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A NEW CONTROL METHOD FOR POWER INVERTER BASED ON DYNAMIC EVOLUTION CONTROL

Ahmad Saudi Samosir
Department of Electrical Engineering, University of Lampung, Bandar Lampung, Indonesia
E-Mail: ahmad.saudi@eng.unila.ac.id

ABSTRACT

This paper proposes a new control method for Power Inverter. The analysis and design of the proposed control technique are provided. A new approach for power inverter controller synthesis based on dynamic evolution control theory is presented. In order to synthesize the controller formulation, the dynamic evolution control employs a simple analysis of nonlinear equation models of the inverter. The performance of the proposed controller is verified through MATLAB-Simulink. To validate the simulation results, an experimental prototype of power inverter is developed.

Keywords: dynamic evolution control, new control method, nonlinear control, inverter control, power inverter.

INTRODUCTION

According to the growth of power electronic application, the use of the power inverter is increased. Power Inverter is the most important part in dc to ac conversion equipment such as the uninterruptible power supply (UPS), induction motor drive and induction heating. The main feature of a well-designed inverter is its ability to provide clean and stable ac voltage regardless of a type of load connected to it. It must also have the ability to recover from transients caused by external disturbances as quickly as possible.

During the past several years, various instantaneous feedback controls on a linear model have been proposed [1-4]. In terms of converter controller design, the use of averaging or sampling techniques, followed by linearization and small-signal analysis allows the derivation of linear time-invariant dynamic models for any converter topology. This approach enables the designer to use a simple linear controller to keep the system stable. However, these are normally dependent on the converter's operating point [5-8].

In few decades, many controller techniques have been proposed for power inverter applications. Since power inverter operated with parameter variation, non-linearity, load disturbance, etc. Therefore, the good controller design to perform tight regulation under large unpredictable load variation is needed.

In this paper, a new approach for power inverter controller's synthesis based on dynamic evolution control theory is presented. The proposed dynamic evolution control exploits the non-linearity and time-varying properties of the system to make it a superior controller. This control method tries to overcome the mentioned problem of linear control by explicitly using the dynamic equation model of the inverter for control synthesis.

The dynamic evolution control is expected to obtain several advantages such as zero steady state error, wide range stability, and robust. The synthesis process is simple and requires a quite low bandwidth, simple calculation, and it is easy to be realized in digital. So, this method is suitable for digital control implementation. Moreover, the dynamic evolution control is operated at constant switching frequency. Therefore, the complexity of power filtering problems is reduced.

DYNAMIC EVOLUTION CONTROL

The dynamic evolution control has been utilized in reference [5] and [9-11]. The basic idea of the dynamic evolution control is to reduce the error state by forcing the error state to follow the specific path, that ensure the error state goes to zero in increase of time. This specific path is named Dynamic Evolution Path. By using dynamic evolution control, the dynamic characteristic of system is forced to make evolution by following an evolution path. With the selected evolution path is an exponential function as shown in Fig. 1, the value of the dynamic characteristic of system will decrease exponentially to zero by equation

$$Y = Y_O . e^{-mt} \qquad (1)$$

where, Y is the dynamic characteristic of system, Y_O is the initial value of Y, and m is a design parameter specifying the rate of evolution.

Hence, the dynamic evolution function of this controller can be written as

$$\frac{dY}{dt} + mY = 0, \qquad m > 0 \qquad (2)$$

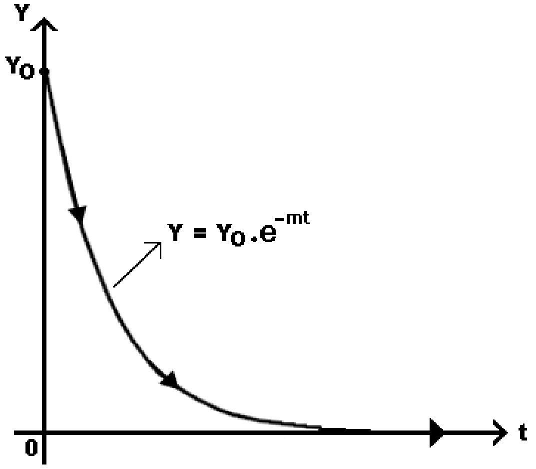

Figure-1. Dynamic evolution path.

In order to obtain the control law that guarantees the dynamic characteristic of system decreased to zero by following the evolution path, the synthesis process is done. In dc-dc power converter, this control law corresponds to the duty cycle equation of the converter. This duty cycle equation $\alpha(v_O, V_{dc}, i_L)$, represents α as a function of the state v_O, V_{dc} and i_L. The duty cycle equation $\alpha(v_O,V_{dc},i_L)$ is obtained by analyzed and substituted the dynamic equation of the converter system into the dynamic evolution function (2).

MODEL OF POWER INVERTER

Power inverter is used to convert a DC voltage source to an AC output voltage. In this paper, a single phase power inverter will be controlled by using the proposed control method to produce a sinusoidal output voltage. Single phase power inverter scheme is depicted as Figure-2.

The operation condition of power inverter can be divided to two conditions as follows:

First: When S1, S2 on and S3, S4 off. The voltage equation of inverter can write written as:

$$V_{dc} = L\frac{di_L}{dt} + V_O \tag{3}$$

Second: When S3, S4 on and S1, S2 off. The voltage equation of inverter can write written as:

$$-V_{dc} = L\frac{di_L}{dt} + V_O \tag{4}$$

Let say the duration time of first condition is t_{ON} and duration time of second condition is t_{OFF}. Thus, the volt-time equations on the first and second condition are

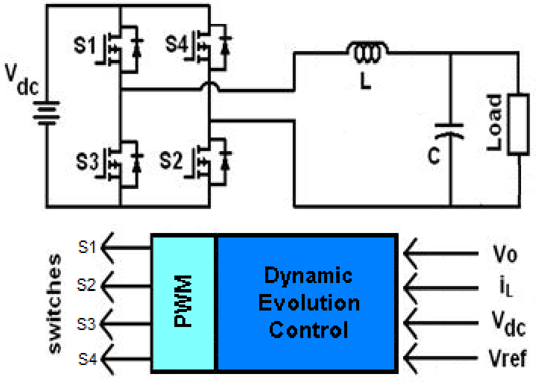

Figure-2. Single phase power inverter scheme.

$$V_{dc} \cdot t_{ON} = (L\frac{di_L}{dt} + V_O) \cdot t_{ON} \tag{5}$$

$$-V_{dc} \cdot t_{OFF} = (L\frac{di_L}{dt} + V_O) \cdot t_{OFF} \tag{6}$$

By summing (6) and (7), and divided the result with the switching period, thus the dynamic equation of single phase inverter is obtained as follows:

$$V_{dc} \cdot (2\alpha - 1) = L\frac{di_L}{dt} + V_O; \qquad 0<\alpha<1 \tag{7}$$

Where V_{dc} is the dc input voltage, $\alpha = t_{ON}/T$ is duty cycle, i_L is inductor current, V_O is output voltage, L is inductor inductance and#T is switching period.

Rearranging (8), the output voltage of inverter can be written as:

$$V_O = V_{dc}(2\alpha - 1) - L\frac{di_L}{dt} \tag{8}$$

SYNTHESIS OF POWER INVERTER CONTROLLER

The dynamic evolution synthesis of the controller begins by defining the state error function (*Y*) as follows

$$Y = k.V_{err} \tag{9}$$

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:

$$\frac{dY}{dt} = k.\frac{dV_{err}}{dt} \tag{10}$$

Substitution (9) and (10) into (2), yields

$$k.\frac{dV_{err}}{dt} + m.k.V_{err} = 0 \tag{11}$$

$$k.\frac{dV_{err}}{dt} + (m.k-1)V_{err} + V_{ref} = V_O \tag{12}$$

Directly substituting the converter voltage output V_O from (8) into (12) we can get:

$$k.\frac{dV_{err}}{dt} + (m.k-1)V_{err} + V_{ref} = V_{dc}(2\alpha - 1) - L\frac{di_L}{dt} \tag{13}$$

Solving for α, the obtained duty cycle is given by:

$$\alpha = \frac{k.\frac{dV_{err}}{dt} + (m.k-1)V_{err} + L\frac{di_L}{dt} + V_{ref} + V_{dc}}{2.V_{dc}} \tag{14}$$

The expression for duty cycle α is the control action for the converter controller.

Duty cycle (14) forces the state error function (Y) to satisfy the dynamic evolution function (2). Consequently, the state error function (Y) is forced to make evolution by following (1) and decrease to zero (Y = 0) with a decrease rate m. so, the state error function (Y) satisfy the equation

$$Y = k.V_{err} = 0$$

Thus the state error of the converter will converge to zero.

$$V_{err} = 0 \tag{15}$$

Substituting $V_{err} = V_{ref} - V_O$ into (15), we can see that the voltage output of converter converges to the converters steady state:

$$V_O = V_{ref} \tag{16}$$

Rearranging the control law equation (14), the control law can be written as:

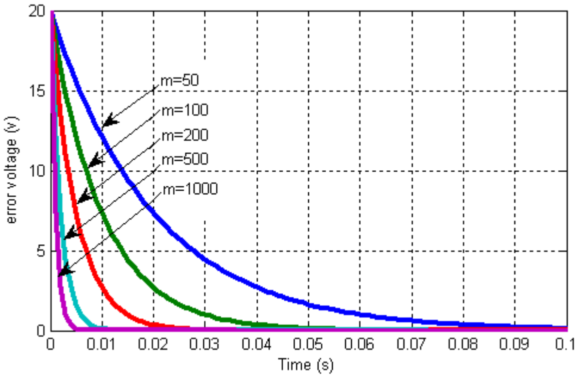

Figure-3. Error converging speed with different m value.

$$\alpha = \frac{V_{ref} + V_{dc}}{2.V_{dc}} + \frac{(m.k-1)V_{err}}{2.V_{dc}} + \frac{k\frac{dV_{err}}{dt}}{2.V_{dc}} + \frac{L\frac{di_L}{dt}}{2.V_{dc}} \tag{17}$$

It is interesting to note that the control law in (17) consists of four distinct parts. The first part is the feed-forward term, $(V_{ref} + V_{dc})/2V_{dc}$, which is calculated based on the duty cycle at the previous sampling instant. This term compensates for variations in the input voltages.

The second and third terms consist of proportional and derivative terms of the perturbations in the output voltage respectively. But the important things that make this controller action is better than the conventional one are the gain value of proportional and derivative terms are not constant. These gains are varying with the output voltage value. The last term consists of the derivative terms of the inductor current. The gain of this term is also varying with the output voltage value.

The last term consists of the derivative terms of the inductor current.

From (17), it is seen that the input voltage, output voltage and inductor current are involved in control output. The advantage is the dynamic evolution control can compensate all of variation in the input and output voltages also the change of inductor current. It contributes to the better dynamic performance of the controlled system.

In addition the controller also has a good response in terms of error converging speed. Duty cycle equation (14) forcing the state error function Y to make evolution by following equation (1) and decrease to zero with a decrease rate m. This means that the larger m

will cause the error decreases faster. Error converging speed with different m values is depicted as in Figure-4.

SIMULATION RESULTS

The performance of the proposed dynamic evolution control was simulated in MATLAB SIMULINK. The single phase power inverter scheme and the dynamic evolution control equation, which is described by (14), are modeled in Simulink as shown in Figure-4. The model parameters are listed in Table-1. The control goal is to produce 120V, 50 Hz sinusoidal output voltage. The reference of the output voltage is specified based on the desired output voltage, which means that

$$V_{ref} = 120\sqrt{2}\sin\omega t \qquad (18)$$

where $\omega = 100\pi$.

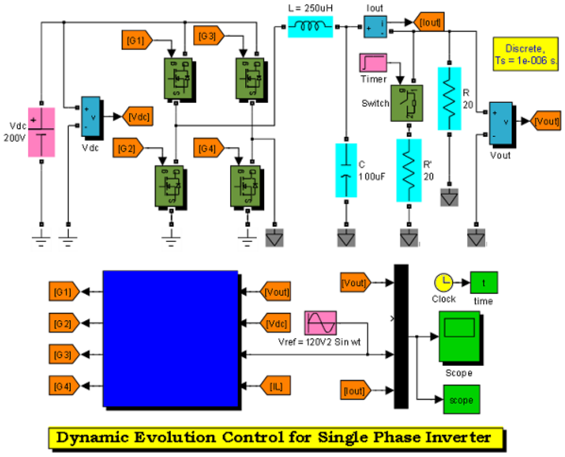

Figure-4. Single phase inverter simulation model.

A. Steady-state performance

Figures 5 and 6 show the result for steady-state performance of the proposed dynamic evolution control for no-load and full-load condition. The results give a satisfactory performance which indicates that the proposed dynamic evolution control is capable to avoid voltage output level from dropping when a load is connected.

B. Small-load disturbance performance

To show the effectiveness of the proposed dynamic evolution control in handling small-signal disturbance, a sudden small load disturbance (from 20% to 50% load) is imposed to the system. Figure-7 shows the results for proposed controller performance. The controller accomplishes to maintain output voltage close to reference voltage.

C. Large-load disturbance performance

The superiority of the proposed controller can be judged by evaluating its performance under large signal disturbance. Figure-8 shows the performance of the proposed dynamic evolution control when a large load disturbance (from no-load to full load) is imposed. From the figures, it can be observed that the proposed controller exhibits good transient performance.

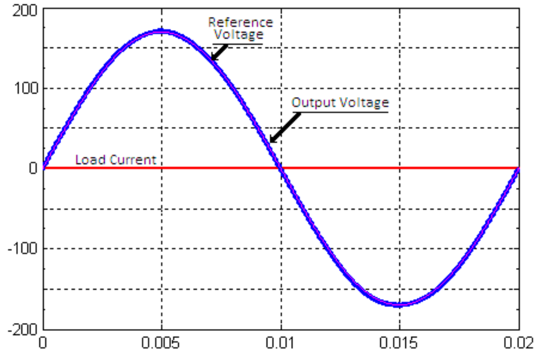

Figure-5. Steady-state performance in no-load condition.

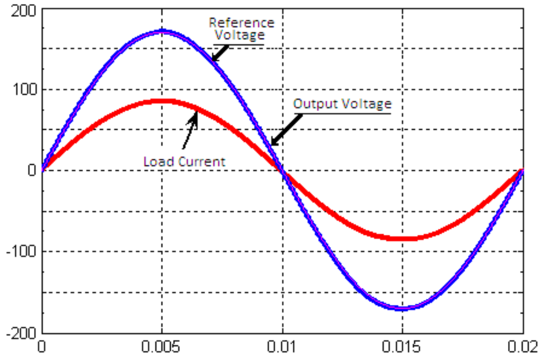

Figure-6. Steady-state performance in full-load condition.

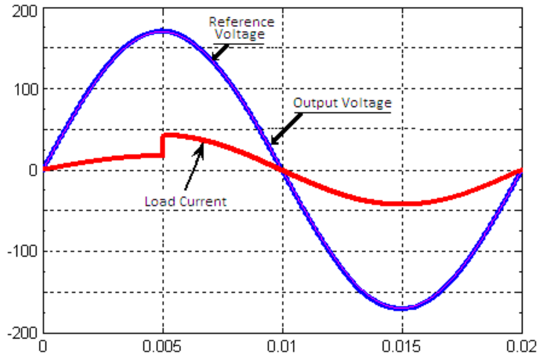

Figure-7. Performance of proposed controller when subjected to small load disturbance.

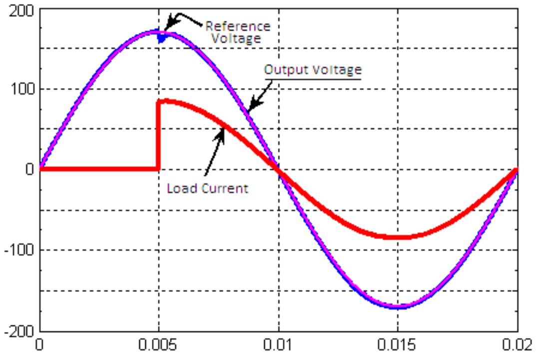

Figure-8. Performance of proposed controller when subjected to large load disturbance condition.

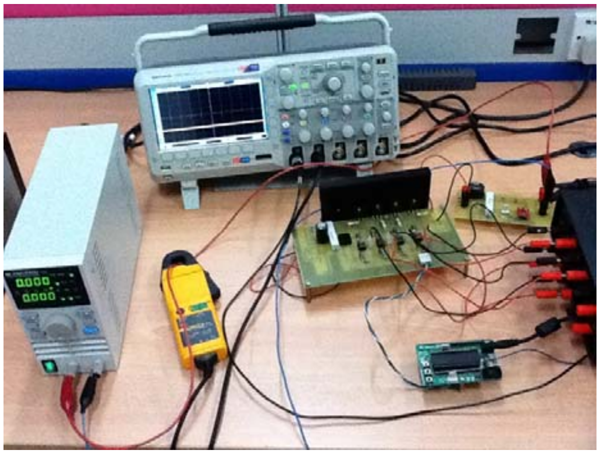

Figure-9. Hardware prototype of system.

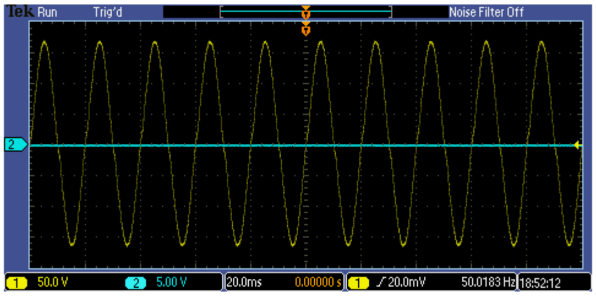

Figure-10. Output voltage and load current when no load condition.

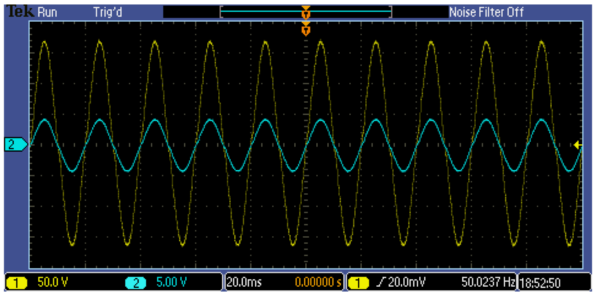

Figure-11. Output voltage and load current with 3A load condition.

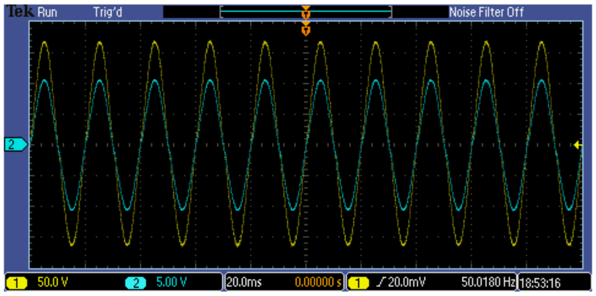

Figure-12. Output voltage and load current with 7.5A load condition.

The experiment results are shown in Figures 10, 11 and 12. Figure-10 presents the waveforms of the output voltage and load current when no load condition. While Figures 11 and 12 presents the waveforms of the output voltage and load current with 3A and 7.5A load condition.

CONCLUSIONS

This paper presents a dynamic evolution control for single phase power inverter. The performance of dynamic evolution control under small and large load disturbance condition has been investigated under simulation test. Simulation results show the dynamic evolution control shown many advantages such as fast response and good transient performance. Hardware results show the controller accomplishes to regulate the converter output voltage keep on steady-state at 120 V, 50 Hz reference.

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