Closed Loop Analysis of Cascaded Boost-Buck Converter for Renewable Energy Sources

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Abstract - *In this paper, a hybrid PV/wind system is designed for cascaded boost- buck operation. It also includes new perturbation-and-observation-based tracking system, which is developed through additional hardware such as a cascaded boost-buck DC-DC converter, an efficiency sensing system, and a controller. At a power level of 40 Watts, the overall efficiency from the power source to the final load is maintained. Through the tracking control, high overall system efficiency can be maintained when variations occur at source. The proposed system will be validated by simulating in MATLAB/Simulink.*

***Key Words*: Buck-boost converter, P&O algorithm, PI controller, Wind, Solar**

1. INTRODUCTION

The demand for electricity is increasing day by day. Due to the complementary nature of renewable energy sources, the demand for Hybrid PV/Wind is growing. This paper presents the design of hybrid energy source.
A feedback mechanism is necessary to improve the robustness and performance of the dc/dc converter system. A static control of a novel cascaded boost-buck DC-DC converter is proposed to provide an optimal equivalent load resistance, and thus a high overall system efficiency for various loads such as resistive loads, ultra capacitors and batteries is achieved. The DC-DC converter not only minimizes the effect of a dynamic load to the system efficiency, but also alleviates the requirements for impedance matching networks. In this paper, cascaded boost-buck converter is compared with rest of the converters and concentrates on the working principle of converter and its control methodology. P&O based tracking control scheme is used to enhance the overall efficiency of the system. PI controllers are also used to provide tracking and control to the system. Particularly, here the overall efficiency of the system is defined as the ratio of the power received by the final load to the incident power from the power source.

2. BLOCK DIAGRAM

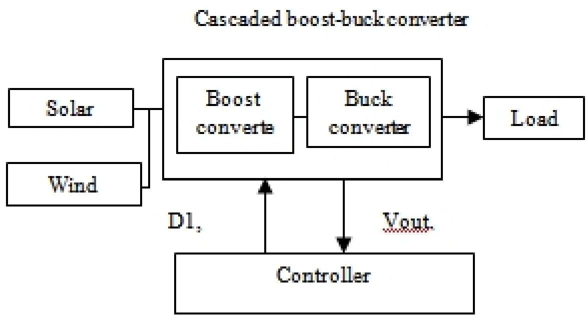

Fig -1: Block diagram of the system

The block diagram of the system is as shown in the Figure 1. Solar and Wind source is connected to the cascaded Boost-Buck converter and the overall efficiency of the converter is controlled by MPPT (P&O algorithm) controller and PI controller and the output of the converter is given to the required load. Input is switched from solar to wind and wind back to solar based on the irradiation constant and the wind speed respectively.

3. HYBRID SYSTEM CONFIGURATION

The hybrid system which is proposed is the combination of solar and wind energy and it is used as an input source. This set-up works efficiently during winter and summer. During winter, more output is generated using wind turbines and during hot summers, PV panels produce more outputs. When hybrid systems are compared with stand- alone models (solar, wind, biomass...Etc used alone), hybrid systems yields better results.

There are drawbacks of using stand-alone renewable energy source but always the drawbacks are overcome by utilizing all the available renewable energy sources. This paper proposes solar-wind sources and its utilization.

3.1 Solar Source

In this paper, a single solar cell is modeled by using controlled current source, a diode and two resistors. Single diode model is as shown is Figure 2. Maximum irradiation of solar is taken as 1000W/m².

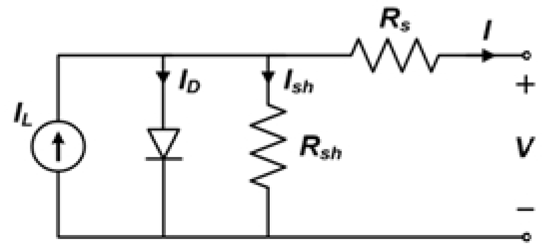

Fig -2: Single Diode model for Solar

The current I is given by

$$I = I_L - I_D - I_{sh} \qquad (1)$$

Based on the required output voltage the number of cells which should be connected is decided. The Irradiance of solar is checked. If the irradiance constant is more than 0.3 then solar is producing enough voltage to drive the cascaded boost- buck converter.

3.2 Wind Turbine

The operation of the wind turbine depends on air flow in the rotor consisting of two or three blades coupled to the generator of the wind turbine. The actual power extracted by the rotor blades is given by the difference between upstream and downstream wind powers.

$$P_m = \frac{1}{2}\, m\,\{V^2 - V_o^2\} \qquad (2)$$

Here P_m is the Mechanical Power extracted, V is the upstream power and V_o is the downstream power.

For different wind speed, the power is extracted and is given to the synchronous machine. When wind speed is more than 3m/s, wind turbine acts as an input. The AC voltage is converted to DC by using a Universal bridge.

4. CASCADED BOOST-BUCK CONVERTER

The boost converter and buck converter has a limited range of input resistance adjustment, while it is known that the Cuk converter has opposite polarity between input and output. It is as shown in table 1.

In Figure 3, considering the needs of battery charging and power management, a cascaded boost-buck DC-DC converter topology is proposed, which can be controlled to match any given load.

Table-1: Comparision of DC-DC converters[5]

Topology	V_{out}	R_{in}	R_{in}(range)	I_{in}
Buck	DV_{in}	$\frac{R_L}{D^2}$	$R_L \sim +\infty$	Discontinuous
Boost	$\frac{1}{1-D} Vin$	$(1-D)^2 R_L$	$0 \sim R_L$	Continuous
Buck-Boost	$\frac{-D}{1-D} Vin$	$\frac{(1-D)^2}{D^2} R_L$	$0 \sim +\infty$	Discontinuous
Cuk	$\frac{-D}{1-D} Vin$	$\frac{(1-D)^2}{D^2} R_L$	$0 \sim +\infty$	Continuous
SEPIC	$\frac{D}{1-D} Vin$	$\frac{(1-D)^2}{D^2} R_L$	$0 \sim +\infty$	Continuous

The input resistance of boost converter is easy to control due to its continuous input current feedback, while the buck converter is widely used in battery charging and power management. It is convenient to control and predict the behavior of the cascaded converter because the boost and buck converters can be separately analyzed. Compared with the traditional "one-switch" topologies, the boost-buck "two switch" topology provides more flexibility in the design and control of wireless power transfer systems.

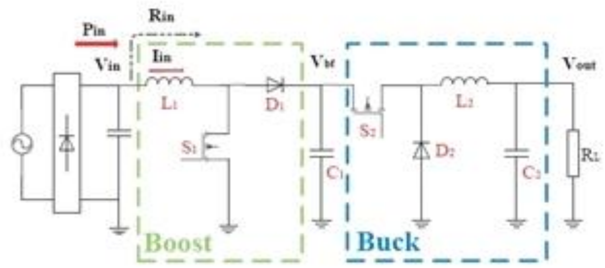

Fig-3: Cascaded Boost- Buck converter [5]

When V_{out} is greater than V_{in}, the output voltage needs to be bucked to get the required output voltage. During buck mode of operation, switch S_1 is disconnected. When switch S_2 is ON, the current passes through the inductor L_1, Diode (D_1), Switch S_2, and inductor L_2 and the voltage appears across the load. The diode D_2 will be reverse biased. When switch S_2 is OFF, the current freewheels through diode D_2 inductor L_2. D_2 acts like a freewheeling diode.

When V_{out} is lesser than V_{in}, the voltage needs to be boosted to get the required output voltage. During boost mode of operation, switch S_2 is provided with continuous pulse. When switch S_1 is ON, the current passes through inductor L_1, switch S_1. The output voltage is the summation of the input voltage the voltage across inductor L_1 and when the Switch S_1 is OFF, the current passes through inductor L_1, Diode D_1 and then to the load.

4.1 P&O-Based Tracking

Tracking of the optimal load is essential to ensure overall high efficiency of the system. Similar consideration can be found in the well-known maximum power point tracking (MPPT) technique, which is widely applied in photovoltaic systems. Unlike MPPT, here the purpose of the tracking is to maximize the overall system efficiency, and the target is determined through a system-level approach, i.e., based on the interactions among subsystems both before and after the DC-DC converter. In order to verify the tracking of the optimal load resistance, a simple perturbation and observation (P&O) method is implemented. Its flowchart is shown in Figure 4, where *n* is the newest sampling instant. $V_{out,n}$ and $I_{out,n}$ are the sampled load voltage and current, respectively.

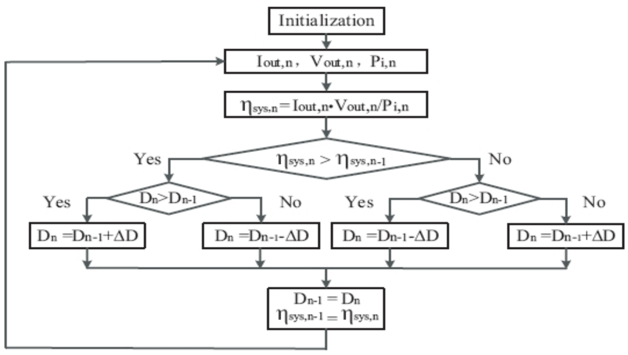

Fig-4: Flowchart of P&O based tracking [6]

In the Flowchart, η is the newest sampling instant. $V_{out,n}$ and $I_{out,n}$ are the sampled load voltage and current, respectively. $P_{i,n}$ is the sampled incident power from PA. System efficiency is $\eta_{sys,n}$. D is the control parameter that adjusts the equivalent load resistance seen by the rectifier, i.e., R_{in}. A small and constant perturbation, ΔD, is applied in a step-by-step manner in order to change the equivalent load resistance. Following each perturbation, the system efficiency variation $\Delta \eta_{sys}= (\eta_{sys,n} - \eta_{sys,n-1})$ is measured. If $\Delta \eta_{sys}$ is positive, the adjusted equivalent load resistance approaches its optimal value, and thus a perturbation with a same sign needs to be applied in the following stage. On the contrary, a negative $\Delta \eta_{sys}$ indicates that the current equivalent load resistance deviates from the optimal value, and a perturbation with an opposite sign has to be applied. This procedure is iteratively repeated until the optimal load resistance is reached. In this P&O-based tracking, three feedback signals are needed, the voltage, current of the load (V_{out} and I_{out}) and the incident power from PA (P_i) [6].

4.2 PI Controller

PI controller is used as the controller for buck converter in the proposed system. The main purpose of using PI controller is, it will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller. PI controllers are very often used in industry, especially when speed of the response is not an issue. A control without D mode is used when: a) fast response of the system is not required b) large disturbances and noise are present during operation of the process c) there is only one energy storage in process (capacitive or inductive) d) there are large transport delays in the system. The tuning of PI controller is shown in Fig 5.

Parameter Increase	Rise time	Overshoot	Settling Time	Steady-state error
Kp	↓	↑	Small Change	↓
Ki	↓	↑	↑	Great reduce

Fig-5: Tuning of PI controller

5. RESULTS

In this section, the simulation results are given to verify the above mentioned theory. Figure 6 represents the solar input voltage from a single diode model of 16 PV cells and Figure 7 represents the wind input DC voltage for a wind speed of 12m/s.

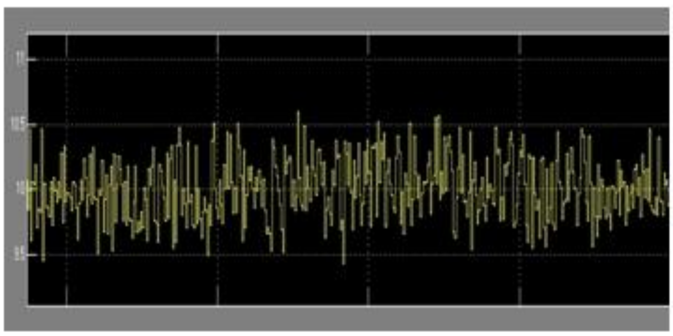

Fig-6: Solar Input Voltage

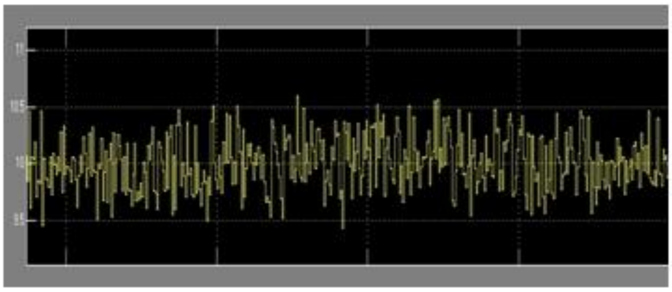

Fig-7: Wind Input voltage

The output voltage of 12V of cascaded Boost- Buck converter is shown in Figure 8 and the efficiency curves are shown in Figure 9.

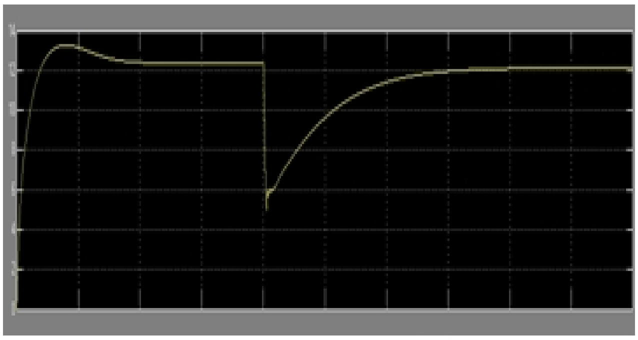

Fig-8: Output voltage of Cascaded Boost-Buck Converter

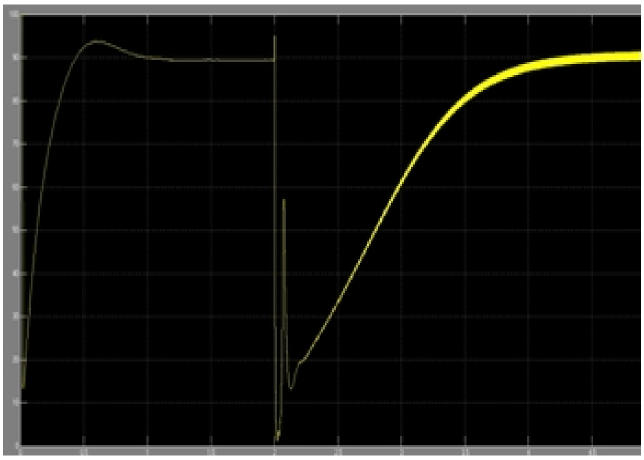

Fig-9: Efficiency of Cascaded Boost-Buck Converter

6. CONCLUSION

A new Cascaded Boost-Buck converter for solar/wind energy system is presented. This paper explains the working and advantages of using cascaded boost buck converter. Closed loop analysis is carried out using P&O algorithm and PI controller. The required output voltage is obtained by the control of the converter. High efficiency is maintained throughout the process from the source to load. Even with the variation in the source the stability and efficiency of the system is maintained.

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