International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 4 (2015) pp. 10877-10889

http://www.ripublication.com

Soft Switching of Positive Output Elementary Super Lift Luo Converter

J.Barnabas Paul Glady
Ass.Professor EEE department
Sathyabama University
Chennai, India
e-mail:paulglady@gmail.com

Abstract

The electric vehicles operated by battery and fuel cell depend on dc-dc converters for their power management. Boost converters are used to step up the voltage from the battery or fuel cell and deliver it to the motor for its operation. In order to increase the fuel efficiency of the vehicle the weight of the converter should be reduced. For the reducing the weight of the converter, the size of the inductor should be reduced because in dc to dc converter inductor size increases the weight of the converter. The solution for this is to increase the switching frequency of the converter by employing soft switching technology and decrease the size of the inductor. This paper proposes a new method for positive output elementary super lift luo converter (POESLLC) by using switched capacitor snubber circuit. The new method does not need any additional inductor and has a simple control scheme.

Keywords: Positive output elementary super lift luo converter (POESLLC), Insulated gate bipolar transistor (IGBT), switched capacitor snubber

Introduction

Dc to dc converters play a vital role in power conversion technology .this field is fast developing with new technology and many converters are available for power conversion. To mention a few the buck, boost , buck-boost, cuk, sepic etc. these converters are used in small power level in the range of few watts (MP3 player, digital camera , laptop etc) to mega watts level like motor drives, electric vehicle, the transmission lines etc. A voltage lift is required in boost converter to step up the low voltage to high voltage which is used in traction motor, micro turbine based power generation, power factor correction and two stage photo voltaic system. Recently a new series of luo converters is becoming popular in power conversion stages because of high voltage gain, high power density, high efficiency and low output ripple content. In this category positive output elementary super lift luo converter (POESLLC) [1] is taken for analysis. For traction motor application it is required to keep the size and mass of the converter minimum in order to increase fuel efficiency of the vehicle. And similalary the converter must provide high efficiency over a wide load range.

The mass of the converter can be reduced if the size of the inductor that is used in the converter is small because inductor forms a major part in the converter. To reduce the inductor size normally the converter is operated in high frequency range, which also enables to have fast transient response. But operating the converter in high frequency range increases the switching loss and increases cooling requirement. The switching loss decreases the converter efficiency and cooling requirement increases the overall cost requirement of the converter. Secondly in high power application high power insulated gate bipolar transistor (IGBT) is used instead of MOSFET. This IGBT is commonly subjected to hard switching under 30 kHz [2] depending upon the power level. When IGBT is used in the converter it restricts the switching frequency. If soft switching is used the switching loss can be reduced and also increases the operating frequency of IGBT to 100 kHz [2] which can reduce the mass of the converter because IGBT can operate without heat sink. Therefore an appropriate soft switching method should be employed in high power boost converters for vehicular applications so that the converter can be operated in high frequency range and can reduce the mass of the converter.

To reduce the switching loss in dc to dc converter a large number of circuits is available in the literature. In resonant and quasi resonant circuit the semiconductor devices are turned on and off at zero voltage or zero current of a resonant mode [3][4][8]. But resonant converters require matching of operating frequency with the resonant tank components value. And one disadvantage in this method is operation failure can occur because of magnetic saturation and surprising drift in resonant frequency. Another main disadvantage in this method is design of filters and control circuit becomes difficult because switching frequency variations. Furthermore the resonant circuit needs additional inductor which increases the size and weight of the converter. Therefore the advantage of operating the converter in high frequency is lost.

Passive soft switching methods [5]&[9] use only passive components like diode, resistance etc for zero voltage or zero current switching at constant switching frequency. But passive soft switching requires auxiliary circuits which contains extra inductors hence they further increase the size and weight of the converter. Most of the passive soft switching circuits are used in MOSFET based dc-dc boost converter of low power application and focus on reducing only reverse recovery losses due to diode that take place during turn on of the circuit of boost converter. But in IGBT the turn off loss is more significant than turn on loss. Finally the passive soft switching methods increase the component stresses and shows only marginal reduction of switching loss.

Active soft switching [6]&[10] use one more additional switch in addition to passive components to achieve zero current or zero voltage switching. It increases the complexity in control of the converter and also uses extra inductor. Similarly the extra switch uses hard switching concept and extra elements are needed for active soft switching increasing the overall size and weight of the converter.

Therefore the literature revels that there is a need for increasing the switching frequency of high power boost converters without adding inductors so that size and weight of the converter does not increase. This paper provides a switched regenerative snubber for high power positive output elementary super lift luo converter. The circuit does not need any extra inductors but needs only extra two IGBTS and two diode and one snubber capacitor. This technique was used in ordinary boost converter [7]&[11] but here it is used in POESLLC.

Circuit Operation

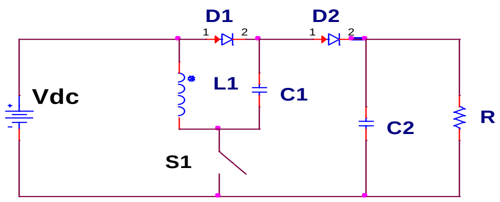

Fig.1 The Positive output elementary super lift luo converter

A. Conventional Circuit

The Fig.1 shows the positive output elementary super lift luo converter. It contains the dc supply voltage V_{dc}, capacitors C_1, C_2, inductor L_1, power switch S_1, freewheeling Diodes D_1, D_2 and load resistance R. it is assumed that all the devices are ideal and the converter operates in continuous conduction mode. The circuit has two modes of operation, Mode I and Mode II.

The switch S_1 is turned on. The current starts flowing in to the inductor L_1 and the capacitor C_1. The inductor stores the electric energy as magnetic energy and capacitor charges to the maximum Value of input voltage V_{dc}. During this mode the diode D_1 is forward biased and diode D_2 is reverse biased because the output capacitor C_0 discharges to the external load. The equivalent circuit of this mode is shown in Fig.2 and the current flow direction also shown.

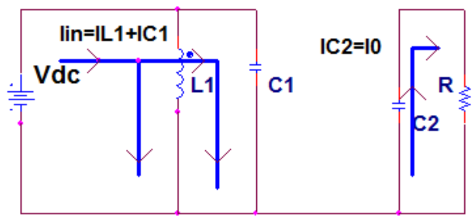

Figure 2: Mode I of Positive output elementary super lift luo converter

In mode II the switch S_1 is turned off. During this mode the diode D_1 is reverse biased due to capacitor C_1 and diode D_2 is forward biased. The inductor L_1 and capacitor C_1 is connected in series with the source voltage. V_{dc}. The series combination of the voltage source V_{dc} , inductor L_1 and capacitor C_1 charges the output capacitor C_2 and supply the external load R. The current flow and the and the equivalent circuit of Mode II is shown in Fig.3

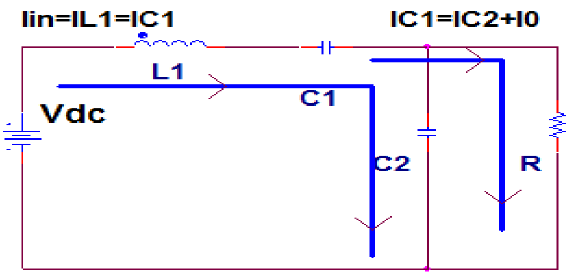

Figure 3: Mode II of Positive output elementary super lift luo converter

B. Analysis

By applying kirchoff Voltage laws for mode I we have

$$V_{dc} = V_{L1} = V_{C1} \tag{1}$$

By applying kirchoff current laws for mode I we have

$$I_{IN} = I_{L1} = V_{C1} \tag{2}$$

$$I_{C2} = I_0 \tag{3}$$

The inductor voltage is given by

$$V_{L1} = L_1 \frac{di_{L1}}{dt} \tag{4}$$

The time taken for mode I is given by

$$t_1 = \frac{L\Delta I}{V_{dc}} \tag{5}$$

The inductor current during mode I is given by

$$\Delta I = \frac{t_1}{L} V_{dc} \tag{6}$$

The output voltage for mode I is given by

$$V_{C2} = V_0 = I_0 R_0 \tag{7}$$

By applying Kirchhoff current laws to mode II we have

$$I_{IN} = I_{L1} = I_{C1} \tag{8}$$

$$I_{C1} = I_{C2} + I_0 \tag{9}$$

By applying Kirchhoff Voltage laws to mode II we have

$$V_{dc} + V_{L1} + V_{C1} = V_{C2} \tag{10}$$

Assuming that capacitor charges to

$$V_{C1} = V_{dc} \tag{11}$$

$$2V_{dc} + V_{L1} = V_{C2} \tag{12}$$

$$V_{L1} = -L_1 \frac{\Delta I}{t_2} \tag{13}$$

$$t_2 = L_1 \frac{\Delta I}{2V_{dc} - V_{C2}} \tag{14}$$

$$\Delta I = t_2 \frac{2V_{dc} - V_{C2}}{L_1} \tag{15}$$

Equating equation and substituting $t_1 = DT$ and $t_2 = (1 - D)T$ and simplifying

$$V_{C2} = 2V_{dc} + \frac{D}{1-D} V_{dC} \tag{16}$$

But $V_{C2} = V_0$

$$V_0 = 2V_{dc} + \frac{D}{1-D} V_{dc} \tag{17}$$

The ratio of time taken for modeI and modeII

$$\frac{t_1}{t_2} = \frac{V_0 - 2V_{dc}}{V_{dc}} \tag{18}$$

The switching period is given by

$$T = L_1 \Delta I \left[\frac{3V_{dc} - V_{C2}}{3V_{dc}^2 - V_{dc} V_{C2}} \right] \tag{19}$$

The peak to peak ripple current is given by

$$\Delta I = \frac{1}{L_1 f} \left[\frac{3V_{dc}^2 - V_{dc} V_{C2}}{3V_{dc} V_{C2}} \right] \tag{20}$$

The capacitor voltage ripple is given by

$$\Delta V_{C2} = \frac{I_0}{C_2 f} \left[\frac{V_0 - 2V_{dc}}{V_0 - V_{dc}} \right] \tag{21}$$

C. Modified Positive output elementary super lift luo converter with regenerative snubber circuit

The conventional circuit is shown in Fig.1. The modified Positive output elementary super lift luo converter with regenerative snubber circuit is shown in Fig.4. The modified circuit has additionally two switches S_2 S_3 and two diodes D_3 D_4 and a snubber capacitor C_s.

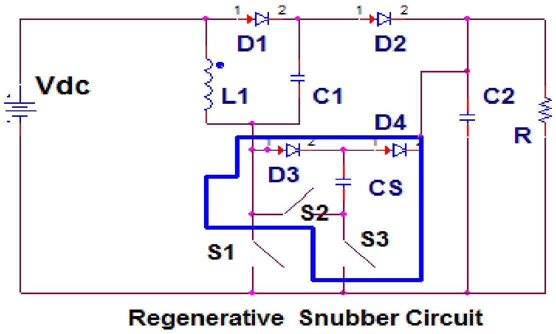

Figure 4: Positive output elementary super lift luo converter with switched capacitor snubber

In high power IGBT based dc-dc boost converters, the switch turnoff loss is greater than that of turn-on loss. The high turn off loss in IGBT is due to the current tail of the current in IGBT. Thus the proposed capacitor switched regenerative snubber circuit can greatly reduce losses during turn-on and turn-off of the switch. This also enables to increase the switching frequency of the IGBT.

The logic in the proposed circuit is to charge the snubber capacitor C_s at one turnoff time and allow it to discharge it in another turnoff time. With this operation the voltage rise across the switch S_1 is slowed down and the current tail of the switch is reduced drastically. And the energy that is used to accomplish this is transferred to the output of the converter and hence the name regenerative snubber. In Fig.5 the auxiliary switch S_3 is closed in order to allow the snubber capacitor C_s to charge from 0 to output voltage V_{out}. This charging action of the snubber capacitor C_s slows down the voltage rise across the switch S_1 and reduces the losses. At next turn on of $S_{1,}$ both S_2 and S_3 are in off condition as shown in Fig.6. Thus the operation of the switch S_1 is not affected by the switched capacitor snubber circuit. The capacitor C_s does not discharge through the diode D_4 and the diode across the switch S_3 because the anode and cathode of the diode D_4 are at the same voltage level. In the next turn on of the switch S_1 the capacitor C_s will discharge to the external load as shown in Fig.7. The diode D_1 conducts and diode D_2 reverse biased when the switch S_1 conducts. When S_1 is in off conduction the diode D_1 and D_3 is reverse biased and diode D_2 is forward biased. Therefore the proposed converter operates very similar to the hard switched positive output elementary super lift luo converter except when the auxiliary switches are turned on.

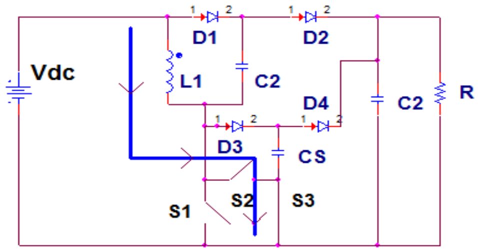

Figure 5: Positive output elementary super lift luo converter with switched capacitor snubber charging

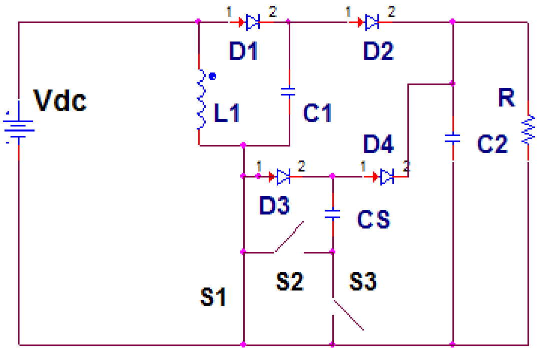

Figure 6: Positive output elementary super lift luo converter with switched capacitor snubber charged

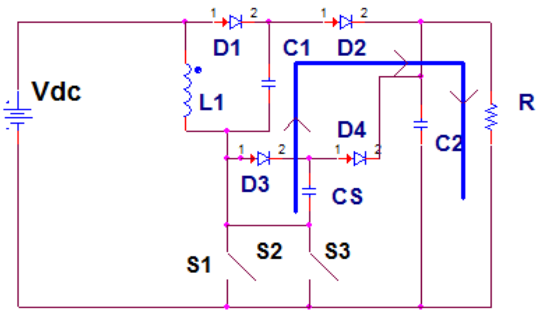

Figure 7: Positive output elementary super lift luo converter with switched capacitor snubber discharging

The control scheme of the main and auxiliary switches as does not have any sensors or feedback. The control scheme requires only micro controller. The triggering pulse for the three IGBT is shown in Fig.7. The control scheme is the auxiliary IGBT2 and IGBT3 must turn on before IGBT1 turns off and the auxiliary IGBT2 and IGBT3 must turn off before the IGBT1 turns on. The auxiliary IGBT2 and IGBT3 are turned on and off at alternative pulse of IGBT1. Care should be taken that IGBT2 and IGBT3 are turned on and off at zero voltage switching such that they do not incorporate switching loss additionally and decrease the efficiency.

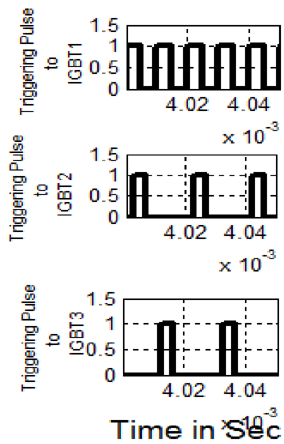

Figure 8: triggering pulse to IGBT

D. Design of snubber Capacitor

The design of the snubber capacitor C_s is simple and it is adopted in [7]. C_s should be small in order to reduce the conduction loss at the same time the voltage spike across the switch IGBT1 should be minimum. The general rule for selecting the snubber capacitor is that the desired time for voltage rise (T_{Vrise}) is equal to three times the turnoff time of the IGBT1 that is used in the circuit. Similarly the snubber equivalent resistance should be small so that restive loss will be minimal. Once T_{Vrise} is found the general formula for snubber capacitor is

$$C_S = I_{CMAX} \frac{T_{Vrise}}{V_{OUT}} \quad (21)$$

The auxiliary IGBT2 and IGBT3 are selected to be same as the main IGBT1 in order to minimize different parts in the circuit.

Simulation Results

The simulation is done using mat lab. The simulation parameters for hard and soft switching is represented in table 1.1

Table 1.1: Simulation Parameter

Parameters Name	**Symbol**	**Values**	
		Hard switching	Soft switching
Input voltage	V_{dc}	220V	220V
Output voltage	V_0	650V	700V
Inductor	L_1	100mh	100mh
capacitor	C_1	30µF	30µF
Filter capacitor	C_2	30µF	30µF
Switching frequency	f_S	30kHz	100kHz
Duty cycle	D	50%	50%
Snubber Capacitor	C_S	30µf	30µf
Load Resistance	R_0	50Ω	50Ω
efficiency	η	92.12	92.34

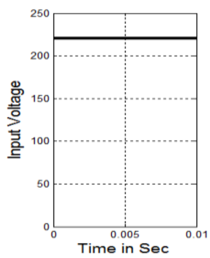

Figure 9: input voltage to the converter

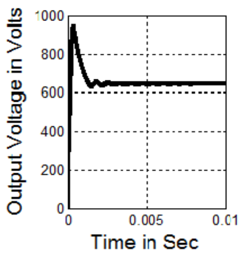

Figure 10: output Voltage of hard switched POESLLC

The Fig.9 shows the input voltage to the converter as 220Volts for both hard and soft switched POESLLC. The Fig. 10 shows the output voltage of hard switched POESLLC which is 650 Volts. Fig. 11 shows the power loss in the IGBT during turn on and turn off of the IGBT. Note the current waveform has the tail ends. It will be interesting to note that the turn off

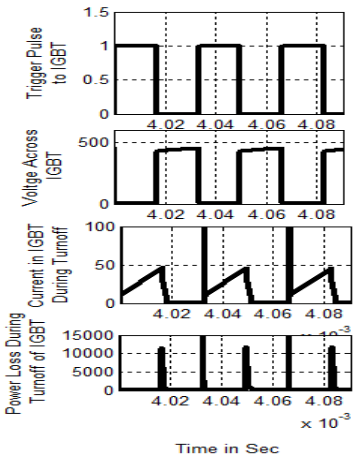

Figure 11: power loss in IGBT in hard switched POESLLC

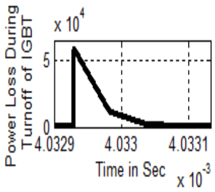

Figure 12: zoomed view of powerless during turnoff of IGBT

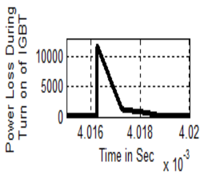

Figure 13: zoomed view of power loss during turn on of IGBT

loss is very higher in IGBT than the turn on loss as shown in the diagram. The Fig.12 and Fig.13 shows the zoomed view of the turn off and turn on loss. It is found the maximum turn on loss is 11kw and maximum turnoff loss is 50kw in hard switched POESLLC.

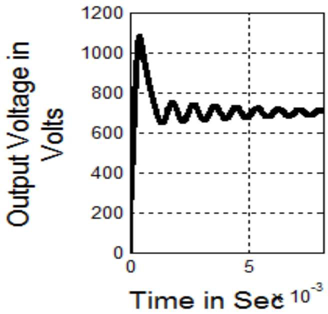

Figure 14: Output Voltage of soft switched POESLLC

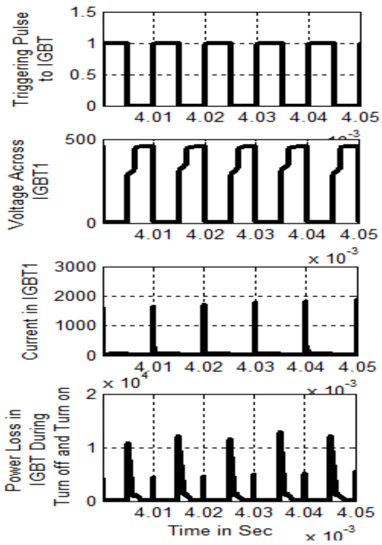

Figure 15: Power loss in IGBT during turn off in soft switched POESLLC

Fig.14 shows the output voltage of soft switched POESLLC. It is found that output voltage is 700 Volts slightly greater than the hard switched circuit because of regeneration that is employed in soft switched concept. Fig. 15 shows the triggering pulse to IGBT1, voltage across IGBT1, current through the IGBT1 and the turn on and turn off loss of the soft switched POESLLC. It can be seen that current magnitude is drastically reduced compared to hard switched POESLLC. Fig.16 and Fig.17 shows zoomed view of the turn off loss and turn on loss of IGBT1 respectively. From the waveform it is understood that the maximum turnoff loss is 10.5kw and the maximum turn-on loss is 4.2kw. Therefore the turn off loss of the IGBT1 is reduced and as well as turn on loss also reduced because of switched capacitor snubber. As the soft switched POESLLC is operated in high frequency the mass of inductor also reduced and therefore the mass of the converter is reduced.

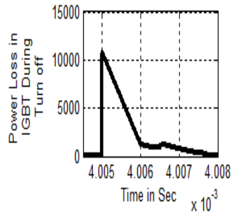

Figure 16: Zoomed view of power loss during turn off in soft switched POESLLC

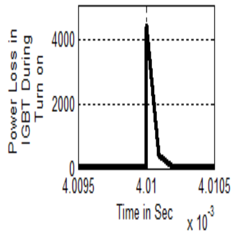

Figure 17: Zoomed view of power loss during turn on in soft switched POESLLC

Conclusion

In this paper POESLLC was presented with switched capacitor snubber circuit for decreasing the turnoff loss in IGBT in high power application. Normally only one switch will be used in POESLLC for its operation but for soft switching two auxiliary switches were additionally used along with snubber capacitor and two diodes. When soft switching was used, the switching frequency of IGBT can be increased from 30 kHz to 100 kHz .if switching frequency is increased the size of the inductor can be decreased and thus decreasing the mass of the converter which is vital for vehicular application. The IGBT turn-OFF loss is reduced because of soft switching and the efficiency of the converter is increased by 0.22%. Overall the goal of reducing the turnoff loss, reducing the converter size and increasing the efficiency is achieved.

References

[1]. F.L. Luo and H.Ye, “Positive output superlift converters”, IEEE transactions on power electronics , Vol.18, No.1,PP105-113, January 2003.

[2]. Powerex CM150DU-12F Data sheet.[online].Available: http://www.pwrx. com.

[3]. C. Chuang and Y.L.Ke. “high efficiency and low stress ZVT-PWM DC-to-DC Converter for battery charger.” IEEE Trans.Ind. Electron., vol.55,no.8,pp.3030-3037, Aug.2008.

[4]. J.M.Kwon, W-Y.Choi and B.H Kwon, "Single switch quasi resonant converter," IEEE Trans.Ind.Electron., vol.56,no.4,pp.1158-1163,Apr.2009.

[5]. M.R. Amini and H. Farzanehfard, "Novel family of PWM soft –single-switched DC-DC converters with coupled inductors." IEEE Trans.Ind.Electron.,vol.56,no.6,pp. 2108-2114,Jun.2009

[6]. B.R.Lin and C.L. Huang "Interleaved ZVS converter with ripple current cancellation," IEEE Tran.Ind Electron ., vol.55,no.4,pp.1576-1585,Apr.2008

[7]. QCJ.Marshall and M.Kazerani, "A novel lossless snubber for boost converters," in proc.IEEEInt.Symp.Ind.Electron., Montreal , Canada, Jul.9-13,2006,pp.1030-1035.

[8]. V.Sivachidambaranathan and S.S Dash , "A Novel Soft Switching High Frequency Ac to Dc Series Resonant Converter", National Journal of electronics Sciences and Systems. Vol 2, No 2 (2011), pp. 30 – 36.

[9]. G. T. Sundar Rajan and C. Christober Asir Rajan, "Input stage improved power factor of three phase diode rectifier using hybrid unidirectional rectifier", in Proc. IEEE conf. on Nanoscience, Engineering and Technology – ICONSET – 2011, Sathyabama Uiversity, pp. 697 – 682, November 28 to 30, Chennai.

[10]. A Ramesh Babu, T.A. Raghavendiran" Performance analysis of closed loop controlled ZVS CCM boost converter for load and source disturbance" International journal of applied engineering and research",vol.9,No.21, pp. 10929-10952, Nov.2014.

[11]. S. Jayaprakash, and V. Ramakrishnan. "Hardware Implementation of Single-Stage Solar Based DC-DC Converter for Inductive Load Application." *Applied Mechanics and Materials*. Vol. 573. 2014.

[12]. M. Sasi Kumar and S. C Pandian, "Modeling and analysis of cascaded H bridge inverter for wind driven isolated self excited induction generators", Journal on Electrical Engineering and Informatics, and Vol. 3, issue 2, PP. 132 – 145, 2011.