APPLICATIONS OF
MODELLING AND SIMULATION
http://arqiipubl.com/ams eISSN 2600-8084 VOL 3, NO. 3, 2019, 173-178

Modelling and Design of Photovoltaic Fed Re-lift Luo Converter for Air Conditioner

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Received 29 August 2019, Revised 18 September 2019, Accepted 20 September 2019.

Abstract: The design of high gain converter with photovoltaic (PV) module is carried out in this paper for air conditioning application. The solar based power system gaining large importance due to the renewable nature and increased life time. To understand power and voltage characteristic of PV module, the five parameter single diode model is evolved and analyzed. Due to the varying power characteristic of PV panel to the temperature and irradiance change, perturb and observe maximum power point tracking algorithm is imposed to harvest the maximal potential PV power. Air conditioner require high currents so solar modules are connected in parallel instead of series configuration. Since the output voltage of PV module is low, it requires a DC to DC power electronic converter with large voltage gain to boost the output voltage. Various converters such as conventional boost, buck/boost and Luo converters to provide high voltage gain are analyzed in this work and Luo converter is found to give small ripple in current and voltage as compared to the other two converters for the same voltage gain. Further, in Luo converter, voltage gain can be improved by lifting technique in which self-lift and re-lift techniques are employed. The Re-lift Luo converter has high voltage gains twice that of self-lift Luo and reduced ripple for solar power application. For air conditioning application AC output is obtained using a full bridge single phase voltage source inverter.

Keywords: Air conditioner; Inverter; Perturb and Observe MPPT; Photovoltaic; Re-lift Luo Converter.

1. INTRODUCTION

The power demand will be increasing nowadays in the power system due to appliances such refrigerator, air conditioner, etc. The power requirement of these appliances is maximum in summer day time. As summer temperature pattern is closely related with power generation of photovoltaic (PV) panel in daytime [1]. Therefore, it is suitable to combine photovoltaic panel for air conditioning system to reduce the power demand at summer daytime. Nowadays, power generation from the renewable energy source is becoming very popular due to increasing power demand and scarcity, rising price and environmental problem of conventional non-renewable energy source [2].

The photovoltaic panel has varying power characteristics with the temperature, light intensity, dust etc. The single diode PV panel model was designed in Matlab Simulink with characteristic equation to understand and design the suitable DC-DC converter for the required application [3,4]. An appropriate DC-DC converter is required to obtain maximum and clean power from PV panel. There are various converters such as buck, boost, buck/boost, Luo converters etc. to acquire power from PV panel to application. Air conditioning application requires large power. The commonly used DC-DC converter with high gain can only be achieved through transformer and coupled inductor topologies. But the use of transformer and couple inductor causes large power loses due to parasitic capacitance. Also the leakage inductance in the transformer causes voltage spikes [5]. The high voltage gain without transformer is achieved through voltage lifting technique of Luo converter. Also Luo converter has advantage reduced output voltage and current ripple with the comparison of other commonly used DC-DC converters [6-9]. As well any MPPT operation can be applied. Moreover, Luo converter will operate in a continuous conduction mode at any operating condition. Therefore, it causes less stress to components and switches.

2. SOLAR ENERGY SYSTEM AND MAXIMUM POWER POINT TRACKING (MPPT)

The solar PV cell shows nonlinear characteristic with temperature, insolation etc. The one-diode model of PV cell was employed to study the characteristics. The solar PV modules for desired power were designed by connecting many PV cells in series and/or parallel configuration [4-5]. The one-diode circuit model of the PV module is given in Figure 1. The simplified characteristic design equation for solar module is given in Equation (1).

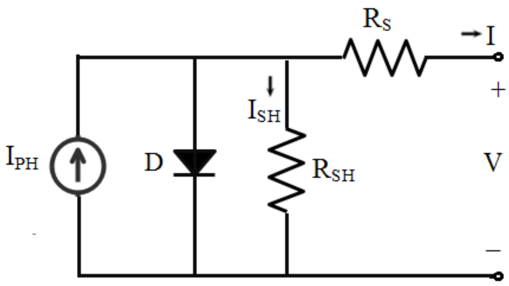

Figure 1. One-diode model of PV module

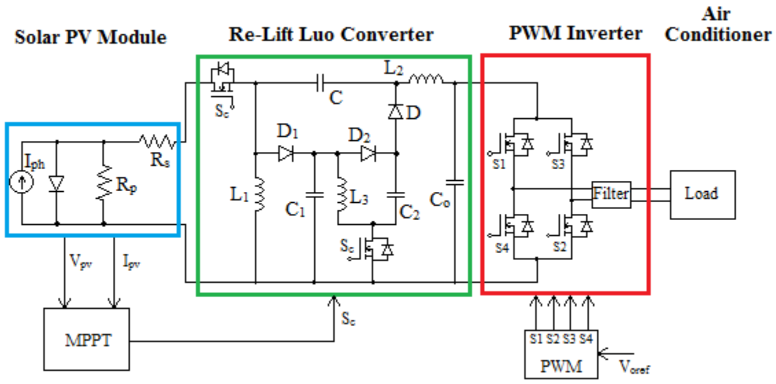

Figure 2. Proposed solar PV power system for air conditioner

$$I = N_{PP} I_{PH} - N_{PP} I_S \left[e^{\frac{q\left(\frac{V}{N_S}\right)}{kT_C AN_{SS}}} - 1 \right] \tag{1}$$

The light generated current or photocurrent depends on solar insolation and the temperature is given Equation (2).

$$I_{PH} = [I_{SC} + K_i (T_C - T_{ref})]\lambda \tag{2}$$

The cell saturation current of solar cell is given in Equation (3).

$$I_s = \left[\frac{I_{sc} + K_I \Delta T}{\exp\left(\frac{V_{oc} + K_V \Delta T}{AV_t}\right) - 1} \right] \tag{3}$$

where k is Boltzmann's constant, A is ideality factor, q is an electron charge, T_C is the cell's working temperature, I_{SC} is the short circuit current of PV cell at 1 kW/m^2 and 25°C, K_i is short circuit current temperature coefficient, T_{ref} is the reference temperature of PV cell, λ is the solar irradiation in kW/m^2, N_{PP} and N_{SS} are parallel and series number of modules respectively.

The production of electric power from solar PV modules is not always constant but varies with respect to insolation and temperature conditions. These changes in solar insolation values and temperature sternly affect the output power of PV module and hence its conversion efficiency. To improve the efficiency of the PV modules an MPPT technique is most commonly suggested. The popular perturbation and observation MPPT method evaluates ΔV and ΔP to guess the momentary operating region. The reference voltage is increased or decreased in a specified manner so that the PV module operates at its maximum power point.

3. DESIGN OF PROPOSED MODEL

The proposed model consists of solar PV module with MPPT, Re-lift Luo converter, Sinusoidal PWM Inverter, and air conditioning load. The proposed model for air conditioner load is presented in Figure 2.

The re-lift Luo converter is deduced from self-lift Luo converter. Voltage lift technique is obtained by circuit design modification so that the voltage gain of converter is increased highly. This voltage lifting techniques are formed by combination of parasitic elements and transistor switch. Re-lift converter has two transistor switches S and S_1, three diodes D, D_1 and D_2, three inductors L_1, L_2 and L_3 and four capacitors C, C_1, C_2 and C_o. The combination of component L_3, D_2, S_1, C_2 added to self-lift Luo converter into Re-lift Luo converter. Commonly the lift circuit has D_1, C_1, L_3, D_2, S_1, C_2. capacitors C_1 and C_2 are to lift capacitor voltage twice the source voltage and inductor L_3 act as link between capacitors C_1 and C_2 to lift the capacitor C voltage to V_c. Assuming output current is continuous and inductor current will rise and fall linearly [10-11]. The voltage and current waveform of inductors L_1, L_2 and voltage waveform of capacitor C is given in Figure 3.

During switch ON condition, Voltage V_{L3} is same as V_{in}. The peak to peak current ripple of inductor L_3 is given in Equation (4).

$$\Delta I_{L3} = \frac{V_{in}DT}{L_3} \tag{4}$$

During switch OFF condition, Voltage is $-V_{L3}$ and current ripple of inductor L_3 is given in Equation (5).

$$\Delta I_{L3} = \frac{V_{L3}(1-D)T}{L_3} \tag{5}$$

The voltage drop across the inductor L_3 during OFF condition is given in Equation (6).

$$V_{L3} = \frac{D}{1-D}V_{in} \tag{6}$$

During switch ON condition, the current I_{L1} increases along the inductor L_1.

$$V_{in} = \frac{\Delta I_{L1}L_1}{DT} \tag{7}$$

If the switch is OFF, current I_{L1} decreases along L_3, C_1 and C .

$$V_C - 2V_{in} - V_{L3} = -\frac{\Delta I_{L1}L_1}{(1-D)T} \tag{8}$$

From Equations (4) and (5), the voltage drop across capacitor C is given by Equation (9).

$$V_C = \frac{2}{1-D}V_{in} \tag{9}$$

During switch ON condition, the inductor L_2 is energized by capacitor C, source and load.

$$V_C + V_{in} - V_0 = \frac{\Delta I_{L2}L_2}{DT} \tag{10}$$

During switch OFF condition, the inductor L_2 is de-energized to L_3, C_1 and load.

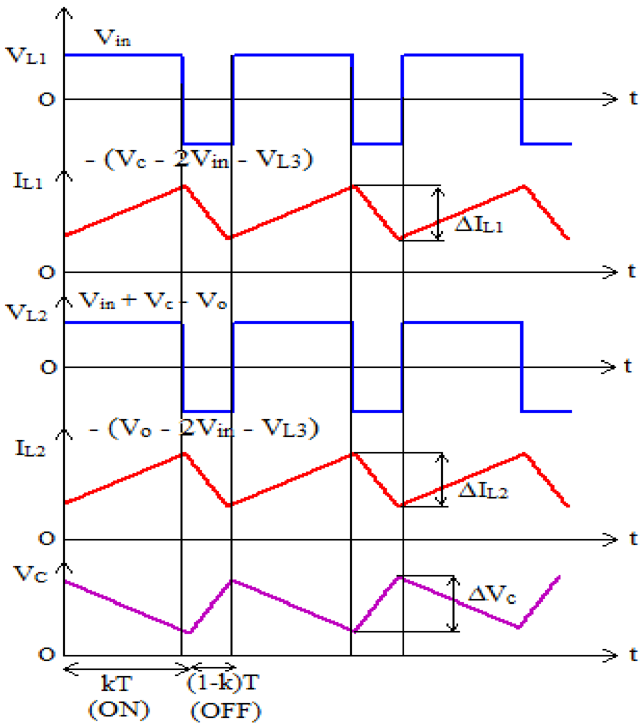

Figure 3. Waveform of Re-lift Luo converter

$$V_0 - 2V_{in} - V_{L3-off} = -\frac{\Delta I_{L2} L_2}{(1-D)T} \tag{11}$$

From Equations (6) and (9), the output voltage is given in Equation (12).

$$V_0 = \frac{2}{1-D} V_{in} \tag{12}$$

Therefore, the output current is given in Equation (13).

$$I_0 = \frac{(1-D)}{2} I_{in} \tag{13}$$

The inductors, L_1 and L_2 for a peak to peak current ripple are

$$L_1 = \frac{DTV_{in}}{\Delta I_{L1}} \tag{14}$$

$$L_2 = \frac{DTV_{in}}{\Delta I_{L2}} \tag{15}$$

The capacitors C, C_1, C_2, C_0 for given peak to peak voltage ripple are

$$C = \frac{(1-D)TI_{L1}}{\Delta V_C} = \frac{(1-D)DT}{\Delta V_C} I_{in} \tag{16}$$

$$C_1 = \frac{(1-D)T(I_{L1} + I_{L2})}{\Delta V_{C1}} = \frac{I_0 T}{\Delta V_{C1}} \tag{17}$$

$$C_2 = \frac{(1-D)T(I_{L1} + I_{L2})}{\Delta V_{C2}} = \frac{I_0 T}{\Delta V_{C2}} \tag{18}$$

$$C_0 = \frac{DT^2 V_{in}}{4\Delta V_0 L_2} \tag{19}$$

4. SIMULATION AND RESULTS

As the output power vs voltage and current vs voltage curves of PV panel shows non-linear characteristic, these curves are sensitive to temperature and insolation changes. The characteristic of power vs voltage and current vs voltage to the temperature changes, by fixing insolation constant of 1 kW/m^2 and vary temperature about 25°C, 30°C and 35°C, are given in the top row of Figure 4. On the other hand, the characteristic of power vs voltage and current vs voltage to the irradiance changes, by fixing the temperature constant of 25°C and vary insolation about 1 kW/m^2, 0.8 kW/m^2 and 0.6 kW/m^2 and 0.6 kW/m^2 are given in the bottom row of Figure 4. From this varying characteristic, MPPT technique is used to maintain at maximum power is shown in the Figure 5. The operating point is moved by the algorithm towards the maximum potential PV power for the present environmental conditions.

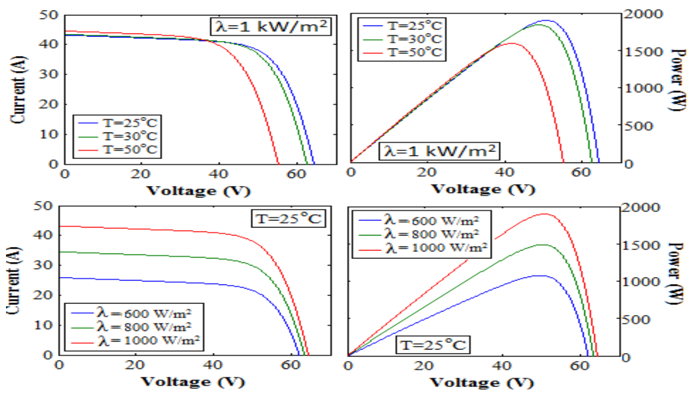

Figure 4. I-V and P-V curves under temperature and insolation variations

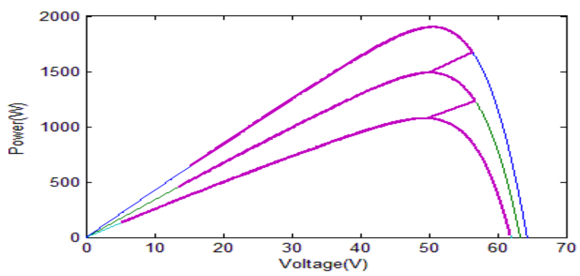

Figure 5. P&O MPPT tracking for varying insolation

The comparison of voltage gains of Boost, Buck-Boost, Self-lift Luo and Re-lift Luo is shown in Figure 6(a). From this voltage gain comparison Re-lift Luo converter has high voltage gain than other converters. The comparison of output voltage ripple of Boost, Buck-Boost, Self-lift Luo and Re-lift Luo is shown in Figure 6(b), where the Re-lift Luo converter has reduced voltage ripple than other converters.

The parameters for solar panel, Re-lift Luo converter, and unipolar sinusoidal inverter are given in the Tables 1, 2 and 3 respectively. From the simulation, output voltage and current waveform of solar PV panel with given parameter and output voltage and current waveform when the load is connected to the output of converter is shown in the Figure 7. The output voltage of unipolar sinusoidal PWM Inverter across the load and DC link voltage across the capacitor *Co* when the load connected via the inverter is shown in Figure 8. The PWM is normally employed to obtain the variable voltage. The modulation index of 0.88 is selected in this simulation so that the required voltage is obtained

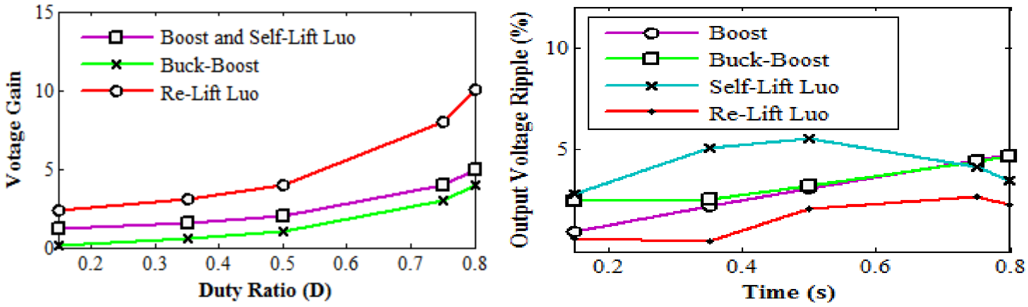

Figure 6. (a) Voltage gain comparison of converters; (b) Output voltage ripple comparison of converters

Table 1. Parameters for proposed model

S.No	PV Module Parameters	Values
1	Open circuit voltage, V_{OC}	21.54 V
2	Voltage at maximum power, V_{max}	17.1 V
3	Short circuit current, I_{SC}	2.55 A
4	Current at maximum power, I_{max}	2.11 A
5	Maximum power, P_{max}	36 W
6	Series number of modules, N_{SS}	3
7	Parallel number of modules, N_{PP}	17

Table 2. Re-lift Luo converter parameter

S.No	Converter Parameters		Values
1	Input voltage, V_{in}		50 V
2	Output voltage, V_0		350 V
3	Input current, I_{in}		35 A
4	Output current, I_0		5 A
5	Inductors L_1, L_2, L_3		0.102 mH
6	Capacitors	C	8.163 μF
		C_1, C_2	5.171 μF
		C_o	2 μF

Table 3. SPWM inverter parameter

S.No	Inverter Parameters	Values
1	DC link Voltage, V_{DC}	350 V
2	Output RMS AC Voltage, V_{AC}	230 V
3	Output RMS AC Current, I_{AC}	7 A
4	Carrier signal frequency, f_C	25 kHz
5	Reference signal frequency, f_{ref}	50 Hz

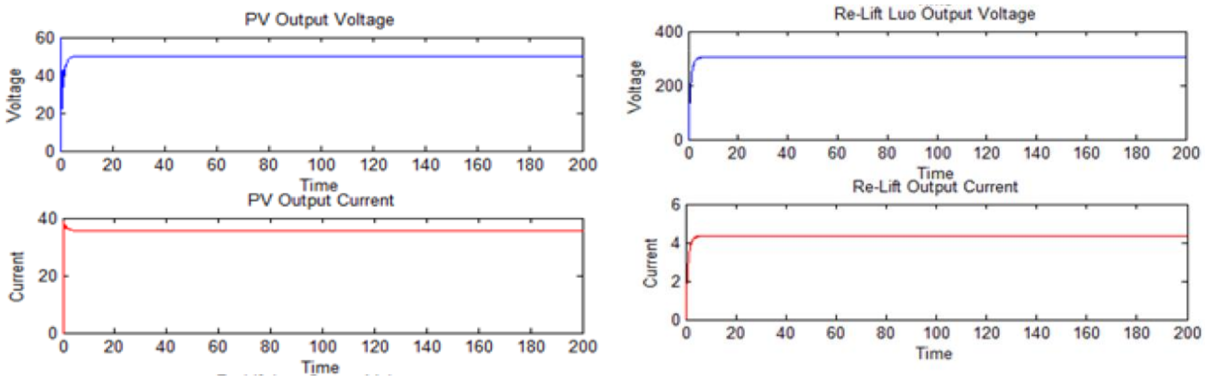

Figure 7. Output voltage and current waveform of PV panel and Re-lift Luo converter

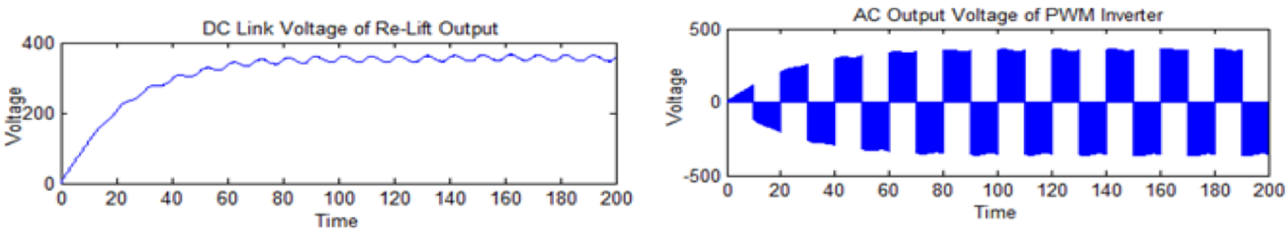

Figure 8. (a) Output voltage of Re-lift Luo converter; (b) Output voltage of PWM inverter

5. CONCLUSION

The development of power system for air conditioner was done based on comparison of different type possibilities and requirements are taken into consideration. Among various modeling techniques for PV available in literature, the single diode model was selected which is simple, easy to model and interface with converters. The I-V and P-V characteristic curves of the PV module were studied using MATLAB. The power electronic converters are being used as the power conditioning circuits to obtain the potential power from PV module. Many DC-DC converters with substantially high voltage gain are considered in this work. There were Boost, Buck-boost, Self-lift Luo and Re-lift Luo converter analyzed and their performance parameters were compared. From above comparison, Re-lift Luo converter was found to render high voltage gain and low voltage ripple. Moreover, an efficiency of around 94.6% is achieved in the conversion. So this converter is suitable for this application. To receive the maximum power under varying irradiance and temperature, Perturb and Observe method is implemented. This work can be extended with other MPPT methods and controllers for performance enhancement.

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