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Simulation and Analysis of DC-DC Boost Converter Using Sliding Mode Controller under Variable Conditions

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Abstract : *As the requirement of power increases, it is required to increase the generation on demand. Now a days, solar PV and wind are increasingly used for generation. The power collected from these energy source need to be converted using DC-DC or AC- DC converters. The main converter used is Boost converter for step up this voltage. These sources are variable by nature, so problem arises is to maintain constant required output in all conditions. Boost converter converts the input voltage into higher value of voltage as per the input is received. This issue of obtaining constant output under variable conditions can be resolved by using sliding mode control of the converter. There are many theories to implement this technology with converter but the problem arises when the inductance and capacitance parameters changes as load varies. The proposed work is to resolve this problem by using sliding mode controller with modified values of parameters and beta factor for precise values using feedback, close loop system. The input source is taken as DC source voltage at variable conditions. The modeling is done in MATLAB/Simulink software.*

Keywords: *Boost Converter, slide mode controller, solar PV, Wind*

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I. Introduction

Now a days, solar and wind are widely used energy sources for the generation of energy. The power collected from these energy sources is converted through DC-DC or AC-DC converters but energy obtained from these sources are variable in nature, so the continuous production is not maintained in all the circumstances from these sources. To eliminate these problems and to obtain desired output voltage various controlled converters are used.

The switched mode dc-dc Boost converters are one the best power electronic circuits thatconvert the input voltage into high value of the output voltage by switch actionand the unregulated output issue can be solved using the converter's sliding mode control. There are many theories to implement this technique with the converter, but the problem occurs when changes in the form of installation and capacitance changes vary and the load varies.

The advantage of converters in the electricity system is to maintain the required production voltage and to control the parameters according to variation in load. To control the output voltage from the converter is necessary to control the duty cycle of the semiconductor device used in the system the idea of proposed work with the controlling technique of the nonlinear controller to control the duty cycle according to the difference in the various parameters of the system by using sliding mode control.

The parameter considered for control is voltage . A unique method has to be prepared to control the converters duty-cycle and increase system efficiency for each parameter.

1.1 Boost Converter

A boost convertor is a power convertor with an output DC voltage larger than its input DC voltage.For example, applications for boost converter operations in DCMotor's rebounding breaking circuit and regulated DC power supply. In this type of converter, the output voltage is always greater than the input voltage. Therefore, the speed-up converter can be applied to the MPPT system where the output voltage should exceed the input voltage such as in the systems connected to the grid, where the boost converter holds a high output voltage, even if the PV array voltage falls at lower prices. Circuit topology of step-up converter as shown in Fig. 1

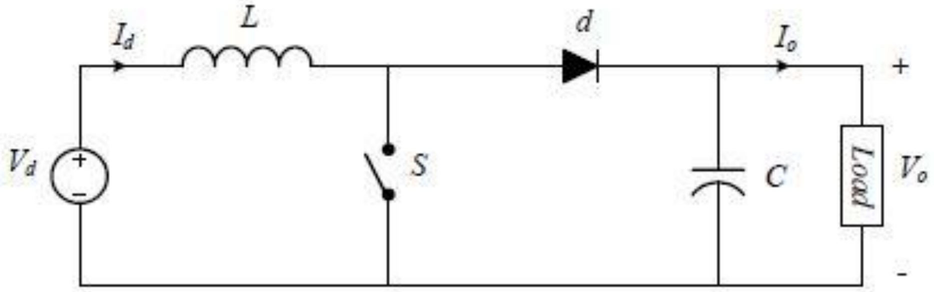

Fig. 1 Equivalent Circuit of Boost Converter

$D = 1 - \frac{V_d}{V_0}$(1)

$L = \frac{V_d D}{2\Delta I_L f_s}$ (2)

$C = \frac{I_0 D}{\Delta V_0 f_s}$ (3)

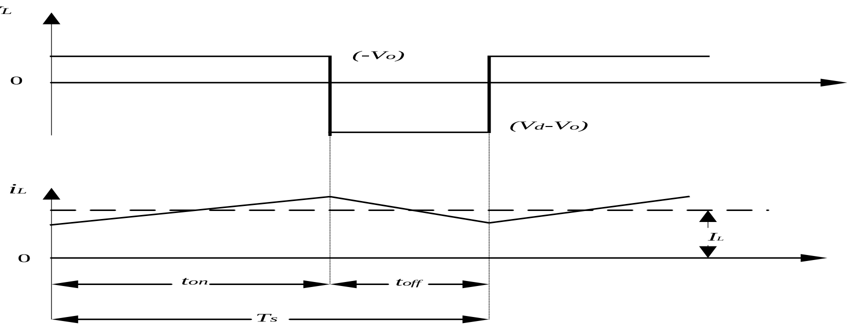

Fig. 2 Triggering Pattern for Boost Converter Pulses

When the converter is working on the state of stable-state, then the duty ratio can be expressed by D, equation (1). Where D is the ratio of voltages, duty ratio indicates the output volts of input and converter, respectively. From the above equation, it can be seen that, the increase in the duty ratio will increase the value of the voltage in the output of D, besides that, the change in duty ratio results in changes in current and output of the converter driven converter operated in continuous conduction mode. The filter inductor and capacitor can be calculated by following the equations.

Designing Boost Converter made in MATLAB. This includes the inductor (L), input DC voltage, MOSFET, diode, capacitor and load resistance. Table 1 shows the basic parameters taken for analysis and designing.

Table 1 Parameters for Boost converters

Input Voltage (V)	L-R (mH-Ohm)	Load R(Ohm)	R-C(mOhm-µF)
200	300 – 0.14	240	69-2300

1.2 Slide Mode Controlling Of Boost Converter

Technically, this controller has a time-separate state-response imbalance control law, in which due to the current situation of state variables in state, switching from one continuous structure to another is possible with high frequency. Its purpose is to control the system's mobility to follow the desired and predetermined.

Sliding mode has been applied to current controller technology to boost converter. Fig. 3 represents the basic circuit diagram of the boost converter controlled by the sliding mode controller. This control plan for boost converter starts with selecting the sliding surface.

To design a Slide mode controlled converter assume that the Output voltage is control variable and the state variable of full order slide mode controller which are to be controlled can be expressed by variables x.

$$X = \begin{bmatrix} X1 \\ X2 \\ X3 \end{bmatrix} = \begin{bmatrix} V_{ref} - \beta v_o \\ \frac{d(V_{ref} - \beta v_o}{dt} \\ \int (V_{ref} - \beta v_o) dt \end{bmatrix} \text{(4)}$$

Where X1 is the voltage error, X2 is the rate of change of voltage error, and X3 is the integral of voltage error.V_{ref} Is reference voltage, βv_o is sensed output voltage, β is the gain/proportion of the sensed output voltage and MOSFET M1 is the control switch.
By substituting the behavioral model of boost converter under continuous conduction mode, the control variable x can be expressed as,

$$X_{boost} = \begin{bmatrix} V_{ref} - \beta v_o \\ \frac{\beta}{C}\left[\frac{V_o}{R_L} - \int \frac{(V_i - V_0)\bar{\mu}}{R_L}\right] \\ \int (V_{ref} - \beta v_o)dt \end{bmatrix} (5)$$

SM For the operation, there are three necessary conditions, the condition of the hitting, existence and stability. The result of the control function to hit the situation;

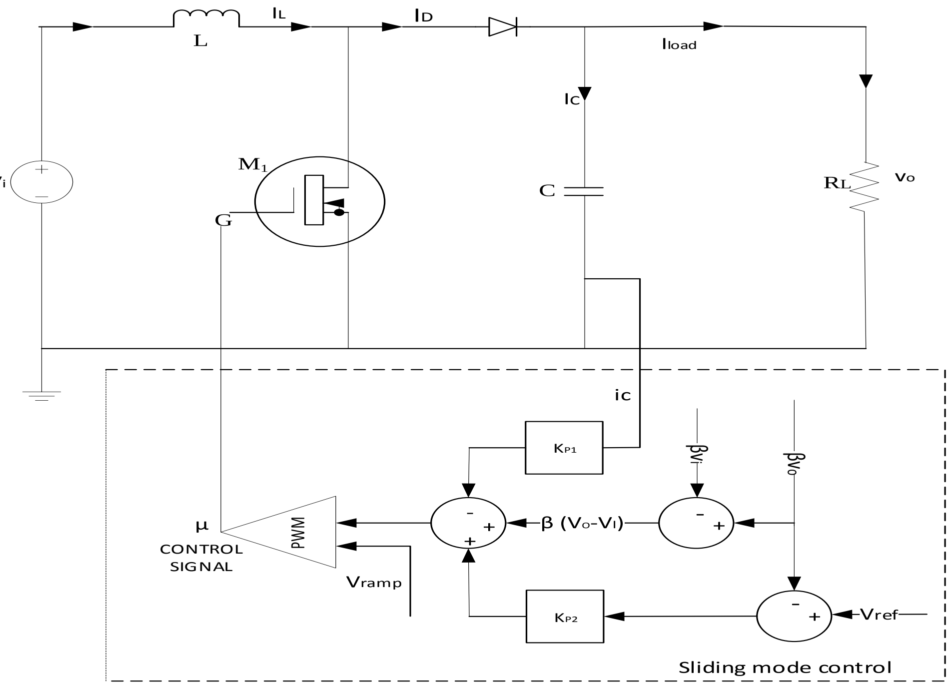

Fig. 3 Boost Converter describing Sliding Mode Control Law

To design the controller the state space representation can be obtained by differentiating equation (5) with respect to time.
Standard form gives:-

$$\frac{dX_{boost}}{dt} = \dot{x} = AX_{boost} + B\bar{\mu}(6)$$

Where $A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & -\frac{1}{R_L C} & 0 \\ 1 & 0 & 0 \end{bmatrix}$ And $B = \begin{bmatrix} 0 \\ \frac{\beta}{LC}(V_o - V_i) \\ 0 \end{bmatrix}$

Where $\bar{u}$= 1 – u, is considered as inverse logic of u.
For this system the control input can be written as,

$$u = \begin{pmatrix} 1 & when\ S > 0 \\ 0 & when\ S < 0 \end{pmatrix} (7)$$

Here, S is the instantaneous state variable trajectory. It can be represented as

$$S = a_1 x_1 + a_2 x_2 + a_3 x_3 = J^T x$$

By solving the equation $\frac{ds}{dt} = a_1 x_1 + a_2 x_2 + a_3 x_3 = 0$ the equivalent control signal would be;

$$\mu_{eq} = -[J^T B]^{-1} J^T Ax = \frac{\beta L}{\beta(V_o - V_i)} \times \left(\frac{a_1}{a_2} - \frac{1}{R_l C}\right) i_c - \frac{a_3 LC}{a2_\beta (V_o - V_i)} (V_{ref} - \beta V_o)(8)$$

Where μ_{eq} is continuous and 0 <$\overline{\mu_{eq}} < 1$. Since $\mu = 1 - \bar{\mu}$, this also implies

$\mu_{eq} = 1 - \bar{\mu}_{eq}$, the substitutionof (8) into the inequality give

$$0 < \mu_{eq} = 1 - \left[\frac{\beta L}{\beta(V_o - V_i)} \times \left(\frac{a_1}{a_2} - \frac{1}{R_l C}\right) i_c - \frac{a_3 LC}{a_2 \beta (V_o - V_i)} (V_{ref} - \beta V_o)\right] < 1 \quad (9)$$

Multiplication of the inequality by $\beta(V_o - V_i)$ gives

$$0 < \mu_{eq} = -\beta L \times \left(\frac{a_1}{a_2} - \frac{1}{R_L C}\right) i_c - \frac{a_3 LC}{a_2}(V_{ref} - \beta V_o) + \beta(V_o - V_i) < \beta(V_o - V_i)$$

Finally, the mapping of the equivalent control function onto the duty ratio control, where $0 < d = \frac{V_c}{V_{ramp}} < 1$, gives the following relationships for the control signal V_c and ramp Signal V_c where

$$V_c = \mu_{eq} = -\beta L \times \left(\frac{a_1}{a_2} - \frac{1}{R_L C}\right) i_c - \frac{a_3 LC}{a_2}\left(V_{ref} - \beta V_o\right) + \beta(V_o - V_i) \quad (10)$$

$$V_{ramp} = \beta(V_o - V_i) \quad (11)$$

$$V_c = -K_{p1} i_c - K_{p2}\left(V_{ref} - \beta V_o\right) + \beta(V_o - V_i) \quad (12)$$

$$K_{p1} = \beta L \times \left(\frac{a_1}{a_2} - \frac{1}{R_L C}\right) \quad (13)$$

$$K_{p2} = \left(\frac{a_3}{a_2}\right) LC \quad (14)$$

To make the duty ratio of the output of the controller always below 1, a multiplier is incorporated for the multiplication of u_{pwm} and u_{CLK}. By a logic AND operator the impulse generator createsu_{CLK}. The control law and the sliding gain coefficients should be designed in such to fulfill the stability condition. This is to make sure that the trajectory is directed by the desired sliding manifold and always towards a stable equilibrium point.

II. Simulation And Results

This section will explain the modeling and design of proposed work. Modeling includes the mathematical calculations and modifications of system and designing gives the description

Representation of circuit designed in MATLAB/ Simulink. The proposed work represents the working and control of boost converter with modified slide mode controller, when the parameters set on different conditions. Proposed system is to give required output at all variable conditions.

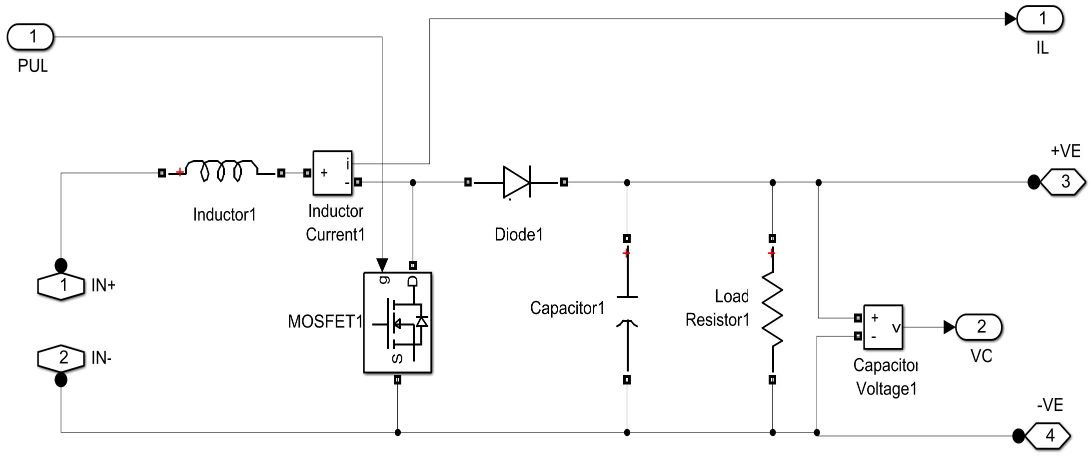

Fig.4 MATLAB model for Boost Converter

Mode of operation of Boost converter slide mode controller

In the proposed work, the sliding mode controller works for different conditions of Boost Converter as listed below:

Boosting mode 200 V to 400 V

Booting mode 220V to 350 V

Boosting mode at different value of load

Boost mode of slide mode controller for 200 to 400 V

In this mode of operation, slide mode controller controls the output to 400 V as the input Dc power is 200 V. As shown in Fig. 5 MATAB model designed and the parameter for the same are:

Table 2 Parameters for Boost converters

S.NO	PARAMETER	RATING
1	Source Voltage(V)	200

2	Output voltage(V)	400
3	L-R (mH-Ohm)	300 – 0.14
4	R-C(mOhm-µF)	69-2300
5	Load R(Ohm)	240
6	Beta1	1/4
7	Beta	1/4
8	Reference Voltage(v)	100
9	K_{p1}	0.12
10	K_{p2}	2.7

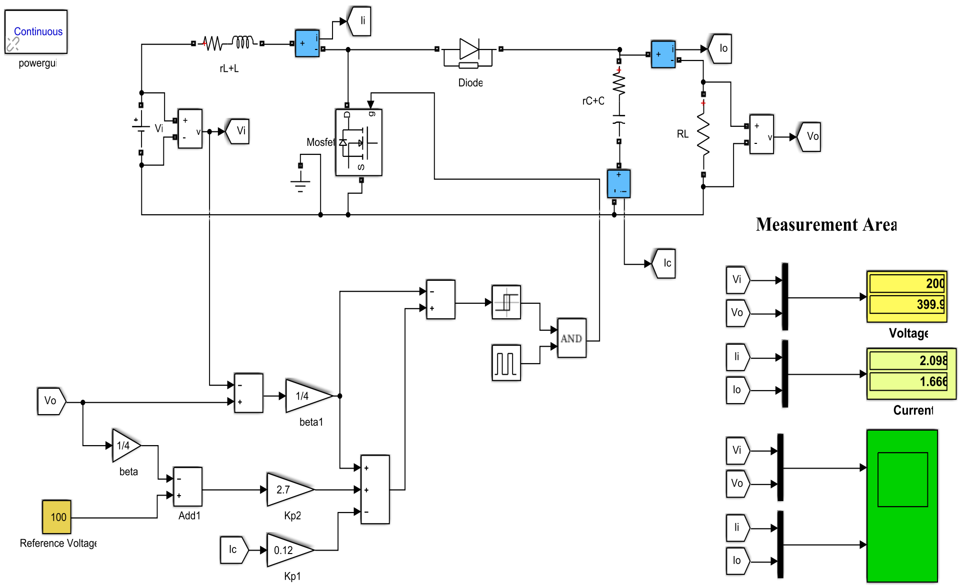

Fig. 5 Slide mode control of Boost Converter at 200 V to 400 V

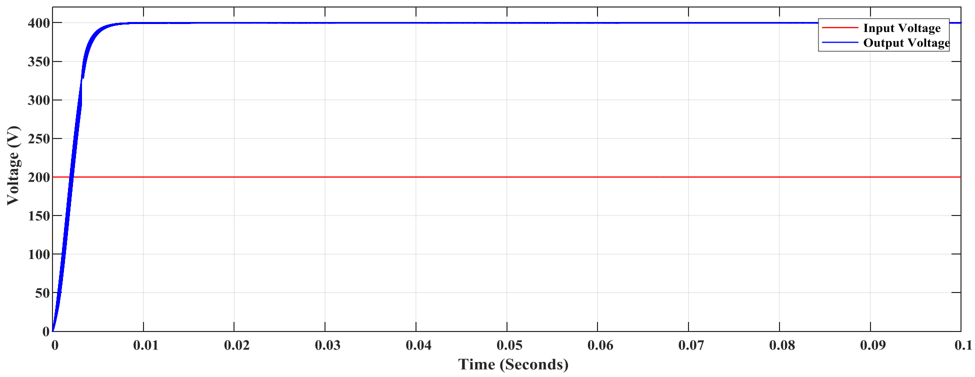

Fig. 6 Comparative analysis of Voltage Waveform for Boost Converter at 200 V to 400 V modes.

Fig. 6 represents the comparative analysis of waveform for Voltage in Boost converter using SM controller when operating at load 240 Ω for 200 V to 400 V conversions. It is observed from waveform that the input Voltage is 200V and output varies to 399.9V

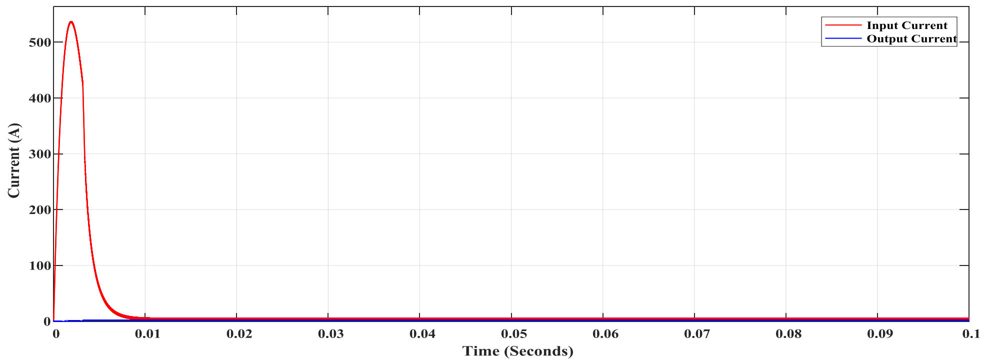

Fig. 7 Comparative analysis of Current Waveform for Boost Converter at 200 V to 400V mode.

Fig. 7 represents the comparative analysis of waveform for current in Boost converter using SM controller when operating at load 240 Ω for 200 V to 400 V conversions. It is observed from waveform that the input current is 2.098A and output varies to 1.666A.

Boost mode of slide mode controller for 220 to 350 V

In this mode of operation, slide mode controller controls the output to 350 V as the input DC power is 220 V. As shown in Fig. 8 MATAB model designed and the parameter for the same are:

Table 3 Parameters for Boost converters

S.NO	PARAMETER	RATING
1	Source Voltage(V)	220
2	Output voltage(V)	350
3	L-R (mH-Ohm)	300 – 0.14
4	R-C(mOhm-µF)	69-2300
5	Load R(Ohm)	240
6	Beta1	1/3.5
7	Beta	1/3.5
8	Reference Voltage(v)	100
9	Kp_1	0.12
10	Kp_2	2.7

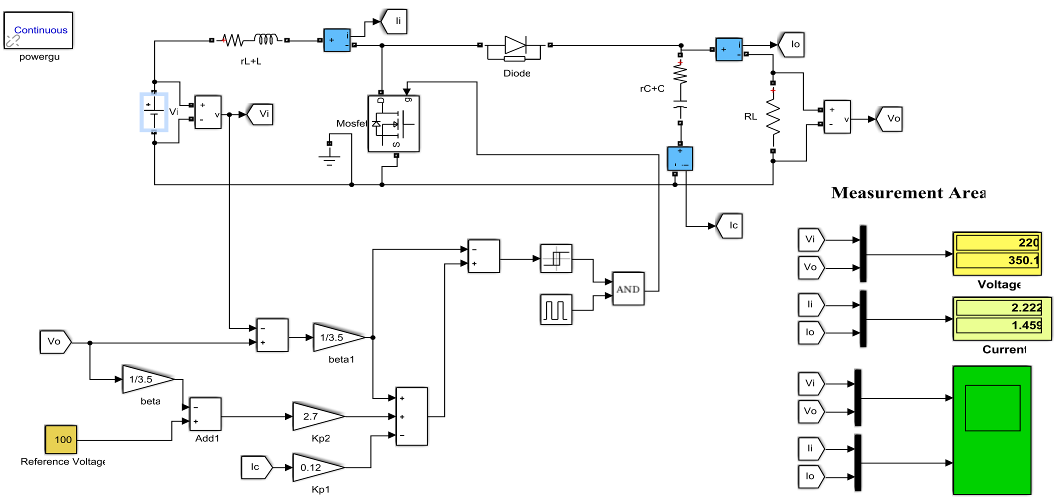

Fig. 8 Slide mode control of Boost Converter at 220 to 350 V

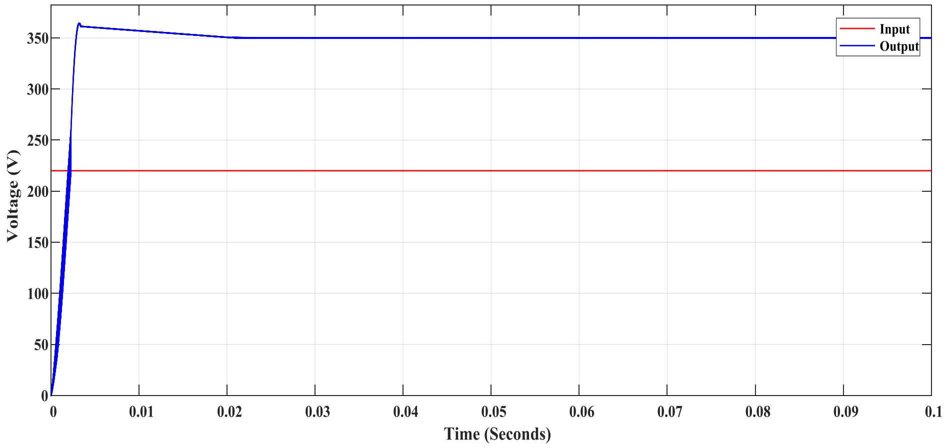

Fig. 9 Comparative analysis of Voltage Waveform for Boost Converter at 220 V to 350 V mode

Fig. 9 represents the comparative analysis waveform for voltage in Boost converter when the operating mode is for 220 V to 350 V conversion. It is observed from waveform that the input voltage is 220 V and output varies to 350V.

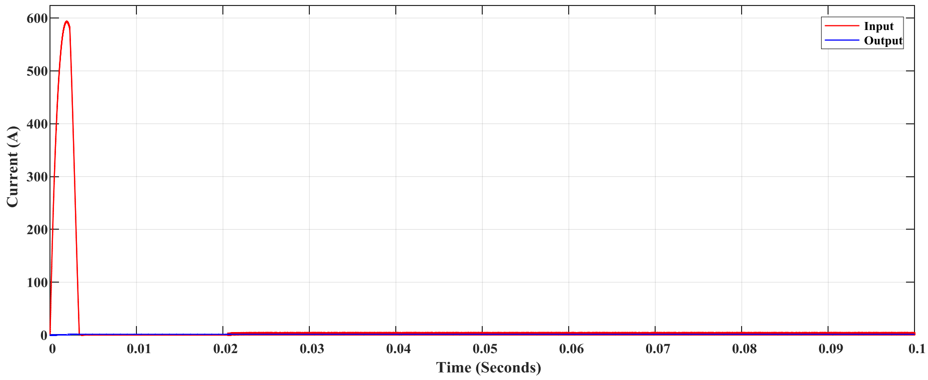

Fig. 10 Comparative analysis of Current Waveform for Boost Converter at 220 V to 350 V mode.

Fig. 10 represents the comparative analysis waveform for current in Boost converter when the operating mode is for 220 V to 350 V conversions. It is observed from waveform that the input current is decreased in output.

Boost mode of slide mode controller for different values of Load

In this mode of operation, slide mode controller controls the output to 400 V as the input DC power is 200 V. In this mode value of Load are varied. As shown in Fig. 11, MATAB model designed and the parameter for the same are:

Table 4 Parameters for Boost converters

S.NO	PARAMETER	RATING
1	Source Voltage(V)	200
2	Output voltage(V)	400
3	L-R (mH-Ohm)	300 – 0.14
4	R-C(mOhm-µF)	69-2300
5	Loads R(Ohm)	120,240 and 480
6	Beta1	1/4
7	Beta	1/4
8	Reference Voltage(v)	100
9	$Kp_{1,}$ Kp_2	0.12, 2.7

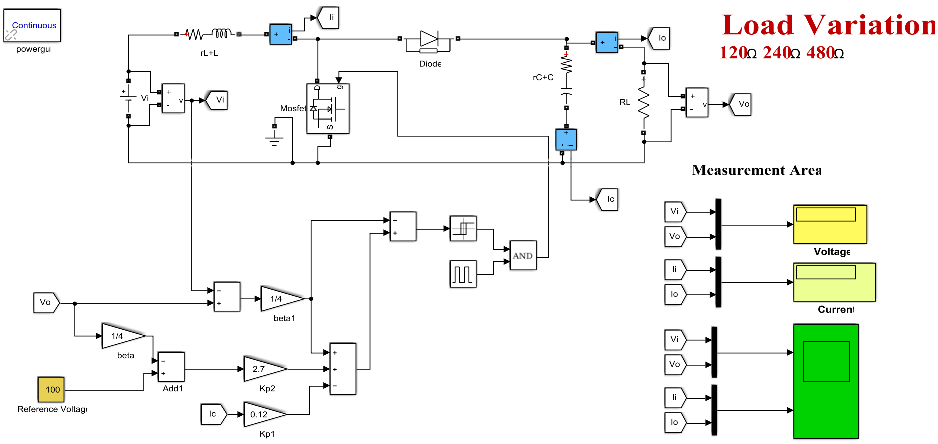

Fig. 11 Slide mode control of Boost Converter value of Load

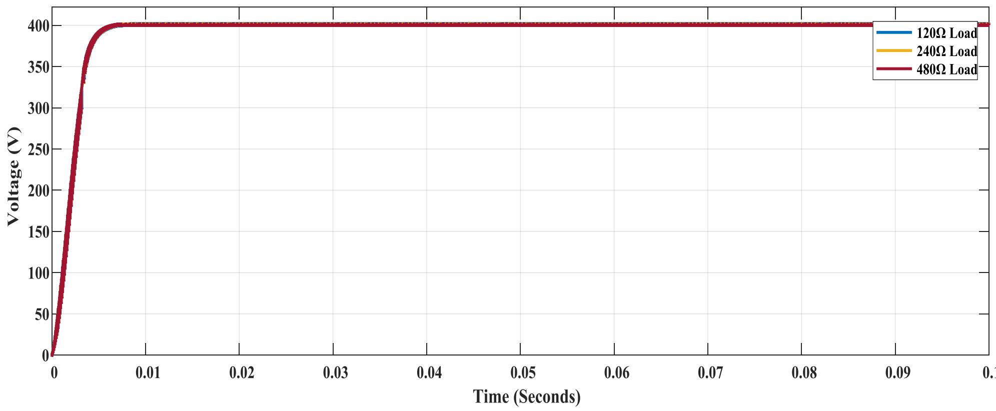

Fig. 12 Output Voltage from Boost converter operating at different load resistance.

Fig. 12 represents the output waveform for voltage in Boost converter Using SM controller operating at load resistance 120Ω, 240Ω and 480Ω mode here the boosting mode is from 200 V to 400 V. It is observed from waveform that the output voltage is nearly equal for different load, which is around 400V also the dynamic behavior of output voltage ripple is similar for all operating load condition and also the transient settling time which is around 3.4ms ,is also independent of load changes.

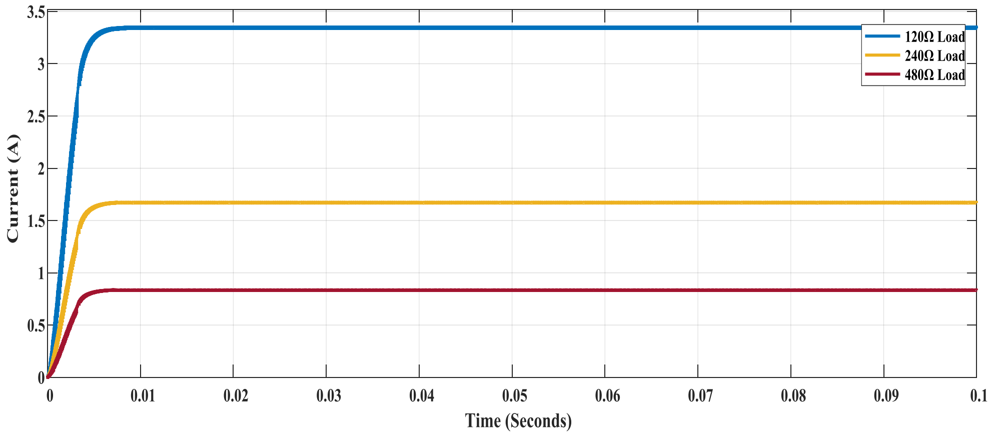

Fig. 13 Output Current from Boost converter operating at different load resistance

Fig. 13 represents the output waveform for current in Boost converter Using SM controller operating at load resistance 120Ω, 240Ω and 480Ω mode here the boosting mode is from 200 V to 400 V. It is observed from waveform that the output current is 3.339 A for 120Ω load, 1.668 A for 240Ω load and 0.8338 for 480Ω load.

III. Conclusion

The proposed system is slide mode controller for Boost converter using variable parameter and beta gain function. The analysis is performed on three different conditions of input 200 V and 220 V at required output of 400V and 350 V. and at load variation. A closed loop system is designed in MATLAB and output voltage and current is measured. The output waveforms show the output of boost converter for different load variation. The output remains nearly same for different load. The settling time for SM controller remains nearly same, which is about 3.4 milliseconds for different load therefore the dynamic behavior of the system is basically unaffected by the change in operating conditions .In both the conditions, the output is maintained constant as per feedback, gain (beta) which gives controlled gate signals to MOSFET.

Various outputs are shown for voltage and current response by comparison of input and output values of voltage and current.

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