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Transformer Less Voltage Quadrupler Based DC-DC Converter with Coupled Inductor and PI Filter for Increased Voltage Gain and Efficiency

C. Sujitha[1], S. Ravi[2], Bakary Diarra[3], Joseph Chuma[4]
[1]Department of Electrical and Electronics Engineering, SRM University, Chennai, India
[2,3,4]Department of Electrical Computer and Telecommunications Engineering, Botswana International University of Science and Technology, Palapye, Botswana

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ABSTRACT

In this paper a voltage quadrupler dc-dc converter with coupled inductor and π filter is presented. The use of the coupled inductor reduces the high leakage inductance which is present in a transformer enabled converter. The output ripples in the converter is reduced by providing a π filter. The interleaved voltage quadrupler is used in this system in order to boost the output voltage. The voltage multiplier improves the output voltage gain. The main advantage of this system is more voltage gain when compared with the transformer eneabled circuit and the overall efficiency of the system is improved. The circuit is simple to control. As a final point of this research, the simulation and the hardware investigational results are presented to demonstrate the effectiveness of this proposed converter.

Corresponding Author:

C. Sujitha,
Department of Electrical and Electronics Engineering,
SRM University, Chennai, India.
Email: saisuji88@gmail.com

1. INTRODUCTION

At present the dependency on renewable energy sources are increasing day by day because of the energy deficiency and the environmental contamination caused by the fossil fuels. The major downside of renewable energy source is that it generates low voltage output. So the high step up DC-DC converter has been widely employed in many renewable energy applications [1-3]. The renewable energy system transfers energy from renewable sources to electrical energy and convert low voltage to high voltage by using a step up converter. Mainly DC boost converters are needed to boost up DC voltage.

If the duty ratio is larger means the output voltage is high, but it leads to high conduction time and also that leads to resulting in high voltage stress on the switching device causes large conduction loss. By the use oftheinterleaved boost converter with voltage quadruplerconcept itwill achieve high output voltage and reduce the voltage stress and conduction loss.

2. CIRCUIT EXPLANATION

The block diagram of the proposed system is shown in Figure 1 and the proposed circuit diagram is given in the Figure 2. The proposed converter topology is basically derived from a two-phase interleaved boost converter. The proposed system is an interleaved boost converter with coupled inductor and voltage quadrupler [4-6]. Two balanced capacitors are connected in the circuits to achieve the balanced output voltage. The conduction period of each of the two stages of inter-leaved switches is 50%. This reduces the switching stress and conduction loss. By using the voltage quadrupler, the output voltage is increased four times. In this work, the π filters are connected at the output in order to reduce the current ripples and thereby reducing the losses in the load.

The use of transformers are detached in theproposed circuit. Instead of using the transformer, coupled inductors are used. Because the use of transformer enhances the saturation loss. The coupled inductors have multiple windings coiled on the same core for high value of inductance in common mode current while giving low value of inductance for the differential mode current. Coupled inductors have lower leakage inductance and AC current losses when compared to the transformers.

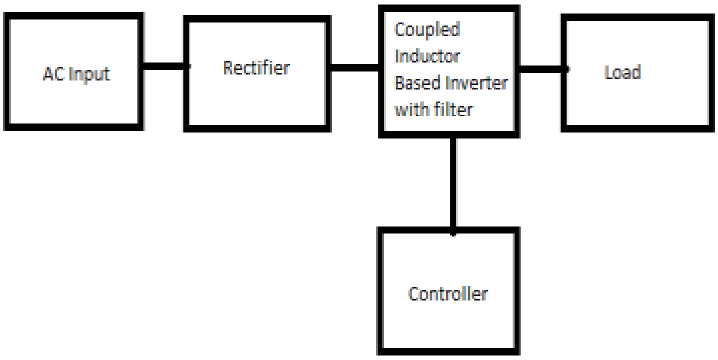

Figure 1. Block Diagram of the Proposed System

In the voltage multiplier circuit, two or more peak rectifiers are cascaded to produce a DC voltage equal to multiplier peak input voltages [7-8]. In this paper voltage quadrupler is used. The association of another diode capacitor section with the voltage tripler circuit produces an output four times the peak voltage. In this circuit, a π filter is proposed. A typical capacitor input filter or a π filter consists of a filter or reservoir capacitor C_1, connected to the rectifier output, an inductor L, in series and another filter or smoothing capacitor, C_2, connected to the load, RL. A filter of this type is designed for use at a particular frequency, generally fixed by the AC line frequency and rectifier configuration. When used in this system, the filter performance is often characterized by its regulation and ripple.

Generally, the capacitor C_1 offers a low reactance to the AC component of the rectifier output while it offers infinite resistance to the DC component. As a result, the capacitor shunts an appreciable amount of the AC component while the DC component continues its journey to the inductor L. The inductor L offers high reactance to the AC component but it offers almost zero resistance to the DC component. As a result the DC component flows through the inductor while the AC component is blocked. The capacitor C_2 shunts the AC component which the inductor had failed to block. As a result only the DC component appears across the load RL. The main merits of using a π filter are that it provides output voltage and also it achieves the ripple free output.

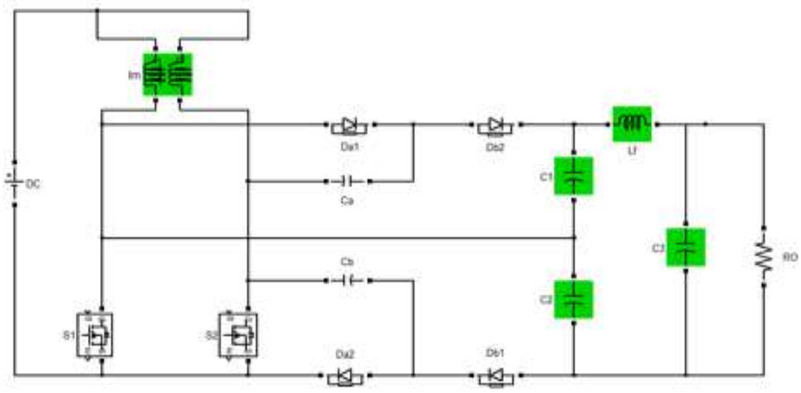

Figure 2. Proposed System Circuit Diagram

3. MODES OF OPERATION

The operation principle of the proposed circuit can be explained with four modes:

3.1. Mode 1 Operation

In this mode of operation, both the switches S_1 and S_2 are conducting which is exposed in Figure 3. So the energy is stored in the coupled inductor. Along with the self inductance, there exists the mutual inductance. Due to the mutual inductance, the output is increased.

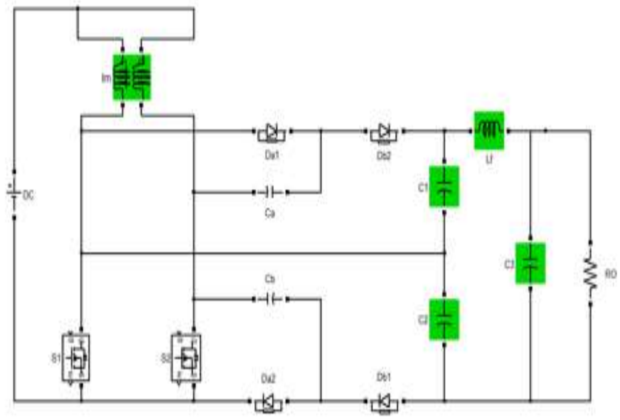

Figure 3. Mode 1 Operation

3.2. Mode 2 Operation

The mode-2 operation is revealed in the Figure 4. In this mode, only the switch S_1 is conducting. The energy is stored by the inductor L_1 and also some energy will be induced in the inductance L_2 by the principle of mutual inductance. The path followed by the induced energy will be C_a–D_{b2}–L_f –C_2.

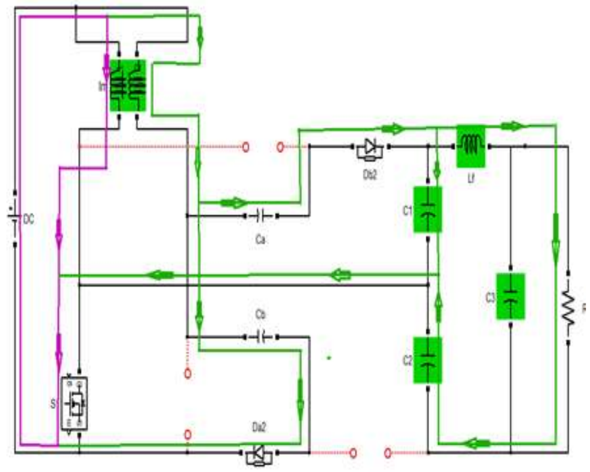

Figure 4. Mode 2 Operation

3.3. Mode 3 Operation

The mode-3 operation is shown in the Figure 5. This mode of operation is similar to the mode 1 operation. In this mode also both the switches S_1 and S_2 areconducting. The energy is stored bythe coupled inductor. Along with the self-inductance, the occurrence of the mutual inductance also takes place and due to this the output value is increased.

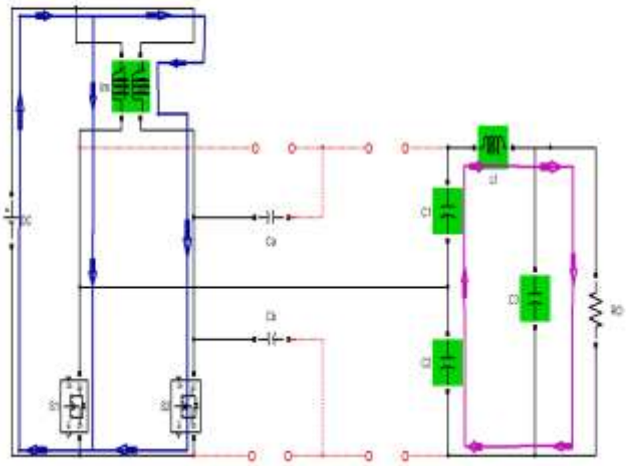

Figure 5. Mode 3 Operation

3.4. Mode 4 Operation

The mode-4 operation is revealed in the Figure 6. In this mode of operation, the switch S_2 will be conducting. In the coil L_1, some energy is induced due to the mutual inductance. The path followed by the induced energy is from C_1–L_f–R D_{b1}–C_2. In this mode, the output capacitor voltage is the sum of the voltage across V_{Cb} andV_{Ca}.

4. MATLAB SIMULATION EXPLANATION

The simulation was done in the MATLAB/Simulink platform. The simulation block diagram is shown the in Figure 7. The proposed converter uses the input of 16 V voltage which is shown in Figure 8 and the output voltage achieved is 240 V which is shown in Figure 9. The switching frequency used in this circuit is 40 kHz and the duty ratio of S_1, S_2 is 0.50. This duty ratio is used to reduce voltagestress and current and finally the conduction loss. The interleaved structure can effectively decrease the switching losses.

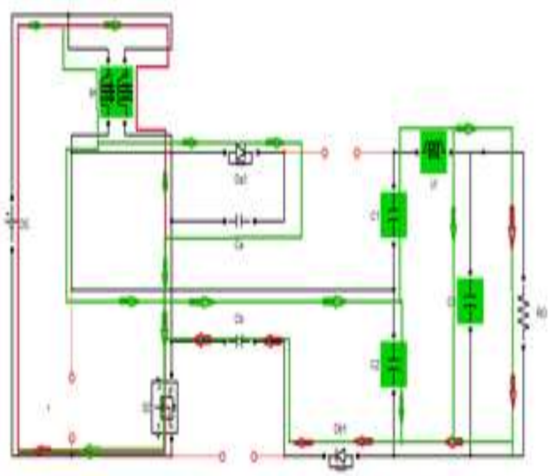

Figure 6. Mode 4 Operation

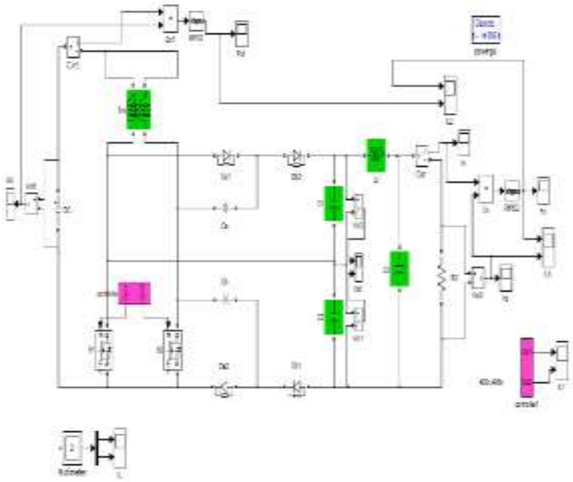

Figure 7. MATLAB Simulink Circuit for the Proposed Converter

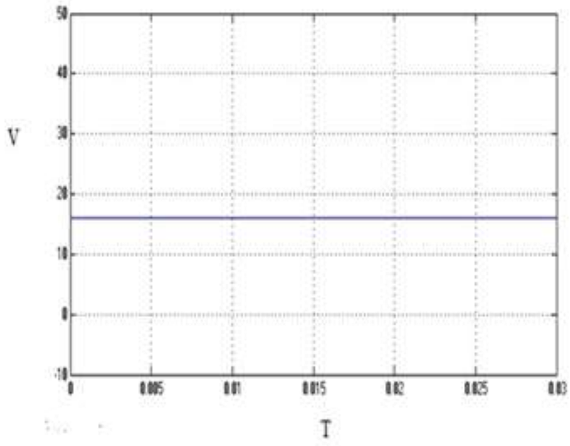

Figure 8. MATLAB Simulation of Input Voltage

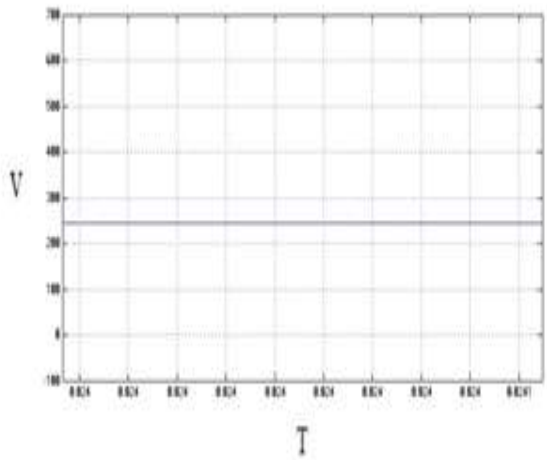

Figure 9. MATLAB Simulation of Output Voltage

5. EXPERIMENTAL MODULE

The overall block diagram of the laboratory prototype is shown in Figure 10. The hardware power circuit is shown in Figure 11. Each block of the laboratory prototype is explained as follows. DC source gives the DC supply to the boost converter. The DC source may be Battery or fuel cell or rectified from AC source. Rectifier converts AC to DC. This output has ripples. It is filtered with thehelp of Capacitor. It is used to run the motor, battery charging, and telecommunication applications. PIC 16F877A microcontroller is used to generate triggering pulse for MOSFETs. It is used to control the outputs. Microcontrollers have more advantages such as fast response, low cost, small size and etc. Interleaved Boost converter converts low voltage dc supply to high voltage DC supply. The output voltage is controlled by controlling the firing angle of the MOSFET. Interleaved concept is used to reduce the output ripple current. Regulated Power supply (RPS) gives 5V supply for microcontrollers and 12V supply for driver. It is converted from the AC supply. The AC supply is step down using step down transformer. The driver 1 and 2 arealso called as power amplifier andthey are used to amplify the pulse output from microcontroller. It is also called asoptocoupler IC. It provides isolation between microcontroller and power circuits. The components and ratings are shown in Table 1.

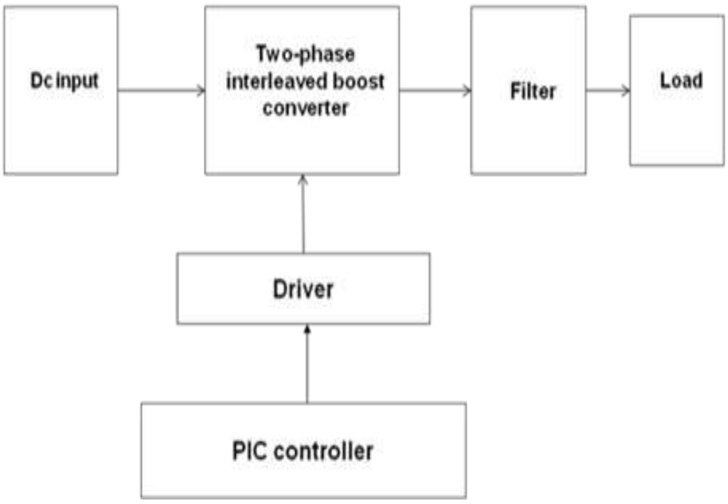

Figure 10. Hardware Block Diagram

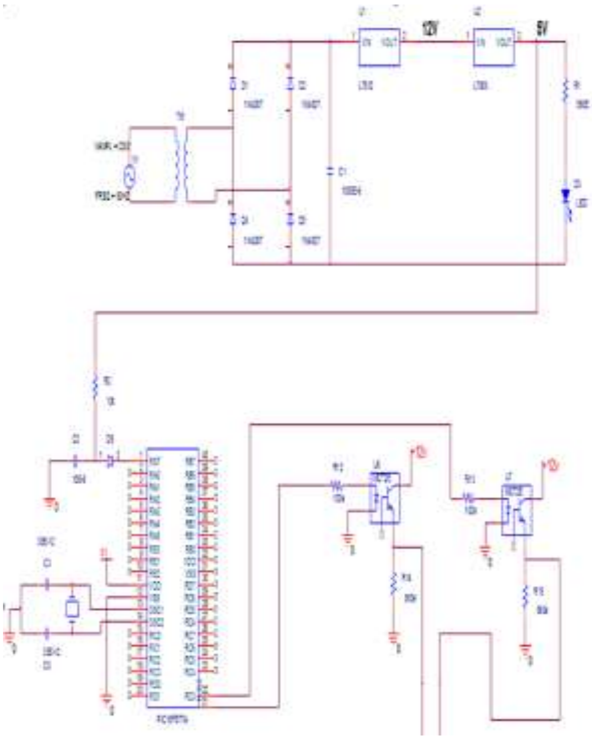

Figure 11. Hardware Power Circuit

Table 1. Components and Ratings

Components	Name	Ratings
MOSFET	IRF 840	500V, 8A
Diode	IN 4007	1000V, 1A
Capacitor		10µf, 63V
Output Capacitor		470µf, 63V
Inductor		150µh, 2 A
Resistor		15KOhms, 10 Watt
Coupled Inductor		1:1 Ratio

6. RESULTS AND DISCUSSION

The input voltage is givenin the simulation of the proposed circuit is 16 V which is shown in the Figure 8. The output voltage achieved in the simulation is 240 V which is shown in the Figure 9. The overall picture of the hardware kit is revealed in the Figure 12. The output voltage from the hardware obtained is 136.4 V which is shown in the Figure 13. The voltage output waveform of the hardware is shown in Figure 14. From the simulation and hardware results, the proposed system achieved increased output voltage gain with high efficiency and also the system is simple to control.For the transformer enabled system without π filter, the voltage gain is 16 times and the efficiency is 78 %. But for the proposed system with π filter, the voltage gain is increased to 18 times and also the efficiency increases by 83%. The output ripples in this system is also reduced to minimum amount by using the π filter. From the simulation and the hardware results obtained for the proposed system, the transformerless interleaved voltage quadrupler converter with π filter and coupled inductor increases the output voltage gain, efficiency and decreases the output ripples by using π filter and also the switching voltage stress can be reduced.

Figure 12. Hardware Picture of the Proposed System

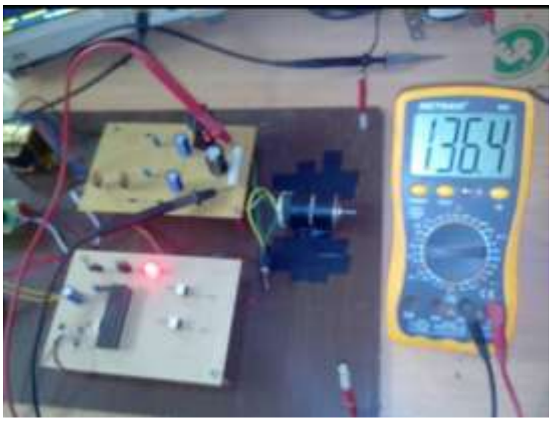

Figure 13. Output Voltage from the Hardware

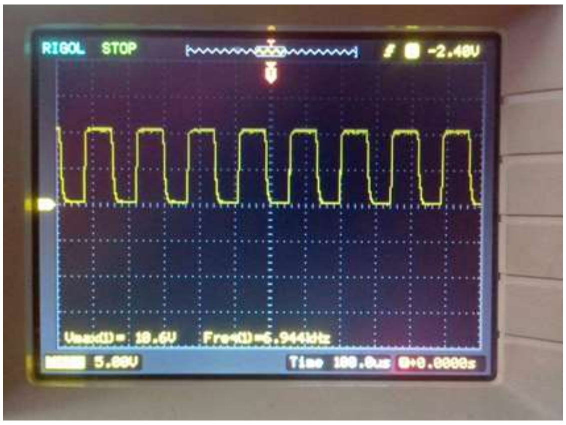

Figure 14. CRO Output Voltage Waveform

7. CONCLUSION

In this paper the interleaved Voltage quadrupler DC-DC converterwith coupled inductor was discussed and it achieved high voltage gain and reduced voltage stress, current ripple and conduction losses. With the help of interleaved boost converter with voltage quadrupler circuits and to get a balanced output voltage connection of balanced capacitor finally the input voltage is 16V and the output voltage is 240V. By using the coupled inductor the saturation loss also can bereduced. Hence the output voltage gain, efficiency is increased and the switching voltage stress, output ripple content, conduction loss and switching loss is reduced in this system. Hence the desired outcome was achieved by the use of interleaved quadrupler voltage DC-DC converter with coupled inductor.

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BIOGRAPHIES OF AUTHORS

Ms. C. Sujitha received his B.E degree in Electrical and Electronics Engineering from Nandha Engineering college, Erode, India in 2009. She received her M.E degree in Power electronics from Kumaraguru College of Technology, Coimbatore in 2011. Also she received her M.B.A. degree in Human Resources from Bharathiyar University, Coimbatore. Presently she is working as an assistant professor in the department of Electrical and Electronics Engineering, SRM University, Kattankulathur, Chennai, India. Her research interests includes the area of renewable energy resources, smart grid, power quality issues, application of power electronics and drives, web and embedded systems. She is a life member of Indian Society of Technical Education, member of Indian Science Congress and a member of IEEE.

S. Ravireceived his B.E degree in Electrical and Electronics Engineering from Periyar University, Salem, India in 2003. He received his M.E degree in Power Electronics and Drives from Anna University, Chennai, India in 2006. He received his Ph.D degree in the area of Intelligent Control Systems from Anna University, Chennai, India in 2012. Presently he is working as a Senior Lecturer in the Department of Electrical, College of Engineering and Technology, Botswana International University of Science and Technology, Botswana. His research areas are intelligent control systems, Solar PV systems, Power Electronic Converters. He has published 50 research papers in reputed International Journals and Conferences.

Bakary Diarra received his B.E degree in Electrical Engineering in 2008 from Joseph Fourier University of Grenoble, France. He received his M.E degree in Electrical Engineering in 2010 from the National Institute of Applied Sciences of Lyon (INSA Lyon), France. He obtained his PhD in 2013 in ultrasound imaging and optimization from Claude Bernard University of Lyon in co-supervision with the University of Florence in Italy. His research focuses on the design and the optimization of 2D matrix sensor array using global optimization algorithms. Currently, Dr Diarra is a lecturer in electrical engineering at Botswana International University of Science and Technology (BIUST).

Joseph M. Chuma is an Associate Professor of Telecommunication and Wireless Communications at the Botswana International University of Science and Technology. He received a BEng in Electrical and Electronic Engineering from University of Nottingham, UK in 1992, an MSc in Telecommunications and Information Systems and a PhD in Electronic Systems Engineering from University of Essex, UK in 1995 and 2001 respectively. His main areas of research are in the design of compact single and dual mode dielectric resonator filters for mobile communications. His research work has led to successful results in the development of dielectric loaded filters and shown that the size of the conventional combline filter can be reduced in excess of 75%. In this example, a dielectric ring has been used to load a conventional combline resonator. Prof Chuma has served as the Dean of the Faculty of Engineering and Technology at University of Botswana. He is also serving as a Board Member in a member of ParastatalsOrganisation in Botswana. He has also served as a Postgraduate and Undergraduate external examiner in a number of Universities.