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REGULAR ARTICLE

Non Linear Lie derivative Control Technique for Improved Voltage Regulation in Flyback Converter

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A renewable energy-based DC micro grid system supports the DC power flow for domestic and industrial purposes. The DC voltage drawn from the source is to be adjusted by using the power electronic converters. So, the controlling of converter came into existence. In this paper the Flyback converter is modelled to get the rated voltage regulation with the desired output voltage with proper duty cycle at the converter. The nonlinear system is converted into the linear one by using the lie derivative control technique. In this technique the relative values of current loop and voltage loop is linearized to get the desired output voltage at the flyback converter. Thus as compared to PI controller the proposed controller flows good for the transient response of the power system. The boost converter designed in the existing has modelled with the low output range but in the Flyback converter the ability to achieve the voltage regulation in DC micro grid with variable inductance and capacitance is defined. Simulation result shows the modelled flyback converter flows good and accurate as compared to the PI controller with the settling time difference of 85s of voltage dynamics in the DC micro grid system. The steady state and transient response of the system is evaluated by comparing the simulation of PI and the proposed controller used in the real time power transmission system to reduce the power loss at receiving side.

Keywords: Flyback converter, Lie derivative control, Voltage regulation, Transient response, DC microgrid, Power electronic converters, Renewable energy.

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1. INTRODUCTION

In the power converter, the switched mode converters are nonlinear system so the switching frequency is not maintained properly in power conversion system. The voltage regulation of the converter is varied with multiple switching frequencies. So that the power factor of each duty cycle gets varied. If this exists, the duty cycle of converter is not attained properly. Therefore the voltage imbalance and harmonics takes place without reaching its regulated voltage [1-5].

Adaptive Controllers:

To overcome these drawbacks the adaptive controller came into existence which only controls the input current of the range 0 – 5 A [6-7].

Siding mode Controllers:

To predict the desired value of output voltage the sliding mode controller for converter is designed which enhances the output voltage by varying the duty cycle of the converter but it does not holds good for varying loads [8-9].

Model Predictive Controllers:

The model predictive controller stays positive for system efficiency but the stability of the system becomes low at non-linear load parameters [10]. The system needs to be control even at the variation in load parameters. Therefore, the Flyback converter is modeled using the lie derivative control technique to define the steady state and the voltage dynamics in the system with its settling time. In this paper Section II gives the mathematical model to design the flyback converter. Section III defines the approach of feedback linearization technique using lie derivative control equation. Section IV provides the implementation of proposed feedback linearization controller for the Flyback converter in outer voltage loop and inner current loop. The simulation results of PID controller are compared in Section V. Finally, the conclusion for the proposed controller and future work is given in section VI.

2. MODELLING THE FLYBACK CONVERTER

The design of the flyback converter is very simple and contains electrical components such as a flyback transformer, a switch, a rectifier, a filter and a control device to control the switch and achieve regulation.

The rectifier rectifies the secondary winding voltage to produce a pulsating direct current and disconnects the load from the transformer secondary winding. The capacitor filters the output voltage of the rectifier and boosts the DC output level according to the desired application.

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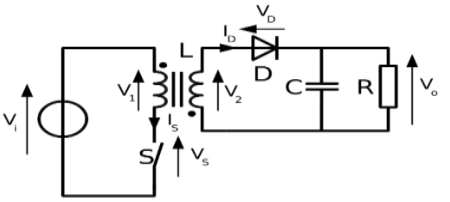

Fig. 1 – Circuit Diagram of Flyback converter

A flyback transformer is used as an inductor to store magnetic energy. It is designed as two linked inductors that act as primary and secondary windings. It operates at high frequencies of around 50 kHz.

Design calculations

It is necessary to take into account the design calculations of the reverse converter of the turn's ratio, the duty cycle and the currents of the primary and secondary windings.

The equation describes the ON and OFF condition of switch.

$$V_l = V_g \qquad V_l = -V/n$$

$$i_c = -V/R \qquad i_c = i$$

$$i_g = i \qquad i_g = 0$$

$$V = \Delta i/\Delta t$$

$$\Delta i = V\Delta t/L$$

When Switch is ON:

$$S_{ON} = \Delta i_{ON} = V_i DT/L \tag{1}$$

When Switch is OFF:

$$S_{OFF} = \Delta i_{OFF} = -V_0 (1-D)T/nL \tag{2}$$

On Average:

$$\Delta i_{ON} + \Delta i_{off} = 0$$

$$V_i DT/L - V_o (1-D)T/nL = 0$$

$$V_i DT/L = V_o (1-D)T/nL$$

$$V_i D = V_o (1-D)/n$$

$$V_0 = nV_i D/(1-D)$$

For one full cycle combining the above equations:

$$L\,di_L/dt = V_g = V_o (1-D)/n \tag{3}$$

Taking current at output node:

$$C\,dv_c/dt = i_L (1-D)/n - V_o/R \tag{4}$$

The results of Eqs. (3) and (4) is Simulated in MATLAB.

3. OVERVIEW OF LIE DERIVATIVE CONTROL TECHNIQUE

Feedback linearization method is:

- A nonlinear control strategy which changes nonlinear system into linear system or a few linear subsystems utilizing nonlinear facilitates change.
- Linearization is free of working point.

Generalized form of non- linear system:

$$\overset{0}{x} = f(x) + g(x)$$

$$y = h(x) \tag{5}$$

Where:

X is the condition of the system which addresses different actual properties of the sys-tem and assuming the request for the system is n.

f and g are the nonlinear capabilities with $g \neq 0$ which address both actual properties and boundaries of the system.

U is the control signal

Y is the result capability

The nonlinear system is changed from x states to z expresses, the nonlinear change can be characterized as follows:

$$Z = \phi(x)$$

With

$$Z = \begin{bmatrix} Z_1 \\ Z_2 \\ . \\ . \\ . \\ . \\ Z_n \end{bmatrix} = \begin{bmatrix} L_f^{1-1} h(x) \\ L_f^{2-1} h(x) \\ . \\ . \\ . \\ . \\ L_f^{r-1} h(x) \end{bmatrix} \tag{6}$$

Scalar function of h(x) of $X = \lfloor X_1 .... X_n \rfloor \wedge T$ and vector field $f = \lfloor f_1 .... f_n \rfloor \wedge T$, the lie derivative of h(x) along the vector field f(x) can be written as follows;

$$L_f h(x) = \partial h(x)/\partial x f(x) = \sum_{i=n}^{n} \partial h_i(x)/n\partial x\, f_i(x) \tag{7}$$

If the lie derivative of the function $L_f^{r-1} h(x)$ along (x) is not equal to zero i.e

$$L_g L_f^{r-1} h(x) = \partial L_f^{r-1} h(x)/\partial x g(x) \neq 0 \tag{8}$$

The system is said to have relative degree r.

The relative degree (r) defines the feedback linearizability of a transformed linear system.

If r = n; the feedback linearized system is called exactly linearized

If r < n; the feedback linearized system is called partially linearized

The feedback linearized system is;

$$\dot{Z}=\begin{bmatrix}Z_1\\Z_2\\.\\.\\.\\Z_n\end{bmatrix}=\begin{bmatrix}L_f^{2-1}f(x)\\L_f^{3-1f}h(x)\\.\\.\\.\\L_f^{r-1}h(x)+L_g L_f^{r-1}h(x)u\end{bmatrix}=\begin{bmatrix}L_f^{2-1}f(x)\\L_f^{3-1f}h(x)\\.\\.\\.\\a(x)=b(x)u\end{bmatrix}=Az=Bv \tag{9}$$

Where $a(x)=L_f^r h(x)$

$$b(x)=L_g L_f^{r-1}h(x)$$

$$A=\begin{bmatrix}0........1\\............\\0..........0\end{bmatrix} \quad \text{and} \quad B=\begin{bmatrix}0\\.\\.\\1\end{bmatrix}$$

$$v=a(x)=b(x)u$$

$$v=L_f^r h(x)+L_g L_f^{r-1}h(x)u$$

Any linear procedure can be applied to plan direct regulator for the Feedback linearized system.

Feedback linearized system can be written as:

$$\dot{Z}=Az=Bv$$

$$y=c \tag{10}$$

For this system, $\boldsymbol{v}$ can be obtained by using any linear control technique. For state feedback control, $\boldsymbol{v}$ can be written as:

$$v=-kZ$$

If the system is exactly linearized, $r=n$, the control law (u) can be written as:

$$u=v-a(x)/b(x)=v-L_f^n h(x)/L_g L_f^{n-1}h(x) \tag{11}$$

If the system is partially linearized, $r<n$,, the control law (u) can be written as:

$$u=v-a(x)/b(x)=v-L_f^r h(x)/L_g L_f^{r-1}h(x) \tag{12}$$

4. CONTROLLER DESIGN FOR FLYBACK CONVERTER USING LIE DERIVATIVE CONTROL TECHNIQUE

$$L d\,i_L/dt=V_b-V_o(1-D)/n$$

$$C d\,V_c/dt=i_L(1-D)/n-V_0/R$$

(i) Inner current linearization:

- The double slope control procedure can be utilized to this DC converter. This double incline comprises of internal current circle and external voltage circle. The inner current loop is determined in view of the flyback converter in Condition (3) and written in summed up structure as Condition (5)

$$i_L=V_g/L-V_0(1-D)/Ln \tag{13}$$

Let take $y_1=i_L$

The relative degree of the system in Eq. (13) is calculated

$$L_g h(x)=\partial(h(x)g(x))/\partial x$$

Let $h(x)=y_1=i_L=V_g D/L-V_o(1-D)/Ln$

$$f(x)=-V_o/L$$

$$g(x)=(V_g/L-V_o/Ln)D$$

$$x=f(x)+g(x)u$$

$$u=v-L_g^r h(x)/L_g L_f^{r-1}h(x)$$

$$L_g h(x)=\partial/\partial x h(x)g(x)$$

$$=\partial/\partial x(V_g/L-V_o/Ln+V_o D/Ln)g(x)$$

$$=-V_o/Ln\neq 0 \tag{14}$$

$$L_f h(x)=\partial(h(x)f(x))/\partial x$$

$$=\partial/\partial x(V_g D/L-V_o/Ln+V_O D/Ln)f(x)$$

$$=V_g/L-V_o/Ln\neq 0 \tag{15}$$

According to Eq. (8), $\boldsymbol{r=1}$

According to Eq. (12), the Control input for inner current loop can be found as

$$u=V-L_g^r h(x)/L_g L_f^{r-1}h(x)$$

$$D=V-L_f h(x)/L_g h(x)$$

$$D=V-(V_g-V_o/n/L)\;/V_o/n/L \tag{16}$$

Sub the value of d in Eq. (13),

$$i_L=(1/L)(V_g-(V_o/n))+((1/L)(V_o/n)(V-V_g-V_o/L)/V_o/n/L) \tag{17}$$

$$i_L=V$$

By taking the controllable variable 'v' as current error V= $K_i(i_{ref}-i_L)$ the current loop is linearized.

(ii) Linearization of outer voltage loop

Based on the flyback converter model in Eq. (4) and written in generalized form as in Eq. (5)

$$V_o=1/C(i_L-i_o-d\,i_L) \tag{18}$$

Sub D from Eq. (16) in Eq. (18) it becomes

$$V_o = 1/C((i_L/n)(1-D)) - (V_o/RC))$$

$$V_o = 1/c((i_L/n)((Lv - V_g - V_o)/L))(L/V_o) - (V_o/RC))$$

$$1/C((i_{L/n})(V_g - Lv)/V_o) - (V_o/R))$$

It is designed in the way the outer voltage loop responds slower than the inner current loop. So, the value of $\boldsymbol{i_L = i_{ref}}$ which gives the below voltage equation:

$$V_0 = 1/C(V_g i_{reg}/V_{ON}) - V_o/R$$

$$y_2 = V_o \tag{19}$$

As given in section III, the relative degree of the system in Eq. (19) is calculated,

$$h(x) = y_2 = V_o = V_g i_{ref}/nV_o C - V_o/RC$$

$$f(x) = V_g i_{ref}/nV_o C$$

$$g(x) = V_o/RC$$

$$L_g h(x) = \partial/\partial x((V_g - i_{ref}/nV_o C) - (V_o/RC))g(x) \tag{20}$$

$$= V_g/nV_o C \neq 0$$

$$L_f h(x) = \partial/\partial x((V_g - i_{ref}/nV_o C) - (V_o/RC))f(x)$$

$$L_f h(x) = \partial/\partial x((V_g - i_{ref}/nV_o C) - (V_o/RC))(V_g i_{ref}/nV_o C) \tag{21}$$

$$-V_o/RC \neq 0$$

$$d = v - L_f^r h(x)/L_g L_f^{r-1} h(x)$$

$$d = (m + V_o/RC)/(V_g/nCV_o)$$

$$= (m + V_o/RC)(nVV_o/V_g)$$

$$= (mnCV_o/V_g 0) + (nCV_o^2/RCV_g)$$

$$d = (mnCV_o/V_g 0) + (nV_o^2/RV_g) \tag{22}$$

Sub d in Eq. (19) the equation becomes:

$$V_o = (1/C)(V_g/nV_o)(mnCV_o/V_g) + (nV_o^2/RV_)) - (V_o/RC)$$

$$= (V_g mnCV_o/nCV_oV_g) + (nV_o^2V_g/CnRV_oV_g) - (V_o/RC)$$

$$= m + V_o/RC - v_o/RC$$

$$V_o = m$$

$$y_2 = V_o$$

Taking the controllable variable 'm' as voltage error, $m = K_v(V_{oref} - V_o)$ the voltage loop is linearized. Thus both the control loops are linearized.

5. PERFORMANCE EVALUATION OF CONVERTER

Case 1: Start up response

Fig. 2 and 3 shows the start up response of feedback linearization and PI controller of Output voltage vs Time Period and open loop case of the system. From the result output voltage flows good with its steady state and stability variations.

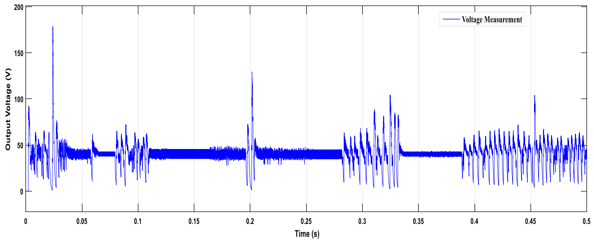

Fig. 2 – Start up response of Proposed Controller and PI Controller

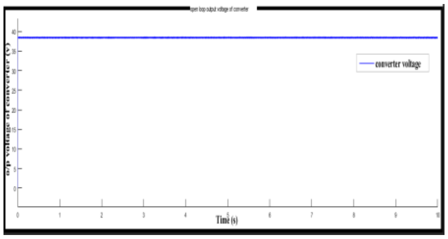

Fig. 3 – Open loop response of Flybackconveter

Case 2: Transient response to input variations (150 V to 100 V)

On comparing the PI with feedback linearization controller the output voltage variation tends to be quite active even in the load variation which is shown in Fig. 4.

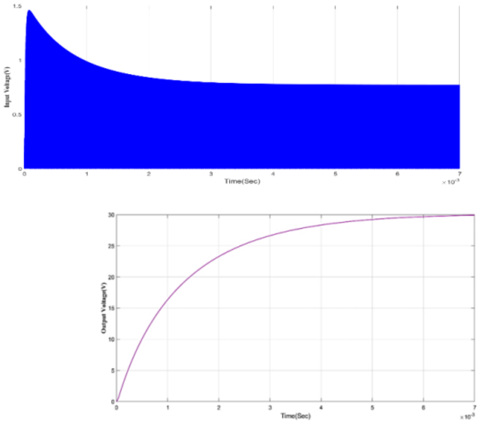

Fig. 4 – Output Voltage with respect to Input Voltage.

Case 3: Transient response to reference voltage variations (30 V to 20 V)

The reference voltage variations flows good with the feedback linearization controller on compared with PI controller. Fig. 5 shows the fast settling time with less effect of transient for both the PI and the proposed controller.

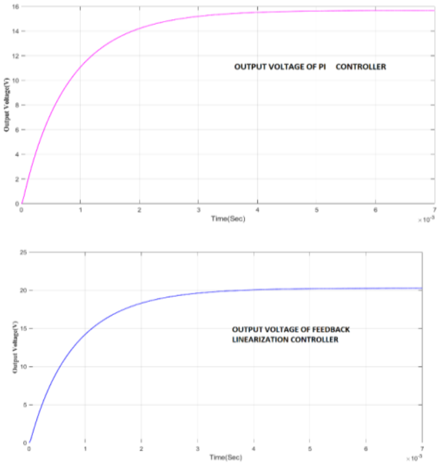

Fig. 5 – Controller output voltage with respect to change in reference voltage

Table 1

CASE	SETTLING TIME	
	PI CONTROLLER	FEEDBACK LINEARIZATION CONTROLLER
1	0.22 sec	0.9 ms
2	0.15 sec	5.5 ms
3	0.9 sec	5 ms

Table 1 illustrates the Feedback linearization controller flows good with fast settling time of 5ms as compared to PI Controller.

6. CONCLUSION

The lie derivative control for the Flyback converter is designed in this paper to overcome the voltage fluctuations caused by the DC-DC power converters. The nonlinear dynamic model is converted into a linear one to get the desired output voltage using lie derivative control. Simulation result shows the enhancement of volt-age dynamics in the dc system with improved settling time. The future wok will focus on the Feedback Linearization Backstepping controller design for the flyback converter by considering the voltage dynamics in the dc micro grid system. The simulation result ensures the perfect stability maintenance of the closed loop system even in the presence of parameters variation and load uncertainties. The comparison of PI controller with proposed controller for the Flyback converter has faster settling time of 5ms and produces good voltage regulation on DC-DC converter. Thus the lie derivative controller flows good to maintain the stability in power system associated with voltage regulation of DC-DC converters.

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Техніка керування нелінійною похідною Лі для покращеного регулювання напруги в зворотно-ходовому перетворювачі

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Мікросистема постійного струму на основі відновлюваної енергії підтримує потік електроенергії постійного струму для побутових і промислових цілей. Напруга постійного струму, отримана від джерела, регулюється за допомогою силових електронних перетворювачів. Так з'явилося управління перетворювачем. У цьому документі зворотно-поворотний перетворювач моделюється для отримання номінального регулювання напруги з бажаною вихідною напругою з належним робочим циклом перетворювача. Нелінійна система перетворюється на лінійну за допомогою методу керування похідною брехні. У цій техніці відносні значення петлі струму та петлі напруги лінеаризуються, щоб отримати бажану вихідну напругу на зворотно-ходовому перетворювачі. Таким чином, у порівнянні з ПІ-регулятором, пропонований контролер добре відповідає перехідним характеристикам енергосистеми.

Підвищувальний перетворювач, розроблений в існуючому, моделювався з низьким діапазоном вихідного сигналу, але в зворотному перетворювачі визначена здатність досягати регулювання напруги в мікромережі постійного струму зі змінною індуктивністю та ємністю. Результат моделювання показує, що змодельований зворотно-поворотний перетворювач працює добре та точно порівняно з PI-контролером із різницею часу встановлення динаміки напруги в системі мікромережі постійного струму 85 с. Стійкий стан і перехідна характеристика системи оцінюється шляхом порівняння моделювання PI та запропонованого контролера, що використовується в системі передачі електроенергії в реальному часі для зменшення втрат потужності на приймальній стороні.

Ключові слова: Зворотний перетворювач, Керування похідною Лі, Регулювання напруги, Перехідна характеристика, Мікромережа постійного струму, Силові електронні перетворювачі, Відновлювана енергія.