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Modelling & Control of DC – DC Converters Incorporating Fractional PID Controller

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Abstract: The purpose of this paper is to compare the behavior of two types of controllers: a traditional controller, represented by a PID controller, and fractional order controllers, represented by a generalized $PI^{\lambda}D^{\mu}$.The well-known PID is the integer order controller chosen whereas the generalized PID which stands for fractional order robust controller are the fractional order controllers studied. Fractional order controller is widely used in most areas of science and engineering, being recognized its ability to yield a superior control in many dynamical systems. This work proposes the applications of a Fractional Order PID (FOPID) controller in the area of Power Electronics. To design Fractional Order PID controller is to determine the two important parameters λ (integrator order) and μ (derivative order). In this article, the response and performance of closed loop DC – DC converters (Buck, Boost and Buck – boost converter) is compared between two controllers of Fractional Order PID controller and conventional PID controller. In all the cases the Fractional Order PID controller is found much better than conventional PID controller for the given system.

Keywords: Buck Converter, Boost converter, Buck-Boost converter, PID, FPID.

1. INTRODUCTION

However, a main difference, other than the way used to synthesize these controllers, is encountered. The number of parameters to be defined differs between these controllers. In fact, the PID needs to define three parameters, the generalized PID needs 5 parameters.

Nowadays, the use of the fractional controllers is almost necessary in almost all engineering domains. The reasons behind this use are diverse; among them we list the most important:

1. The identification of several physical and natural properties showed that a fractional order differentiation in implemented when modelling them using transfer function. Some of the examples are the thermal diffusive interfaces [7], the muscles activities [8] and much more…
2. The analogue [9] and digital [10] implementation of the fractional order controllers is easy;
3. Once the user specifications and/or the open loop shape are defined, the synthesis of the fractional order controller is not complicated

1.1 System components and user specifications:

In this section, the representation of the system containing the plant and the controller will be introduced as well as the performance specifications that the user would specify in order to get the best performance from the designed controller [2].

1.1.1 System components:

The component of control system is as follows:

I. Reference signal – Step II. Feedback – Negative III. PID controller
IV. Transfer functions V. Scope VI .Disturbances if any.

Figure 1.1 presents the block diagram of the feedback control system

1.2 PID controller

1.2.1 Integer order PID

First, the well-known PID controller is described. It is the eldest controller. It consists on a gain, an integration of order 1 and a derivation of order 1.

$$C(s) = K_P + K_i S^{-1} + S K_D \ldots\ldots (1.1)$$

Two different arrangement of the PID controller exist: the parallel arrangement and the cascade arrangement.

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The cascade arrangement will be treated here. Its transfer function can be presented as follow:

$$C_{PID}(s) = C_0 C_I(s) C_D(s) \text{ ……………………..……………………………………..(1.2)}$$

$$C_I(s) = \left(1 + \frac{S}{W_i}\right) / \left(\frac{S}{W_i}\right) \text{ ……………………..…….………………………………………..(1.3)}$$

$$C_D(s) = \left(1 + \frac{S}{W_b}\right) / \left(\frac{S}{W_H}\right) \text{ ………………………..…………………………(1.4)}$$

Where WI, WH, Wb are the transitional frequencies and C0 is a constant.

In order to calculate these parameters, the user constraints must be used. In the following, the method to calculate the optimal values of the PID parameters is shown.

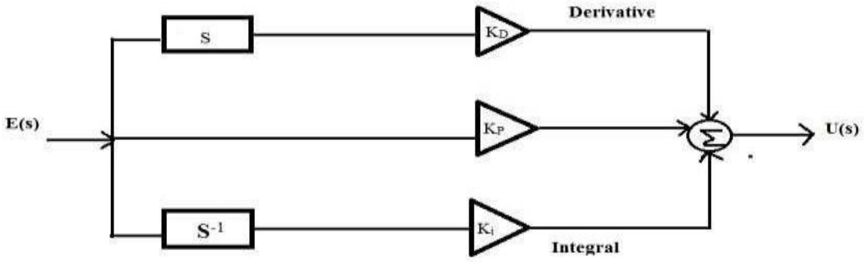

Figure 1-1 Model diagram configuration of Integer Order PID controller

2 LITERATURE REVIEW

2.1 Fractional PID controller:

Paper presents a comparison between fractional order controllers and integer order controllers [1].Three controllers are applied to a hydro-electromechanical test bench based on a double-direction pump, a uniform tank and a level sensor. In order to design the three controllers, an uncertain linearized model of the test bench is established using the grey-box approach. Then, a synthesis method for each controller, in frequency domain, is developed. In accordance with the user specifications and in order to do a significant comparison, the three control systems have the same behaviour for the nominal operational point. Finally, a sensitivity analysis is made to observe the robustness of each control system [2].Work proposes the applications of a Fractional Order PID (FOPID) controller in the area of Power Electronics for a DC-DC power converter to evaluate the use of Fractional Order PID controller with soft computing techniques [3-6].

2.2 DC – DC converter:

DC-DC converters are some of the simplest power electronic circuits. They are widely used in the power supply equipment for most electronic instruments and also in specialized high-power applications such as battery charging, plating and welding. In addition to a controllable and theoretically lossless DC voltage transformation, DC-DC converter circuits may also provide voltage isolation through the incorporation of a small high-frequency transformer. The wide variety of circuit topologies ranges from the single-transistor buck, boost and buck/boost converters to complex configurations comprising two or four devices and employing soft-switching or resonant techniques to control the switching losses. However, similar methods of analysis and control are applied to many of these converters [7-10].

3 DC – DC CONVERTER

Switched mode DC-DC converters need aid a few of the simplest energy electronic circuits which change over you quit offering on that one level about electrical voltage under an alternate level Eventually Tom's perusing exchanging movement. These converters need accepted an expanding arrangement from claiming enthusiasm toward numerous zones. This may be because of their totally provisions like control supplies for particular computers, office equipment, machine control, telecommunication equipment, dc engine drives, automotive, aircraft, and so forth. That analysis, design, control What's more adjustment from claiming exchanging converters would those fundamental factors that have on be recognized. A large number control techniques would utilized to control about switch mode DC-DC converters and the straightforward What's more low expense controller structure is generally popular to mossy cup oak modern and helter skelter execution requisitions. Every control strategy need its own points of interest What's more drawbacks, What's more its viability will be resolved by the provision the place it will be connected [7].

If it will be to planning your own result alternately exactly experimenting with Different calculations and designs, Recreation runs need aid compulsory preceding that real physical execution. Different instruments need aid accessible to constructing What's more simulating electrical Also electronic circuits, including math meets expectations Sim force frameworks. However, exactly may not bring right to these devices What's more Suites. It is conceivable with circumvallate this by speaking to those framework in the manifestation of a scientific model. Therefore, in this paper we delineate how will model Converters utilizing those The greater part simple obstructs of Simulink, same time even now giving those same degree from claiming exactness Concerning illustration different instruments. This paper clarifies the attempting of the model What's more every about its subsystems [7].

3.1Classification of Converters:

The converter topologies are classified as

- **Buck Converter:** The buck converter is venture down converter and produces an easier Normal yield voltage over the dc information voltage.
- **Boost converter:** The output voltage is always greater than the input voltage.
- **Buck-Boost converter:** The output voltage can be either higher or lower than the input voltage.

3.1.2Buck Converter:

- A buck converter (step-down converter) might make a DC-to-DC control converter which steps down voltage (while stepping up current) beginning for its data (supply) for its yield (load). It cam wood an opportunity will a chance to be said that voltage wander down chopper proselytes unregulated dc with regulated dc. It might be a populace something like switched-. An buck converter meets expectations should consistent mode in the exhibit through those inductor never tumbles for zero All around the individuals substitution cycle. In this mode, the individuals working guideline is portrayed by the plots Previously, figure.:.
- When the switch pictured above is closed (top of figure 3.1), the voltage across the inductor is VL = Vi -V0. The current through the inductor rises linearly. As the diode is reverse-biased by the voltage source Vi, no current flows through it;
- When the switch is opened (bottom of figure 3-1), the diode is forward biased. The voltage across the inductor is VL= -V0 (neglecting diode drop). Current IL decreases [8-9].

The energy stored in inductor L is [8-10]:

$$E=\frac{1}{2}LI_L^{\,2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3.1)$$

Therefore, it can be seen that the energy stored in L increases sduring on-time as IL increases and then decreases during the off-state. L is used to transfer energy from the input to the output of the converter.
The rate of change of IL can be calculated from

Increase in current during the on-state is given by:

$$\Delta I_{Lon}=\int_0^{t_{on}}\frac{V_L}{L}dt=\frac{(V_1-V_0)}{L}t_{on} \ldots\ldots\ldots\ldots,,,,,,,\ldots......................(3.3)$$

$$t_{on}=DT \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.4)$$

Where, D is a scalar called the Duty Cycle with a value between 0 and 1. Conversely the decrease in current during the off-state is given by:

$$\Delta I_{Loff}=\int_{t_{on}}^{T=t_{on}+t_{off}}\frac{V_L}{L}dt=\frac{(-V_0)}{L}t_{off} \ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots\ldots\ldots(3.5)$$

$$t_{off}=(1-D)T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(3.6)$$

If we assume that the converter operates in the steady state, the energy stored in each component at the end of a commutation cycle T is equal to that at the beginning of the cycle. That means that the current IL is the same at t = 0 and at t = T [8-10]. So we can write from the above equations:
As can be seen in figure t_{on} = DT and t_{off} = (1-D) T,

$$\frac{(V_i - V_0)}{L} t_{on} - \frac{(-V_0)}{L} t_{off} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.7)$$

This yields

$$(V_i - V_0)DT - V_0(1-D)T = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.8)$$

$$V_0 - DV_i = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3.9)$$

$$D = \frac{V_0}{V_i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(3.10)$$

From this equation, it cam wood a chance to be seen that those yield voltage of the converter varies linearly for those obligation cycle for An provided for information voltage. Likewise those obligation cycle d will be equivalent to the proportion between tonal and the time T, it can't make more than 1. Therefore, V0 ≤ Vi. This is the reason this converter will be alluded will concerning illustration venture-down converter.

3.1.2Boost converter:

A support converter (step-up converter) is a DC-to-DC energy converter steps dependent upon voltage (while going down current) from its information (supply) will its yield (load). It will be An class of switched-mode control supply (SMPS) holding in any event two semiconductors (a diode and a transistor) What's more no less than you quit offering on that one vitality stockpiling element, a capacitor, inductor, alternately the two over mix. To decrease voltage ripple, filters constructed for capacitors (sometimes clinched alongside blending with inductors) would regularly included on such a converter's yield (load-side filter) Also enter (supply-side filter) [3. 1]. Operating in this mode. The yield voltage camwood make computed Similarly as follows, on account from claiming a perfect gas converter (i. E. Utilizing parts for a perfect gas behavior) working to unfaltering states.

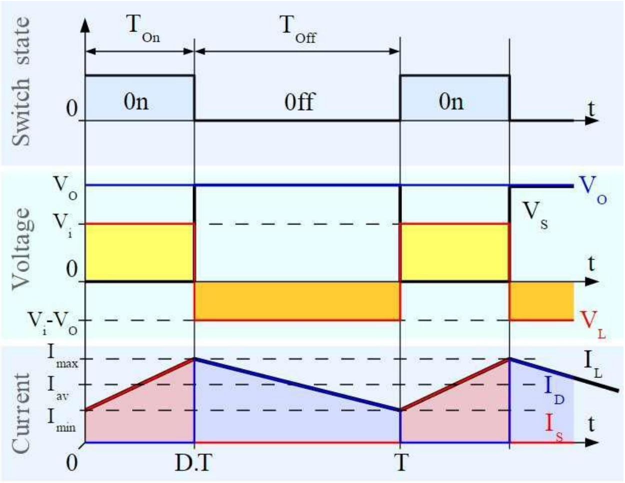

Figure 3-1 Voltage & current of Boost converter continuous conduction mode

In On-state, the switch S is closed, which appear across the inductor to makes the input voltage (Vi) r, which causes a change in current (IL) flowing through the inductor during a time period
(T) by the formula:

$$\frac{\Delta I_L}{\Delta t} = \frac{V_1}{L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3.11)$$

$$\Delta I_{Lon} = \int_0^{DT} \frac{V_i}{L} dt = \frac{DT}{L} V_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.12)$$

D is the duty cycle. It represents the fraction of the commutation period T during which the switch is on. Therefore, D ranges between 0 (S is never on) and 1 (S is always on).
During the Off-state, the switch S is open, so the inductor current flows through the load. If we consider diodehave zero voltage drop , and a capacitor large enough for its voltage to remain constant, the evolution of IL is

$$(V_i - V_0) = L\frac{dI_L}{dt} \quad \ldots\ldots(3.13)$$

$$\Delta I_{Loff} = \int_{DT}^{T}\frac{(V_i - V_0)}{L}dt = \frac{(V_i - V_0)(1-D)T}{L} \quad \ldots\ldots(3.14)$$

Therefore, the variation of IL during the Off-period is:
Similarly as we Think as of that the converter works Previously, steady-state conditions, the measure about vitality put away done every about its parts need with make those same during those starting What's more at the limit of a substitution cycle. In particular, those vitality put away in the inductor is provided for by:.

$$E = \frac{1}{2}LI_L^{\;2} \quad \ldots\ldots(3.1)$$

So, the inductor current has to be the same at the start and end of the commutation cycle. This means the overall change in the current (the sum of the changes) is zero:

$$\Delta I_{Lon} + \Delta I_{Loff} = 0 \quad \ldots\ldots(3.16)$$

Substituting the values by their expressions yields:

$$\Delta I_{Lon} + \Delta I_{Loff} = \frac{V_i DT}{L} + \frac{(V_i - V_0)(1-D)T}{L} = 0 \quad \ldots\ldots(3.17)$$

This can be written as:

$$\frac{V_0}{V_i} = \frac{V_i}{1-D} \quad \ldots\ldots(3.18)$$

Those over comparison reveals to that the yield voltage is dependably higher over those enter voltage (as the obligation cycle dives from 0 should 1), What's more that it builds for D, hypothetically with boundlessness Similarly as d methodologies 1. This will be the reason this converter may be now and then alluded on as An venture-up converter. Rearranging those comparison uncovers the obligation cycle will be.

$$D = 1 - \frac{V_i}{V_0} \quad \ldots\ldots(3.19)$$

3.1.3 Discontinuous mode

The inductor may be completely discharged before the end of a whole commutation cycle. If the ripple amplitude of the current is too high This commonly occurs under light loads. In this case, the current through the inductor falls to zero during part of the period (see waveforms in figure 3-3)

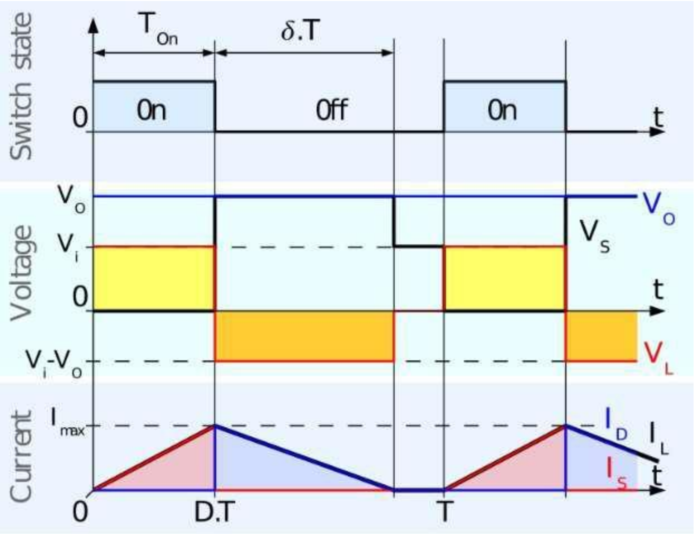

Figure 3-2 Voltage & current of Boost converter discontinuous conduction mode

Although slight, the difference has a strong effect on the output voltage equation. It can be calculated as follows. As the inductor current at the beginning of the cycle is zero, its maximum value ILmax (at t = DT) is

$$I_{L \max} = \frac{V_i DT}{L} \qquad \text{……(3.20)}$$

During the off-period, IL falls to zero after δT:

$$I_{L \max} + \frac{(V_i - V_0)\delta T}{L} = 0 \qquad \text{……(3.21)}$$

Using the two previous equations, δ is:

$$\delta = \frac{(V_i}{(V_i - V_0)} D \qquad \text{……(3.22)}$$

The average diode current (I_D) is equal to the load current Io. As can be seen in the figure, the diode current is equal to the inductor current during the off-state. Therefore, the output current can be written as [12]:

$$I_0 = I_D = \frac{I_{L \max}}{2}\delta \qquad \text{……(3.23)}$$

Replacing $I_{L\max}$ and δ by their respective expressions yields:

$$I_0 = \frac{V_i DT}{2L}\frac{V_i D}{(V_0 - V_i)} = \frac{V^2{}_i D^2 T}{2L(V_0 - V_i)} \qquad \text{……(3.24)}$$

Therefore, the output voltage gain can be written as follows:

$$\frac{V_0}{V_i} = 1 + \frac{V_i}{2LI_0} D^2 T \qquad \text{……(3.25)}$$

Contrasted with that statement of the yield voltage get to constant mode, this statement is a great deal more confounded. Furthermore, On spasmodic operation, those yield voltage addition not just relies on the obligation cycle (D), as well as on the inductor worth (L), those enter voltage (Vi),. That substitution period (T) and the yield present (Io) [12].

3.2 Modelling:

Equations used in the Modelling are following:

$$I_L = \left(\frac{(V_i D - V_0 D + V_0)}{sL}\right) \qquad \text{……(3.26)}$$

$$V_0 = \frac{1}{s}\left[\left(\frac{(V_i D - V_0 D + V_0)}{sL}\right)\left(\frac{1}{C}(D-1)\right) + \frac{V_0}{RC}\right] \qquad \text{……(3.27)}$$

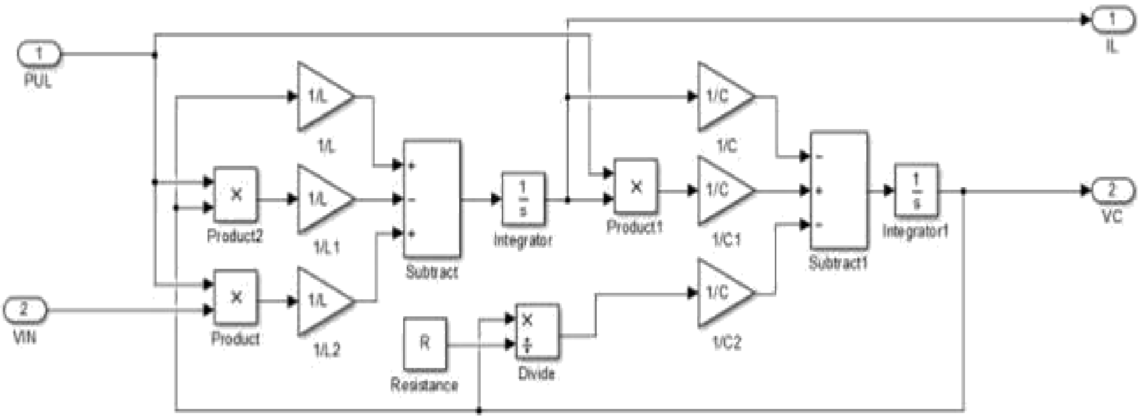

Fig 3-3 shows the modelling of buck – boost converter

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CONCLUSION

That response of conventional PID controller & Fractional PID controller looks almost same but at the same time we find that Fractional PID controller has better transient response than conventional classical PID controller. From Fractional PID control has same rising characteristic as conventional classical PID controller. So it is not giving even sluggish response

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