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Design of 2LC-Y DC - DC Converter for High Voltage/ Low Current Renewable Energy Application

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Abstract:

With the current problems encountered by the conventional sources of energy, photovoltaic (PV) is a very useful and friendly source of renewable energy. Normally, photovoltaic provides low voltage level and it is usually not enough to supply the voltage level required at the load. In this work, three DC-DC converter topologies are presented to regulate the power extracted from the PV, which are highly suitable for renewable energy application that requires high ratio of DC – DC conversion. When benchmarking the traditional converters to the proposed one, the new designed 2LC-Y has been found to be superior in many aspects. Such as, the new designed 2LC-Y converter can provide higher output voltage comparing to the old ones, even though it uses less reactive components and less number of devices, which consequently reduces the complexity of the designed circuit. The results obtained from the simulation have shown that, the designed 2LC-Y converter requires only a single switch to control it. Furthermore, it has the ability to obtain negative output voltages by the use of non-isolated topologies. Also, it doesn't require the use of high duty cycle in order to achieve high conversion ratio as other available converters in the literature. Promising results have been obtained to support the validity of this new generation of 2LC-Y converters.

Keywords: *DC-DC converter topology; High Conversion ratio; Non-isolated; Renewable Energy.*

I. INTRODUCTION

Renewable energy is important in electricity generation, especially the photovoltaic energy. Energy from sun is the one of the best renewable energy for electricity generation. This source is directly from sun which makes it easy to harvest with low cost. Other advantages of PV such as, it has many benefits such as noise-free, secure, and unpolluted and cost of maintenance and operating are low, and have a very long life time. The energy can be easily extracted and free, which is derived from solar energy. Photovoltaic module can generate electricity from the sun with the help of auxiliary devices. The module of photovoltaic come with various voltage levels to meet the installed load [1]. In Malaysia the average sunshine is 6 hours, so it is considered as the best alternative as a cleaner electrical energy source to replace the conventional generation methods.

Photovoltaic supply direct current (DC) source to the load. DC is a flow of current that always takes place on the same direction. In industrial, commercial as well as domestic, AC has been chosen as the power delivering while DC is usually used in computer, batteries and electronic component. Nowadays, we use inverter to convert DC to AC, so the inverter device is used in PV application to convert the power supply. So the use of inverter is increasing daily because of the wider use of renewable energy such as photovoltaic. Considering the nature of the photovoltaic, the power generated by this method is not stable and fluctuate according to the weather and other factors. Therefore, before converting the power generated by this method into AC, it has to go through DC-DC converter to stabilize it and boost it or buck it accordingly [2]- [7].

The design of DC – DC converter in industry is usually made either to reduce the voltage generated or magnify it. One of the DC-DC converter topologies is the booster to convert DC voltage from low to high DC voltage. Before this vibrator is used to change DC to AC in low power application. This process is not efficient and too expensive process because they do not have alternative [8]- [12].

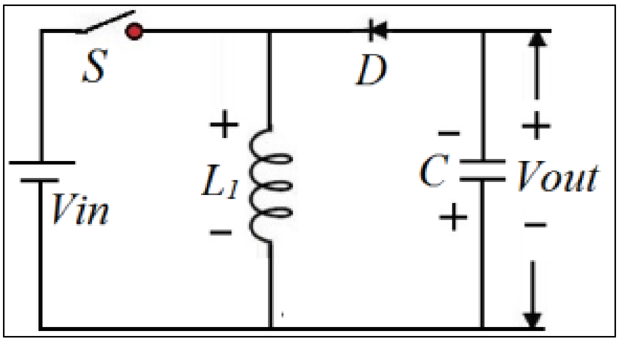
In renewable energy like solar system, the common idea of connecting the solar arrays in series to achieve and produce high voltage lacks the practicality. In such case and when it comes to the application especially renewable energy, the use of DC-DC converter is preferred to be used, especially the ones that have higher conversion ratio. Normally, the boost converter loses its characteristics in case of any increment that may be encountered in the duty cycle of the main power switch. Another reason may help to deteriorate the performance of any converter is that, the leakage resistance of the inductor. Taking these practical issues and drawbacks into consideration, the conventional DC-DC converters are not able to produce high conversion ratio to serve the renewable energy application [13]- [17]. Moreover, the use of conventional converters has limitation in term of ratio, whereas the conversion ratio can't exceed four times. In other words, to achieve a certain high conversion ratio by using conventional converters, one may have to use many sets of converters which is not practical and not cost effective. Another disadvantage appears when relying on the traditional buck-boost converters which is that, the discontinuous input current that uses the minimum value of the input source. The common solution employed to solve the problem of the leakage resistance is that, the converter's switching frequency has to be increased till a certain value or the maximum allowed limit of ripples in the circuit. Normally, the limit of the switching frequency in power devices is controlled by the finite switching time in case the duty ratio is too low or too high from a certain amount [18]- [22]. Considering the above mentioned drawback, the isolated converters can be used to provide higher values of voltage without the need for high duty cycles.

II. REVIEW OF EXISTING CONVERTER TOPOLOGIES

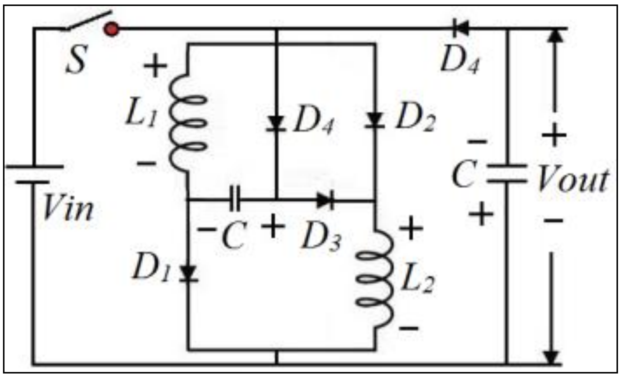
There have been several topologies proposed for DC-DC converters to tackle the encountered drawbacks. Among the important topologies are:

Table I. Ratio of Conversion

Buck Boost Converter	Voltage Conversion Ratio
L Converter	D/(1-D)
2LC converter	1+D/1-D



(a)



(b)

Figure 1. (a) Traditional Buck Boost (L converter). (b) Voltage Lift Switched Inductor Converter (2LC Converter)

A. *General Structure of X-Y Buck Boost Converter*

The general concept employed in buck boost converters is by using the inductor considering its boosting abilities. The conventional buck boost converter is shown in Figure 1 (a), commonly known by the BBC or L converter. On the other hand, the voltage lift switched inductor converter (2LCY) is illustrated in Figure 1 (b). table I represents the conversion ratio of the demonstrated buck boost converter. Meanwhile, the general and common structure of the XY converters family is illustrated in Figure 2. This generation of converters

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normally consists of double circuits of converters, namely converter X and converter Y. This kind of converters varies from others, where the voltage source is connected in a direct way to the converter X and the input of converter Y is attached is series to the voltage source as well as the output voltage of the converter X. Normally, the total achieved output voltage of the XY converters generation is equivalent to the value of inverting sum of output voltage of converter X as well as converter Y, as illustrated in Figure 2.

B. 2LC -2LC Converter Topology

The 2LC-2LC converters structure is illustrated in Figure 3 (a). This family of converters can be simply defined as a combination of double circuits of 2LC converters. The circuit consists of 4 capacitors, 4 inductors and 9 diodes. This kind of converters are normally connected to a single switch. It’s possible to analyze and determine the performance of this kind of converters in the steady state condition operation mode. Whereas during a single switching state the pure DC voltage is assumed to be supplied to the circuit. Also, all the components are assumed to operate ideally and have 100% efficiency. Furthermore, the inductors LX1 and LX2 must be identical and have the same ratings. Similarly, inductors LY1 and LY2 have to be identical and must have the same ratings. A very low percentage of ripples is allowed in the capacitors during the operating of the switching frequency. The input voltage will charge in parallel both inductors LX1 and LX2 during the conduction of switch S. simultaneously, the series connection of the input voltage and the voltage across the capacitor Cx will charge both inductors LY1 and LY2. The input voltage of the diodes Dx2 and DX3 will charge the capacitors X and C1. The same process happens again, where the connection of input voltage and voltage across Cx will help to charge the capacitor Y and C2. Generally, the output voltage obtained from this kind of converter is equivalent to the negative sum of the voltage across the capacitors Cx and CY.

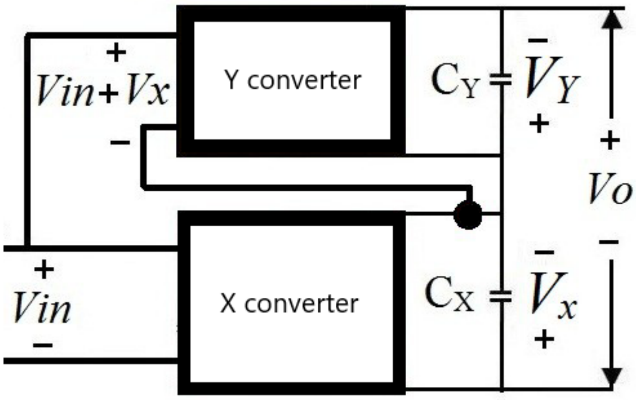
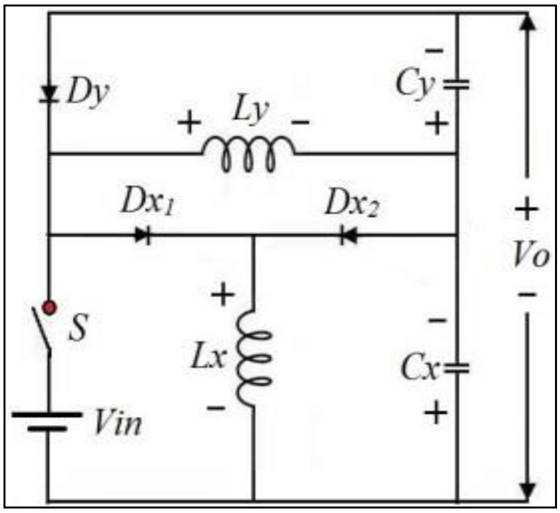
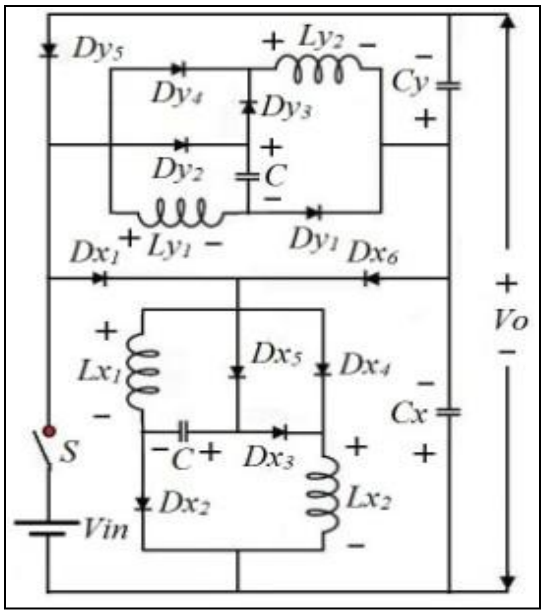


Figure 2. The Structure of X-Y Family



(a)



(b)

Figure 3. (a) L-L Buck Boost (b) 2LC-Y

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III. VOLTAGE CONVERSION RATIO ANALYSIS OF EXISTING AND PROPOSED 2LC-Y CONVERTER

Many considerations have been taken into account for the purpose of analysing the performance of the proposed 2LC-Y converter. The steady state case of operation is assumed and during the switching some factors have to be considered. Such as, a pure input DC voltage is supplied to avoid any side issues such as ripples. All have power devices have no voltage drop during conducting state, highly efficient in other words. Also, the ripple percentage across the capacitor during switching frequency is too small and has no effect on the performance of the overall circuit.

A. Conventional Converter

Power circuit of the conventional converter is shown in Figure 1 (a).

$$\frac{\mathrm{Vout}}{\mathrm{Vin}} = \frac{-\mathrm{D}}{1-\mathrm{D}} = G \tag{1}$$

B. L-L Converter

Power circuit of L-L Converter is shown in Figure 3 (a).

$$Vx = \frac{D}{1-\mathrm{D}}\, Vin \tag{2}$$

$$Vy = \frac{D}{1-\mathrm{D}}\left(\frac{D}{1-\mathrm{D}} + 1\right) Vin \tag{3}$$

$$Gyx = \frac{\mathrm{Vout}}{\mathrm{Vin}} \tag{4}$$

where *GXY* or GL-L is voltage gain of L-2 converter.

C. 2LC-2LC Converter

$$Vx = \left(\frac{1+D}{1-\mathrm{D}}\right) Vin \tag{5}$$

$$Vy = \frac{D}{1-\mathrm{D}}\left(\frac{1+D}{1-\mathrm{D}} + 1\right) Vin \tag{6}$$

$$Gyx = \frac{\mathrm{Vout}}{\mathrm{Vin}} \tag{7}$$

TABLE II

Type of converter	Calculation			Simulated		
	Vcy	Vcx	Vout	Vcy	Vcx	Vout
conventional	-	-	-18v	-	-	-17.99v
L-L	45v	18v	-63v	50.5v	12v	-62.5v
2LC-Y	240v	48v	-288v	251.2v	36.8v	-290v

IV. SIMULATION RESULT AND DISCUSSION

Conventional, L-L and proposed 2LC-Y are simulated in MATLAB with input voltage of 12 V, 50kHz and 60% duty cycle. The results of the conventional converter obtained from the simulation can be summarized as, the conventional converter is able to increase the pure DC source to a higher inverting output DC voltage. It is proven that the conventional converter can step up the 12v to -18v with -1.5 gain ratio. The output voltage of the buck boost converter is done in the Simulink which has obtained almost the same result with the output voltage and this makes the strength of the theoretical value, the difference between the theoretical value and the one obtained from the simulation designed is small and can be neglected.

The results of L-L from the simulation illustrates and credence that the L-L converter is able to increase the pure DC source to a higher inverting output DC voltage. It is proven that the L-L converter can improve voltage gain ratio from 1.5 (conventional) to 5.25 (L-L). by comparing the theoretical value of the output voltage to that obtained from the simulation one may notice that, the difference is quite small and can be neglected. The result obtained confirm the applicability of the design since it tallies with the designed value.

The results of 2LC-Y obtained from the simulation proves that the 2LC-Y converter is able to step up a fixed input DC voltage to a higher inverting output DC voltage. It is proven that the 2LC-Y converter can improve voltage gain ratio from 5.25 (L-L) to 24 (L-L). The output voltage of the buck boost converter obtained in the simulation is also close to the theoretical output voltage and this further proves that the designed buck boost converter functions in well condition according to the calculation and theoretical.

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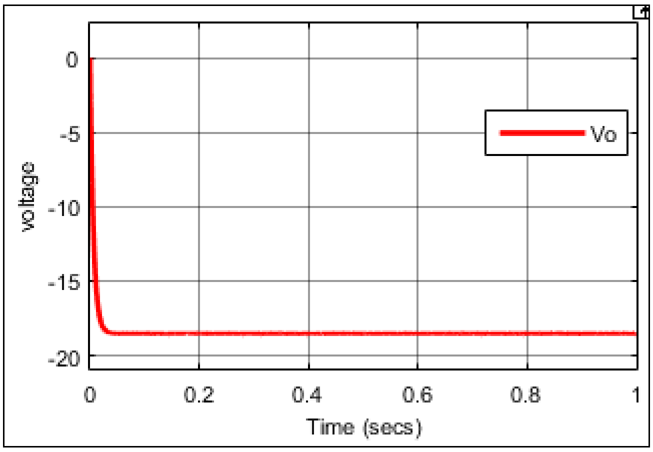
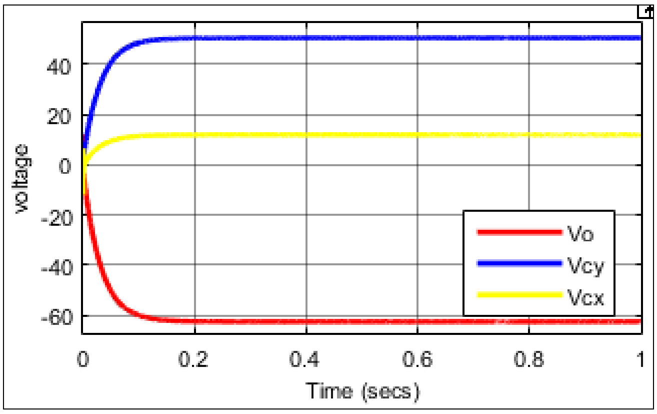
The obtained results credence that, the proposed 2LC-Y converter can produce high negative output voltage comparing to the conventional converters. This topology of 2LC-Y is able to cover the disadvantages of the previous converters, where it can produce much higher conversion ratio.



(a)



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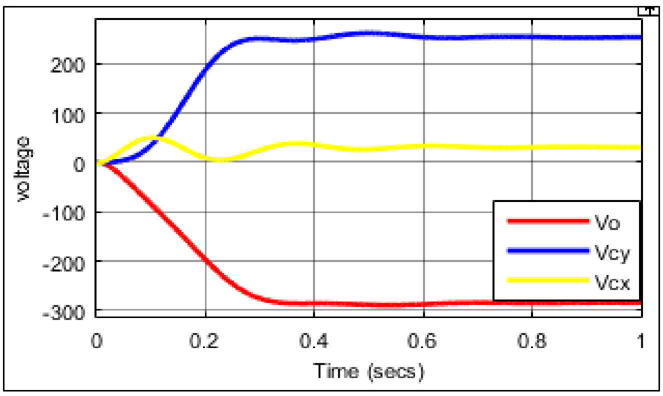
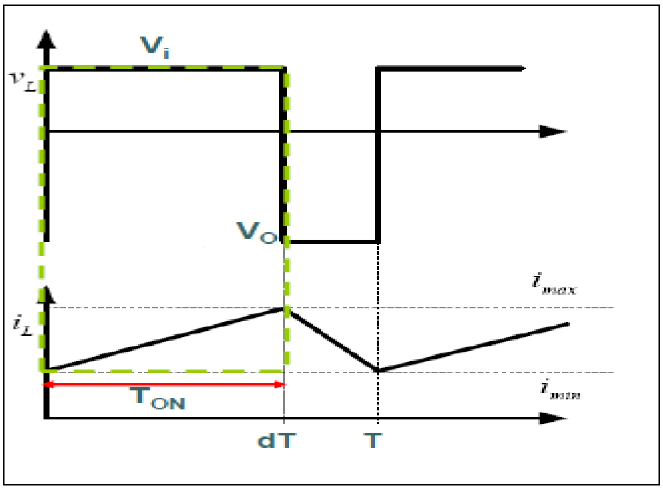
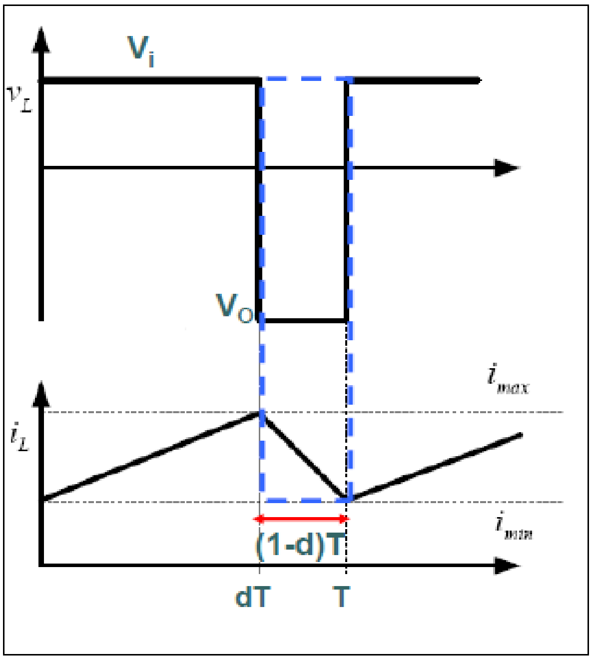


(c)



Switch is closed

When the Switch is closed, $V_L = V_i$ and i_L increases linearly with time. It means that, in the case of non-conduction of the switch S there will be no supply from the power circuit since it has been disconnected. In such case, the inductors Lx1 and Lx2 will be in discharging mode, hence they will discharge in series and in a simultaneous manner with the capacitors X and C1 through the load of the circuit and charges the capacitor Cx. The same process occurs where the both inductors L_{Y1} and L_{Y2} will be in discharging mode and that happens in series with the capacitor Y, similarly, C2 will charge the C_Y capacitor. Also, both of the inductors L_{Y1} and L_{Y2} will discharge in series manner with the Y capacitor, meanwhile C2 will charge the capacitor C_Y



When switch is open

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The source in this case is disconnected and I_L doesn't change instantly since the diode in forward biased mode which provides a path for the load current to circulate. In this work, it is determined that the inductors are quite vital and highly impact the performance of the proposed converter. Whereas, when the switch is conducting, the converter will be in charging state. Otherwise, the discharging state will take a place in case of no conduction of the switch.

V. CONCLUSION

In this paper, 2LC-Y buck boost converter has been successfully designed in MATLAB to step up the low voltage produced from the renewable energy source to a higher invert DC voltage output**.** Simulation has been done to prove that the 2LC-Y DC – DC converter achieves the objective which is to get a high gain voltage compared to conventional DC-DC converter with one switch only. Therefore, 2LC-Y DC – DC converter is the best solution for renewable energy that need a high voltage conversion ratio such as multilevel photovoltaic inverter, hybrid system and automotive application that only produce low voltage. The results obtained from the simulation have shown that, the designed 2LC-Y converter requires only a single switch to control it. Furthermore, it has the ability to obtain negative output voltages by the use of non-isolated topologies. Also, it doesn't require the use of high duty cycle in order to achieve high conversion ratio as other available converters in the literature. Promising results have been obtained to support the validity of this new generation of 2LC-Y converters.

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