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MODELING AND PERFORMANCE ANALYSIS OF CUK CONVERTER USING PI AND OCC METHOD

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Abstract- In this study, One Cycle Control (OCC) and PI control methods are implemented to the Cuk Converter. A Cuk converter provides an output voltage that may be less than or greater than input voltage. An important advantage of Cuk converter is a continuous current at both the input and the output of the converter. Disadvantages of the Cuk converter are a high number of reactive components and high current stresses on the switch. The Cuk converter uses an additional inductor and capacitor to store energy. Due to the feedback loop is required to keep on regulation, some type of compensation is inevitable to satisfy the loop stability. The scope of the control methods is that the controlling the load voltage according to variable supply voltage, reference voltage and load power. PI controller, being the most widely used controller in industrial areas where speed of the system is not an issue. OCC method is nonlinear method that uses the concept of control of average value of switching variable at every cycle. Cuk converter is the most commonly used SMPS circuit for power applications. In order to observe the behavior and robustness of the controlled circuit; load current, input voltage and reference voltage are changed to obtain constant output voltage. These methods are stimulated by MATLAB/Simulink program.

Keywords: Cuk Converter, One Cycle Control, PI Control, Duty Cycle, PWM, Power Converter.

I. INTRODUCTION

Cuk converter is a type of DC to DC topology that has an output voltage magnitude is either greater or less than the input voltage value. It is a boost converter followed by a buck converter with a capacitor to couple the energy. Similar to the buck–boost converter, Cuk converter is inverting Sepic and also a Flyback typology. It uses a capacitor as its main energy-storage component, unlike most other types of converters which use an inductor [1].

Negative to positive voltage conversion methods are used in various applications such as industrial applications, space stations and automobiles. The DC to DC topologies used for this purpose include switched capacitor (SC), switched inductor (SI) and both are included [2]. The circuit of Cuk converter can be seen from Figure 1.

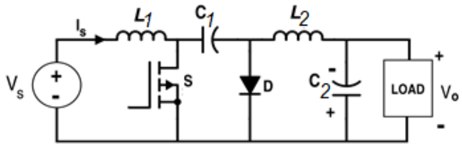


Figure 1. The scheme of Cuk converter topology

In order to achieve a controlled DC/DC converter both PI and OCC methods are applied to Cuk converter. Software simulations are made by using MATLAB/Simulink to observe the reactions of the DC to DC converter to input voltage, load current and reference voltage variations. In fact, software simulations helped to set the inductance and capacitance values that are used in the converter.

II. CONVERTER DIAGRAM AND WORKING

There are different topologies used in DC to DC converters. The topology used in this study is a Cuk converter whose circuit diagram is shown in Figure 1. This converter is composed Buck converter and Boost converter. An important advantage of this topology over the similar DC to DC converters is that the input and output currents of the circuit are continuous. Hence, the converter performance is high. The output voltage regulation and the control strategy are achieved by controlling the switch S is on state or off state. The different operating modes of the converter during on state and off state are shown in Figure 2(a) and 2(b), respectively [2].

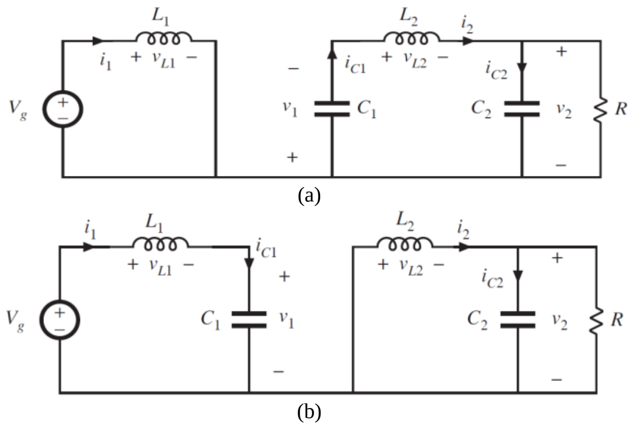


Figure 2. Equivalent circuits of the converter for on/off states of the switches during; (a) On state, (b) Off state

The converter circuit is divided into two parts as shown in Figure 2. During On state, when transistor switch is closed then current through inductor L_1 rises. At the same time the voltage of capacitor C_1 reverse biases diode D_1 and turns it off. The capacitor C_1 discharges its energy to the circuit formed by L_2, C_1, C_2 and the load (Figure 2(a)). During Off state, when the input voltage is turned on and switch S is open, then diode D_1 is forward biased and capacitor C_1 is charged through L_1, D_1 and the input supply V_g. The energy which is stored in the inductor L_2 is transferred to the load. The diode D_1 and the switch S provide a synchronous switching action (Figure 2(b)).

The Cuk converter can step the voltage either up or down, depending on the duty cycle. The Cuk converter contains the series inductors at both input and output; hence, it has much lower current ripple in both circuits. The average output voltage can be calculated in terms of the switch duty cycle [3].

$$\text{Duty cycle,} \quad D = \frac{-V_o}{V_s - V_o} \tag{1}$$

where, D is on time duration of switch/ total switching time period.

$$\text{Output voltage,} \quad V_o = -\frac{DV_s}{1-D} \tag{2}$$

In this study, the input voltage value (V_s) is determined 28 V and the output voltage value (V_o) is determined 12 V. According to Equation (1), the duty cycle is 30%.

Design parameter and equations for non-isolated Cuk converter are as follows:

$$L_1 = \frac{DV_s}{(\Delta I_{L_1}) f_s} \tag{3}$$

$$L_2 = \frac{(1-D)V_o}{(\Delta I_{L_2}) f_s} \tag{4}$$

$$C_1 = \frac{D}{(Rf_s)(\frac{\Delta V_{C_1}}{V_o})} \tag{5}$$

$$C_2 = \frac{(1-D)}{(8L_1 f_s^2)(\frac{\Delta V_{C_2}}{V_o})} \tag{6}$$

where, f_s is switching frequency, ΔI_{L_1} is peak to peak ripple current I_{L_1} (assuming 20% of I_{L_1}), ΔI_{L_2} is peak to peak ripple current I_{L2} (assuming 20% of I_{L2}), ΔV_{C_1} is voltage ripple (assuming 5% of V_o), ΔV_{C_2} is voltage ripple (assuming 20 mV), and D is duty cycle.

According to Equations (3)-(7) calculated value of design variables are D=0.3, L_1=117 µH, L_2=50.4 µH, C_1=1 mF and C_2=3mF.

Table 1. Parameter used in Cuk converter

Output power	P_o	500 W
Output voltage	V_o	12 V
Input voltage	V_s	28 V
Switching frequency	f_s	20 kHz
Inductance values	L_1, L_2	117µH, 50.4µH
Capacitance values	C_1, C_2	1 mF, 3 mF

III. IMPLEMENTATION OF PI CONTROL METHOD TO CUK CONVERTER

The PI controller is control strategy that calculates an error value as the difference between a set point and measured value [4], [5], [6]. Such a control strategy applied to a Cuk converter and its performance is observed by using MATLAB/Simulink. The circuit diagram of Cuk converter with PI control can be seen from Figure 3.

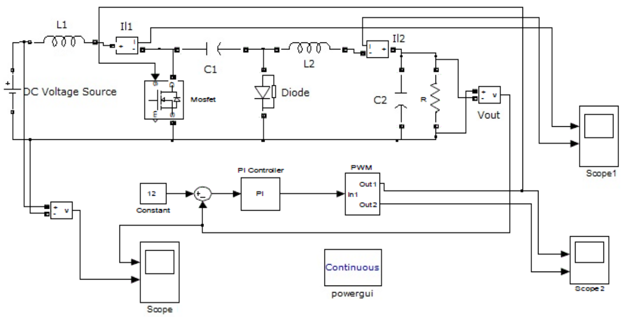


Figure 3. The circuit diagram of Cuk converter with PI control

Firstly, the input voltage is suddenly increased to 42 V that is 50% higher than the actual source voltage. Input and output voltage during this variation can be seen in Figure 4. The output voltage is equal to 12 V in steady-state although the increasing of input voltage. It shows the control method achieved proposed strategy.

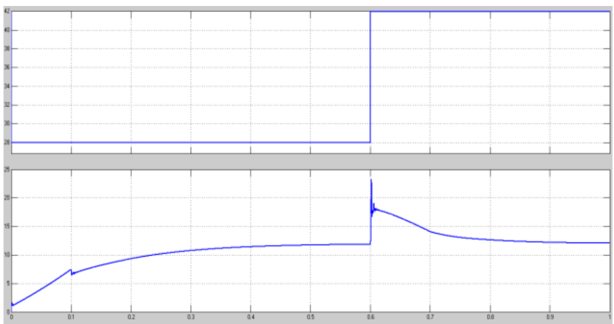


Figure 4. Input and output voltage waveform of Cuk converter when input voltage increased 50%

After that, the input voltage is suddenly decreased to 14 V that is 50% lower than the actual source voltage. Input and output voltage during this variation can be seen in Figure 5. Oscillation of output voltage at beginning is due to switching of voltage source and should be ignored.

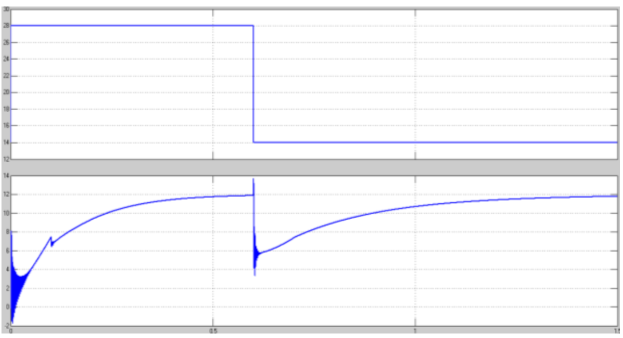


Figure 5. Input and output voltage waveform of Cuk converter when input voltage decreased 50%

The output voltage is equal to 12 V in steady-state although the decreasing of input voltage. Secondly, the load current is suddenly increased to 62.5 A which is 50% higher than the actual load current. This current change is achieved by changing the load resistor. Input voltage was not been varied during this operation. Input and output voltage during load current variation is shown in Figure 6.

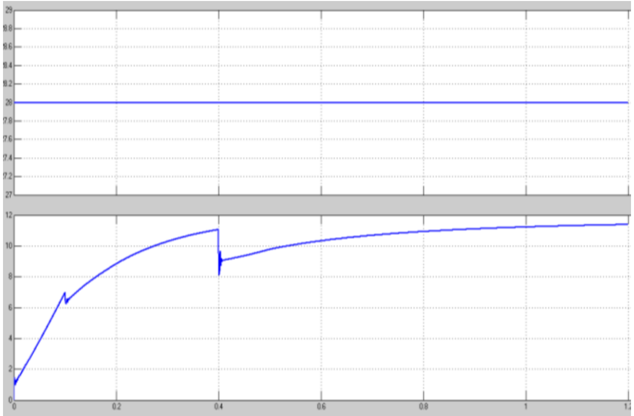


Figure 6. Input and output voltage waveform of Cuk converter when load current is increased 50%

The load current is suddenly decreased to 20.83 A which is 50% lower than the actual load current. Input voltage was constant during this operation. Output voltage during load current variation can be seen in Figure 7. For both variations of load and input voltage, the output voltage is regulated 12 V using PI control method.

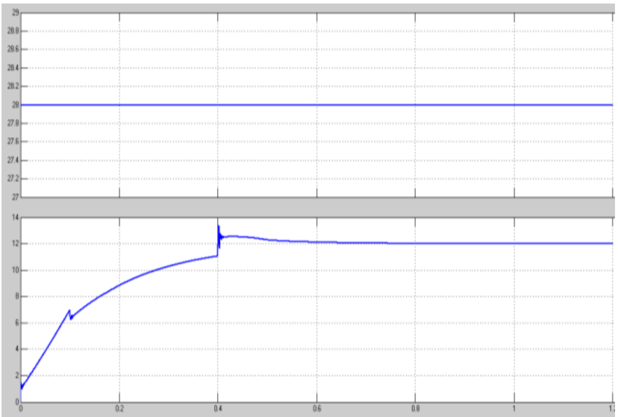


Figure 7. Input and output voltage waveform of Cuk converter when load current is decreased 50%

Finally, the reference voltage is instantly changed from 12 to 15 in order to set the output voltage to 15 V value. Output voltage during the variation of reference voltage can be seen in Figure 8. The output voltage is followed the reference voltage when it is increased by 50%.

IV. IMPLEMENTATION OF ONE-CYCLE CONTROL METHOD TO CUK CONVERTER

One-cycle control (OCC) method that is implemented to Cuk converter is simulated by using MATLAB/Simulink. Block diagram of the Cuk converter that is controlled by OCC method is shown in Figure 10.

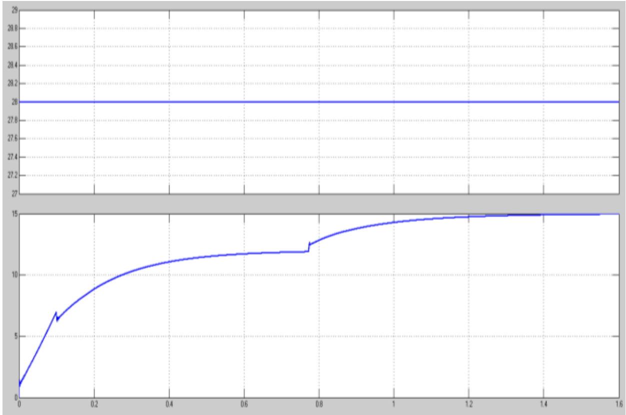


Figure 8. Input and output voltage waveform of Cuk converter when reference voltage is increased 50%

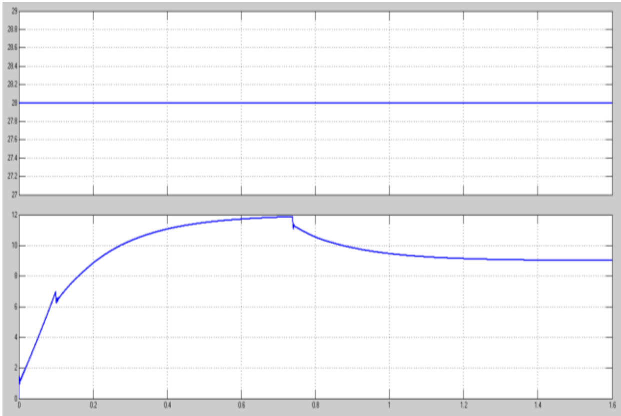


Figure 9. Input and output voltage waveform of Cuk converter when reference voltage is decreased 50%

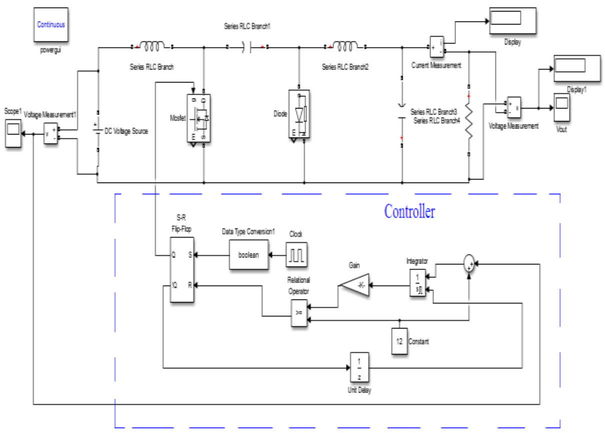


Figure 10. The block diagram of One-Cycle Control method with Cuk converter

The theory of OCC method is shown in Figure 11[6]. Its operating waveforms can be seen from Figure 12 [7]. A nonlinear control technique is used to control the duty ratio (T) of the switch. OCC method of Cuk converter has been verified on MATLAB/Simulink which proposed system is being run, values of V_{in} and R_{Load}, is increased and decreased ratio of 50 %, reference voltage, V_{ref} is increased and decreased too.

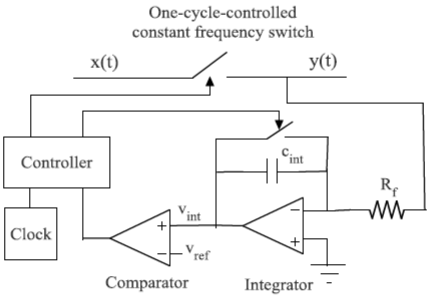


Figure 11. Block diagram of OCC method constant frequency switch

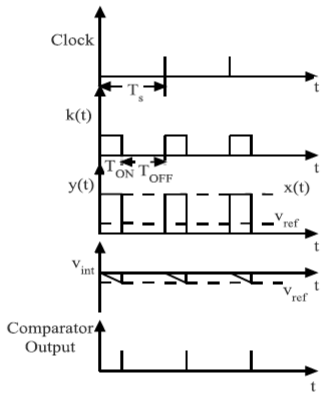


Figure 12. The waveforms of OCC method constant frequency switch

OCC method is nonlinear control technique and uses the concept of control of average value of switching variable [8], [9]. In closed loop, the output voltage, V_o should be equal to reference voltage V_{ref}.

$$V_{ref}(1-D)=DV_s \tag{7}$$

$$V_{ref}=D(V_s+V_{ref}) \tag{8}$$

$$V_{ref}=\frac{1}{T_s}\int_0^{Ton}(V_d+V_{ref})dt \tag{9}$$

Output voltage of Cuk converter when input voltage is varied from 28 V to 42 V and 42 V to 14 V can be seen from Figure 13. Output voltage of Cuk converter when output power is varied from 500 W to 1 kW and 1 kW to 250 W can be seen from Figure 14. Output voltage of Cuk converter when reference voltage is varied from 12 V to 9 V and 12 V to 15 V can be seen in Figure 15.

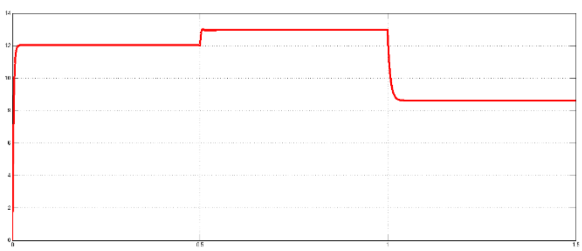


Figure 13. Output line voltage value for input voltage variations: 28 V to 42 V and 42 V to 14 V

The output voltage is maintained constant using OCC control method irrespective of the variation in load, input voltage and reference value. This method improves the dynamic and steady state characteristics of the system according to the PI control method.

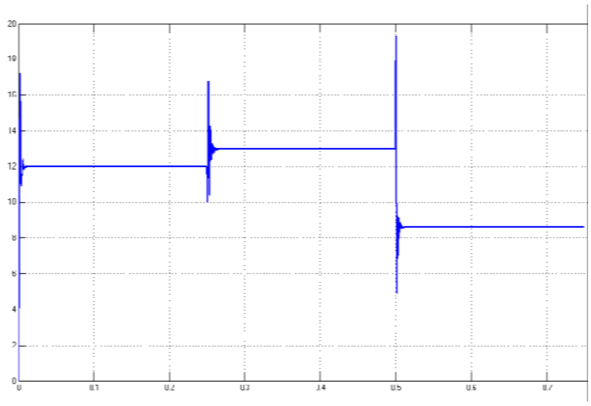
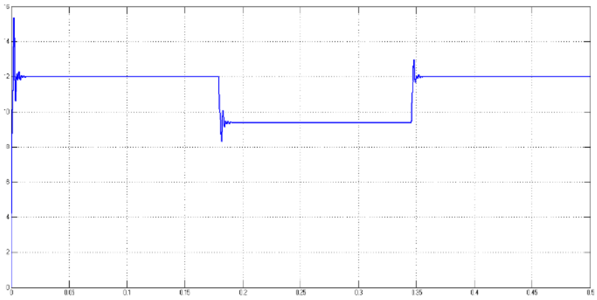
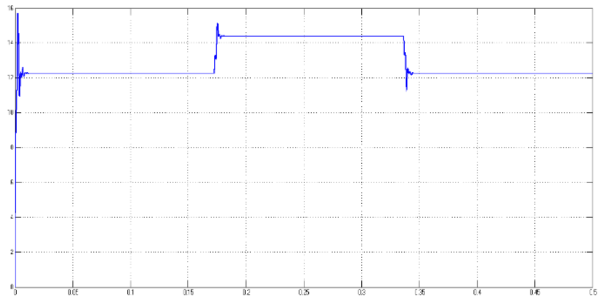


Figure 14. Output voltage waveform for load Changes: 500 to 1kW and 1 kW to 250 W



(a)



(b)

Figure 15. Output line voltage waveform for reference voltage variations: (a) 12 to 9 V (b) from 12 to 15 V.

The implementation of PI controller, two parameters (the proportional gain, K_p; the integral gain, K_i) must be determined carefully. Many approaches have been developed to determine PI controller parameters. Among the well-known approach is the Ziegler-Nichols method. These parameters are given in Table 2.

Table 2. K_p and K_i parameters using PI control method

K_p	K_i
0.0001	0.15

In OCC method, the chosen performance criterion is often a weighted combination of various performance characteristics such as settling time, overshoot, rise time. The various performance characteristics of settling time values are given in Table 3.

The proposed system response should have minimal settling time with a small or no overshoot in the step response of the closed loop system.

Table 3. Simulation results of settling time

Conditions	PI	OCC
V_s increased 50%	0.27s	0.05s
V_s decreased 50%	0.85s	0.15s
Load current increased 50%	0.6s	0.03s
Load current decreased 50%	0.25s	0.02s
V_{ref} increased 25%	0.44s	0.02s
V_{ref} decreased 25%	0.65s	0.15s

V. CONCLUSION

In this study, Cuk converter is analyzed in detail and both PI and OCC method is simulated by using MATLAB/Simulink. The input voltage, load current and reference values are changed and the response of the Cuk converter is observed. Finally, Cuk converter using PI and OCC control is compared. When compared to PI control, OCC has faster transient response, less settling time and less maximum deviation from steady state. On the other hand, steady state error of PI control is very small. Some spikes can occur when load is changed when OCC is implemented. However, Cuk converter using PI control does not have these spikes. When reference voltage is changed, the output voltage of Cuk converter using PI control reaches to new reference voltage value slowly. The design is approved by way of simulation and results. Eventually both system has been conducted the constant output voltage value.

REFERENCES

[1] N. Mohan, T.M. Undeland, W.P. Robbins, "Power Electronics", John Wiley and Sons Inc., 2003.

[2] M. Zhu, F.L. Luo, "Self-lift Cuk converter for Negative to Positive Voltage Conversion", IEEE Transactions on Power Electronics, Vol. 25, No. 9, September 2010.

[3] R. Dwivedi, V.K. Dwivedi, R. Sharma, "Parametric Variation Analysis of Cuk Converter for Constant Voltage Applications", Vol. 3, Issue 2, February 2014.

[4] A. Karaarslan, "The Implementation of One Cycle Control Method to Inverting Buck-Boost Converter", International Journal of Technical and Physical Problems of Engineering (IJTPE), Issue 35, Vol. 10, No. 2, pp. 14-19, June 2018.

[5] A. Karaarslan, "The Analysis of Average Sliding Control Method Applied on Sheppard-Taylor Power Factor Correction Converter", Electrical Engineering, Vol. 95, No. 3, pp. 255-265, 2013.

[6] A. Karaarslan, I. Iskender, "The Analysis of AC-DC Boost PFC Converter Based on Peak and Hysteresis Current Control Techniques", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 7, Vol. 3, No. 2, pp. 100-105, June 2011.

[7] K.M. Smedley, S. Cuk, "One-cycle Control of Switching Converters", Power Electronics Group, California Institute of Technology, Pasadena, CA, 91125.

[8] P.M. Binitha, T.G. Sanish Kumar, "Comparison of PWM and One-Cycle Control for Switching Converters," International Journal of Emerging Technology and Advanced Engineering, Vol. 3, Issue 4, April 2013.

[9] K.I.M. Smedley, "Control Art of Switching Converters," Ph.D. Thesis, California Institute of Technology, 1990.

[10] K. Subramanian, V.K. Sarath Kumar, E.M. Saravanan, E. Dinesh, "Implementation of One Cycle Control Technique in DC-DC Buck Converter", Indian Journal of Science and Technology, Vol. 8 (S2), pp. 200-206, January 2015.

BIOGRAPHY

Ahmet Karaarslan received the M.Sc. and Ph.D. degrees in Electrical and Electronics Engineering from Gazi University, Ankara, Turkey, in 2005 and 2011, respectively. He is currently an Associated Professor with the Faculty of Engineering and Natural Sciences in Yildirim Beyazit University, Ankara, Turkey. His research interests are in the application of circuits of power electronics, energy conversion systems, programming microprocessors, renewable energy sources, electrical machines and computer applications.