lined refrigerator in order to replace the ac motor driven compressor cooling system. Peltier elements can be directly supplied from a 12 Volt battery, from a solar cell array, or from the 230 Volts ac mains through a lightweight switched mode power supply. Such system could exhibit the following advantages:

- built-in option to supply power from either a 12 Volt battery, from a solar cell array, or from the 230 Volts ac mains,

- lightweight construction, completely static cooling system, reliable and maintenance free,

- no starting problem with the compressor motor,

- no special batteries required, the vaccine refrigerator can be operated from the on-board electrical system of any car.

5.1.8 High Power PWM Inverter Using GTO-Thyristors

Gate turn-of thyristors will be increasingly used for static power conversion in controlled high-power ac machine drives. The technology is not yet fully developed in industrialized countries. Special attention in research is presently given to develop efficient and reliable methods for recovering the trapped energy in GTO snubber circuits.

In view of the importance of this technology for high power drives work should be taken up in this field. Owing to the complexity of the subject it is recommended to obtain a transfer of the presently available know-how in high-power GTO inverter technology, such as circuit design, gate drive techniques, overload and short circuit protection, and efficient snubbering. It is advised to seek collaboration in this field with an experienced agency.

5.2 Augmentation of Laboratory Facilities

In order to adapt the development work to modern requirements, the laboratory equipment needs to be augmented. It is suggested to procure the following instruments:

1 transient-recorder, 4 channels with individual trigger facility, 50 ns sampling rate, 20 MHz analog bandwidth, IEC-bus interface, external 10 " CRT display, personality module, IEC-bus connection cable, software for the transfer of recorded data to a personal computer,

1 Tandon AT computer, PC-DOS, 1 Mbyte working memory, 40 Mbyte harddisk, floppy disk drive, with Logimouse and IEC-bus interface, to be used for further processing and analysis of the waveforms transmitted by the transient-recorder and for the development of software for single-chip microcomputer (see 5.1.4 above),

1 Turbo Pascal compiler, version 4.0,

1 cross-assembler for single-chip microcomputer,

1 matrix printer,

1 logic-analyzer, 32 channels, 100 MHz,

1 digital storage oscilloscope, 2 channels, 50 MHz,

2 dc current probes, 100 Amp,

2 dc chokes, 4 separate windings for 0.375/1.5/6 mH at 800/400/ 200 Amp,

- various special components such as GTOs, fast power diodes, ferrite cores, laser-trimmed analog multipliers.

5.3 Recommendations for Staff Development

With respect to the f.ture development of the CEERI Power Electronics Group two facts should be considered:

1. The recent progress in semiconductor technology and new solutions for the implementation of fast switching high current power semiconductors in solid state power converters are presently making the traditional approach to system concepts and circuit design more and more obsolete, as these concepts are basically oriented to the requirements of the thyristor technology. The new trend is expected to accelerate, fostered by the enhanced switching capabilities of new power semiconductor elements such as IGBTs (isolated gate bipolar transistors), ETDs (easy to drive transistors), MOS-controlled GTO thyristors, ZTOs (zero turn-off time thyristors), and SITs (static induction thyristors.

2. In India, the economic and social conditions are different from those of abroad. This applies as well to the technical requirements and operating conditions of power electronic equipment, and to the demand of the national market. Accordingly, the objectives of research and development work as well as the methods applied to solve the current problems of this country may differ from the research topics of current interest as represented by the publications in international scientific journals. To exemplify this, reference is made to the problems associated with the application of power transistors in India which were discussed under 5.1.1.

It must be considered imperative for a research institute like CEERI to keep abreast with the new developments in the field of power electronics. This does not necessarily imply an immediate application of novel power semiconductor components, especially so as these are not all considered fully developed. It is important, however, to adopt and develop more modern and more systematic design methods for power electronic systems on one hand and give special emphasis on the aspects of reliability, minimization of cost, volume and weight, and the requirements of industrial production and serviceability on the other. This requires the engineer to acquire a broader professional background, to get exposed to the concepts of a large variety of practical applications related to power electronics by which he will develop a better understanding of the technical and economic aspects in the design and fabrication of power electronic systems.

The above objectives need to be pursued with priority.
It is recommended that:

- one engineer to be added to the group to support the expanded activities,

- two engineers of the CEERI Power Electronics Group to be sent abroad for a duration of 1 to 2 years each, for special training in the above areas on some collaborative research and development program.

Acknowledgement

An expression of appreciation and thanks is extended to all members of the Power Electronics Group for the fruitful co-operation, and for the mutual benefit which has resulted from the technical discussions. Gratitude is also expressed for the attention and care extended to the expert by the Institute during his stay at Pilani.