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Design of Power Converters for Solar Fencing System Employed in Agriculture

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Abstract-This paper presents design of power converters for solar fencing system employed in agriculture. Wild animals especially elephants destroys farmer's year of hard work in just few hours. Solar fencing system can be used in which the animals experience a high voltage low current shock for a very short time. This paper presents a design and analysis of very low current, high voltage converters for fencing system.

Keywords - Solar fencing system, Luo converters, Agriculture, MATLAB

I. Introduction

Agriculture in India is the broadest economic sector and plays a significant role in the overall socio-economic factor of India. The increasing news articles in television and newspaper on wild elephants raiding agricultural crops during harvest season shows that these animals can destroy a farmer’s livelihood. The report says that elephants damage crops on 0.8 to 1 million hectares annually which on an average affects about 5, 00,000 families. The farmers are normally poor, smallholders and the damage caused by these animals can be financially ruinous to them and their families. Their fight to protect the fields includes many techniques such as lighting fires, banging drums making noise, setting off firearms and fire crackers, digging trenches etc. Unfortunately often these methods are to no avail. Hungry elephants are difficult to frighten off as they become acclimatized to such techniques. In such areas Electric fencing system can be employed in which the animals experience a high voltage low current shock for a very short time. Because of the small magnitude of current there is no threat to the animal’s life at the same time the large magnitude voltage scares away the animals.

Solar energy can be utilized to energize such fence arrangement. Solar power has been chosen for this application due to which the dependency on the conventional power supply can be reduced and problem of energy crisis can also be overcome. In comparison with the non-renewable energies such as coal, gasoline and oil, solar power is becoming increasingly popular as it produces no pollution and requires minimum maintenance. The energy from the sun is free and it also has the advantage of reducing the power losses when converting the energy.

Usually, the high voltage is produced by a single-phase transformer and a rectifier bridge. However equipment is large and has high power consumption. In order to produce a high voltage gain and low current in the order of mA the Luo converter series is considered. The super-lift technique of the Luo converter series implements the output voltage increasing in geometric progression. It effectively enhances the voltage transfer gain in power law. From the super lift Luo converter series two converters namely triple lift additional circuit and triple lift enhanced circuit is considered. Super-lift technique increases the voltage transfer gain in geometric progression. However, these circuits are a bit complex. Another novel approach is the positive output cascade boost converter that implements the output voltage increasing in geometric progression, but with simpler structure. This method also effectively enhances the voltage transfer gain in power-law. Hence from the positive output cascade boost converter series, three stage boost re-double circuit was considered for study and simulation.

From the comparative analysis of the three proposed power converters it is observed that the three stage boost re-double circuit effectively fulfilled the objective of obtaining high voltage gain and low current in the order of mA. Hence this converter topology is employed in the proposed solar fencing system and presented [1]-[7].

II. System Description

The block diagram of the solar fence set up is shown in Fig. 1.

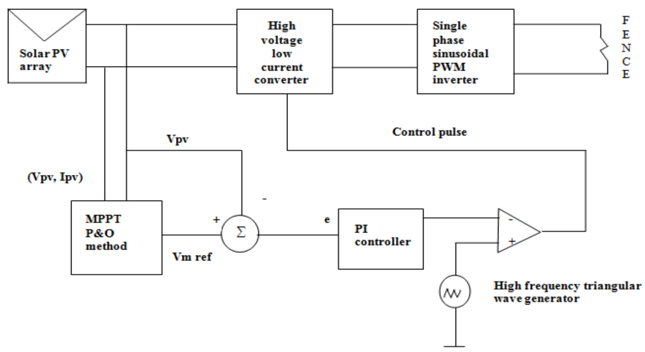

Fig.1. Block diagram of the solar fence set up

The solar photovoltaic (PV) array converts light energy into electrical energy. The PV voltage and PV current are sensed from the panel and given to the Maximum Power Point Tracking (MPPT) block which uses the Perturb and Observe method to track the maximum power point. The corresponding voltage V_{mref} at which maximum power is tracked is then compared with PV voltage and the error is processed through a PI controller. The output of the PI controller is compared with triangular wave generated at the required frequency and the PWM pulses obtained from the output of the comparator is given as gating pulse to the high voltage low current converter. The PV voltage from the solar panel is given power the high voltage low current converter. The high voltage low current dc output obtained from the converter is then fed to single phase sinusoidal PWM inverter and the ac output from the inverter is given to energize the fence. The modeling and simulation of the system is discussed in the following sections [7]-[8].

Mathematical Modeling of Solar PV Panel

The solar PV panel is modeled mathematically using the equivalent basic structure consisting of a current source and a diode in parallel. For the purpose of simplicity and accuracy the single diode model (Fig 2) is adapted. The equivalent circuit consists of a series resistance and shunt resistance that accounts for losses in ohmic contacts and losses on the edge of the cell, because of leakage of current from one terminal to the other due to poor insulation respectively [2].

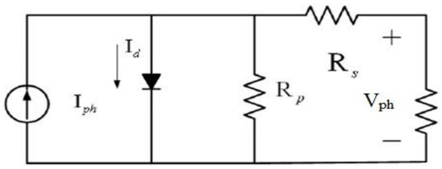

Fig.2. Equivalent circuit of solar cell

From the equivalent circuit the following equations are obtained:

$I_{pv}= I_{ph}-I_r[\exp(V_D/V_T)-1]-(V_D/R_p)$ (1)

$I_{ph}= G*I_{sc}$ (2)

$I_{sc}= I_{sch}[1+K_I dT]$ (3)

$I_o= I_r[\exp((V_{D*}V_{ta})/N_{ss})-1]$ (4)

$I_m= N_{pp}[I_{ph}-I_o]$ (5)

Using (1)-(5), solar PV panel with 37.08 W rating is simulated using MatLab-Simulink.

Maximum Power Point Trackers (MPPT)

PV system has non-linear characteristics and it changes with the solar irradiation and temperature. To overcome this problem, MPPT technique will be used. For the solar fencing application the simplest MPPT algorithm namely the perturb-and-observe (P&O) method can be used in which the voltage at which maximum power occurs is always tracked. The algorithm is implemented in MatLab and the tracking characteristics is presented in Fig 3 [9].

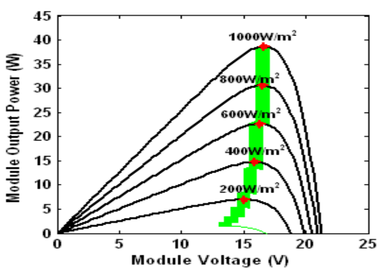

Fig. 3 Simulation of P&O algorithm

High Voltage Low Current Converter

Triple-lift additional circuit

The circuit diagram of the triple lift additional circuit is shown in Fig.4.

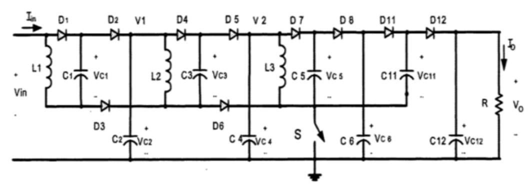

Fig.4. Triple-lift additional circuit

During switching on period the diodes D_1,D_4,D_7,D_{11} conduct while the diodes $D_2,D_3,D_5,D_6,D_8,D_{12}$ do not conduct . Therefore the voltage across capacitor C_1 is charged to V_{in} , voltage across C_2 is charged to the voltage V_1 and voltage across C_4 is charged to V_2 which are presented in (6) and (7) respectively.

$$V_1 = \left(\frac{2-k}{1-k}\right)V_{in} \quad (6)$$

$$V_2 = \left(\frac{2-k}{1-k}\right)^2 V_{in} \quad (7)$$

The voltage across C_5 is charged to V_2 and the voltage across C_6 and C_{11} to V_3 during switching on period .During switching off the diodes D_1, D_4, D_7, D_{11} do not conduct and the diodes D_2, D_3, D_5, D_6, D_8, D_{12} conduct. The voltage across the capacitors is discharged to the load and hence V_o appears across the load. The current flowing through inductor L_3increases with voltage V_2 during switching-on period and decreases with voltage (V_o-2V_2) during switching-off period (1-k)T. The gain of this converter topology is G given in (8) [3]-[4]-[5].

$$G = \frac{V_0}{V_{in}} = \left(\frac{2-k}{1-k}\right)^2\left(\frac{3-k}{1-k}\right) \quad (8)$$

Triple-lift enhanced circuit

The circuit diagram of the triple lift enhanced circuit is shown in Fig.5.

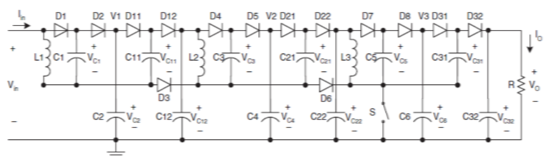

Fig.5. Triple-lift enhanced circuit

The voltage across capacitor C_1 is charged to V_{in}. The voltage V_1 across capacitor C_2 and voltage V_2 across capacitor C_4 is given in (9) and (10) respectively.

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$$V_1 = \left(\frac{2-k}{1-k}\right)V_{in} \quad (9)$$

$$V_2 = \left(\frac{2-k}{1-k}\right)^2 V_{in} \quad (10)$$

The voltage across capacitor C_5 is charged to V_2. The voltage across capacitor C_6 and C_{11} is charged to V_3 which is given by (11).

$$V_3 = \left(\frac{2-k}{1-k}\right)V_2 = \left(\frac{2-k}{1-k}\right)^2 V_1 = \left(\frac{2-k}{1-k}\right)^3 V_{in} \quad (11)$$

The voltage across capacitor C_{12} is charged to V_{C22}= (3-k/1-k)V_{in} , and the voltage across capacitor C_{22} is charged to V_{C12}= (3-k/1-k)²V_{in}. The voltage across capacitor C_5 is charged to V_{C22} and voltage across capacitor C_6 and C_{31} is charged to V_{C6} given in (12) [3]-[4]-[5].

$$V_{C6} = \left(\frac{2-k}{1-k}\right)V_{C22} = \left\{\left(\frac{2-k}{1-k}\right)\left(\frac{3-k}{1-k}\right)^2\right\}V_{in} \quad (12)$$

The voltage transfer gain G is given by (13) as,

$$G = \frac{V_0}{V_{in}} = \left(\frac{3-k}{1-k}\right)^3 \quad (13)$$

Three Stage Boost Re-Double Circuit

Three stage boost redouble circuit is shown in Fig. 6. The voltage across capacitors C_1 and C_{11} is charged to V_1 given in (14) and voltage across capacitors C_{12} and C_{13} is charged to $V_{C13} = 2V_1$.

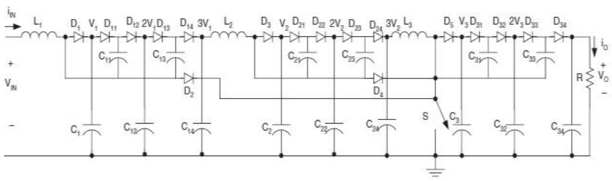

Fig. 6. Three-stage boost re-double circuit

$$V_1 = \left(\frac{1}{1-k}\right)V_{in} \quad (14)$$

The output voltage of the 1st stage is V_{01} as given in (15).

$$V_{01} = V_{C1} + V_{C13} = 3V_1 = \left(\frac{3}{1-k}\right)V_{in} \quad (15)$$

Hence the capacitor C_{14} is charged to $3V_1$. The voltage across capacitors C_2 and C_{21} is charged to V_2 and voltage across capacitors C_{22} and C_{23} is charged to $V_{C23} = 2V_2$. The current flowing through inductor L_2 increases with voltage $3V_1$ during switch-on period kT, and decreases with voltage – (V_2–$3V_1$) during switch-off period (1–k)T. The voltage V_2 is given in (16).

$$V_2 = \frac{3}{1-k}V_1 = 3\left(\frac{1}{1-k}\right)^2 V_{in} \quad (16)$$

The output voltage of the 2nd stage is presented in (17) as,

$$V_{02} = V_{C2} + V_{C23} = 3V_2 = \left(\frac{3}{1-k}\right)^2 V_{in} \quad (17)$$

The voltage transfer gain of the 2nd stage is given in (18) as,

$$G = \frac{V_{02}}{V_{in}} = \left(\frac{3}{1-k}\right)^2 \quad (18)$$

Similarly the voltage gets boosted in each stage by a factor (3/1-k) and hence the voltage transfer gain of the converter topology G is given by (19) as,

$$G = \frac{V_{03}}{V_{in}} = \left(\frac{3}{1-k}\right)^3 \quad (19)$$

where V_{03} is the output voltage of the 3rd stage [3]-[6].

III. Results and Tables

Triple-Lift Additional Circuit

Upon simulating the above circuit for an input voltage of 16 V dc, switching frequency of 9 kHz , duty ratio 0.5 and load resistance of 20 kΩ an output voltage of 580 V dc and output current of 19 mA are obtained as shown in Fig. 7.

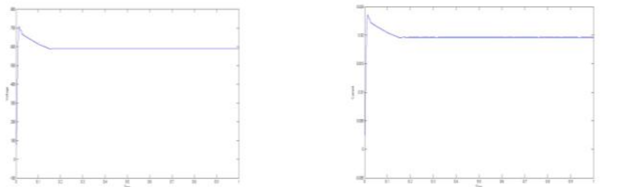

Fig.7. Simulated results of the Triple Lift Additional Circuit

Triple Lift Enhanced Circuit

The Triple-Lift Enhanced Circuit is simulated. For an input voltage of 16 V dc, switching frequency of 9 kHz, duty ratio 0.5 and load resistance of 20kΩ an output voltage of 1900V dc is obtained and an output current of 180mA is obtained as shown in Fig. 8.

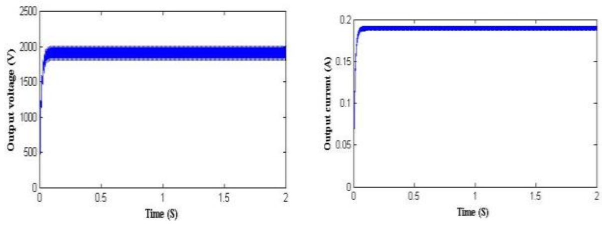

Fig.8. Simulated results of the Triple Lift Enhanced Circuit

Positive Output Cascade Boost Converter: Three Stage Boost Re-Double Circuit

The three Stage Boost re-Double Circuit is simulated. Upon simulation, for an input voltage of 16V dc, switching frequency of 9 kHz, duty ratio 0.5 and load resistance of 20 kΩ an output voltage of 3450 V dc and output current of 350mA as shown in Fig. 9 are observed.

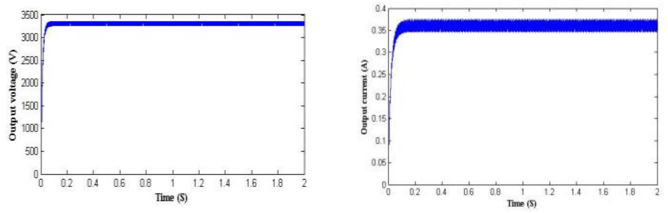

Fig.9. Simulated results of the Three Stage Boost Re-Double Circuit

Selection of Appropriate Converter Topology for the Solar Fencing Application

The output voltage gain for different converter types for a duty cycle of 0.5 has been calculated using the equations

Triple Lift Circuit-Two Stage Additional Series	-	45
Positive Output Super-Lift-Luo Converters: Triple Lift Enhanced Circuit	-	125
Positive Output Cascade Boost Converters: Three-Stage Boost Re-double Circuit	-	216

As per the application requirement high voltage magnitude is obtained in Positive Output Cascade Boost Converters: Three-Stage Boost Re-double Circuit. Hence it is selected as the converter topology for the solar fencing system.

Interfaced Simulation Output of the Solar Fence Set Up

The selected High Voltage Low Current Converter topology is interfaced with the Fence set up discussed in Fig. 1 as shown in the Fig. 10.

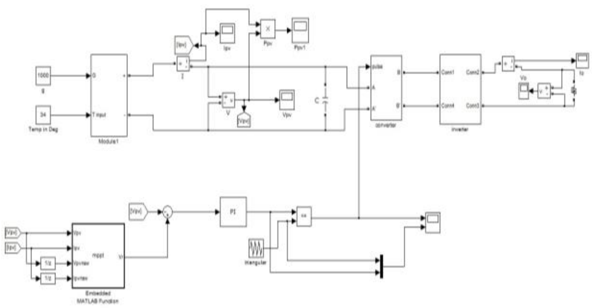

Fig. 10. Simulation circuit of the solar fence set up

Upon simulating, an ac voltage of 3450V and current of 350 mA is observed as shown in the Fig.11 for an Insolation constant G=1000W/m^2 and Temperature 34^{0}C as input to the PV Panel.

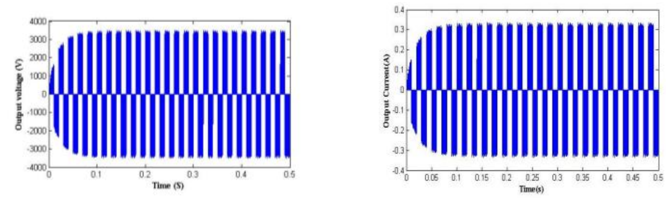

Fig.11. Simulated results of the fence set up

Due to unavailability of hardware components and safety concerns hardware implementation of two stage cascade boost converter is done with an input voltage of 3V. The power converter which can be employed for solar fencing is implemented in hardware as shown in the Fig. 12 given below:

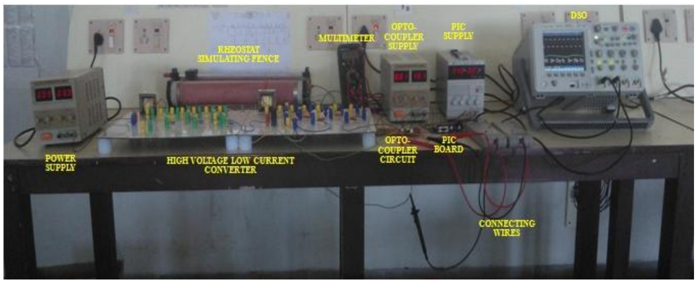

Fig.12. Hardware set up of the high voltage converter

Gating pulse for the switching device used in the power converter is obtained from 18F4550 PIC controller which is then fed to the switch through an opto-coupler circuit. The hardware set up of the two stage cascade boost converter is shown in Fig. 13.

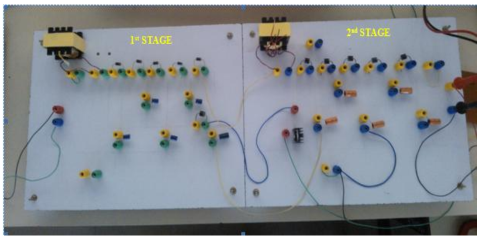

Fig.13. Closer view of the two stage cascade boost converter circuit in hardware

The converter output voltage waveform for an input voltage of 3V is observed on the DSO as shown in the Fig. 14 below.

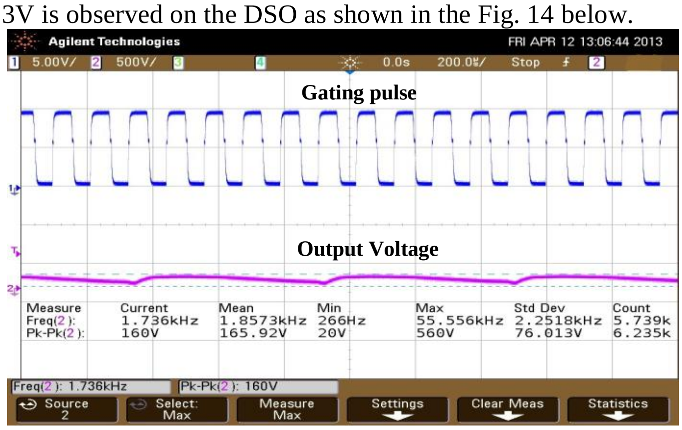

Fig.14. Gating pulse and Output voltage waveform observed on DSO

The input voltage & output voltage was measured and their waveforms with respect to time using Fluke meter are obtained as shown in the Fig. 15.

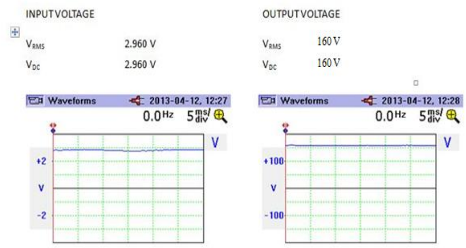

Fig.15. Input Voltage and Output Voltage values and waveforms observed on Fluke meter

IV. Conclusion

Efficient power converters are simulated for the solar fencing system employed in agriculture. Three stage boost re-double circuit is chosen as the best converter for this application. A compact solar fencing model is available that can be extended to agricultural practices followed in any land topography with no harm to the wild animals.

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