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Design of Advanced Control of Flyback Converter using Lyapunov-based Feedback Linearization and Backstepping Controller for Improved Voltage

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Abstract

Machine Modern power system require the high voltage and minimum transmission losses to ensured stable and efficient power delivery while AC system suffer from frequency mismatch and reactive power issues. However, DC systems still face problems like voltage drops and power mismatches at the load side, mainly due to nonlinear switching in converters. Isolated DC–DC converters, such as flyback converters, are widely used for safety, but controlling them is complex. To address these challenges, this work proposes a Lyapunov stability analysis-based Feedback Linearization and Backstepping Controller (FBBSC). It handled the nonlinear system into a linerar one for easier control . MATLAB simulation is used to compare the response of the proportional integral (PI), feedback (FB), and FBBCS controllers in terms of input voltage, input current, output current, and output voltage.Compared to conventional controllers the FBBSC illustrated the superior performances. The controller achieved the faster response with reduction time in 1.5 ms. Therefore the proposed FBBSC ensures better rise time, settling time and peakovershoot responses.This improvement in energy storage , electric vehilces where speed and accurate voltage regulation is essential for maintaining system performances.

Keywords: DC Voltage; FBBSC; FeedBack; Proportional Integral; Flyback Controller; Lyapunov stability; power quality; voltage regulation

1. Introduction

The need for the shift towards renewable energy harvesting is well known [1]. But, the issues behind the process of harvesting renewable energies become the main concern and challenge for the researchers. The designing of power converters with controllers takes a significant part in renewable energy generations. The use of power converters is increased in the recent era due to their superior performances and wide applications. Despite being the best in its performance, but it is also challenging when it comes to its controlling part [2-6].

The challenge behind the design of controllers is the uncertain behavior or pattern of the loads which makes the DC-DC converters unstable. This unstable behavior of DC-DC converters needs to be regulated. This leads the researchers to concentrate on control strategies for controlling these DC-DC converters to normalize the voltage at the output. Therefore, till now researchers are finding new techniques to design linear and nonlinear controllers for DC-DC converters. These controllers are designed by keeping transient and steady-state conditions within the limit. But the robustness of the converter is not maintained under uncertainty behaviors of loads to retain the regulated output voltage[7-9].

The main disadvantage of designing the traditional linear controllers is that the dynamics of the converter are not considered while implementing the closed-loop system [10]. The linear PID controller will always operate at certain operating range which is generally decided through the gain parameters of the controller. This could be useful in high power applications and not in low level and medium power levels. For the low and medium range of power levels, these controllers give the poor performance. Due to which it may be noticed that these controllers are not suitable for wide power ranges. So, there is a need to design Artificial Neural Network (ANN) based nonlinear controllers [11-12]

Controller design with ANN based algorithm was proposed by various researchers. These controllers can be operated in two ways. The two types are the supervised model and the unsupervised model. In the case of a supervised type, the values are compared to obtain the optimum output. But, in the case of an unsupervised type, the optimum output is obtained using the trial-and-error method. ANN-based algorithms can be applied to any type of power electronic device by which the control mechanism can be improved. Even after applying Artificial Neural Network algorithm-based controllers, the boost converters performwith low efficiency when there is a sudden change in system parameters caused by uncertainty. The radial function-based neural network makes the process more intense and trickier due to its complexity [13-15].

The fuzzy logic-based controllers believed to be superior control strategy as it givesfast transient response, negligible steady-state error, and negligible amount of deviation under all kind of uncertainty conditions [16-17]. As the fuzzy-based controller needs a lookup table, there are chances for loss of information. Because of the loss of information, the optimizing parameter of the control rule may get disturbeddue to which the output voltage may get deviated from the required value [18].

The Backstepping controller approach was created to address all of the aforementioned limitations and to construct controllers for nonlinear systems. As the internal transients are stabilized, this backstepping concept can be used in a variety of non-linear systems. But the absolute understanding of uncertainties caused by the disturbance must be needed for back stepping control.

The “Constructive Approach” is best involved in the adaptive backstepping control method. This constructive approach systematically makes the model while making a control rule strategy [19-21]. As the system becomes nonlinear due to the uncertain behavior of the load conditions, the load side functions are required to be approximated using the adaptive estimation technique. The duty cycle of the converter is obtained by Lyapunov stability functions helps in obtaining stable systems. Therefore, the uncertainties at the load side are rectified to get the desired output voltage. But this control scheme does not give a better convergence rate [22-23].Despite these, it also requires a deep understanding of uncertainties that are caused by external disturbances at the load side [24-25].

The above problem is overcome using approximation function for internal and external disturbances which causes a wide range of uncertainty. According to approximation logic, fuzzy logic control and neural network can be employed which makes the intelligence of controller, and the control rule is obtained even without altering a system's mathematical model [26-28]. As the rules of the fuzzy use to perform the task, it requires a more intense control rule to obtain the actual result.

The sliding mode control is nonlinear next to ANN and fuzzy logic-based controller design. With a neural network as an approximation function. But, in the case of adaptive backstepping control, the error will not converge to zero at the time of t tends to infinite which makes the system unstable. To overcome this, adaptive backstepping sliding mode controller is introduced.

The sliding mode controller helps in changing the order of the system from a higher to a lower order system. Hence, the designing of the controller and its stability condition analysis becomes easy. The main drawback is it cannot be used for a wide range of uncertainty [29].

Feedback linearization approach [30-31] modifies the non linear device right into a linear one through enhancing the non linear traits of the device. Although this approach wishes to be greater perfect for the precise operation of non linear device conversion and this wishes to be greater specific to perform the linear manage operations. In fact, genuine parameters of a flyback converter can not be decided precisely. The downside of the comments linearization controller and the backstepping controller is alleviated with the aid of using combining the comments linearization and backstepping controller. Hence in our proposed system, Feedback linearization primarily based totally lower back stepping controller is proposed on the way to offer us the improved temporary and consistent nation responses with the aid of using making sure the robustness of the proposed controller for any sort of uncertainty [32-33].

The fundamental goals of this paper are as follows:

- To acquire the desired manipulate regulation for flyback converter the use of remarks linearization primarily based totally backstepping controller.
- To get stepped forward steady-country and brief responses through suitable law of the manipulate regulation.
- To study the strong nature of the proposed controller, the flyback converter is examined via simulation below various enter voltage, reference voltage and cargo resistance and through evaluating its outcomes with the remarks linearization controller and traditional PI controller.

The list of contribution includes:

- The Flyback converter is modelled based on lyapunov stability algorithm
- The FeedBack Linearization based backStepping controller is designed for flyback converter.
- The control law is derived for flyback converter.By adjusting duty cycle of flyback converter, the desired output voltage is achieved.
- The settling time, rise time and peak overshoot of roposed controller shows faster response as compared to other conventional controllers.
- Finally, the output voltage and power quality is improved better with steady state stability to make the system in to linear one.

2. Literature Survey

The adaptive neural network controller for boost converter shows better steady state stability response but the linearity of the system is lagging [34,35]. Te real time implementation of the neuro controller for the DC-DC controller is modeled which lag in its desired output voltage [36,37]. The backstepping controller is designed for the DC-DC converter. The uncertainity parameters of the system is regulated but the non-linear system of the controller leads to poor voltage stability [38,39]. The controller is designed for the power system state machine fed PMDC motor which only enhances the overall current gain of the system and output voltage is not considered. The efficiency of the motor is improved for fast transient response [40,41]. The optimum feedback linearization controller based DC-Dc converter maintains the linearity of the system. There is a lagging of voltage regulation and power quality in the system [42,43]. The lie derivative control for the DC-DC converter shows good transient response in power system. The non-linear system is converted into ,inear system. The low power application cannot able to use the control scheme for further load variation. It can only able to boost the load under different inputs [44]. Thus the FeedBack Linearization based Backstepping Controller for flyback converter is proposed using lyapunov stability function to make the power system to achieve linearity and better steady state response by controlling the duty cycle of flyback converter.Thus both output voltage and power quality is improved in the system with better settling time and rise time.

Section I contains the Introduction and related work. Section II defines the System modeling and Problem statement. Section III proposes the Feedback Linaerization based backstepping controller for flyback converter. Section IV shows the results and discussuions. Finally the work is concluded in Section V.

3. System Modeling and Problem Statement

In order to tackle existing adversarial attack

Isolation between input voltage and the load is provided by the single stage flyback arrangement converter which is shown in (Figure 1) and operating in Continuous Conduction Mode (CCM). This configuration of flyback converter is preferred for small power lighting applications because of high PF and low complexity.

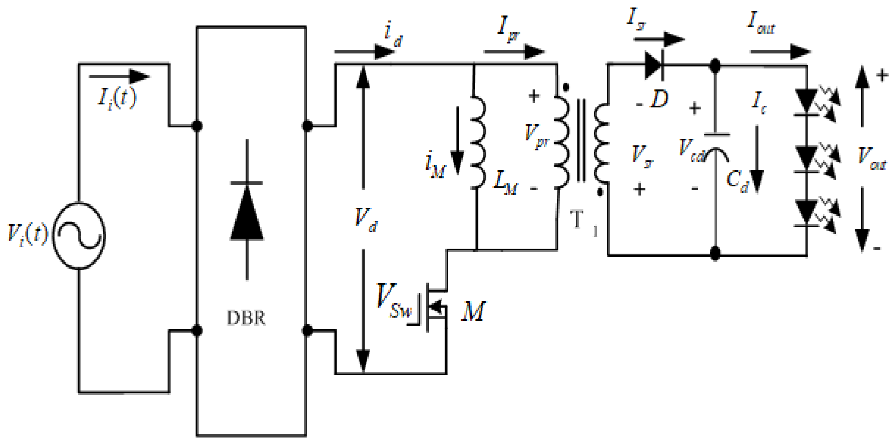

Figure 1. Flyback converter in CCM mode The Flyback converter average state space model is given by,

$$\dot{V}_o = \frac{I_L(1-D)}{nC} - \frac{V_o}{RC} \tag{1}$$

$$\dot{I}_L = -\frac{V_o(1-D)}{nL} + \frac{V_g D}{L} \tag{2}$$

where D is the duty cycle of the controller, R is the load resistance, C is the Capacitance of converter and n represent the transformer coil turns. I_L and V_O represent the transformer magnetizing inductance current and output load voltage respectively.

By putting X_1 □ V_0 and X_2 □ I_L in the state space model it can be rewritten as

$$\dot{X}_1 = \frac{X_2(1-D)}{nC} - \frac{X_1}{RC} \tag{3}$$

$$\dot{X}_2 = -\frac{X_1(1-D)}{nL} + \frac{V_g D}{L} \tag{4}$$

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Due to variations in the input voltage and load the output voltage will not be stable. As a result, the transient and steady-state responses are changed unintentionally, which reduces the system's overall efficiency.

4. Proposed Feedback Linearization based Backstepping Controller for Flyback Converter

Here, a well-structured experimental design for validation of the merging framework of Deep Dyna Q Learning and VARMAx operations is established and runs sequentially to validate the efficacy of detection and resilience from adversarial attacks under dynamic but n conditions. In this section, we present the configuration of the experimental environment, the datasets, the parameter settings of models, and the evaluation metrics for performance evaluation. The suggested feedback linearization based backstepping controller is tuned to obtain the desired output reference voltage in order to generate the desired output voltage of the flyback converter. The duty cycle of the converter is properly tuned to achieve the correct output reference voltage in order to acquire the output voltage.

4.1 Conversion of Non-Linear System in to linear system using exact feedback linearization method

For the nonlinear system to be fully linearized it has to meet the conditions,

1. The rank of the matrix $[(a), adfg(a), \ldots \ldots.\, adfm-2\,(a), adfm-1\; g(a)]$ should need to be equal to the m, where m is the dimension of the system.

2. At a = a0 from the matrix $[(a), adfg(a), \ldots \ldots.\, adfm-2\,(a), adfm-1\; g(a)]$ it should be coextensive.

If the above two conditions are met, it is possible to do coordinate transformation as given below

$$\dot{Z} = Z_2 \quad]$$ (5)

$$m-1 \square(y)u$$

$$[\dot{Z}2 = Z3$$

$$m \quad (\ )$$

$$\dot{Z}_m = L_f \square\; y \; + L_g L_f$$

where $L^m_f h(y)$ is the Lie derivative of the function $\square(y)$ with respect of $f(y)$ and $L_g L^{m-1}_f h(y)$ is the Lie derivative of the $L_f h(y)$ with respect to $g(y)$

For our proposed flyback converter, the dimension of the system m is 2, hence from Eqn (5)

$$\dot{Z}_1 = Z_2 \quad]$$ (6)

$$[$$

$$\dot{Z}_2 = L^2_f \square(x) + L_g L_f \square(x)D$$

where

$$L_f \square(x) = \frac{\partial(\square(x))}{} + \frac{\partial(\square(x}{}$$

)) (7)

g $\partial x1(x1)$

$\partial x2(x2)$

$L^2 \square(x) = L \ (L \ \square(x))$ (8)

f f f

$L \ (L \ \square(x)) = \frac{\partial(Lf\square(x))}{\partial x1(x1)} + \frac{\partial(Lf\square(x))}{\partial x2(x2)}$ (9)

f f

$L \ L \ \square(x) = \frac{\partial(Lf\square(x))}{\partial x1(x1)} + \frac{\partial(L \ f\square(x))}{\partial x2(x2)}$ (10)

g f

From Eqn (3) and (4)

. .

$X = (x) + g(x)D$ (11)

$\square(x) = x_1$ (12)

$[\dot{x}_1 \ \dot{x}_2] = [-\frac{1}{RC} \ \frac{1}{nC} \ ; \ -\frac{1}{nL} \ 0][x_1 \ x_2] + [-\frac{x2}{nC} \ \ x_1/nL + V_g/L] D$ (13)

Hen$_x$ce by$_x$substitution of Eqn (12) and (13) in (7), (8), (9) and (10), the lie derivatives can be obtained as

$L_f \square(x) = - \frac{1}{RC} + \frac{2}{nC}$ (14)

$L_f^2 \square(x) = L_f \ (L_f \square(x))$ (15)

$L_f \ (L_f \ \square(x)) = \frac{\partial(Lf\square(x))}{\partial x1_x(x1)} x_1 + \frac{\partial(Lf\square(x))}{\partial x2(x2)} x$ (16)

$L_f^2 \square(x) = - \frac{2}{R^2C^2} - \frac{}{RnC^2} \frac{1}{n^2LC}$ (17)

$L_g L_f \ \square(x) = \frac{\partial(Lf\square(x))}{\partial_x x1(x1)} x + \frac{\partial(L \ f\square(x))}{\partial x2(Vx2)}$ (18)

$L_g L_f \ \square(x) = \frac{2}{RnC^2} - \frac{1}{n^2LC} - \frac{g}{nLC}$ (19)

.

By substituting (19) and (17) in (6) $Z2$ can be obtained as

.

$$\dot{Z} = \frac{x1}{R^2C^2} - \frac{x2}{RnC^2} - \frac{x1}{n^2LC} + \left(\frac{x2}{RnC^2} - \frac{x1}{n^2LC} - \frac{Vg}{nLC}\right) D \quad (20)$$

The new state space Eqn after the coordinate transformation using feedback linearization method is

.

$$Z = Z2_{x1} \quad (21)$$

$$Z = \frac{x2}{R^2C^2} - \frac{x1}{RnC^2} - \frac{x2}{n^2LC} + \left(\frac{x1}{RnC^2} - \frac{}{n^2LC} - \frac{Vg}{nLC}\right) D \quad (22)$$

$1 \quad (24)$

where Z1 is the output voltage.

The primary goal of the suggested Feedback Linearization backstepping controller is to achieve the control law by tracking the desired output voltage while minimising error by indirectly managing the error variable to zero where the control input lies. (25) which is going to act as the .

4.2 Calculating the Lyapunov control function

The error variable

$$e_1 = Z_1 - V_{ref} \quad (23)$$

The derivative of the error variable Z_1 is obtained as

$$\dot{e}1 = \dot{Z}1 - \dot{V}ref$$

By substituting (21) in (24)

$$\dot{e}1 = Z2 - \dot{V}ref$$

The error value e1 is reduced by introducing the new control input Z_{2d} second reference value that will make error e_1 to zero by making $Z_2 \to Z_{2d}$. Put $\dot{e}_1 = -c_1e_1$ in (25) and solve for Z_{2d} the virtual control input where c_1 is the gain constant.

$$Z_{2d} = \dot{V}_{ref} - c_1e_1 \quad (26)$$

The second error variable

$$e_1 = Z_2 - Z_{2d} \quad (27)$$

.

By putting $Z_2 = e_2 + Z_{2d}$ and by substituting (26) in (25) $\dot{e}_1$ becomes

.

$$\dot{e}_1 = e_2 - c_1e_1 \quad (28)$$

The derivative of e2 is

$$\dot{e}_2 = \dot{Z}_2 - \dot{Z}_{2d} \quad (29)$$

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By taking derivative of (26)

$$\dot{Z}_{2d} = -c_1 Z_2 + c_1 \dot{V}_{ref} + \ddot{V}_{ref} \quad (30)$$

By Substituting (20) and (30) in (29)

$$\dot{e}_2 = \frac{x_1}{R^2C^2} - \frac{x_2}{RnC^2} - \frac{x_1}{n^2LC} + \left(\frac{x_2}{RnC^2} - \frac{x_1}{n^2LC} - \frac{V_g}{nLC}\right) D + c_1 Z_2 - c_1 \dot{V}_{ref} - \ddot{V}_{ref} \quad (31)$$

The Lyapunov characteristic is chosen such that e1 and e2 must vanish that allows you to acquire the asymptotic strong system. The Lyapunov characteristic is described as

$$V = \frac{1}{2}e_1^2 + \frac{1}{2}e_2^2 \quad (32)$$

By differentiating the above Lyapunov control function $\dot{V}$ can be obtained as

$$\dot{V} = e_1\dot{e}_1 + e_2\dot{e}_2 \quad (33)$$

By Substituting (31) and (28) in (33)

$$\dot{V} = e_1(e_1 - c_1 e_1) + e_2\left(\frac{x_1}{R^2C^2} - \frac{x_2}{RnC^2} - \frac{x_1}{n^2LC} + \left(\frac{x_1}{RnC^2} - \frac{x_1}{n^2LC} - \frac{V_g}{nLC}\right) D - c_1 Z_2 - c_1 \dot{V}_{ref} - \ddot{V}_{ref}\right) + c_2 e_2^2 - c_2 e_2^2 \quad (34)$$

where c_2 is the gain constant.

By solving $\dot{V}$ becomes

$$\dot{V} = -c_1 e_1^2 - c_2 e_2^2 + e_2\left(x_1/R^2C^2 - x_2/RnC^2 - x_1/n^2LC + \left(\frac{x_1}{RnC^2} - \frac{x_2}{n^2LC} - \frac{V_g}{nLC}\right) D - c_1 Z_2 - c_1 \dot{V}_{ref} - \ddot{V}_{ref}\right) + c_2 e_2 + e_1 \quad (35)$$

To obtain the asymptotic stable system the Lyapunov function should need to be

$$\dot{V} = -c_1 e_1^2 - c_2 e_2^2 \quad (36)$$

1 2

2

4.3 Determining the control law

For attaining stable system Eqn (35) needs to be equated to zero;

$$((x_1/R^2C^2 - x_2/RnC^2 - x_1/n^2LC + (x_2/RnC^2 - x_1/n^2LC - V_g/nLC) + c_1Z_2 - c_1V_{ref} - V_{ref}) + c_2e_2 + e_1) = 0 \quad (37)$$

The control law can be written as

$$D = \left(-\frac{1}{R^2C^2} + \frac{x_2}{RnC^2} + \frac{x_1}{n^2LC} - c_1Z_2 + c_1V_{ref} + \dot{V}_{ref}\right) - c_2e_2 - \frac{e_1}{\frac{x_2}{RnC^2} - \frac{x_1}{n^2LC} - \frac{V_g}{nLC}} \quad (38)$$

Thus, the control law of the feedback linearization based backstepping controller for the flyback converter is obtained. To get better transient responses,the gain parameters c_1 and c_2 has to be chosen effectively.

5. Results and Discussion

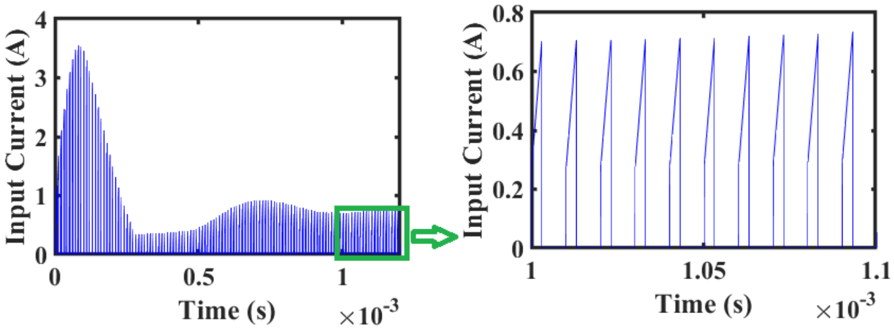
The proposed criticism linearization based back Stepping Controller controls the flyback converter to get the ideal result voltage for changing info voltage. The proposed regulator is reenacted utilizing MATLAB programming and wanted voltage ans current is obtained by adjusting the duty cycle given by the situations (38). A stage size of 1µs is utilized to recreate the flyback converter. The converter boundaries and regulator boundaries are given in Table 1. To accomplish better unique and static attributes, the addition constants c1 and c2 are chosen cautiously. To guarantee the vigor of the proposed regulator, it is contrasted and the input linearization regulator and traditional PI regulator. The reactions of the information current, obligation cycle, yield current and result load voltage are gotten for every one of the three regulators. To guarantee its reasonableness progressively, tphe flyback converter is exposed to change in input voltage, reference voltage and burden obstruction is examined in the accompanying seven contextual analyses.

Table 1. Simulation Parameters

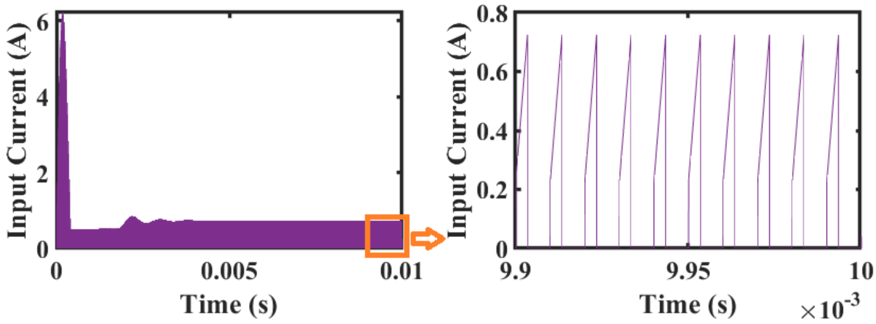
Flyback converter Parameters	**Value**
Output capacitance C	200 µF
Nominal power	25 VA
Nominal frequency	100 kHz
Transformer primary voltage	150 V
Transformer primary inductance	30 µH
Transformer secondary voltage	30 V
Input voltage (V_{in})	150 V
Load resistance (R)	10 Ω
Parameters of Controller	**Value**
Gain constant c1	5e6
Gain constant c2	10

(i) Case 1: Initial response

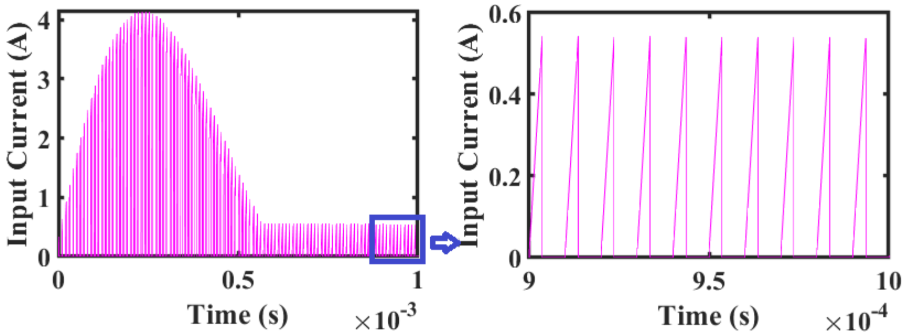
Here, the flyback converter is simulated using the parameters as shown in table 1 for all three controllers. The nature of input current, control input, output current and output voltage are portrayed in Figure 2 for FB, PI and proposed controller. From the responses,it is apparent that the controller which is proposed gives better responses, and the details of transient response and steady state for the obtained output voltage are enumerated in Table 2.



i. Input Current of PI Controller

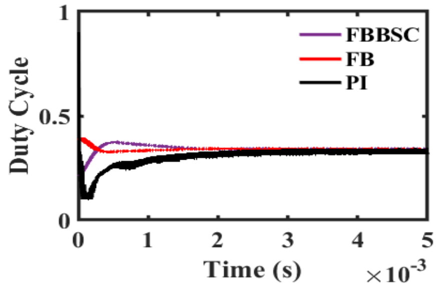


ii. Input Current of FeedBack linearization Controller

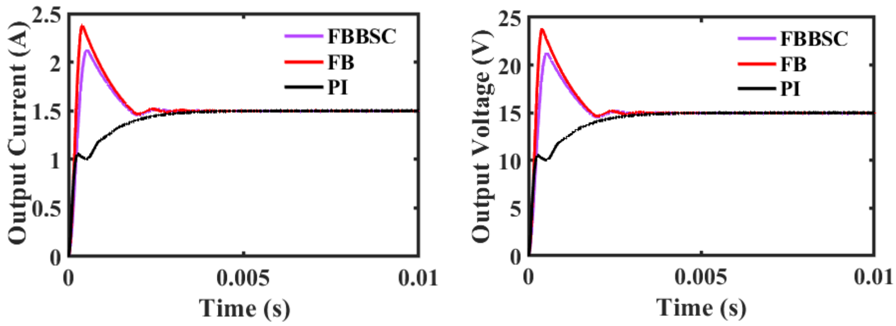


iii. Input Current of FeedBack Back Stepping controller

a. Input current of three controllers in Case 1



b. Duty cycle of all the three controllers in Case 1



c. Output Current d. Output Voltage

Figure 2. Waveforms of FBBSC, FB AND PI controller for case 1

Figure 2 (a) shows the input current of all the three controllers with better transient response.Figure 2 (b),(c) and (d) shows the duty cycle, output current and output voltage of three controllers in which the proposed controller has better voltage regulation and power quality improvement with 1.9 ms faster response as compared to other conventional controllers.

Table 2. Output voltage responses during Case 1

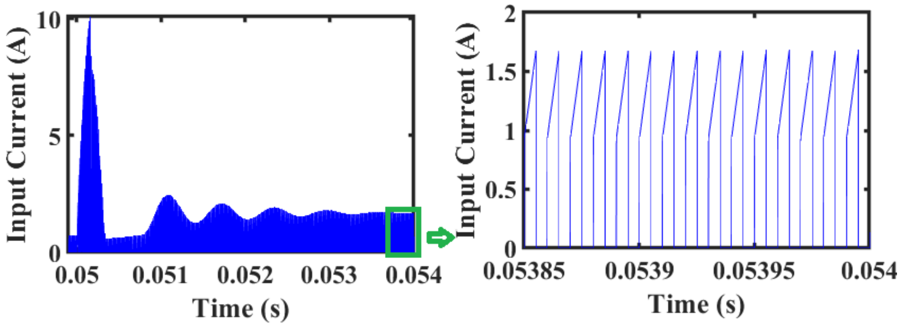
Power electronic Controller	Rising Time(s)	Settling Time(s)	Peak Overshoot(s)
PI	0.0015	0.0030	0.0149
FB	1.4903e-04	0.0014	56.3490
FBBSC	2.0642e-04	0.0011	42.3800

From this table, it is evident that the proposed controller manifested enriched transient as well as steady state responses than other two controllers.

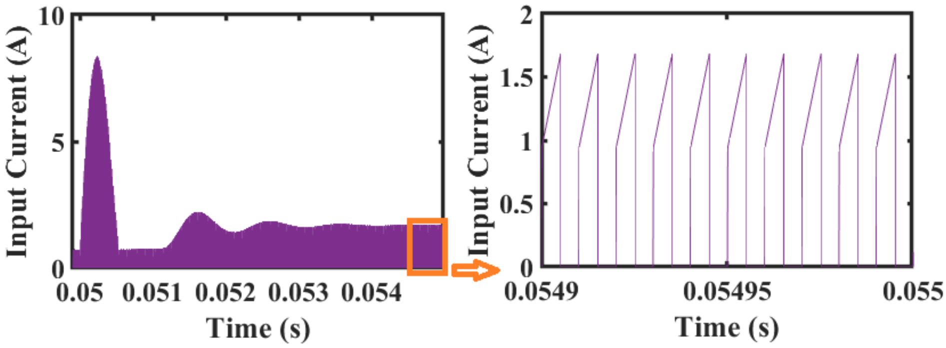
(ii) Case 2 :Value of Reference voltage from 15 V to 30 V

To look at the robustness of the FBBSC over a extensive variety of running points, the converter is subjected to growth in reference voltage from 15V to 30V at time t = 0.05 seconds. The responses of all 3 controllers in the course of such big uncertainty are proven in Figure 3. By the web weight replace rule, the extrade in reference voltage is approximated quick which in flip affects the manage rule of the projected controller. Hence the responses for the proposed controller are acquired in short time with minimal overshoot and their info are given in Table 3 *(iii)* Case 3 Value of Input voltage from 150 V to 100 V

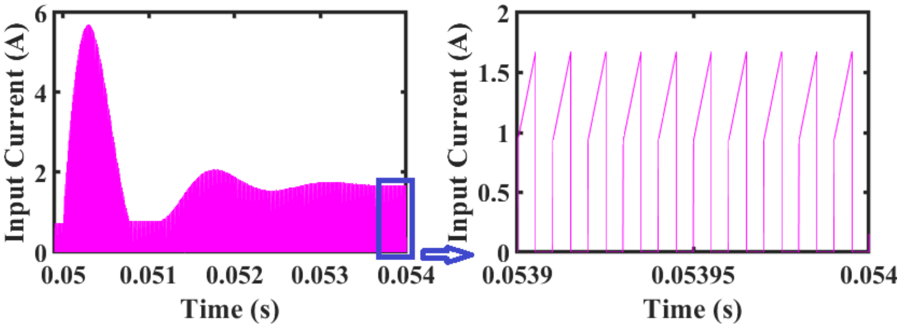
The input voltage is decreased from 150 V to 100 V at t = 0.1 seconds in this case study. The responses of all three controllers are shown in figure 4. Based on these responses, the proposed Feedback linearization controller tracks the desired voltage in minimum time and less overshoot and their details are given in table 4.



i. Input current of PI controller

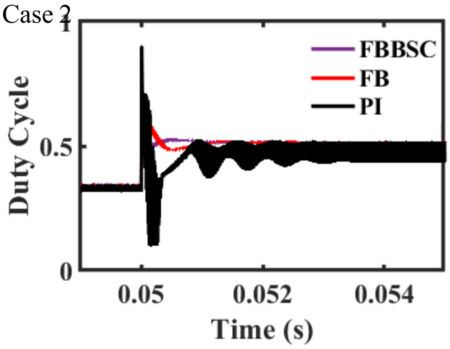


Input current of FeedBack linearization Controller

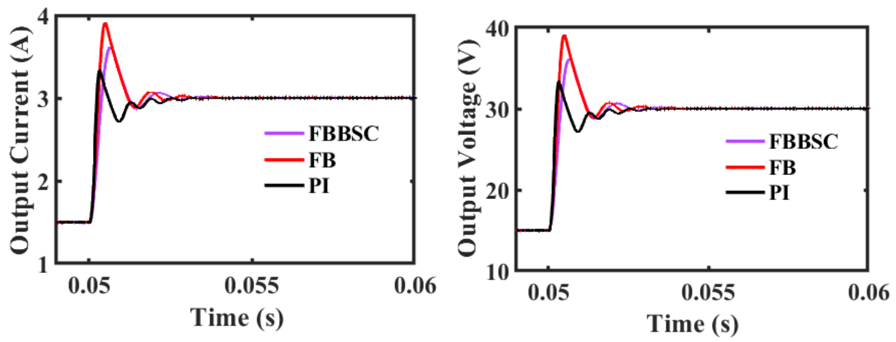


ii. Input current of FeedBack Back Stepping controller

a. Input current of three controllers in Case 2



b. Duty cycle of all the three controller in Case 2



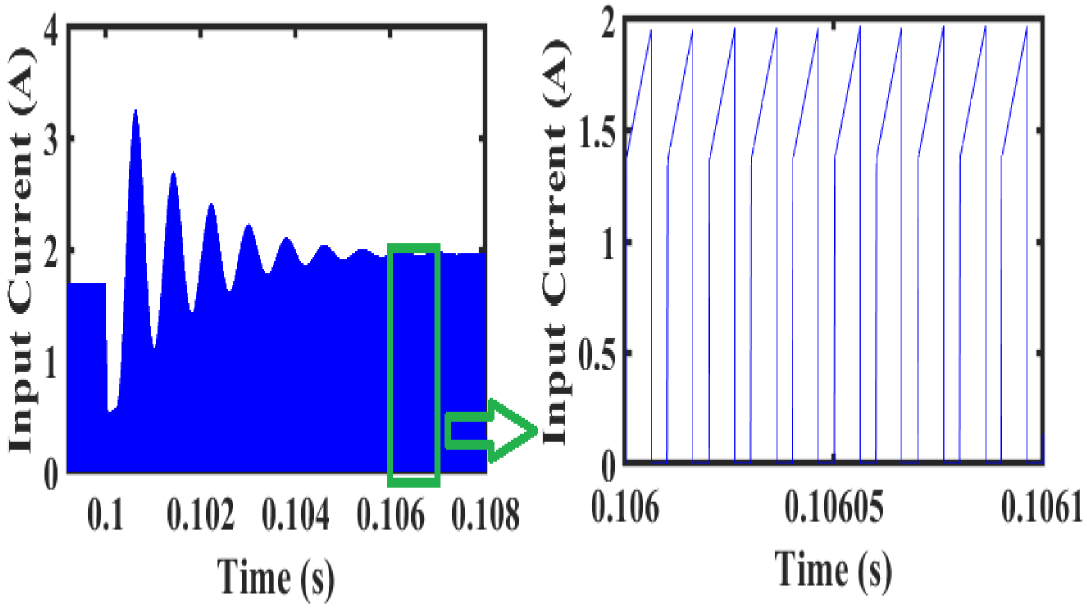
c. Output Current d. Output Voltage

Figure 3. Waveforms of FBBSC, FB AND PI controller for case 2

Figure 3 (a) shows the input current of all the three controllers with better transient response.Figure 3 (b),(c) and (d) shows the duty cycle, output current and output voltage of three controllers in which the proposed controller has better voltage regulation and power quality improvement with 1.4 ms faster response as compared to other conventional controllers.

Table 3. Output voltage responses during case 2

Power electronic Controller	**Rising Time(s)**	**Settling Time(s)**	**Peak Overshoot(s)**
PI	1.3561e-04	0.0023	11.4832
FB	1.7117e-04	0.0011	30.7902
FBBSC	2.5130e-04	0.0009	20.4083



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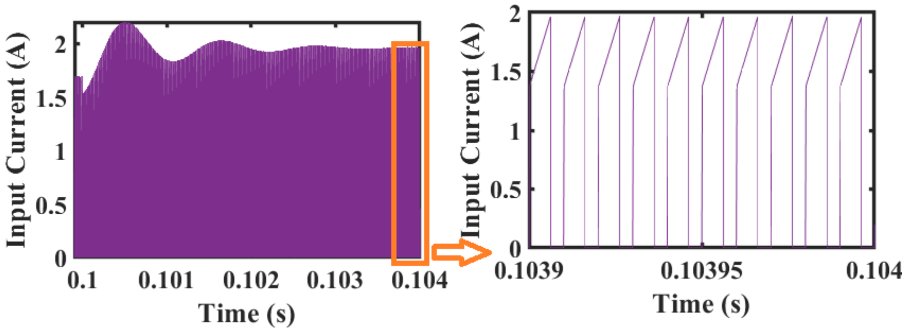
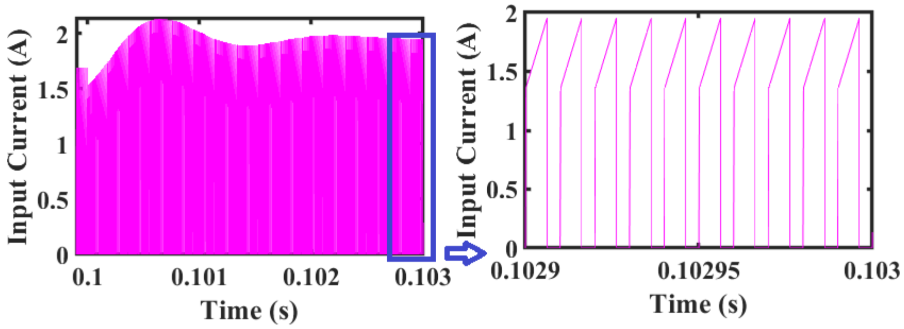
i. Input current of PI controller

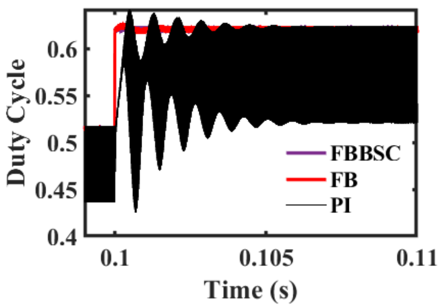


ii. Input current of FeedBack linearization Controller

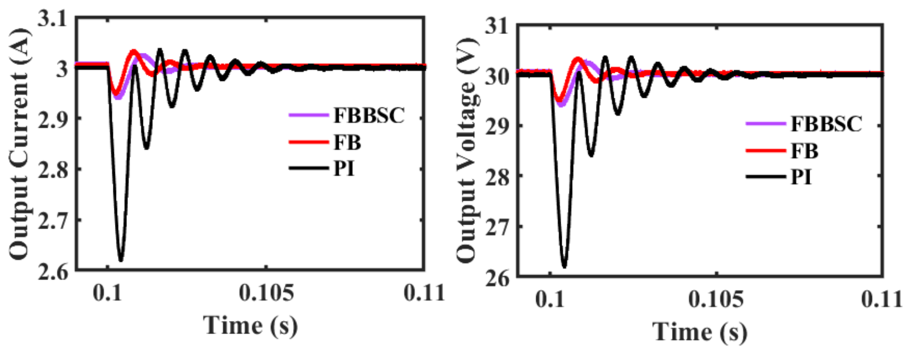


iii. Input Current of FeedBack linearization Back Stepping controller

a. Input current of all three controllers in Case 3



Duty cycle of all the three controllers



b. Output Current d. Output Voltage

Figure 4. Waveforms of FBBSC, FB AND PI controller for Case 3

Figure 4 (a) shows the input current of all the three controllers with better transient response.Figure 4 (b),(c) and (d) shows the duty cycle, output current and output voltage of three controllers in which the proposed controller has better voltage regulation and power quality improvement with 1.4 ms faster response as compared to other conventional controllers.

Table 4. Output Voltage responses during case 3

Power electronic Controller	Rising Time(s)	Settling Time(s)	Peak Overshoot(s)
PI	2.6749e-08	0.0029	1.3888
FB	5.4244e-04	0.0027	1.29334
FBBSC	3.1963e-06	0.0015	1.0464

From table 4, it is very clear that the FBBSC controller can able to track the voltage at 1.5 ms which is faster than other controllers.

4. Conclusion

The Flyback converter is modeled based on the Feedback Linearization based Backstepping Controller using Lyapunov stability analysis to extract the desired voltage from the Flyback converter.The response of the PI, FB, FBBSC controller reacts more rapidly for the changes in various load uncertainities. The performance of the proposed controller under various case studies flows good for the desired output voltage, output current and duty cycle. The settling time, rise time and peak overshoot of the proposed controller performs more efficient in tracking the required voltage even at varying load conditions as compared with the conventional PI, FB controllers. The duty cycle of the proposed controller 1.5 ms faster response as compared with the other conventional controllers.

Declarations

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Conflict of Interest

The authors declared that they have no conflicts of interest to this work. We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

Availability of data and material

Not applicable **Code availability** Not applicable

Author contributions

The corresponding author claims the major contribution of the paper including formulation, analysis and editing. The co-authors provides guidance to verify the analysis result and manuscript editing.

Compliance with ethical standards

This article is a completely original work of its authors; it has not been published before and will not be sent to other publications until the journal's editorial board decides not to accept it for publication.

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