Identification and Simulation of Dc-Dc Boost Converter for Charging Up PV Voltage for 24-Volts Battery

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This manuscript is a piece of report on the identification of a DC-DC Boost switched mode converter for charging up Photovoltaic (PV) voltage for 24-volts battery. A DC-DC Boost converter with unknown mathematical characteristic is identified using Auto-Regressive with Exogenous Input (ARX) model. The identification of such DC-DC converter, on the basis of recorded data from PV is conducted to obtain the mathematical model of the converter. The knowledge about the converter is then beneficial for the design process of a PV's maximum power point tracking (MPPT) system. The identification process that exploits the advantage of linear parametric ARX gives beneficial information such as correlation, best fit and poles-zeros location. The purpose of identification is to obtain the best model of the converter and hence, beneficial the simulation and controller design phase which include the MPPT.

Keywords: maximum power point tracker (MPPT), Boost converter, P&O alghorithm

1. Introduction

Photovoltaic (PV) generation offers many advantages in producing renewable source of energy as it incurring no fuel costs, not being polluting, requiring less maintenance and emitting no noise compared to its counterpart [1]. DC-DC Boost converter is used to magnify the voltage from PV to a suitable form of energy accepted by the load. Boost converter's brain will be the Maximum Power Point Tracker (MPPT) in which it tries to stabilize the voltage produced by the boost converter through its intelligently controlled algorithm. Boost converter is a second order system [2] consists of an inductor, a capacitor, a diode, and with the load resistance connected in parallel with the capacitor. The use of DC-DC boost converter in boosting up PV output voltage is essential for charging up 24-volts battery. As the output from PV is not constant due to the ambient temperature and environmental condition, the modelling of such converter is crucial to ensure regular charging up of the battery. This paper however, focuses on the modelling and identification of DC-DC boost converter based on the output voltage produced by the photovoltaic module. A DC-DC boost converter can be modelled based on the knowledge about PV voltage as well as a calculated duty cycle for MPPT.

MPPT systems are used mainly in systems where source of power is nonlinear such as the solar PV modules. In this work, MPPT integrated boost converter system is used in solar PV applications with a battery charger connected stand-alone PV system. The purpose of charging a battery (lead acid/NiCad) is nothing but for the storage of electrical energy. This energy if it comes from the solar PV systems then fast charging of the battery can be done with the help of the MPPT-boost converter charge controller. The good controller is expected to be designed. As such, the MPPT and boost converter need to be identified beforehand. Fig.1 shows the overall system configuration whereas Fig.2 indicates a typical PV circuit diagram. Note that in Fig.2, the current source proportional to the light falling on the cell in parallel with a diode D_0. I_{ph} is the temperature dependence of the photo-generated current. I_0 is the temperature dependence of the reverse saturation current of the diode D_0. A series resistance (R_s) gives a more accurate shape between the maximum power point and the open circuit voltage.

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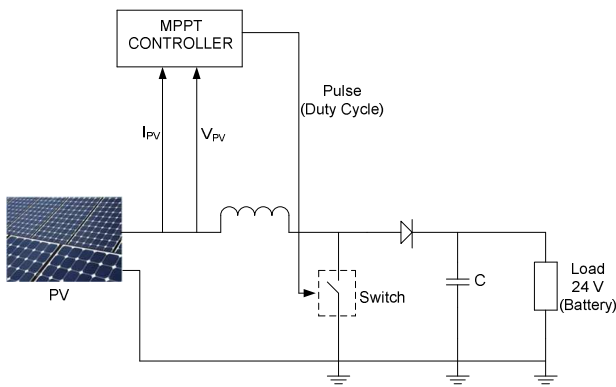Email: aziah@utem.edu.my

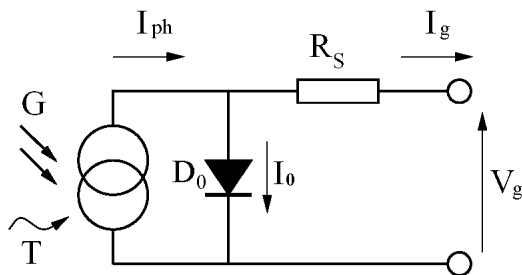Fig.1: MPPT controlled Boost converter.

Fig.2: The circuit diagram of the PV.

2. Modeling and Simulation

2.1 The Converter

DC-DC converters are dynamical systems with highly nonlinear behavior. The use of semiconductor devices as a switch makes the system non-linear. Moreover, the parasitic capacitances and inductances of the switches produce nonlinear phenomena of the converter built up by these power electronic components. Another source of nonlinear phenomena comes from the control circuits comprise of comparators, PWM generators, phase-locked loops, timers and digital controllers [3]. In DC-DC converters, load fluctuation behaves as disturbances to the system. As such, the system is non-linear in nature and cannot be easily solved analytically using Laplace transform. Therefore, the utilization of power-ful computer aided design package is required. Simulink from Mathwork is known as one of the tool used for modeling and controller design [4]. Author in paper [5] exploit state-space averaging model of the converter while modeling and designing the converter. In this paper, a mathematical model of DC-DC converters is obtained by performing system identification process. System identification process offers less complex mathematical derivation and worthwhile for controller design phase. The general model identification process

is shown in Fig.3 [6]. Through system identification process, all important information such as best fit, residual analysis, correlation, and pole-zero location are obtained. As such, the mathematical model and esti-mated model of DC-DC converter is acquired. From the identification knowledge, a controller and estimator of such DC-DC converter is designed easily. As DC-DC converters suffer from chaotic behavior and bifurcation phenomena, the use of identification tool in MATLAB is beneficial. As paper [7] presents a study of the chaotic behavior of the buck converter by simulating the buck converter in PSCAD/EMTDC, this paper however use MATLAB due to pre-defined advantages such as easily to observe transient behavior and assessable user friend-ly built in tool in it. The aim of identification process is nothing but to obtain the mathematical representation of such converter and hence, good controller as well as good estimator is to be designed.
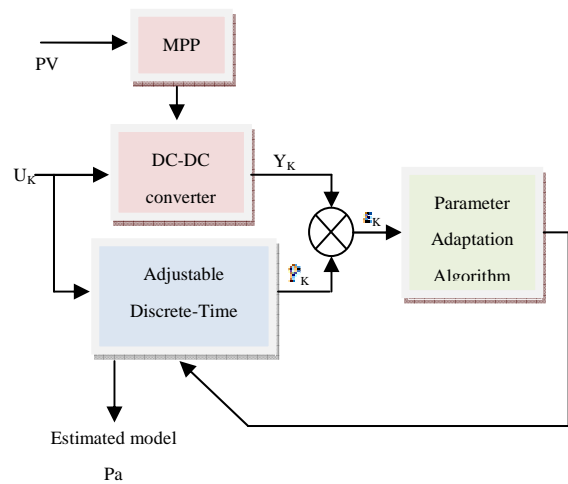

Fig.3: DC-DC converter identification process.

A few structures of parametric model such as ARX model, Auto-Regressive Moving Average with Exogen-ous Input (ARMAX) model, output-error (OE) model and Box-Jenkins (BJ) model can be used as MPPT integrated Boost converter model structure. ARX model serves the basic structure as this structure ignores the moving average or the error dynamics of the system. As such, ARX model is used and the general model with appearance of error dynamics e(k) is represented by the difference equation (1). Lowercase 'd' is time delay which represent the difference between u(k) and y(k). The general ARX model is shown in Fig.4.

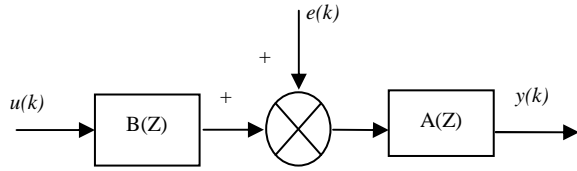$$A(Z^{-1})y(k) = B(Z^{-1})u(k-d) + e(k) \quad \cdots\cdots(1)$$

Fig.4: ARX Model Structure.

2.2 Identification Process

The experimental PV output voltage is shown in Fig.5. The PV module is tested and the outputs of voltage are taken starting from 9.00a.m until 6.00p.m for three days continuously. It was taken using 50W PV of Conergy Solar India.
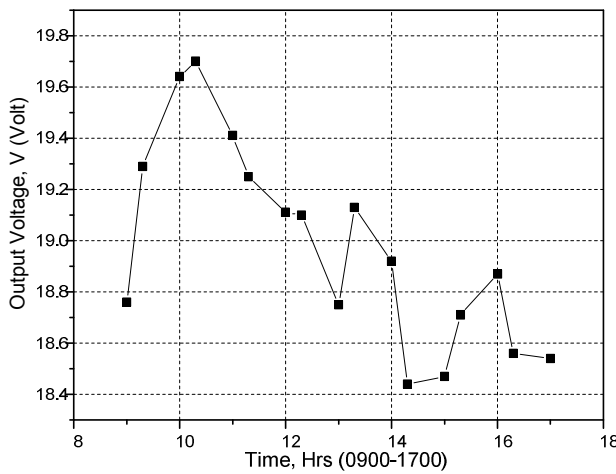

Fig.5: Recorded PV Voltage.

The PV produced nearly constant voltage with small fluctuation occurred. However, good parameters identification requires the usage of input signal that are rich in frequencies. As such, the sinusoidal signals with DC offset which shown in the equation (2) is introduced.

$$u(k) = V_{dc} + \sum_{i=1}^{p} a_i \cos \omega_i \, t_s k \cdots\cdots\cdots (2)$$

The Pseudo-Random Binary Sequences (PRBS) that generating the sequence of square pulses that modulated by different width can also be used. However, this method is bit difficult to be implemented as compared to the first one [6]. In equation (2), a_i is amplitude; ω_i is frequency and t_s for sampling time. Note that P is determined by the number of buck converter parameter, n that needs to be identified.

2.3 Dc-Dc Converter Model

The set of input-output data is evaluated and estimated by the identification tool of SIMULINK / MATLAB. The relationship of a measured and simulated input-output data is shown in Fig.6. The converter model output yields 82.89 best fit. Fig.7 shows the plot of frequency response for the identified converter system. By examining the plot, it is acceptable that the converter is the best model of the identification process, plus it is stable in nature. However, the plot shows that the stability need to be improved as the phase plot has not meet the required -180° when the magnitude plot intersect 0dB line. The previous Fig.4 depicts the structure of ARX model in which the identification process of converter system took place.

The identification tool in MATLAB generates discrete time polynomial shown in equation (3). As ARX model ignore error dynamic of the converter or plant, equation (4) can be simplified further. Equation (4) provides information on the mathematical model of the converter system in discrete time domain.

$$A(Z^{-1})y(k) = B(Z^{-1})u(k) + e(k) \quad \cdots\cdots\cdots\cdots (3)$$

$$\therefore A(Z^{-1}) = 1 - 1.651Z^{-1} - 0.6634Z^{-2}$$

$$\therefore B(Z^{-1}) = 0.012991Z^{-1} + 0.00773Z^{-2}$$

$$G(Z^{-1}) = \frac{B(Z^{-1})}{A(Z^{-1})}$$

$$G(Z^{-1}) = \frac{0.012991Z^{-1} + 0.00773Z^{-2}}{1 - 1.651Z^{-1} - 0.6634Z^{-2}}$$

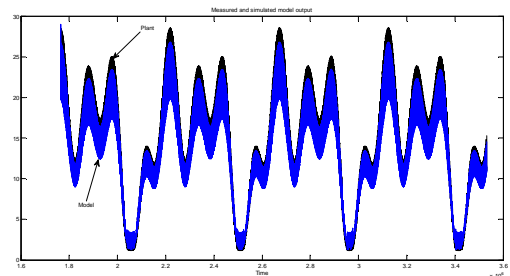$$G(Z) = \frac{0.012991Z + 0.00773}{Z^2 - 1.651Z - 0.6634} \quad \cdots\cdots\cdots (4)$$

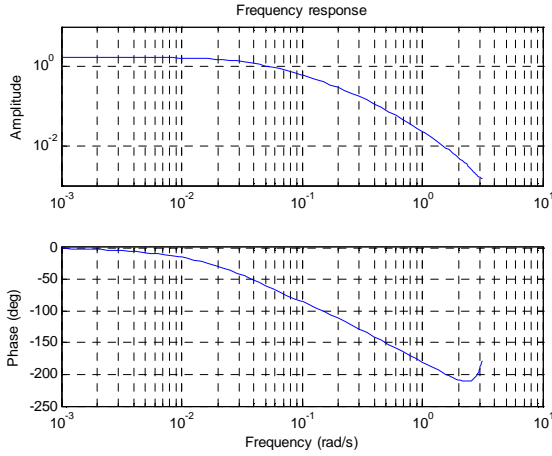Figure 6: Measured and simulated model output yields best fit of 86.93

Figure 7: Frequency response

3. Result and Discussion

3.1 MPPT Design and Controller Tuning

Upon completion of identification process, the controller can be designed easily. The amount of power generated by the PV is highly depends on the operating point of the PV array where the maximum power point (MPP) varies with solar insulation and temperature. For that reason, PV modules still have relatively low conversion efficiency. As such, controlling MPPT is a must in a PV system. As the PV operates at its highest efficiency at the MPP, many methods have been developed by several researchers to track MPP and hence design the MPPT. For instance; in paper [8], the authors utilize the look-up table on a microcomputer to track MPP. Whereas in paper [9], the authors apply a dynamic MPP tracker to PV supported appliances. Some researchers develop an intelligence control methods such as fuzzy logic [10, 11] and artificial neural network to track MPP as well as in MPPT design method. In most of the research, a question arises on how vary the duty cycle and in which direction so that peak power is reached. Researchers proposed an automatic tracking by exploiting various algorithm such as Perturb and Observe (P&O) [5, 12], Incremental Conductance [13, 14], Parasitic Capacitance [14], Voltage Based Peak Power Tracking [14] and Current Based peak power Tracking [14].

In this work, P&O method is used and being optimized with PID compensator. P&O MPPT algorithm is shown in Fig.8 [5]. The algorithm start by reading and processing the PV output voltage V(k) and current I(k). The generated power P(k) is then computed and processed further. PID is the best-known controller in industries. This scheme offers simple structure as well

as robust performance. In the design process, further increase of K_p will result in the closed loop system becoming unstable. Therefore, additional integral is to improve steady state accuracy without introducing instability. Integrator gives the system one pole at origin, hence reducing steady state error as a steady-state error of a system depends upon the number of poles at the origin of the closed loop characteristic function [15]. The tuning of PID parameters called K_p, K_i and K_d for the MPPT optimization are based on Open Loop Zigler-Nichols tuning algorithm. The dynamics of PID is tabulated in Table 1. The compensator is represented in equation (5). Fig.9 depicts the output of the DC-DC boost converter without MPPT attached to it. Whereas Fig.10 represents the output of the MPPT-plus-Compensator equipped DC-DC boost converter of the PV solar system for charging up a 24-Volts battery.
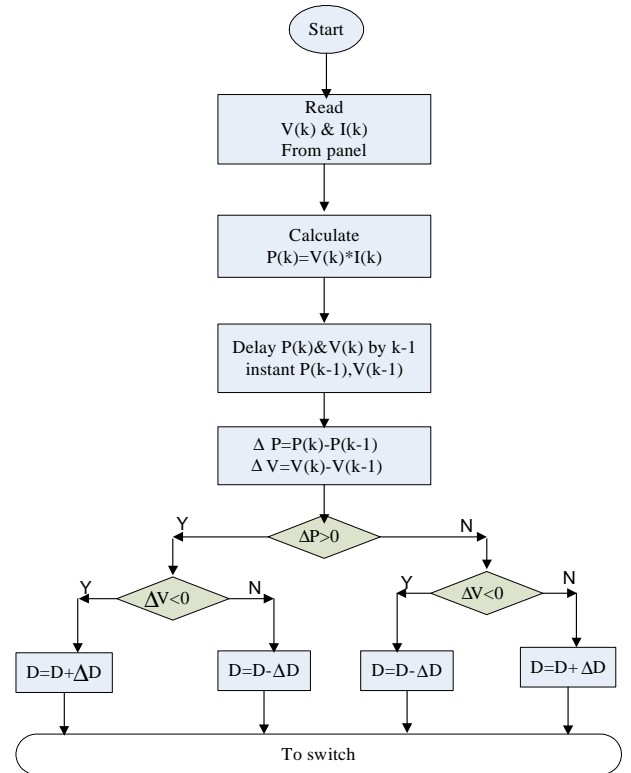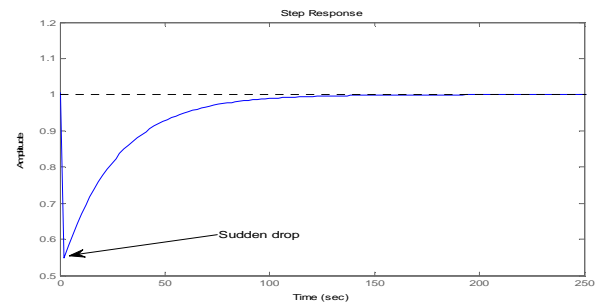

Fig.8: P&O MPPT algorithm.

Fig.9: Sudden drop in PV output without MPPT and Compensator.

Table 1: Dynamics of PID Compensator for MPPT

Type	Location	Damping	Frequency
Real Zero	-13.2	1	13.2
Real Zero	-0.0755	1	0.0755
Integrator	0	-1	0

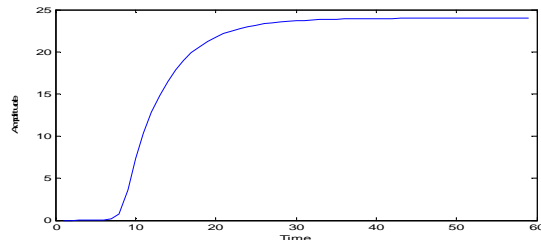$$C(S) = 5 \times \frac{(1 + 0.076S)(1 + 13S)}{S} \quad \cdots (5)$$

Fig.10: Final voltage output

4. Conclusion

The identification of Dc-Dc converter using P&O algorithm method and by optimization of PID compensator can be design using MATLAB simulation. This would give the output of converter model yields at 82.89 best fit. Besides, it is acceptable that the converter is the best model of the identification process, plus it is stable in nature.

Acknowledgment

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