

# Modeling and Control of Power Converters and Drives

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*Editor*

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# 3

## **DYNAMIC EVOLUTION CONTROL FOR STEP DOWN DC-DC CONVERTER**

Ahmad Saudi Samosir  
Abdul Halim Mohd Yatim

### **3.1 INTRODUCTION**

In recent years, the application of power electronics converter has grown extremely. Some applications that are increasingly being dominated by power electronics are: 1) switched-mode power supplies; 2) adjustable speed motor drives; 3) efficient control of heating and lighting; 4) efficient interface for photovoltaic; 5) fuel cell and high voltage dc system for efficient transmission of power, etc.

Much power electronic application operated with parameter variation, non linearity, load disturbance, etc. Therefore, there is an increasing need for a good controller design to perform tight regulation under high unpredictable load variation. In designing of classical control theory, e.g. PID controller, small signal linear approximations have been applied to the nonlinear system. This approach enables the designer to use a simple linear controller to keep the system stable. But the main disadvantage using this type of control is that it is applicable for operation only near a specified operating point.

Since power converters are non-linear time-varying systems, the design of controllers must have capability to cover up the nonlinearity and time-varying properties of the system.

In this paper, a new approach for converter controllers synthesis based on Dynamic Evolution Control theory is presented. The Dynamic Evolution Control exploits the non-linearity and time-varying properties of the system to make superior controller. The Dynamic Evolution Control tries to overcome the mentioned problem of linear control by explicitly using dynamic equation model of the converter for control synthesis. The Dynamic Evolution Control has several advantages, i.e. wide range stability, zero steady state error, simple synthesis process and suitable for digital control implementation, because it requires a quite low bandwidth for the controller, because it requires simple calculations, which can be realized digitally easily. Moreover, The Dynamic Evolution Control is operated at constant switching frequency, so that it causes less power filtering problems in power electronics applications.

### 3.2 DYNAMIC EVOLUTION CONTROL THEORY

The objective of the Dynamic Evolution controller is to control the dynamic characteristic of the system to operate on the target equation,  $Y = 0$ . In Dynamic Evolution controller, the dynamic characteristic of converter system is forced to make evolution by following an evolution guideline. The selected evolution guideline is an exponential function as shown in Fig. 1. The equation of this exponential function can be written as:

$$Y = Ce^{-mt} \quad (1)$$

Where  $C$  is the initial value of  $Y$ , and  $m$  is proportional to the initial decrease rate of  $Y$ .

In this exponential function, the value of  $Y$  is decrease

exponentially to zero as a function of time. The decrease speed of  $Y$  is proportional to the decrease rate  $m$ .

Let  $Y$  represent the state error function of the converter. Then, the state error function( $Y$ ) is forced to follow the evolution guideline as show in fig.1, so the dynamic evolution of the state error function ( $Y$ ), with initial value  $Y_0$ , will fixed according to the equation (2).

$$Y = Y_0.e^{-mt} \quad (2)$$

It means that the state error function ( $Y$ ) is driven decrease to zero exponentially with decrease rate  $m$ .

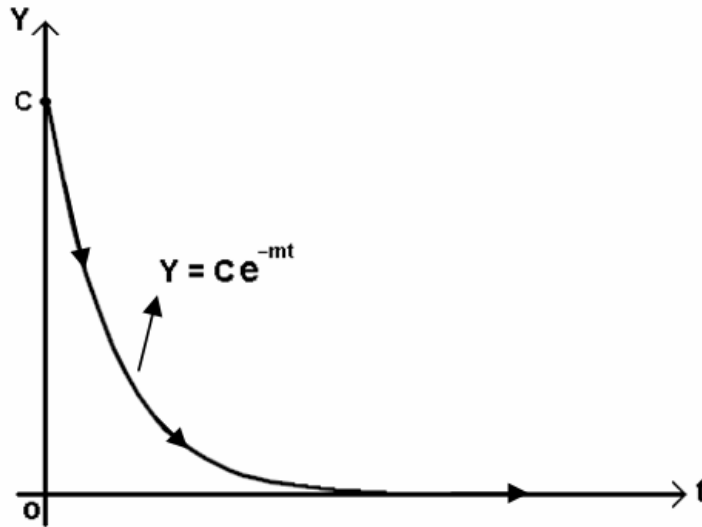


Fig. 1. Dynamic Evolution Guideline

Since,  $Y$  is the state error function of converter as describe in equation (2), therefore, the derivative of  $Y$  is given as:

$$\frac{dY}{dt} = -m.Y_0.e^{-mt}$$

$$\frac{dY}{dt} = -m.Y$$

As a result, the Dynamic Evolution Function can be written as equation (3).

$$\frac{dY}{dt} + m.Y = 0; \quad m > 0 \quad (3)$$

Where,  $m$  is a design parameter specifying the rate of evolution.

In order to synthesize the control law, the dynamic equation of the converter system is analyzed and substituted into the Dynamic Evolution Function (3) to generate the control law of controller, which ensure the state error function ( $Y$ ) of converter decrease to zero follow the evolution guideline.

The obtained results work on the full non-linear system. Hence, the designer does not need to make any simplification in the modeling process to obtain a linear model as in classical control theory.

### **3.3 SYNTHESIS OF SEP DOWN DC-DC CONVERTER CONTROLLER**

The Buck or step-down converter is one of the most common topologies. It is used extensively in high efficiency power supplies. The Buck Converter scheme is shown as Fig. 2. As already mentioned, to synthesize the control law of the Dynamic Evolution Controller, the dynamic equation of the converter system must be analyzed and substituted into the Dynamic Evolution Function (3). In this time, we use the average model of Buck Converter. The

dynamic equation is obtained as follows:

$$Vg.\alpha = L\frac{di_L}{dt} + V_o; \quad 0 < \alpha < 1 \quad (4)$$

Where  $V_g$  is input voltage,  $i_L$  is the inductor current,  $V_o$  is output voltage,  $\alpha$  is the duty cycle and  $L$  is inductor inductance.

From (4), output voltage of converter can be written as:

$$V_o = Vg.\alpha - L\frac{di_L}{dt} \quad (5)$$

The main part of the synthesis mission is to obtain the control law  $\alpha(i_L, V_o)$  as a function of the state  $i_L$  and  $V_o$  which give the required values of converter output voltage for various operating modes. In addition, the constraint of duty cycle (4) must be satisfied in synthesis process.

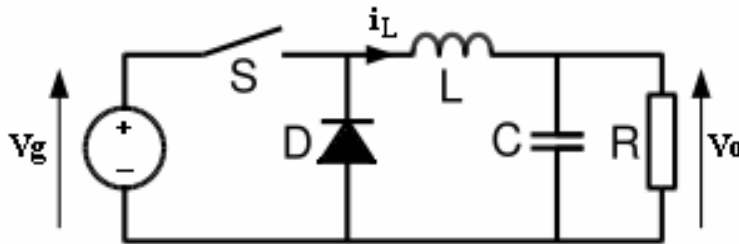


Fig. 2. Step down DC-DC Converter scheme

The Dynamic Evolution synthesis of the controller begins by defining the state error function ( $Y$ ) as follows

$$Y = k.V_{err} \quad (6)$$

Where  $k$  is a positive coefficient and  $V_{err}$  is error voltage



**$(V_{err} = V_{ref} - V_o)$ .**

The derivative of Y is given by:

$$\frac{dY}{dt} = k \frac{dV_{err}}{dt} \quad (7)$$

Upon substitution of Y (6) and the derivative of Y (7) into the Dynamic Evolution Function (3), yields

$$k \frac{dV_{err}}{dt} + m.k.V_{err} = 0$$

$$k \frac{dV_{err}}{dt} + (m.k - 1)V_{err} + V_{ref} = V_o \quad (8)$$

Directly substituting the converter voltage output  $V_o$  from (4) into (8) we can get:

$$k \frac{dV_{err}}{dt} + (m.k - 1)V_{err} + V_{ref} = V_g.\alpha - L \frac{di_L}{dt} \quad (9)$$

Solving for duty cycle  $\alpha$ , the control law is obtained which is given by:

$$\alpha = \frac{k \frac{dV_{err}}{dt} + (m.k - 1)V_{err} + L \frac{di_L}{dt} + V_{ref}}{V_g} \quad (10)$$

The expression for duty cycle  $\alpha$  is the control action for the converter controller.

Control law (9) forces the state error function (Y) to satisfy equation (6). According to this equation, the state error function (Y) forced to make evolution follow equation (2) and decrease to zero ( $Y = 0$ ) with a decrease rate  $m$ . so, the state error function (Y) satisfy the equation

$$Y = k.Verr = 0$$

Consequently state error of the converter will converges to zero.

$$Verr = 0 \quad (11)$$

Substituting  $Verr = Vref - Vo$  into (11), we can see that the voltage output of converter converges to the converters steady state:

$$Vo = Vref \quad (12)$$

From the synthesis procedure, it is clear that the Dynamic Evolution Controller works on the full nonlinear system and does not need any linearization or simplification on the system model at all as is necessary for application of traditional control theory.

Rearranging the control law equation (10), the control law can be written by:

$$\alpha = \frac{Vref}{Vg} + \frac{(m.k-1)Verr}{Vg} + \frac{k \frac{dVerr}{dt}}{Vg} + \frac{L \frac{diL}{dt}}{Vg} \quad (13)$$

It is interesting to note that the control law in (13) consists of four distinct parts. The first part is the feedforward term,  $V_o/V_g$ , which is calculated based on the duty cycle at the previous sampling instant. This term compensates for variations in the input and output voltages. The second and third terms consist of proportional and derivative terms of the perturbations in the output voltage respectively. The last term consists of the derivative terms of the inductor current.

From (13), it is also seen that the input voltage, output voltage and inductor current are involved in control output. It makes the Dynamic Evolution Control can compensate all of variation in the input and output voltages also the change of inductor current. The advantage is that it contributes better dynamic performance to the controlled system.

The Dynamic Evolution Control law theoretically not requires precise knowledge of the model parameters. The parameter which required is only inductor inductance. This requirement places a small limitation on the control system for two reasons: sometimes it is not easy to identify the parameters; sometimes the system parameters change with time. But, as will be demonstrated later, this problem can be solved.

### **3.4 SYSTEM SIMULATION AND VERIFICATION**

A comprehensive simulation analysis was conducted to verify the controller performance. The performance of Dynamic Evolution control law under step load variation condition is tested through simulation by using MATLAB SIMULINK. The step-down converter scheme and the Dynamic Evolution control law, which is described by (10), are modelled in Simulink as shown in Fig. 3. The model parameters are listed in Table I. The control goal is to regulate output voltage  $V_o = 12V$ . The reference of the output voltage is specified based on the desired output voltage, which means that  $V_{ref} = 12V$ . These reference values are not

varied during the operation. The selected parameters of the controller are  $k = 0.1$  and  $m = 6000$ .

Here the situation where the load changes suddenly from one value of resistance to another is considered. This is particularly interesting because it is a typical problem for power electronics, where the power supply is supposed to compensate quickly for the load variation.

At 50 ms, the load changes from nominal  $5\Omega$  to  $2.5\Omega$ , and change from  $2.5\Omega$  to  $5\Omega$  at 110ms. The simulation waveform of output voltage and inductor current are shown in Fig. 4. When a step load variation occurs, the resistance of the load changes suddenly, it is shown that the output voltage is not disturbed by the step load variation. The controllers accomplish to regulate the converter output voltage keep on steady-state at 12V reference. This condition indicates that the state error of the converter goes converge to zero and there is no steady-state error in the output voltage.

TABLE I  
SIMULATION MODEL PARAMETERS

Parameter	Value
Nominal Input Voltage	20V
Reference Voltage	12V
Inductance L	500uH
Capacitance C	200uF
Initial Load	5 $\Omega$
Addition Load	5 $\Omega$

The simulation result of converter output voltage for variation of  $m$  is shown in figure 5. From this picture we can see that the

converter output voltage when  $m=6000$  is better than the other, and trajectory of dynamic evolution control is depicted in figure 6.

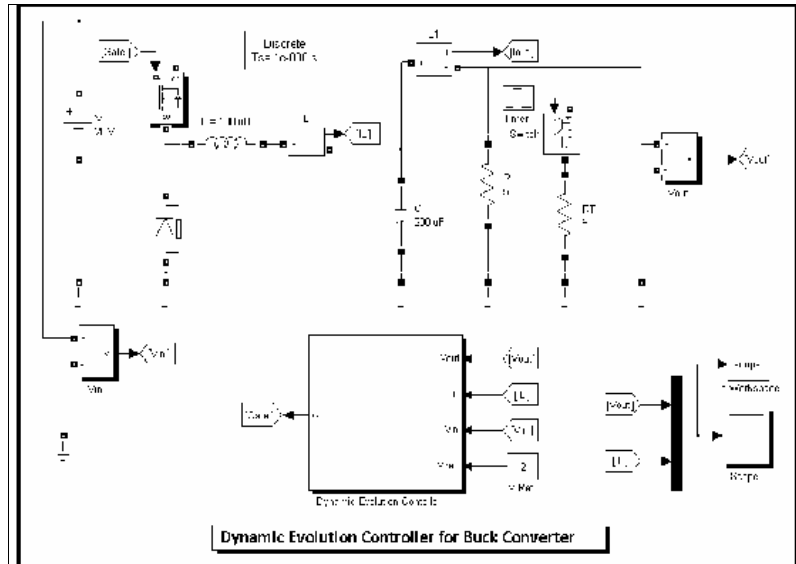


Fig 3. Buck Converter Simulation Model

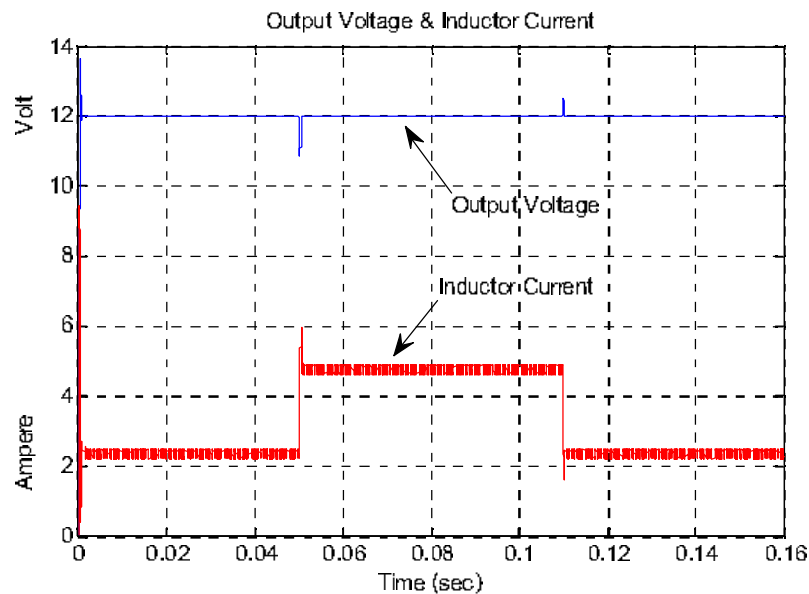


Fig 4. Simulation result of  $V_o$  and  $I_L$  under Load change condition

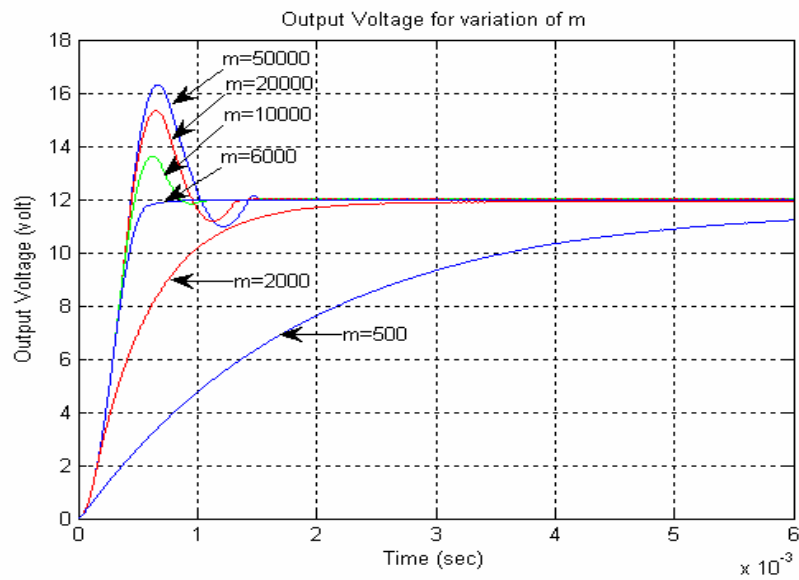


Fig 5. Output Voltage for variation of  $m$ , with  $k = 0.1$ .

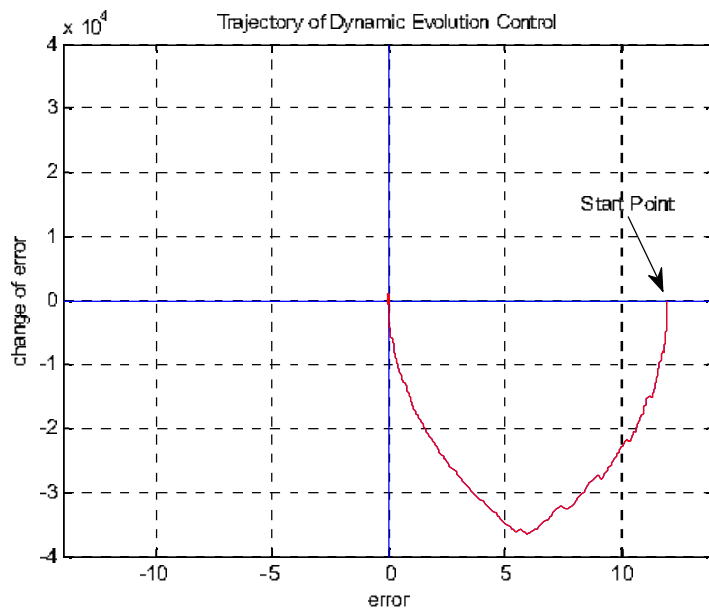


Fig 6. Trajectory of Dynamic Evolution Control



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