POWER OPTIMISATION AND PERFORMANCE EVOLUTION OF HIGH STEP-UP SOLAR PV SYSTEM FOR DC DRIVES

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ABSTRACT:In this paper, a DC-DC boost converter is used for a Solar PV Panel for a drive application. The DC-DC boost converter is performed using a Soft-Switching technique, Zero Voltage Switching (ZVS) for a smooth and effective operation. The ZVS reduces the voltage stress during the switching of DC-DC boost converters. The Solar PV Panel is considered as the source of renewable energy for producing the DC supply. The Solar PV panel is designed to produce the maximum power out from the panel. The maximum power extraction is performed using the Maximum Power Point Technique (MPPT) which has greater output efficiency. The proposed system can be used for a stand-alone application. The stand-alone application here considered being the drive operation of a DC Motor. This drive application can be used in small scale industries or in home applicant for the DC motor application. The proposed method is performed in MATLAB Simulink for the various components and the results are analysed.

Keywords: Zero Voltage Switching (ZVS), Soft-Switching Technique, Solar PV Panel, Maximum Power Point Tracking (MPPT), DC-DC boost converter.

I.INTRODUCTION

The solar Energy is considered to be one of the most desired renewable energy resources. The Solar PV panels [10] are used to obtain the solar energy from the Sun and which is converted into electrical energy for various applications. Among the renewable energy sources, the solar is considered to be the easy technique is obtaining the electric power because of the simple installation, and compact arrangement that can be considered to be more equivalent in the domestic and household requirements. The output of the solar PV panel is DC and which requires some DC-DC [3] [4] converters to provide a constant supply for many applications. The energy output generally depends on the radiations in the panel which usually observed to have variations with respect to the angle of incidence, temperature and location. This perhaps requires a boosting technique as the output from the panel may be low. The DC-DC boost converters are preferably used to boost up the voltage level to certain range. So most of the PV panels are usually connected to the DC-DC Boost circuit. Another important factor is to extract the maximum power from the solar radiations. As the output depends on the solar energy and the maximum extraction levels, the use of Maximum Power Point Tracking (MPPT) [6] [7] technique is quite common in the field of Solar Energy Systems. In this proposed method, a solar PV panel is connected to a DC-DC boost converter and to a load. The load here is a Stand-Alone application as DC Motor load. The proposed method has introduced the soft-switching technique for the boost converter to minimize the switching losses. Usually when switches turn ON and OFF cause losses in the circuit due to the voltage stress. The technique involved is to turn ON and OFF the switches without any voltage stress involving which reduced the losses and increases the efficiency of the system. The block diagram of the proposed system is shown in the fig. 1.
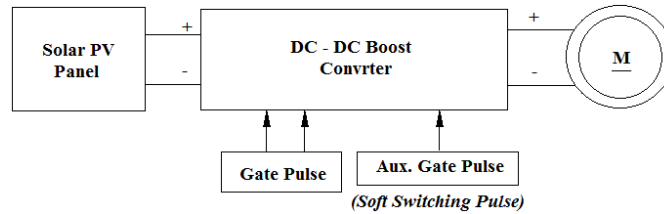
Fig. 1 Block Diagram of the Proposed System

II. CIRCUIT DIAGRAM AND DESCRIPTION

The circuit diagram consists of the Solar PV Panel connected to a DC-DC boost converter. The output of the DC-DC boost converter is given to the motor. The circuit diagram of the proposed method with a DC motor load is connected to the output as in the fig. 2.
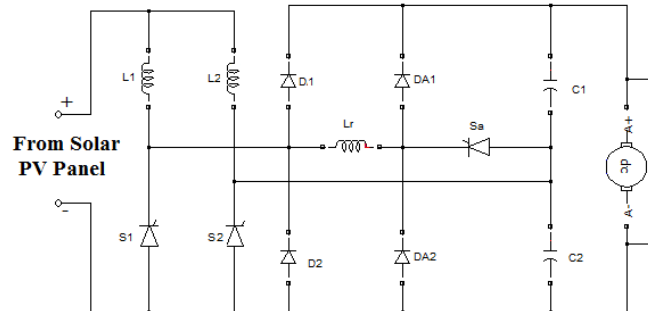

Fig. 2 Circuit Diagram of the proposed work

The proposed work shows the DC-DC boost converter consisting of who thyristor switches S1 and S2 connected in series to the inductor L1 and L2 respectively. The switches S1 and S2 are turned ON and OFF using gate pulses. This converter circuit is then connected to the boost circuit connected through a resonant inductor Lr. This circuit consists of the Diodes D1 and D2 in series and parallel to the auxiliary diodes DA1 and DA2. The Auxiliary thyristor switch Sa is used to for the soft switching operation which is turned ON and OFF using separate gate pulses. The auxiliary switch turns ON and OFF during the time when the voltage across the switches becomes zero thus involving in the Zero Voltage Switching (ZVS) [1] [2] of the boost converter circuit. The DC motor, here a DC shunt motor is connected as the load. The motor is driven at its rated speed. The boosting nature of the circuit produces the voltage step up level at the motor rated voltage thus driving the motor.

III. MODELING OF SOLAR PANEL

The modeling of the Solar PV Panel [13] is based on the equivalent circuit of the PV panel. The equivalent circuit diagram of the PV Panel is show as in fig 3.
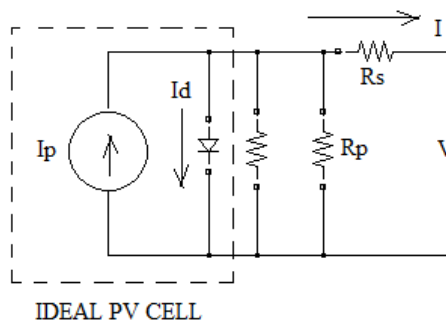

Fig. 3 Equivalent Circuit of the PV Panel

The basic equation from the theory of semiconductors that mathematically describes the I–V characteristic of the ideal PV cell is

$I = I_p - I_d$

Where,

$I_d = I_{0,cell} \left[\exp(\frac{qV}{akT}) - 1 \right]$

Therefore,

$I = I_p - I_{0,cell} \left[\exp(\frac{qV}{akT}) - 1 \right]$

Where

$I_{pv,cell}$ is the current generated by the incident light (it is directly proportional to the Sun irradiation), I_d is the Shockley diode equation, $I_{0,cell}$ is the reverse saturation or leakage current of the diode, q is the electron charge (1.60217646 × 10^{-19} C), k is the Boltzmann constant (1.3806503 × 10^{-23} J/K), T (in Kelvin) is the temperature of the p–n junction, and a is the diode ideality constant.

The fig 4 shows the origination of the I – V curve for the equation. Practical arrays are composed of several connected PV cells and the observation of the characteristics at the terminals of the PV array requires the inclusion of additional parameters to the basic equation.

Hence,

$I = I_{pv} - I_0 \left[\exp(\frac{V+R_s l}{v_t a}) - 1 \right] - \frac{V+R_s I}{R_p}$

Where,

$V = N_s kT/q$ is the thermal voltage of the array with N_s cells connected in series.

R_S & R_P is the equivalent series and parallel resistance of the array. The cells connected in parallel which increases the current and the cells connected in series provide greater output voltages. If the array is composed of N_p parallel connections of cells the PV and saturation currents may be expressed as,

$I_{pv} = I_{pv,cell} * N_p$, and
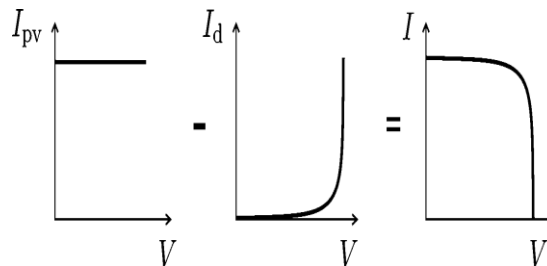
$I_0 = I_{0,cell} * N_p$.

Fig. 4 Origination of the IV Curve

This equations originate the I-V curve in fig. 5 below, where the three remarkable points are highlighted: short circuit $(0, I_{sc})$, Maximum Power Point (MPP) (V_{mp}, I_{mp}), and open circuit $(V_{oc}, 0)$.
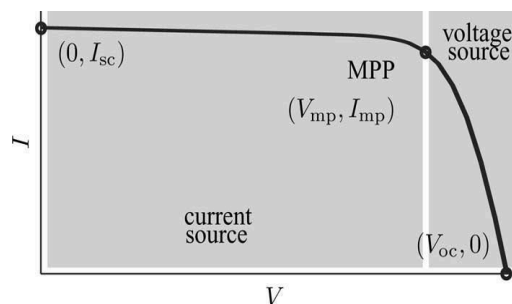

Fig. 5 Characteristic I-V curve of a practical PV module

The PV panel is modeled as an equivalent current source. The various equations describing the PV panel characteristics

are modeled using suitable mathematical blocks from the MATLAB Simulink library. This simulation is done for standard test condition (STC) when temperature is 25°C and Irradiation is 1000 W/m². The modeling diagram is thus shown in the fig. 6 as below.
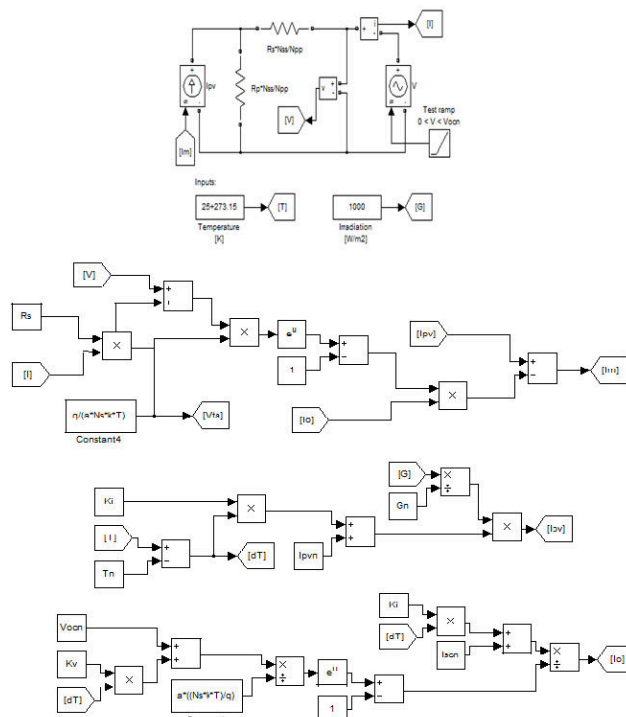
Fig. 6 Modeling of Solar PV Panel

IV. OPERATION OF ZVS DC-DC BOOST CONVERTER

The power stage diagram of the proposed soft-switching dc power supply system is shown in Fig. 2. The circuit can be divided into three sections. The first section is the input rectifier (boost power factor pre-regulator) that is designed to operate at PWM continuous conduction mode (CCM). This section performs the functions of PFC and boost ac/dc conversion. The switches S_1 and S_2 are synchronously turned on and turned off. The operation of input rectifier is the same as the conventional boost power factor pre-regulator, and it operates at fixed frequency and variable duty ratio dependent on the amplitude of line input voltage. This duty ratio is a sinusoidal function. The duty ratio is lower when the rectifier operates at higher amplitude of line input voltage, and it is higher when the rectifier operates at lower amplitude of line input voltage. Thus, the maximum duty ratio is located on that the line input voltage is equal to zero, and the minimum duty ratio is located on that the line input voltage is equal to its peak value. This method can control the current of input inductor to follow in the line input voltage and reduce its total harmonic distortion to get high power factor. The second section is to provide the soft switching on the switches S_1 and S_2. It is composed of the auxiliary diodes DA_1 and DA_2, the resonant inductor Lr, and auxiliary switch S_a. It is rated for a small power when compared to the output power. For convenience in analysis, only the positive-half period of the line voltage is described. To simplify the analysis, it is assumed that the proposed dc power supply system is operating in steady state and the following assumptions are made during one switching cycle.

1. During one switching cycle, the power factor pre-regulator inductor L_1 and L_2 are large enough to assume that the input current is constant and is much greater than resonant inductor L_r.

2. The capacitor C_1 is large enough to assume that the voltage V_{C1} is constant and ripple free.

The ZVS DC-DC boost converter has been designed significantly to perform the lossless switching operation. This includes the design of inductor values, capacitor values and the switching pulses for both the thyristor switches and the auxiliary switches. The auxiliary thyristor perform the operation of ZVS of the converter switches which turns ON and OFF during the zero voltage crossing.

V. SIMULATION SNAD RESULTS

The proposed work is performed using MATLAB/SIMULINK for the various components. The simulation Matlab diagram is shown in the fig. 7.
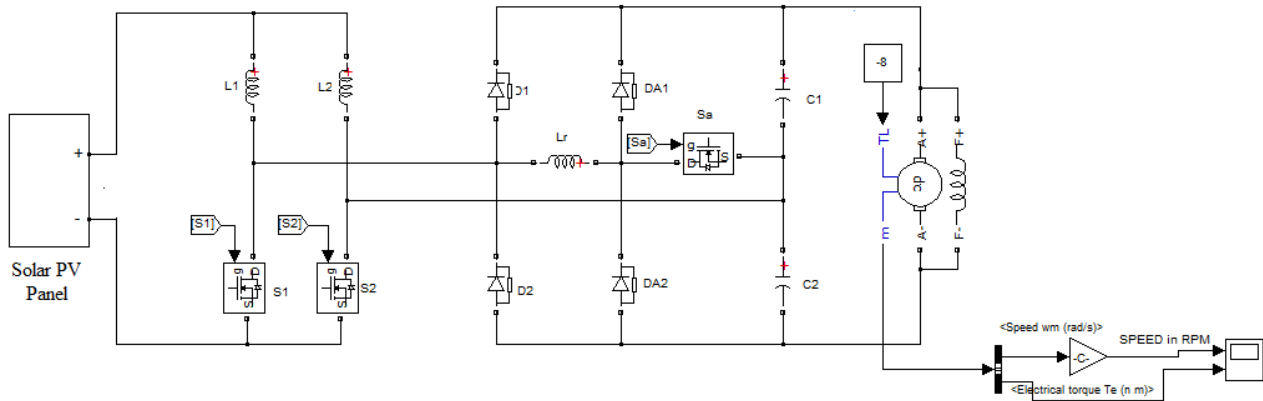

Fig. 7 Simulink Model of the Proposed System

The simulation model is performed and the results are generated. The outputs from the solar PV panel are given in the fig. 8. The solar panel output current is 3.25A for a voltage of 24V. The power obtained from the panel is about 78W.
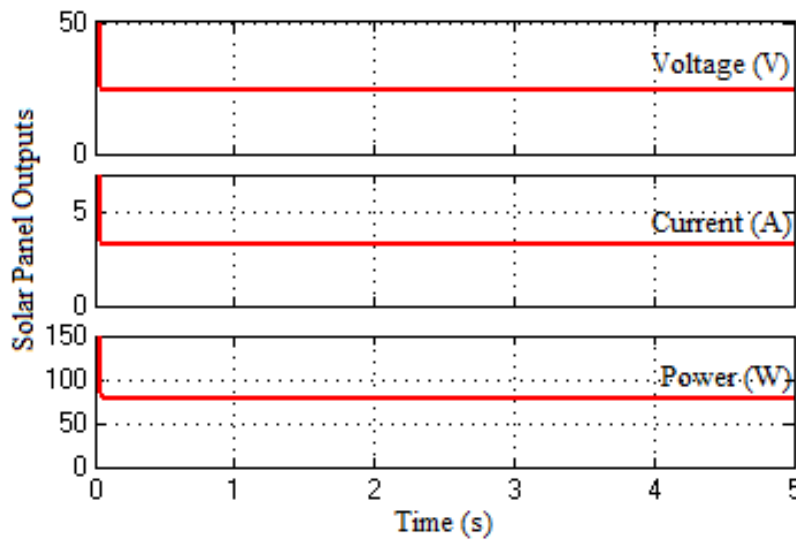

Fig. 8. Solar output waveforms, Current, Voltage and Power

The output of the solar PV Panel is given to the ZVS based DC-DC boost converter and the results are shown in the fig. 9. The boosted voltage is 400V and the current is 1.5A.

The DC motor of 400V / 1.5A / 1450rpm connected as a shunt DC motor in the load terminals. The output of the motor is shown in the fig 10. The Speed of the motor is 1450rpm with the electromagnetic torque of 8.0 N-m. The motor is driven at its rated speed under loaded condition. The effectiveness of the result can be considered for the stand-alone applications.

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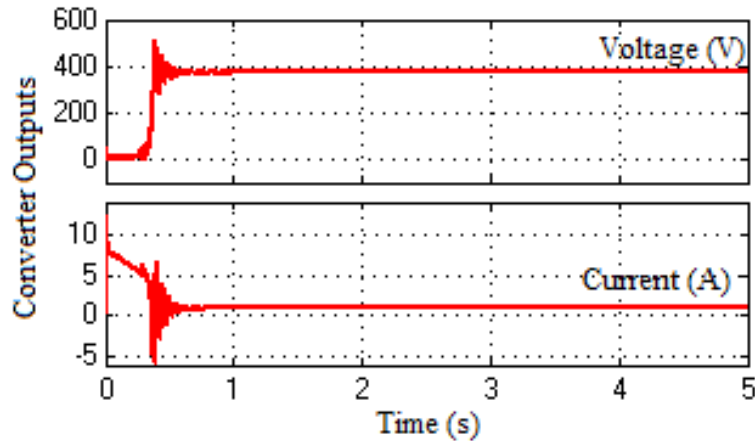
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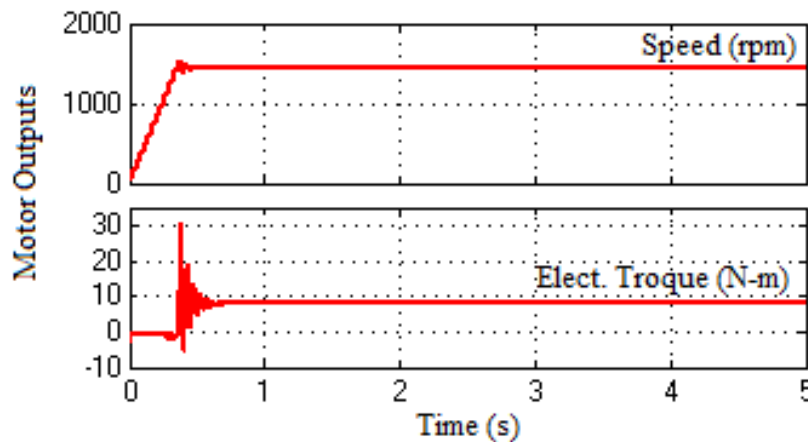Fig. 9 Output Voltage and Current from DC-DC boost converter

Fig. 10 Motor Speed and Electromagnetic Torque

The 400V/1.5A /1450 rpm DC shunt motor is thus driven using the Solar PV Panel through the ZVS based DC-DC boost converter.

The simulation parameters are shown in the table 1.

TABLE I: SIMULATION PARAMETERS AND VALUES

Components	Values
Solar Panel Output Voltage	24V DC
Solar Panel Output Power	78W
Line Inductance, L_1 and L_2	500μH
Resonant Inductance L_r	21mH
Capacitance, C_1 and C_2	680μF
Converter Switching Frequency	400Hz
Auxiliary Switching Frequency	70kHz

VI. HARDWARE SETUP

The proposed simulated work has been implemented in hardware using a prototype model consisting of a solar panel for the input source. The input terminal is connected to the ZVS boost DC-DC converter as shown in the fig 11. The input voltage from the solar panel is 12V.

Fig. 11 Prototype Model of the proposed system

The input is given to the ZVS DC-DC boost converter whose output is booster to 113.4V and 1.3mA. The output is measured with the power quality meter and the result is shown in the fig 12.

Fig. 12. Output result from the power quality meter

The load connected is a low speed DC motor. The output ZVS boost pulse waveform is given as in the fig 13.
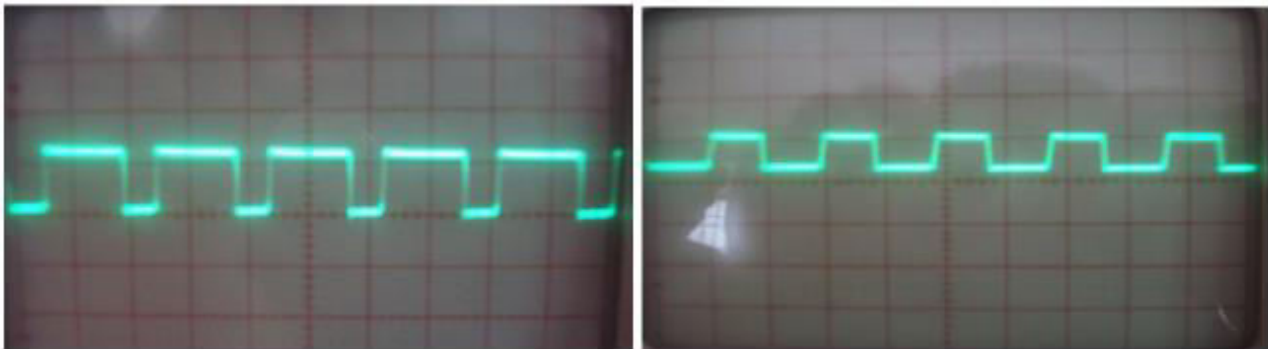
Fig. 13 Switching Pulses

VII. CONCLUSION

The performance of the ZVS DC-DC boost converter is effective in the field of DC-DC boost converter as the switching losses are well minimized in the converter operation. The DC operation of drive system being sensitive to variations in the voltage and current requires a lossless output to drive the motor drives. The proposed Simulink system is a ZVS DC-DC boost converter which is sourced through a Solar PV Panel of 78W to drive a 400V/1.5/1450rpm DC shunt motor. The gate pulses of the converter switching have the switching frequency of 400Hz and the auxiliary switching frequency of 70kHz. The line inductor L_1 *and* L_2, resonant inductor L_r and the capacitor C_1 *and* C_2 are calculated for their values performing the effective operation. The hardware prototype model is shown for the system having the input of 12V from the solar panel which is connected to the ZVS DC-DC boost converter to a dc motor load. The output obtained to drive the motor load is 113.4V and 1.3mA. Thus by implementing the practical work the system for a Stand-Alone application can be used in the DC drive applications with minimized losses and high efficiency performing system.

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