# Solar Powered Luo Converter for Wiper Motor Application

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### Abstract

**Objectives:** This paper is to design a positive output elementary luo converter whose output can be used to power the wiper motor. **Method/Statistical Analysis:** The perturb and observe algorithm is used to obtain the maximum power from the solar panel. The positive output luo converter is simulated using MATLAB/Simulink software. **Findings:** In conventional converters the output voltage increases in arithmetic progression. But, in luo converter the output voltage increases in geometric progression, thus the voltage gain of the converter is enhanced than conventional converters. The output of the luo converter is validated with r-load and motor load. With the help of luo converter, the ripple content in the output can be highly reduced in the output. **Applications:** Wiper motors are used for applications such as to operate wiper blades in car, automatic parking system, wheel movement in robots etc.

**Keywords:** DC-DC Conversion, DC Motor, MPPT Technique, Perturb and Observe Algorithm, Positive Output Luo Converter, Ripple

# 1. Introduction

The conversion of solar power to useful DC source is being a major role in recent years. Hence DC-DC converters are widely used in many applications like industrial applications such as dc motor drives, computer systems, communication systems, medical equipments, welding applications, hybrid electric vehicles etc. The conventional types of DC-DC converters includes Buck converter, Boost converter, Buck-Boost converter, Cuk converter, Zero voltage switching converter and Zero current switching converters which are usually named after their operation and performances. Among those converters boost converter is found to be widely used in large number of applications. The DC-DC conversion technique was established in early 20th century. The conversion used at that time was voltage divider<sup>1</sup> which has a simpler method. But now various advanced methods are used for the conversion process ranging from voltage lift technique to super lift and ultra-lift technique.

With some statistical studies, there have been more than 500 prototypes of DC-DC converters, which are developed in past five decades<sup>1</sup>. Here voltage lift technique is being used due to its simple implementation. Use of voltage lift technique has provided a gateway to design high voltage gain converters which allows the voltage to be increased stage by stage in geometric progression whereas the conventional converters increases the output voltage in arithmetic progression. Luo converters are the simplest form of DC-DC converters, which operates under voltage lift technique. Positive output luo converter is a high voltage gain converter. The output voltage of the proposed converter is increased stage by stage in geometric progression. Thus voltage gain is increased<sup>1,2</sup>.

Now-a-days many researches for the development of alternative energy sources are done by researchers and scientists. Solar energy is, found to be one of the main alternative clean energy sources, which had shown a tremendous growth. Since India has excellent sunshine condition, it will be very suitable for India to develop photovoltaic power generation. But Maximum Power Point Tracking (MPPT) is needed to gain the maximum available solar energy, which can be gained from the solar panel. There are many MPPT algorithms, developed by researchers and delegates across the world. They are Short Circuit method, Open Circuit method, Perturb and Observe, Incremental conductance, DC link capacitor voltage drop voltage, Current sweep method, Support vector regression (SVR), One cycle control, Estimated perturb and observe, Fuzzy logic based MPPT method, Artificial neural network (ANN) based MPPT method, Model reference adaptive control method (MRAC), Distributed maximum power point tracking, Model predictive control<sup>3</sup>. Out of which perturb and observe algorithm is used in this paper to obtain the maximum power from the solar panel.

As a survey, many controllers have been used to control positive output luo converters. Sliding Mode controller has been implemented with Positive output Luo converter to eliminate the steady-state error apart from the input disturbance and load variation. Due to their non-linear property, it is an effective control method for these converters<sup>4</sup>. PI controller with zero steady state error has been implemented to justify the transient region and steady state region<sup>5</sup>. The luo converter with impedance network has been incorporated for high voltage applications. It has its own advantages such as low inrush current, low EMI distortion and easy start-up<sup>6</sup>. Soft switching of positive output luo converter is achieved by using switched capacitor snubber circuit, with decreased inductor size<sup>2</sup>. The power converter has been designed with positive output re-lift converters for solar fencing system to employ in agriculture to prevent wild animals from damaging crops<sup>8</sup>. An automatic wiper system has been designed to avoid the distraction of driver's attention from driving, using wiper motor and a plated based water sensor. This system has low cost requirement and gives high performance<sup>9</sup>.

# 2. Proposed System

In this paper the positive output elementary luo converter is implemented with an MPPT technique. The PV array is used as the source to the converter. The most widely used MPPT technique is Perturb and Observe algorithm. It is used to obtain the maximum power from the solar panel. The simulation of the Perturb and Observe algorithm with the Positive output luo converter is carried out in MATLAB/Simulink. The converter is designed in such a way that it is used to drive the wiper motor. The wiper motors are used in locomotives. It is used to keep the windshield screen clean for clear visibility of driver in high speed vehicles. Figure 1 shows the Block diagram of the proposed system with positive output luo converter.



Figure 1. Block diagram of proposed system.

In Figure 1, the PV panel is used as source; the battery is connected across the PV panel so that it stores the charge during day time. The PV panel supplies the Positive output luo converter with 12V DC. Through the converter a 24V DC output is obtained, which is fed to the DC motor. In this paper wiper motor is used as load. During night time, the battery supplies the converter with 12V DC, which is stored from the PV panel during day time.

The wiper motors are used in locomotives, trains, cars etc for cleaning the glass of the vehicle for the driver's clear visibility while driving, to avoid accidents. There are two types of wiper motors. They are Permanent-magnet type and Shunt Wound Motors. Mostly Permanent-magnet three brush type is used in recent years. These motors are driven through a gear called worm gear to increase torque and reduce speed. The above mentioned motor allows two speed operations.

# 3. Positive Output Elementary Luo Converter

### 3.1 Circuit Operation

Positive output elementary luo converter for PV system usually consists of an Inductor L, Capacitors C1 and C2, Diodes D1 and D2, Switch, Source and Load R. The circuit of positive output luo converter is shown in Figure 2.



Figure 2. Positive Output Luo Converter.

The equivalent circuits of positive output luo converter for switching on and switching off period is shown.



Figure 3. Circuit diagram for Mode1.

The equivalent circuit of positive output luo converter is shown in Figure 3 when the switch is closed. During this turn on time the capacitor C1 is charged to  $V_{IN}$ . The current through the inductor L increases with the input voltage  $V_{IN}$ . The input current during model is equal to  $(I_L + I_{C1})$ .



Figure 4. Circuit diagram for Mode 2.

During Switching-off period of the MOSFET, the inductor L and the capacitor C1 will be connected in series as shown in Figure 4. The current I<sub>L</sub> flows through the inductor L decreases with voltage  $(V_O - 2V_N)$ . The

capacitor current  ${\rm I}_{_{\rm C1}}$  is equal to  ${\rm I}_{_{\rm L}}$  since they become series connected devices.

### 3.2 Analysis

#### 3.2.1 Mode 1

By Kirchhoff's voltage law,

$$V_{IN} = V_L = V_{C1} \tag{1}$$

Applying Kirchhoff's current law,

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

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

Time taken is given by  $T_{ON}$ ,

$$T_{ON} = \frac{L\Delta I}{V_{IN}} \tag{4}$$

From the above equation, the inductor current is derived as,

$$\Delta I = \frac{T_{ON}V_{IN}}{L} \tag{5}$$

Inductor voltage is given by,

$$V_L = L \frac{di_L}{dt} \tag{6}$$

Therefore, Output Voltage is given as,

$$V_{C2} = V_O = I_O R_O \tag{7}$$

#### 3.2.2 Mode 2

When applying Kirchhoff's voltage law to mode 2 circuit, we get

$$V_{IN} + V_L + V_{C1} = V_{C2}$$
(8)

By Kirchhoff's current law,

$$I_{IN} = I_L = I_{C1} \tag{9}$$

Current through capacitor C1 is given by,

$$I_{C1} = I_{C2} + I_{O} \tag{10}$$

Now assuming that capacitor C1 charges to the input voltage,

$$V_{C1} = V_N$$
 (11)

Substituting (11) in (8), we get,

$$V_{IN} + V_L + V_{IN} = V_{C2}$$

$$2V_{IN} + V_L = V_{C2}$$
(12)

Inductor Voltage is given as,

$$V_L = -L \frac{\Delta I}{T_{OFF}} \tag{13}$$

Where  $T_{OFF}$  is the time taken for mode 2,

$$T_{OFF} = L \frac{\Delta I}{2V_N - V_{C2}} \tag{14}$$

From the above equation inductor current  $\Delta I$  can be derived as,

$$\Delta I = T_{OFF} \, \frac{2V_N - V_{C2}}{L} \tag{15}$$

Equating equations (5) and (15) and substituting  $T_{ON} = DT$  and  $T_{OFF} = (1 - D)T$  and simplifying we get,

$$V_{C2} = 2V_{IN} + \frac{D}{1 - D}V_{IN}$$
(16)

But according to mode 1,  $V_{C2} = V_O$ 

$$V_{O} = 2V_{IN} + \frac{D}{1 - D}V_{IN}$$
(17)

Now, the ratio of time take for mode 1 (during ON time) and mode 2 (during OFF time) is calculated as,

$$\frac{T_{ON}}{T_{OFF}} = \frac{V_O - 2V_{IN}}{V_{IN}}$$
(18)

The Switching period is given as,

$$T = T_{ON} + T_{OFF}$$
  
$$T = L\Delta I \left[ \frac{3V_{IN} - V_{C2}}{3V_{IN}^2 - V_{IN}V_{C2}} \right]$$
(19)

The peak to peak ripple current can be given as,

$$\Delta I = \frac{1}{Lf_s} \left[ \frac{3V_{IN}^2 - V_{IN}V_{C2}}{3V_{IN}V_{C2}} \right]$$
(20)

And the capacitor ripple voltage on the output side is given as,

$$\Delta V_{C2} = \frac{I_o}{C_2 f_s} \left[ \frac{V_o - 2V_{IN}}{V_o - V_{IN}} \right]$$
(21)

The voltage gain 
$$G = \frac{V_o}{V_N}$$
 (22)

### 4. Design Of MPPT Technique

The most commonly used MPPT technique for PV array is Perturb and Observe method. Perturb means change. Here the current or voltage of the PV array is changed periodically and the output power is observed.

If increase in power is traced with increase in voltage, the control system moves the operating point of PV array in that same direction. This procedure is continued until maximum power point is reached. The most basic form of Perturb and Observe algorithm works as follows. The operating Voltage of the PV array is perturbed or changed with a small increment and the resulting change in power i.e.,  $\Delta P$  is measured.

If  $\Delta P$  is positive, then the perturbation or change in the voltage of the PV panel, moves the PV array's operating point closer to maximum power point. In other case if  $\Delta P$  is negative, then the PV array's operating point is moved away from maximum power point<sup>10</sup>. Flow chart of perturb and observe algorithm is shown in Figure 5<sup>11</sup>.



Figure 5. Flowchart of Perturb and Observe method.

The simulation of the Perturb and Observe MPPT algorithm is carried out in MATLAB/Simulink software and is shown in Figure 6. The Input parameters for the simulation of perturb and observe algorithm is obtained from the PV panel, which is the source to the positive output luo converter.

### 5. Simulation of Proposed Method

The simulation of positive output luo converter has been performed with Solar input and MPPT control is shown in Figure 7. The simulation of the converter carried out for PV system using perturb and observe algorithm using MATLAB/Simulink software. The simulation parameters for positive output luo converter with motor load are listed in Table 1.



Figure 6. Simulation of Perturb and Observe algorithm.



**Figure 7.** Simulink model of Positive Output Luo Converter – motor load with solar input.

 Table 1. Circuit Parameters for Positive output luo converter

Parameters	Symbols	Values
Input Voltage	Vin	12 volts
Output Voltage	Vo	24 volts
Inductor	L	350 milli Henry
Capacitor	C1,C2	470 micro farad
Switching Frequency	Fs	100 kHz

The positive output luo converter is designed with the above listed parameters such that the output voltage is regulated to 24 volts which can be supplied to the wiper motors and car starters.

# 6. Simulation Output

The positive output luo converter has been simulated using MATLAB/Simulink. The input voltage and input current of the positive output luo converter with MPPT algorithm for Motor is shown in Figure 8 and Figure 9.



Figure 8. Input voltage vs. time for motor load from PV panel.



Figure 9. Input Current vs time for motor load.

The Voltage and Current across the MOSFET is shown in Figure 10. When the switch is ON, there will be no voltage across the switch but current will flow through the switch.



Figure 10. Voltage and current across switch vs. time for motor load.

The input power is shown in Figure 11. The ripple content is high in input power.



Figure 11. Input Power vs. Time for motor load.

The current through the inductor is shown in Figure 12.



Figure 12. Inductor current vs. time.

The capacitor C1 charges to somewhat less than the input voltage and stores it. The voltage across C1 is shown in Figure 13.



Figure 13. Voltage across C1 vs. Time.

The Capacitor C2 charges to twice the Input voltage. The voltage across C2 passes through the motor load. The voltage across the capacitor is shown in Figure 14.



Figure 14. Voltage across C2 vs. Time.

The Output voltage measured across the motor is shown in Figure 15. It is found that the output voltage is measured to be 24V DC.

The Output current measured across the motor is shown in Figure 16. It can be seen that the ripple content in the output current is eliminated when compared with the Input current waveform.

The Output power is shown in Figure 17. There is no ripple in the Output power waveform, When compared

with the Input power waveform, the ripple in the input power is eliminated in the output power.



Figure 15. Output voltage vs. Time.



Figure 16. Output Current vs. Time.



Figure 17. Output Power vs. time for motor load.

There is no ripple in the Output power. The measured speed of the motor is shown in Figure 18. The speed is measured in terms of radians per second in simulation.

Therefore from graph, the speed of the DC motor is measured to be 13.12rad/s. Since the speed is in radians

per second, it is needed to be converted into rotations per minute.

1 rad/s = 9.549 rpm



Figure 18. Speed of the DC motor vs. time.

Hence after conversion, the speed of the motor is calculated as 125 rpm. For a wiper motor, the speed ranging from 100 rpm to 150 rpm is required for operation. Hence the maximum speed is achieved. The Table 2 shows the measured values from the simulation for both r-load and motor load. The armature current Ia, field current I<sub>f</sub> and the torque T of the motor is shown in Figure 19.



**Figure 19.** Armature current, Field current and Torque vs. Time.

PARAMETERS	DC MOTOR
Input voltage (Volts)	12

Output voltage (Volts)	24
Input current (Ampere)	0.378
Output current (Ampere)	0.369
Input power (Watts)	8.966
Output power (Watts)	7.633
Efficiency (%)	85.13

Since the motor used is permanent magnet motor, the field current across the motor is zero.

# 7. Conclusion

Thus the conversion of positive load voltage from positive source voltage is performed by the Positive Output Luo Converter. Thus the converter is regulated to produce an output voltage of 24 volts from 12 volts input voltage, which is received from the solar PV system. The DC motor especially, the wiper motor is successfully supplied with the 24 volt output voltage from the positive output luo converter. The Perturb and Observe MPPT algorithm is successfully implemented to track the Maximum Power Point. It has been proved to be intact around the operating point. Thus 85.13% of efficiency is obtained from the DC Motor load by simulation. The speed of the wiper motor can be controlled by using permanent magnet three brush type, which are driven by worm gears.

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