Recent Research of Power Electronics and Drives in Hong Kong

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***Abstract*—The research in Power Electronics and Dives at The Hong Kong Polytechnic University has been undertaking for many years. Recently, a Power Electronics Research Centre (PERC) has been developed that is contributed towards the research and development in the area. It encompasses the high frequency power supplies, chaos and bifurcation, soft-switching power converters, electrical machines, high precision motion control, traction and traffic control, alternative energy and electrical building services.**

***Index Terms*—Education, Research centre, Power converters, Machines, Drives.**

I. Introduction

HONG KONG has been an idealized area for the conducting power electronics research. This is mainly because the location and the industry in the area that enable its rapid development in the field. Hong Kong is a small city but with very high population and traffic network. The Kowloon-Canton Railways and the Mass Transit Railways are two major railway organizations. It provides a platform for the research development in the traction area. The computer industry in Hong Kong also enables the computer power supply development. The power supply research varies from a few watts to kW of server power supplies. The intelligent motion control for rotational, 2D and 3D linear actuation system is also one of the important research to support the Hong Kong industry in computer related peripheral and industrial drives. Because of the building industry in one of the major development in Hong Kong, electrical building services are therefore one of the important research area to support the local building industry. Electronic ballast, power factor correction and motion drives for Heating, ventilation and air-conditioning are also required input from power electronics. Alternative energy based on solar system, wind energy and fuel cell have been studied in building and transportation. Building integrated photo-voltaic (BIPV) is now being installed in buildings in Hong Kong.

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The Power Electronics Research Centre at The Hong Kong Polytechnic University is actively involved in the above research area. The centre is formed by two well-established power electronics research groups from Department of Electrical Engineering and Department of Electronics and Information Engineering in 2000. Today the centre has 20 academic staff members and over 30 research personnel. The centre has equipment over $8 million and 4 laboratories for conducting research and development. Annual journal publication is over 40. The research funding acquired from industry, government and university is over HK$4 million a year. The major areas of research and development as mentioned above are basic theory in power electronics, static power conversion, machines, drives, railways system and power conditioning. As power electronics requires multidisciplinary research areas, the centre focuses on the following areas:

High frequency power conversion is one of the major categories of electronic products. The typical applications include the electronic ballasts and power supplies. We have been very active in conducting researches in chaotic study of power converters, topology analysis, switched capacitor converters, improvement in efficiency, magnetics and switching techniques.

Motor and drives is a very important area for motion related products. The research areas include intelligent motion control, electric vehicle, motor loss analysis, phantom load and switched reluctance motor drives. Power conditioning, power quality and using power electronics to protect environment are also our research focus. We are also developing fuel cell, photo-voltaic, power factor correction and power quality optimization, superconducting energy storage and more green power supplies.

In addition to conducting research and development work, the centre provides various services to industry, such as consultancy, testing of utility system components, quality assurance evaluations, intelligent-home solution and professional training. We have equipment and facilities in all the general power electronics testing setup, electromagnetic compliance, power conversion testing, environmental testing and computer aided design. In the next sections, the salient research results are introduced and briefly discussed the mainly challenge that has been encountered.

II. STATIC POWER CONVERSION

This area is one of the very active topics of power electronics. The recent research results in this areas can be summarized as follows:

A. *Switched capacitor converters*

Conventional switched capacitor converter has the advantage of elimination of inductor but the main drawback is the pulsational current that increases the loss and EMI. Using a resonant method, the conventional switched capacitor converter can be changed into a resonant version [1-2]. All the devices are under zero-current switching. This significantly improves the efficiency and the emission. Therefore the converter can be operated in high power. There are many topologies for the circuits. This can be classified into step-up, step-down and inverting mode that is named by the voltage conversion ratio. Fig 1 shows a typical circuit of the step-down converter with conversion ratio equal to 1/n.

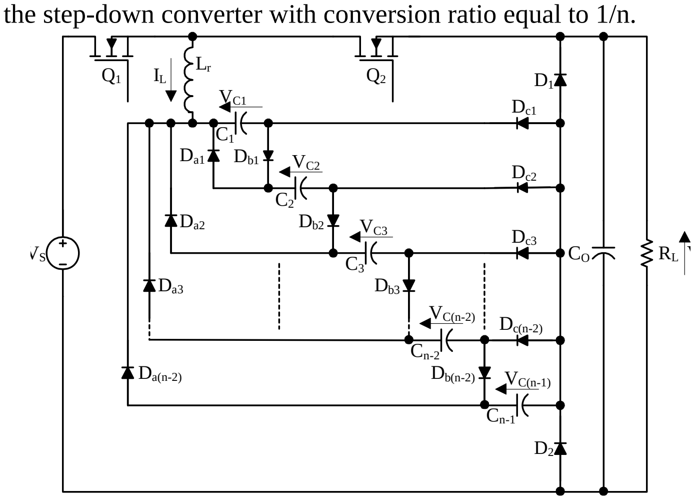


Fig 1. Step-down (1/n) resonant switched capacitor converter

B. *Chaos and bifurcation*

Power converters are highly nonlinear and exhibit chaos under certain operation condition. The conventional study of this areas are based on a simulation of the state-space equation of the converter through a wide range of operation in order to obtain the first flip bifurcation and the converters then goes into period-2, and then period-4 and eventually becomes chaos. Therefore in many cases, the prediction of another operational point for the bifurcation may not be simple. The common experimental verification is usually low frequency, less than 10kHz, which is not practical as most of the converters, because to avoid the acoustic problem, is operated at 20kHz or above.

Using an iteration mapping method, the equations under a frequency scaling and the linear mapping of the bifurcation parameters have been derived. It can be found that the circuit parameters after changed can predicted easily if the frequency are scaled proportionally provided that the impedance of the L or C is unchanged. These results enable the prediction of any frequency of operation for the bifurcation [3-4]. Experimental results at 20kHz and 50kHz have been used to verified the results. Fig 2 shows the results.

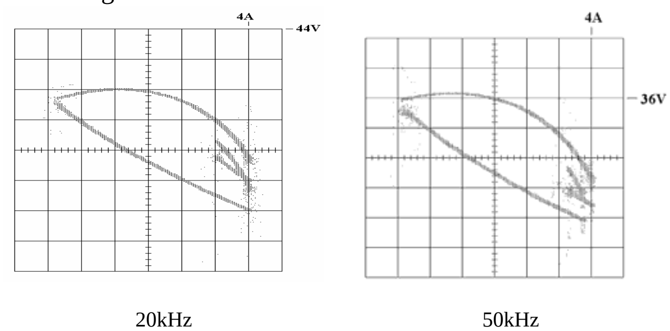


Fig 2: Experimental Period-2 phase trajectory 4V/div; Hor: 0.5A/div)

C. *Phase-shifted power converters*

Phase-shifted power converters as shown in Fig 3 are based on the phase-angle between two single-phase legs to obtain a constant frequency variable mark-space ratio. The main advantage is that the converter is under zero-voltage switching (ZVS) an the operation is at constant frequency and therefore the design of the filter is also easier, but the range of operation under ZVS is very limited [5]. Using an extended range method [6] where the light-medium load can be operated under ZCS and therefore the resonant transition rage can be extended to very light load. The voltage conversion characteristics can be improved to light load condition and monotonic variation. The typical characteristic is shown in Fig 4.

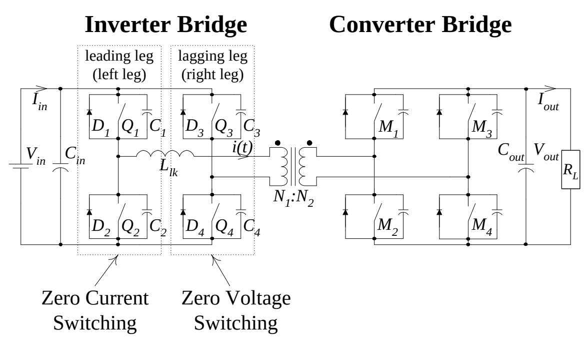


Fig 3 Phase-shifted DC/DC converter

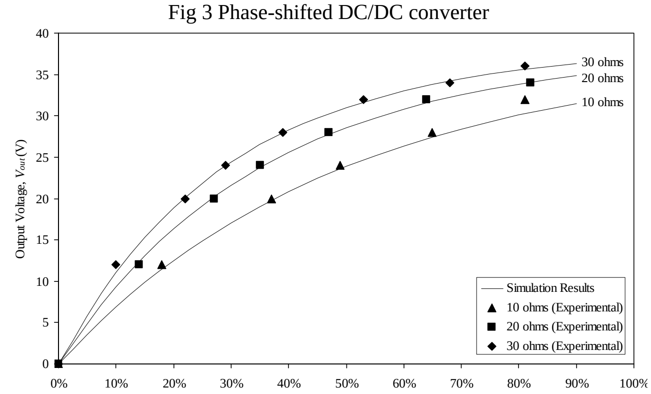


Fig 4 Characteristics of the conversion ratio under resonant transition

D. *Power factor correction*

The power factor correction is now a mandatory feature for all the systems that draws power from the mains. The research in this areas has been concentrated on both 3-phase and single phase circuits for the improvement of the controllability and stability using intelligent control [7] and the reduction of the power devices for electronic ballast circuit[8].

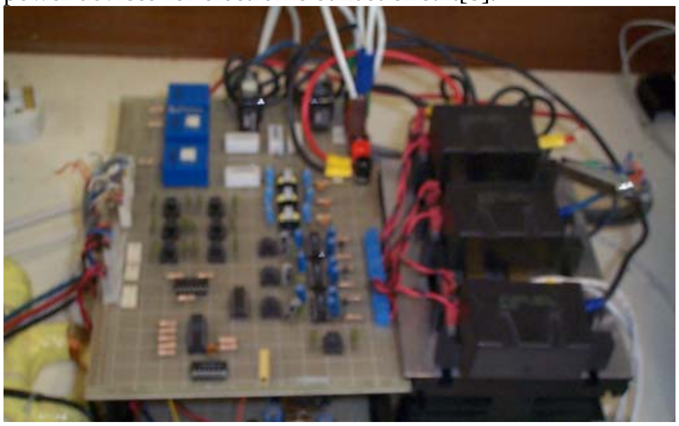


Fig 4: Three-phase power factor correction prototype.

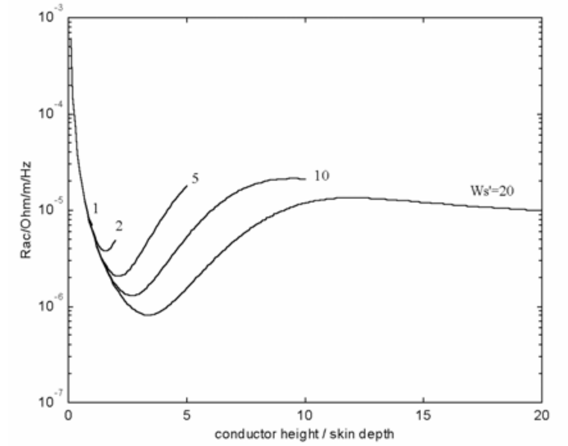


Fig 5: R_{ac} against bundle size with various turn pitches – 3 layers and 36 strands

III. MAGNETICS

Magnetics is one of the important elements in the power conversion. It can be used as an isolation transformer for voltage-stepping, resonant inductor and filter inductor. Recent research on integrated magnetics is also imposed an important research area for this study.

A. Integrated magnetics

The integration of the inductor and transformer is now a modern trend for the minimization of the converter size [9]. By suitably looking into the conduction condition of the inductors and transformers, and also the geometry of the core, the magnetic components can be integrated and optimized in terms of the performance in both switching, efficiency and energy storage. A systemic design procedure is developed for this work.

B. Winding loss calculation

The transformer and inductor's windings are usually wounded in multi-layer and multi-strand. In the pass, the single stranded wire modelling method cannot be applied directly for high frequency inductor and transformer where the windings are stranded wire. The reaction field among strands and other layers imposed a strong eddy current and the corresponding AC loss varies significantly with frequency and parameters of the magnetic device. A multi-layer and multi-layer generalized modeling has been developed [10] that can calculate the AC resistance accurately. The method is programmed in a normalization manner so that it can be applied to any frequencies and conductor and core sizes. The most prominence is the high accuracy of the resistance calculation. Fig 5 shows the normalized AC resistance of 3 layers and 36 stranded winding.

C. Magnetic core modelling

Classical one-dimensional field analysis is usually restricted to simple inductor and transformer. This type of calculation for winding losses of high frequency transformer based on one-dimensional field analysis is normally inapplicable for complex winding configurations. A matrix modeling method [11] which can produce a generalized mechanism to solve the ac winding losses has been investigated. The transformer is modelled in a matrix connected filament as shown in Fig 6. The method is analogous to the finite element but is now a filament method. Experimental results and computation results using the proposed method are found to have good agreement.

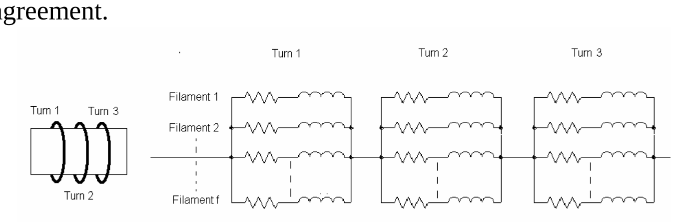


Fig. 6: Illustration of the construction of filament from turns.

D. Polymer-bonded magentics

A new magnetic bonded material has been developed. It offers many advantages compared to the conventional type of magnetic materials including shape, physical property and cost. This is a new type materials will form a new era of power conversion and is also a new area of research. Until today, no research has been reported on use of polymer bonded magnetic materials. It is especially useful for high frequency operation because the material is an evenly distributed airgapped materials and the eddy-current loss is low. One of the typical problems is for application in high power conversion such as more than 20kW system where the transformer or inductor requirement is getting very difficult to obtain because the mechanism of formation of Ferrites or powder iron is very difficult and expensive. The polymer-bonded magnetic material is composed of polymer matrices and magnetic powders which can be produced by traditional polymer processing methods. Hence, it offers significant advantages over the conventional counterparts. One of the important advantages is the ease of moulding such as injection moulding which can save on manufacturing costs and quality control. Fig 7 shows the waveform of a flyback converter which is using this new material for the coupled inductors.

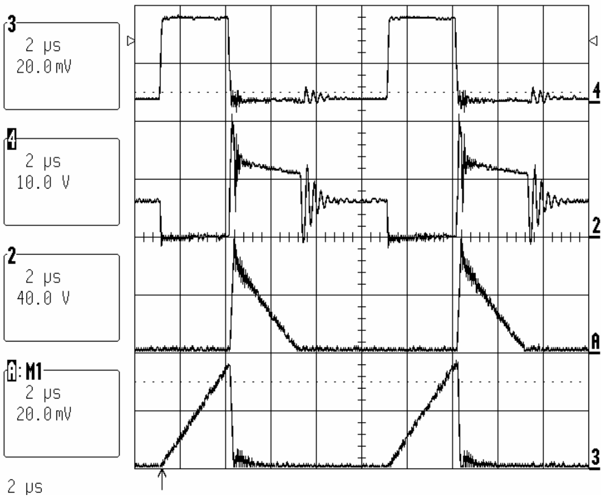


Fig 7: Po=20W, efficiency=70%, duty ratio=0.3
(Ch3: Primary current: 2A/div; ChA: Secondary current 2A/div, Ch2: V_{DS}:10V/div; Ch4: V_{GS} 10V/div)

IV. TRACTION AND TRANSPORTATION

A. Traffic control

The traffic control in congested rail work is studied. In order to avoid traffic conflict and to have safe passage, suitable signaling and interlocking system is needed [13]. The additional requirement is to minimize the delays imposed on the trains by assigning the right-of-way sequence. A deterministic method with heuristic has been proposed to solve the above problem. Fig 8 shows a train simulator developed. The advantage of this method will lead to an intelligent time-table for the improvement of the services, power consumption and safety.

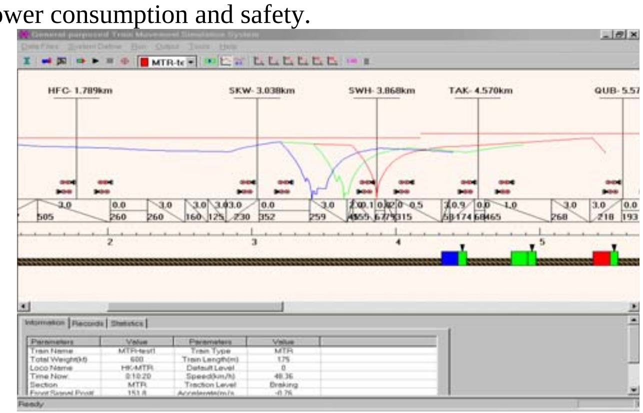


Fig 8: Train simulator

B. Load flow in Railway Systems

The load in a railway system is complicated and the involvement includes some dynamic movement among various networks and the system involves the transformer substations, track segregating feeding points. This study includes the use of stochastic method, probabilistic load flow techniques to deal with the uncertainties. A probability distribution function is developed for various load conditions.

C. Electric Vehicle

The research area includes the power conditioning and improved drives for the vehicle. The study of the batteries for the vehicle is also undertaken. The study includes 4-wheel vehicle, scooter and bicycle. Fig 9 shows vehicles under development.

Fig 9: Electric vehicles

D. Traction motors

The traction motors suffers from frequent starts and stops. The thermal management, control strategy, environmental condition, etc are important factors affect the performance. The test of the motor is also difficult because of the rating. Phantom loading is a proposed method which can remove the problem for testing using huge dynamometer [14].

V. ALTERNATIVE ENERGY AND BUILDING SERVICES

A. Fuel cell

Fuel cell is one of the cleanest and efficient technologies for generating electricity [15]. Since no combustion is need, there is no pollutant produced. The area of research that is pursuing is the modeling of the Proton Exchange Membrane (PEM) for fuel cell. Also the system optimization, power conditioner design and over system design will also be studied. Fig 10 shows the fuel cell under study.

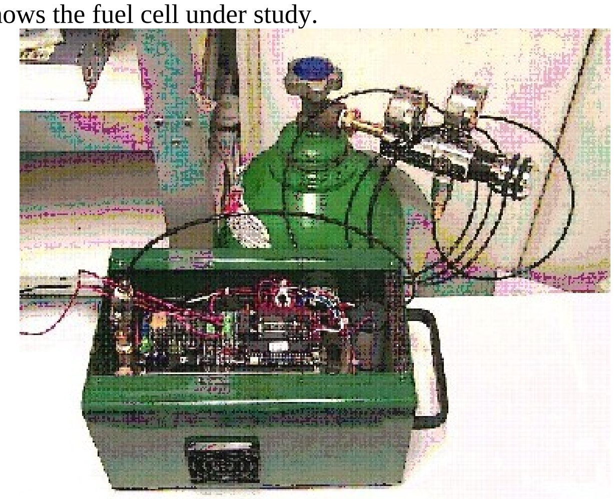


Fig 10: A low power fuel cell under test

B. Building services

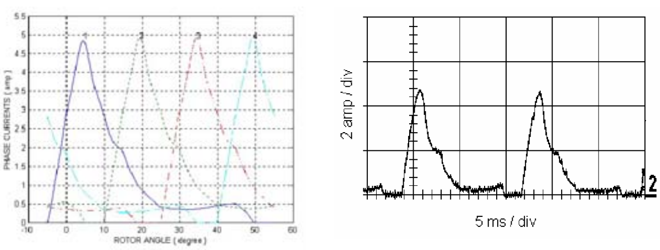
Today the Electrical network for buildings is complicate. Sensitive electronic and computer devices are connected to the building installation. Study on switching transient in common electrical installation and to ensure good power quality in the electrical supply network for satisfactory operation is necessary for recent research in building services.

VI. Machines and Drives

The research in this area has been concentrated on the switched-reluctance motor (SRM) and induction machines. Both rotational and linear versions are investigated.

A. Coupling between the windings for SRM

A non-linear modeling of multiphase switched reluctance motors (SRMs), in which both self- and mutual couplings between all phases is described by self-inductance, mutual inductance and coupling coefficient. Moreover, an iteration algorithm to solve initial value problems of the modeling is proposed [16]. Expressions for computing instantaneous torque from both self- and mutual coupling are derived. The method is very fast in calculation as compared with other conventional method. The simulation and experimental results of an SRM under test are shown in Fig 11.



Simulated Measured

Fig 11: Phase current waveforms

This study is very helpful for accurately simulating multiphase SRMs, accurate performance predictions of SRMs, and accurate computer aided-design of SRMs, as well as studying effects of mutual coupling on some performances and improving some performances of SRMs.

B. Modelling for the magnetic characteristics for SRM

A novel simulation algorithm [17] switched reluctance motor drives is studied. With the proposed algorithm the two-dimensional bicubic spline interpolation is used to describe the nonlinear magnetic characteristics in switched reluctance motors. The corresponding computational method of two-dimensional bicubic spline function is used for this studied. The simulation results as shown in Fig 12 give a very accurate characteristic with only very limited input data. The method has been confirmed by experiment. The simulation algorithm is more accurate even though it requires relatively little information on the magnetic characteristics of the motor.

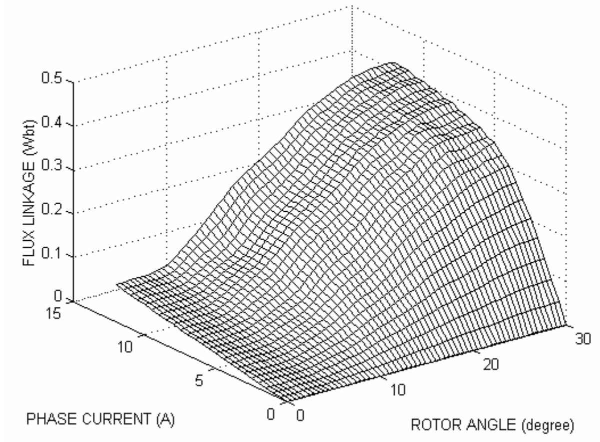


Fig. 12:. Interpolated magnetic characteristics

C. Finite element for motors

A 2D and 3D finite element program has been developed for the analysis for the motor and its associated field problem. The program has been used to study various research problems in electric machines. Numerous journal publications have been produced [18]. Fig 13 shows one slice of an 11kW motor using FEM mesh

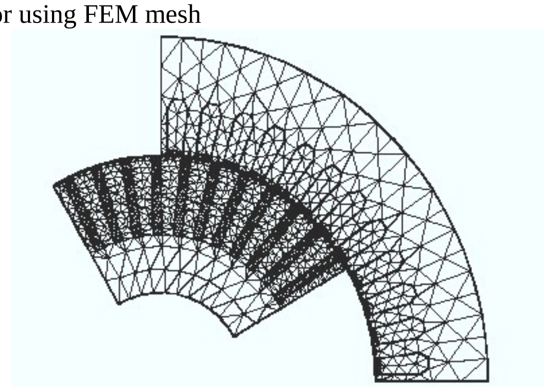


Fig 13: Mesh analysis of Electric motor

D. Induction generator

Single-phase operation of a -3phase induction generator has been analyzed using symmetrical components [19]. The condition for achieve good balance are deduced. Fig 14 shows a Smith connection and capacitances required for the connection.

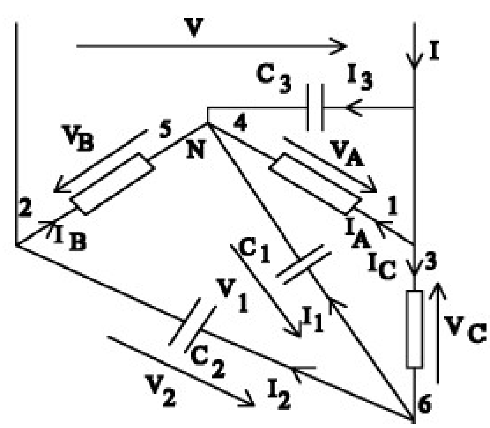


Fig 14: Smith connection for single phase operation of induction generator

VII. Conclusions

The Power Electronics Research Centre at the Hong Kong Polytechnic University is one of the leading research groups in the region. It is fully supported from the industry and the local government. The research topics that are conducting are the latest research and to work together with the local industry. Research in fundamental study of power electronic system as well as applied research is also been undergoing. Our aims are to use the above experience to help local industry and the region to improve competitiveness through consultancy services, cooperative projects and research development of new technologies.

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