Modeling and Simulation of Dynamic Evolution Controller based Photo Voltaic System

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***Abstract*- Photovoltaic system is on demand recently since it produces electric power directly from solar radiation. But since solar radiation never remains constant, the photovoltaic cell has a wide voltage range and hence the DC-DC converter should be able to handle wide input voltage range and maintain constant output voltage . This circuit is designed in such a way that it produces constant stepped up dc voltage by using a boost converter controlled by Dynamic Evolution Controller (DEC). The change in duty cycle with variation in insolation level and the regulated output with closed loop DEC is investigated and the simulation is performed in MATLAB/SIMULINK. It is found that the DEC is superior to other conventional controllers due to its rapid and stable response nature and faster settling time. This system could be used to provide constant dc voltage to dc load**.

Keywords— Photovoltaic array, Dynamic Evolution Controller, duty cycle

I. INTRODUCTION

Photovoltaic generation and its control has gained importance recently due to reduction in fuel cost as well as maintenance and hence it has a new focus on the power electronic converter interface for DC energy source. As the fuel cells and PV cells have low output voltage, DC-DC boost converter is used to further boost the voltage to the required level. The boost converters are used as front end converters for battery sources, PV solar systems and fuel cells [1-3]. Under open loop condition the converter presents poor voltage regulation and poor dynamic response. There is a need for high step up DC-DC converters in areas such as renewable energy conversion, uninterruptible power supplies (UPS) and high intensity discharge lamp for automobile head lamps. Hence the DC-DC converter should be able to handle wide input voltage range and maintain constant output voltage[4].

In some applications, few researchers have put their effort in improving the converter performance by proposing intelligent techniques such as Neural network, fuzzy, adaptive fuzzy [5] [6] [7] [8]. But these controllers cannot guarantee that it will remain stable for large disturbance.

The main role of the controller in a converter is to switch ON and OFF the MOSFET to get the desired voltage at the output. Linear PI and PID controllers were used in DC-DC converters using small signal linearization. The PI and PID give better performance around the operating point [9]. The drawback of PI and PID controllers is that it is only suitable for operation near a specified operating point.

The performance of dynamic evolution control for a step load change has been discussed and tested in [10] [11] but the input is considered to be constant. But in the case of practical system, there will be variation in input as well as output. A Dynamic Evolution control based strategy is presented in this paper. It exploits the non-linearity and time varying properties of the system to make it a better controller

II. SYSTEM DESIGN

A. Solar Panel

A photovoltaic system converts the energy of photons directly into electrical energy. The output thus obtained is sensitive to variation in parameters like insolation and temperature. For analysis, a single diode model of solar panel with the equivalent circuit shown in Fig.1 is presented. Iph represents the cell photo current and Rsh and Rse represents the intrinsic series and shunt resistances respectively. Usually Rsh is very large and Rse is very small that it may be neglected. It is modeled using the following equations.

$$I = I_{ph} - I_D - I_{sh}$$

$$= I_{ph} - \left(I_o\, [\mathrm{e}\frac{q(V+R_s I)}{mkT} \;-1]\right) - I_{sh}$$

and

$$I_{sh} = \frac{V + IR_s}{R_{sh}}$$

The photocurrent mainly depends on solar insolation and cell's working temperature which is described as

$$I_{ph} = [I_{sc} + K_1\,(T_c\; - T_{ref}\,)]H$$

Where I_{sc} = cell short circuit current at 25^0C and $1KW/m^2$

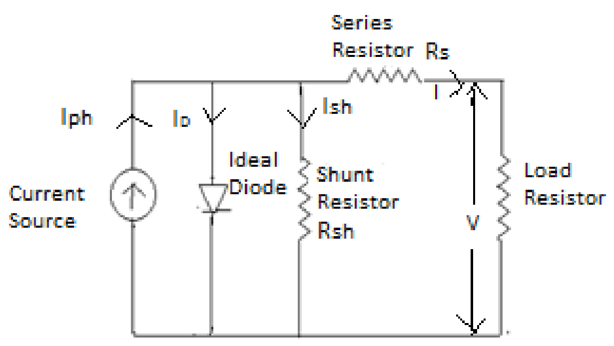

Fig.1. Solar Cell

The parameters of the Solar panel used for the analysis have been taken from MS Shell Power 85P and the data sheet is given in Table 1.

Table 1
Specification of PV system
MS Shell Ultra SQ85-P (1000W/m^2, 25^{o}C)

Short circuit current, Isc	5.45A
Open Circuit Voltage, Voc	22.2V
Current at Peak Power, Imp	4.95 A
Voltage at peak power, Vmp	17.2V
Maximum power, Pm	85W

Six modules are connected in series as one array and two such solar arrays are connected in series to form a panel to get an output voltage of 210V with a maximum power 1 KW from the cell having peak current of 4.95A and maximum peak voltage of 17.2 V .

B. DC-DC Boost Converter

As the output of PV is variable DC, an interfacing circuit which is a switched mode DC-DC converter is needed which converts this variable voltage to constant voltage.

A simple DC – DC boost converter using MOSFET as a switch is shown in Fig.3.It consists of input voltage source Vin , boost inductor L, controlled switch Q, diode D, filter capacitor C and load resistance R. When switch Q is ON, the inductor current increases by charging from the input Vin and the diode is OFF and the capacitor discharges across the load. When switch is OFF, the energy stored in inductor is supplied through the diode to load Resistor.

The main objective is to bring the output voltage V_{out} at a desired voltage V_{ref} , which is higher than V_{in}

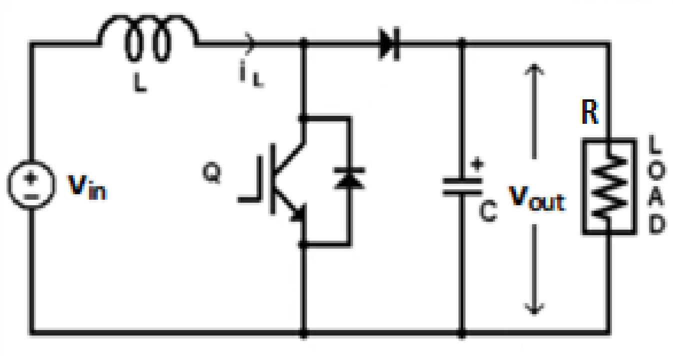

Fig.2.Simple Boost converter

$$\text{Duty Cycle},\ D = \frac{(V_{out} - V_{in})}{V_{out}}$$

The value of the inductance determines the mode of operation and the inductor current ripple and is calculated using the formula

$$L = \frac{DR(1-D)^2}{2f}$$

As per IEC standards the current ripple factor should be within 30%. Here a ripple current of 10% is assumed for the design.

$$\left(\frac{\Delta I}{I}\right) = 10\%$$

The value of capacitance determines the output voltage ripple and is designed using the formula

$$C = \frac{D}{Rf}\left(\frac{V_{out}}{\Delta V_{out}}\right)$$

Here 5% voltage ripple factor is assumed.

$$\frac{\Delta V_{out}}{V_{out}} = 5\%$$

The input ripple current and output ripple voltage can be maintained within permissible limits by proper selection of the above two components.

The load resistance is designed from

$$R = \frac{V_{out}}{I_{out}}$$

The designed values are shown in Table 2

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Table 2
Parameters of DC-DC boost converter

Parameters	**Value**
Input Voltage, V_{in}	220 V
Reference Voltage, V_{ref}	570 V
Switching Frequency , f	10KHz
Inductance, L	59.4 mH
Capacitance, C	9.45 µF
Initial Load, R	130 Ω

III. PROPOSED METHOD

Since the system is highly non linear, the controller should perform reasonably on a wide range of boost converter. Hence Dynamic Evolution Controller is proposed here.

A. *Dynamic evolution Concept*

In feedback control system the actual output quantity is compared with the reference quantity and it attempts to reduce the error, whether the error is present or not. This forms the basic law of Dynamic Evolution controller(DEC) [10 & 11]. The nutshell of a DEC is to make the error to track a specific path so that the error decreases to zero as time increases. The path selected is an exponential function as shown in Fig.3.

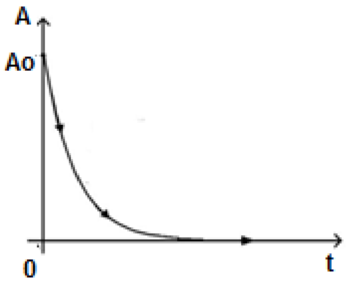

Fig.3 Exponential Path

The equation for exponential evolution is given as

$$A = A_0\, e^{-mt} \qquad (1)$$

A - error function

A_0 - initial value of the error function

m - rate of evolution

After taking derivative and simplifying , equation 1 becomes

$$\frac{dA}{dt} = -\, mA_0\, e^{-mt}$$

where $m > 0$

$$\frac{dA}{dt} + mA = 0 \qquad (2)$$

which is the dynamic evolution function.

The PWM signal used for the gate pulse is generated by comparing the error with a constant switching frequency saw tooth waveform. The duty cycle equation which forces the error state to zero can be derived from the boost converter output as follows.

Based on the state space average model the voltage and current dynamics of the boost DC-DC converter are given by

$$V_{in} - L\frac{diL}{dt} - V_{out}\,(1 - D) = 0 \qquad (3)$$

On rearranging (3)

$$V_{out} = V_{in} + V_{out}D - L\frac{diL}{dt} \qquad (4)$$

Inorder to apply DEC to boost converter, the state error function of error voltage is

$$A = K\, V_e \qquad (5)$$

K - Positive coefficient
V_e - Error voltage which is given by

$$V_e = V_{ref} - V_{out} \qquad (6)$$

Simplifying equation (6) we get

$$\mathrm{K}\,\frac{dVe}{dt} + (m\,K - 1)\,V_e + V_{ref} = V_{out} \qquad (7)$$

Substitute V_{out} from (7) in (4) and simplifying we get

$$D = \mathrm{K}\frac{\frac{dVe}{dt}}{V_{out}} + \frac{(m\,K-1)\,V_e}{V_{out}} + \frac{L\frac{diL}{dt}}{V_{out}} + \frac{V_{ref} - V_{in}}{V_{out}} \qquad (8)$$

D is the control action for the converter controller which forces the state error function A to satisfy the dynamic evolution path and decrease to zero with decreased rate of m.

It is clear that the above equation has four parts.

The first term consists of the derivative of disturbance in the output voltage.

The second term consists of the proportional term of the disturbance.

The third term is the derivative of the inductor current which controls the current to desired value.

The fourth term compensates for changes in the input voltage.

Properly tuning the controller parameter ‘m’ enables the output of the system to match the output of the reference model, at which the error converges to zero and the maximum power is obtained.

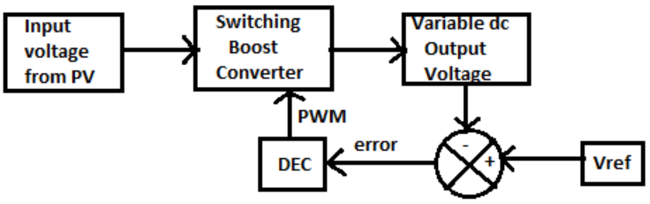

Fig.4 Block diagram of proposed method

The input of the controller is the error which is the difference between the measured voltage and the desired value with the output as the switch position. In the proposed system ,the gate of the power switch of the converter is supplied from the Dynamic Evolution controller which takes the difference between the output and the reference voltage and applies the control law eqn (8) and generates a duty ratio D which is a non negative scalar less than or equal to 1.

IV. SIMULATION RESULTS AND DISCUSSION

The above mentioned model is developed in MATLAB/SIMULINK with the DEC intended to create the control signal for the switches and to investigate the behavior when connected to a PV system.

The PV array is interfaced with the boost converter by using a controlled voltage source. The proposed simulation diagram of DEC is shown in Fig.5

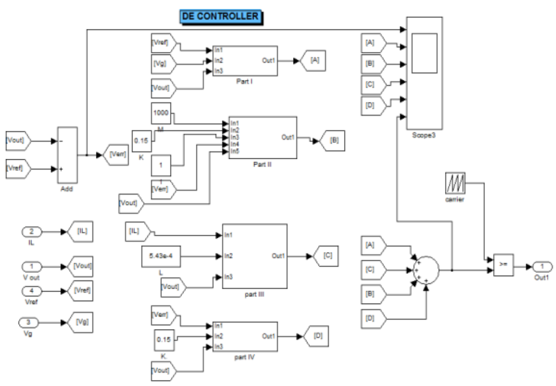

Fig: 5 Simulation block diagram of Dynamic Evolution Controller

The behavior of DEC with different inputs and outputs and the corresponding variation in duty cycle of the switching pulse is presented.

While simulating, the voltage proportional to change in the current with change in insolation is given as the input parameter for DEC.

The effectiveness of the Dynamic Evolution Controller(DEC) used in DC-DC boost converter driven by photovoltaic module is tested first with constant insolation of 1000W/m^2 and then the same panel is checked with variable insolation ranging from 880 to 1000W/m^2.

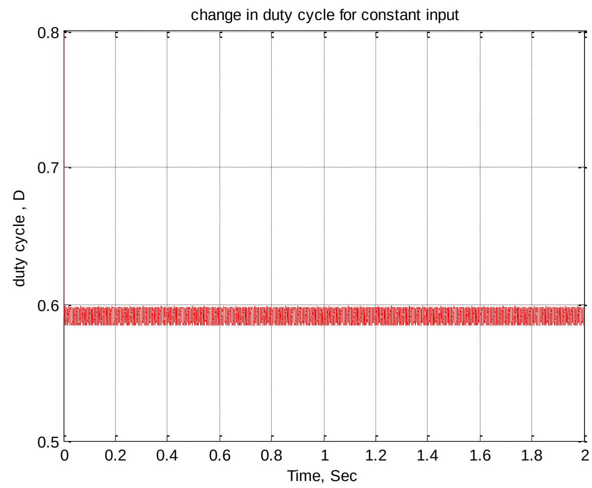

Fig.6 duty cycle for constant input

Fg.6 shows that there is no duty cycle variation with time since the input is constant.

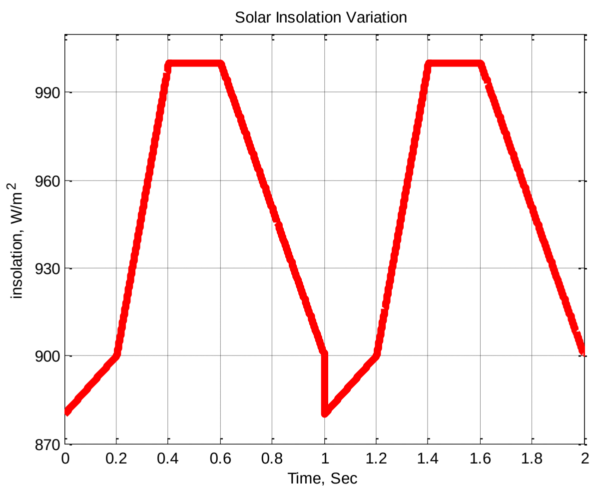

Fig.7 simulated solar insolation variation

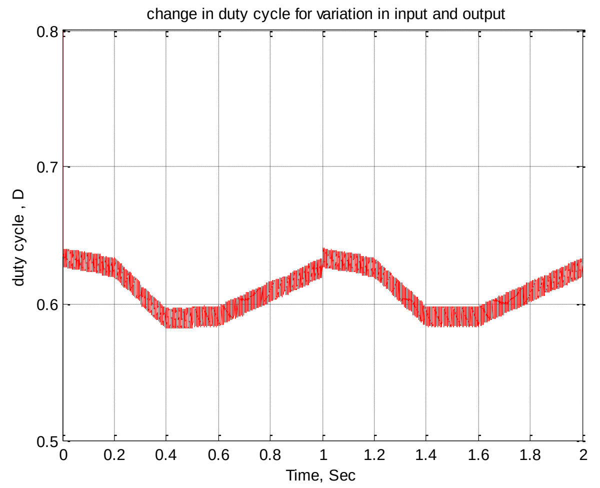

Fig.8 Change in duty cycle for variation in input

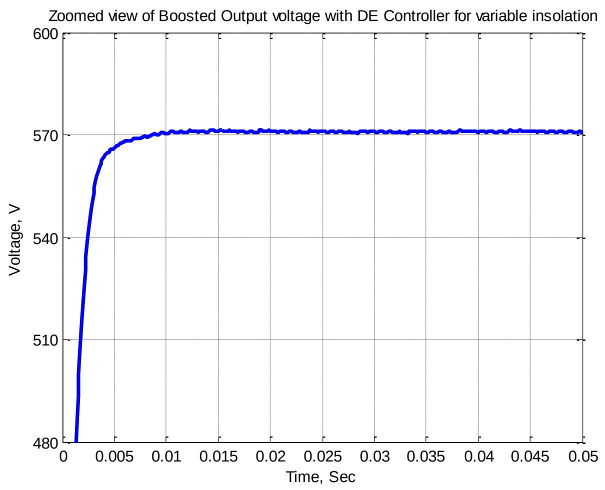

Fig. 9 Boosted output voltage with DEC for variable insolation

In Fig.7 a variation in solar insolation is created from 880 to 1000W/m^2 which repeats for a time period of 2 sec.

Fig.8 shows that the duty cycle is adjusted automatically for variation in input as well as output which explains that as the input voltage increases the duty cycle reduces and the switch will be ON for lesser time and vice-versa.

Fig.9 shows the zoomed view of the boosted output voltage with variable insolation and the simulation results prove that the controller is stabilizing the voltage to the reference value of 570V within a settling time period of 0.006 sec with absolutely no overshoot .

The above responses ensure the ability of the proposed controller in keeping the output voltage equal to that defined by the reference value and at the time of occurrence of change, the voltage is maintained constant without overshoot and settling times are limited to an acceptance levels.

V. CONCLUSION

In this paper a dynamic evolution based controller is proposed for a DC-DC boost converter applied to variable solar photovoltaic system. The output voltage of the converter is regulated for varying input using the controller. Additionally, it is shown that the dynamic evolution controller has fast transient response with no overshoot which avoids stability problems when connected to the grid.

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