Design of Conventional Controller for KY Converter based Standalone Hybrid System with State Space Modelling

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***Abstract:-* This paper presents the improved performance of Standalone PV System with a PI controller to control DC-DC Converter used in 24V DC Applications. Mathematical Model of the Solar PV System and Fuel Cell system is obtained first. Then Mathematical model and Controller design Process is presented in detail for KY Converter. Steady state tracking capability of the converter with designed controller is observed in both Frequency and Time Domain analysis. All the analysis and simulations were performed using MATLAB software. The results confirm the capability of the control method in the performance improvement of the considered converter functioning.**

Keywords:- DC Applications, DC-DC Converter, KY Converter, Mathematical Model, Solar PV System.

I. INTRODUCTION

In the modern society, DC-DC converters were widely used in portable electronic devices such as: mobile phones, laptops and digital still cameras (DSC). In order to converts the battery voltage into different voltage domains. For power supply applications using low voltage battery, in most instances, it is necessary uplift from low voltage to high voltage, thus a boost converter is usually applied, but with a pulsating output current leading to a large voltage ripple [2].
Recently, a voltage-boosting converter has been proposed, named as KY converter. KY converter can be employed for delivering power to the grid. A solar panel is being used for delivering the DC supply and this DC voltage is stored in the battery [3-6]. The voltage thus stored in the battery is then given to the KY converter for boosting its voltage level. Then the output of KY converter circuit is given directly to the load. By this a continuous output can be obtained with reduced ripple counts. The circuit of KY converter can be designed which consists of a diode, capacitors, a resistor and inductors.Thusa better transient response can be obtained by using KY converter [7]. Hence a ripple free output with comparatively high efficiency can be obtained which can be implemented for low power applications as mentioned above.

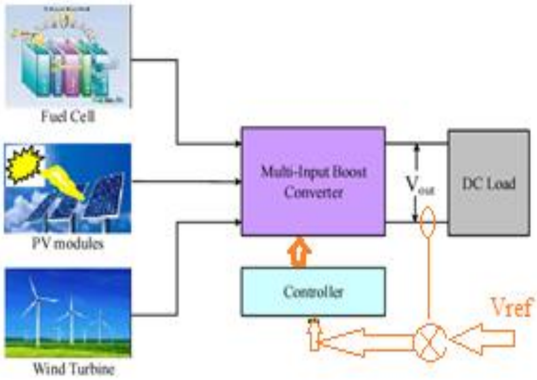

Fig.1.over View of the considered system

Consequently, the regulation of the converters can be a difficult task, especially when the operating range is large. It necessitates the design of a controller to achieve the desired response [8]. Some efforts were made in the design of parameters of KY converter for renewable energy system but no details about the mathematical model of the system [9]. The main objective of this paper is to present step by step design procedure to design a controller for the KY Boost converter and to present mathematical model of the converter.

This paper organized as follows, Section II explains operating principle of KY Boost Converter. Section III explains the Modelling of the Converter. Section IV describes the methodologies to design parameters of the converter, SectionV presents controller design procedure and computer simulations Section VI presents conclusion.

II. WORKING OF DC-DC CONVERTER

The behavioural aKY Boost Converter is a switch mode DC to DC converter in which the output voltage is greater than the input voltage. Which is more suitable for the DC Load applications when the input is need to step-up to higher value. KY Boost Converter is able to step up the voltage with voltage gain of 1+D. Where D is the duty cycle of the converter.

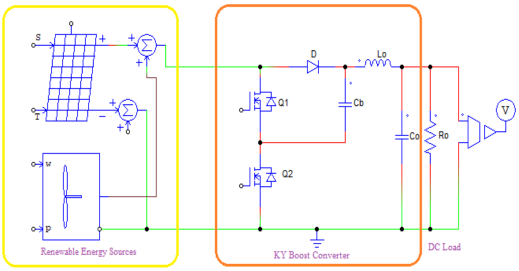

Fig.2. Basic DC-DC KY Boost Converter

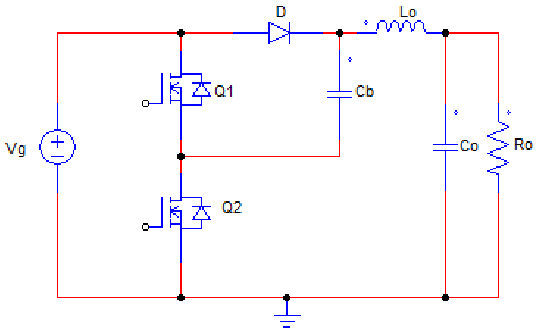

Fig.3.Basic DC-DC KY Boost Converter

The main working principle of KY Boost Converter is that the inductor in the input circuit resists sudden variations in input current. When switch$Q_1$is ON and Q_2 is OFF the inductor stores energy in the form of magnetic energy and discharges it when switch is Q_1 is OFF and Q_2 is ON. The capacitor in the output circuit is assumed large enough that the time constant of RC circuit in the output stage is high.

A. *Modes of operation of KY Boost Converter*

The KY Boost Converter can be operated in two modes.

a) Continuous conduction mode: Here current through the inductor never goes to zero i.e. inductor partially discharges before the start of the switching cycle.

b) Discontinuous conduction mode: Here current through the inductor goes to zero i.e. inductor is completely discharged at the end of switching cycle.

B. Circuit analysis of KY Boost Converter under Continuous conduction mode:

Assume in the entire analysis that the current swing(maximum to minimum value) through inductor and voltageswing through capacitor is very less so that they vary in alinear fashion. This is to ease the analysis and the results wewill get through this analysis are quite accurate compared toreal values.

Case-1: When switch Q_1 is ON and Q_2 is OFF

When switch in ON the diode will be open circuited since the n side of diode is at higher voltage compared to p side which is shorted to ground through the switch. Hence the KY Boost Converter can be redrawn as shown in Fig.4.

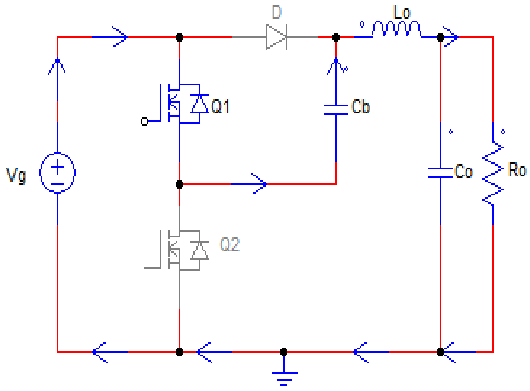

Fig.4.KY Boost Converter during t_{on} period

During this state the inductor charges and the inductor current increases. Assume that prior to the opening of switch the inductor current is I_L, off. Since the input voltage is constant.The switchQ_1 is ON and Q_2 is OFF for t_{on} seconds which is given by D*Ts where D is duty cycle and Ts is switching time period. Thecurrent flowing through C is equal to the current i flowing throughL minus the current flowing through R. Besides, in this mode, Cbis discharged.

The voltage across the inductor and currents through the capacitors during on state is given as (1-3).

Hence,

$V_{Lo} = Vg + V_{Co} - V_0(1)$

$i_{co} = i_L - i_o$ (2)

$i_{cb} = i_{in}$ (3)

Case 2: When switch Q_1 is OFF and Q_2 is ON

When switch $Q_1$is OFF the diode will be short circuited and the KY Boost Converter circuit can be redrawn as shown in Fig.5.

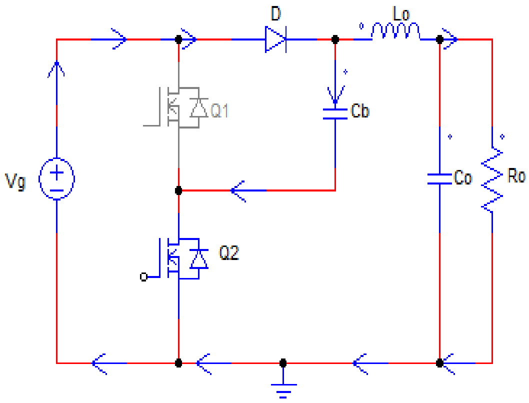

Fig.5.KY Boost Converter during t_{off} period

The inductor now discharges through the capacitor C $_b$ and RC combination. Assume that prior to the closing of switch the inductor current is I_L, off. Note the negative sign signifies that the inductor is discharging. Assume the switch is open for toff seconds which is given by (1-D)*Ts where D is duty cycle and Ts is switching time period. The voltage across the inductor and currents through the capacitors during on state is given as (4-6).

Hence,

$V_{Lo} = Vg - V_0$ (4)

$i_{co} = i_L - i_o$ (5)

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$i_{cb} = i_{in} - i_L$
(6)

In steady state condition as the current through the inductor does not change abruptly, the current at the end of switch on state and the current at the end of switch off state should be equal. Also the currents at the start of switch off state should be equal to current at the end of switch on state.

$Vout/Vg = 1 + D(7)$

Since 0< D<1, V_{out}> V_g. Assuming no losses in the circuit and applying the law of conservation of energy.

$Vout * Iout = Vg * Iin$ (8)

This implies $Iout/Iin = (1 - D), Thus\ Iout < Iin.$

III. STATE SPACE MODELLING OF DC-DC CONVERTER

KY Boost Converter is modelled by using state space modelling technique which helped to analyse the KY Boost Converter in both time as well as frequency domain[9] .In state space modelling the state matrix are represented by A,B.C and D, X is the state variable, is state variable derivative ,U is the input and Y is the output. Here average large signal modelling is used to get state space model of KY Boost Converter.

X = *A* X + B*U* (9)

*Y = C*X +D*U* (10)

On assuming Voltage across the output Capacitor and Current through the Output inductor as State variables and by omitting the Voltage across the Capacitor Cb, the state model is derived by considering CCM mode of operation. When Main switch Q1in KY Boost Converter is ON, the state variable and output Y are obtained as

$$\begin{bmatrix} \dot{i} \\ \dot{v} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & \dfrac{-1}{R_0 C_0} \end{bmatrix} \begin{bmatrix} i \\ v \end{bmatrix} + \begin{bmatrix} \dfrac{1}{L} \\ 0 \end{bmatrix} \begin{bmatrix} v_g \end{bmatrix}$$

$$\begin{bmatrix} y \end{bmatrix} = \begin{bmatrix} 1 & 1 \end{bmatrix} \begin{bmatrix} i \\ v \end{bmatrix} \quad (11)$$

When Main switch Q1 in KY Boost Converter is OFF, the state variable and output Y are obtained as

$$\begin{bmatrix} \dot{i} \\ \dot{v} \end{bmatrix} = \begin{bmatrix} 0 & \dfrac{-1}{L} \\ \dfrac{1}{C_0} & \dfrac{-1}{R_0 C_0} \end{bmatrix} \begin{bmatrix} i \\ v \end{bmatrix} + \begin{bmatrix} \dfrac{1}{L} \\ 0 \end{bmatrix} \begin{bmatrix} v_g \end{bmatrix}$$

$$\begin{bmatrix} y \end{bmatrix} = \begin{bmatrix} 1 & 1 \end{bmatrix} \begin{bmatrix} i \\ v \end{bmatrix} \quad (12)$$

By applying averaging technique to the equations (11) and (12), average large signal state space model is obtained as follows.

$$\dot{x} = Ax + Bu \quad (13)$$

Where A= dA_{ON} + (1- d) A_{OFF}

B= dB_{ON} + (1 – d) B_{OFF}

$$\begin{bmatrix} \dot{i} \\ \dot{v} \end{bmatrix} = \begin{bmatrix} 0 & \dfrac{-(1-d)}{L} \\ \dfrac{(1-d)}{C} & \dfrac{-1}{R_0 C} \end{bmatrix} \begin{bmatrix} i \\ v \end{bmatrix} + \begin{bmatrix} \dfrac{1}{L} \\ 0 \end{bmatrix} \begin{bmatrix} v_g \end{bmatrix} \quad (14)$$

$$\begin{bmatrix} y \end{bmatrix} = \begin{bmatrix} 1 & 1 \end{bmatrix} \begin{bmatrix} i \\ v \end{bmatrix} \quad (15)$$

Equation (14) and (15) are implemented in state space functional block as shown in fig.

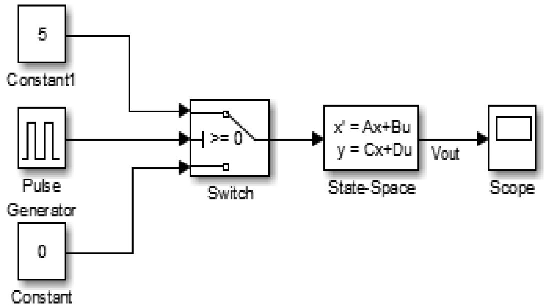

Fig.6. State space function block diagram

IV. DESIGN OF CONVERTER PARAMETERS

To get steady response from converter, a controller is required and PI Controllers is designed first and then a FLC is designed to get better performance. Before designing a controller Converter Components are calculated using the desired input and output parameters and is presented in Table. I. Based on this different controllers are designed to get better performance.

Table.I: Converter Parameters

Parameter	**V**	**Un**
Input Voltage (Vg)	16 (1	Vo
Output Voltage (Vo)	24	Vo
Switching Frequency	10	Hz
Output Power (Po)	10	Wa
Filter Components (Lo &Co)	8	μH

From the above considered converter specifications parameters of the converter are calculated as follows,

a) Gainformula of KY converter = 1+D(16)
b) Output CurrentI_O = P_O /V_O= 100W / 24V = 4.16A(17)
c) Input Current

Assume that the converter efficiency is about 100%

P_O = Pin

Iin = Pin/Vin= 100W/16V= 6.25A

d) Voltage Gain Calculation

Gain =V_O /V_{in}= 24V / 16V = 1.5(18)

e) Duty Cycle Calculation

Voltage gain of converter = (1+D)
1.5 = (1+D); D = 0.5= 50(19)

f) Inductor Value Calculation
In mode 1 when the switch s1 is on and s2 is off, voltage across the inductor
$V_L = 2V_{in} - V_O$ =2* 16V - 24V =8V
For an inductor voltage current basic relation is
VL = L _ dI/dt
then, L = VL _ dt/dI
Here dt = duty cycle / frequency
Assume that operating frequency of the switch (mosfet here) =100 kHz and di is the ripple current of inductor
$I_L = I_{IN}$*2 = 6.25*2=12.5A
From the industrial viewpoint, the output inductor is generally Designed to have no negative current when the output current isabove 20%_40% of the rated output current. Therefore, in thispaper, the boundary between the positive current and the negativecurrent is assumed to be at 40% of the rated output current. Hence,the value of Lo can be obtained as follows:Assume that inductor ripple current = 40% of inductor current
dI = 40% _ IL
dI =40% * 6.25A *2 = 5 A
L = VL * dt/dI = VL* D/(F *di)(20)
= 8V * 0.5 / (100000 Hz * 5 A) =8µH

g) Input Capacitor Value Calculation
Input capacitor value for a capacitor voltage current basic relation is
I = C * dV / dt
dV is output ripple voltage. Assume that output ripple voltage is about 0.05% of output voltage
dV = 0.1% * 16V
dV = 0.016V
C = Iin* dt/dV
We have dt = duty ratio/frequency
C = Iin*D/(F * dV)(21)
= 6.25A * 0.5/ (100000 Hz* 0.016 V)=1953µF
h) Output Filter Capacitor Value Calculation

Charge pump capacitor value for a capacitor voltage current basicrelation isI = C * dV / dt. dV is output ripple voltage. Assume that output ripple voltageis about 0.05% of output voltage

dV = 0.1% * 24V
dV = 0.024V
C = I_O* dt/dV
We have dt = duty ratio/frequency
C = Io* D/(F * dV)(22)
C = 4.16A * 0.5/ (100000 Hz* 0.024 V)
C = 866µF

V. CONTROLLER DESIGN

With the considered specifications shown in Table.1 anddesigned parameters is section IV a controller is designed as follows. Fig.7. and Fig.8 shows the simulation view of a DC-DC Converter with PI Controller.

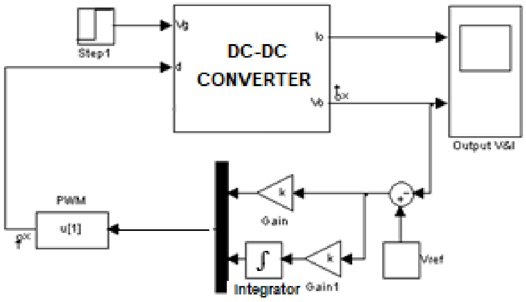

Fig.7 Converter with PI controller

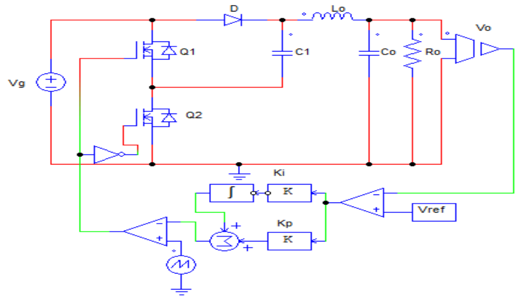

Fig.8 Representing a PI controller for Converter

The controller transfer function was Kp+Ki/S. It was simulated in MATLAB shown in Fig.9 & Outputs are shown in Fig.9. And observed the output voltage and current by applying the disturbances but it was unable to make the steady state tracking without any controller as shown in Fig.10. But in practical applications there is a possibility to get variation in source, load or parameters of the converter. Hence it necessitates the requirement of the converter. With this a PI controller is designed to get the steady state output as shown in Fig.11. And the PWM signals generated by the controllers is shown in Fig.12. And the obtained results with PI controllers shown in Fig.13.

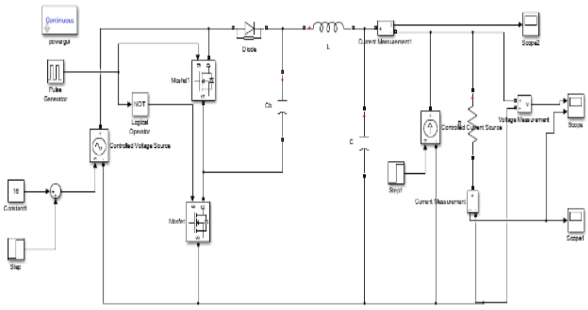
Fig.9.Simulation diagram of the considered system with open loop

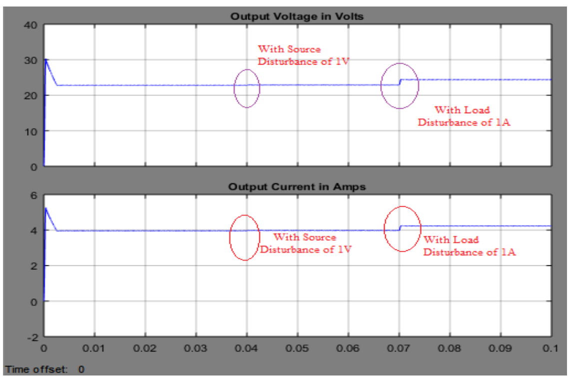

Fig.10. Output of the considered system without controller

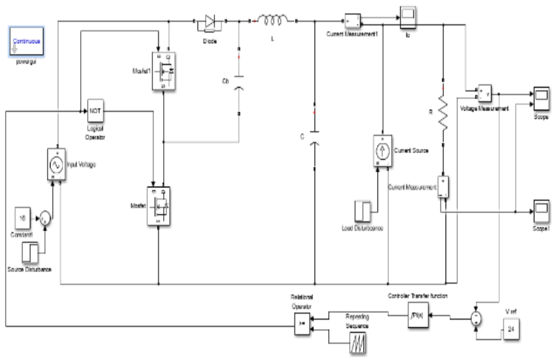

Fig.11.Simulation diagram of the considered system with PI controller

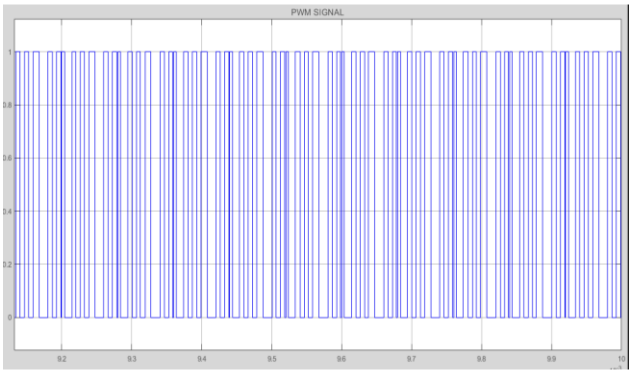

Fig.12. PWM signal generated by the Controllers

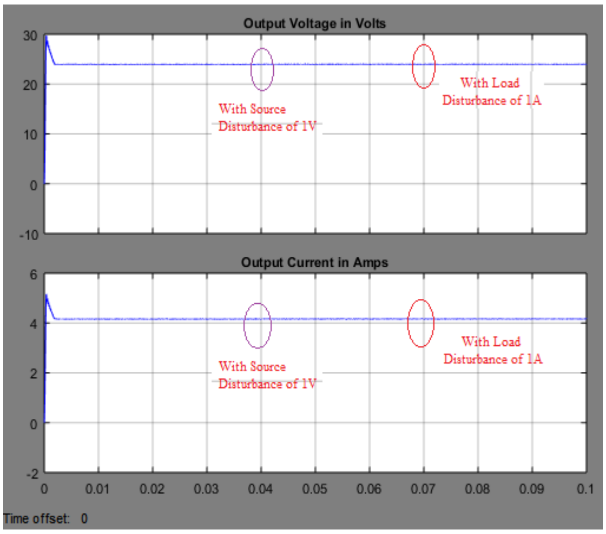

Fig.13. Output of the considered system with PI controller

The obtained results of PI Controller shown in above Fig.13 showsthe achievement of desired response even though source and load disturbances occurs at 0.04 Sec and at 0.07 Sec.

VI. CONCLUSION

In this paper, step by step design procedure is shown for reducing the output voltage ripple across the capacitor and to achieve the better performance from the KY Converters, these KY Converters are operating in Continuous Conduction mode (CCM) inherently, it possess non-pulsating output current, by reducing the output voltage ripple it's also able to reduce current stress on the output capacitor. The KY Converter can be used efficiently without the ripple voltages in the Converter. The output response of the system with designed PI controller confirms the validity of the designed controller.

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