Open Loop Buck Converter and Microgrid HIL Real-Time Simulation

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DC-DC Power Electronics Step-Down Converter (Open Loop Buck Converter)

Due to environmental effects of conventional energy resources (fossil fuels), renewable energy resources (such as solar energy and fuel cells) have gained more attention. The electric cars are also gaining popularity among the masses being environment friendly and having lower long-term costs. DC-DC power electronics converters are an essential item in solar powered appliances and electric cars. In such applications, a bidirectional DC-DC converter is used to implement two types of purposes: acts like a high gain step-up converter in instances where fuel cell is powering the fully electric vehicles, and a synchronous step-down converter when fuel cell is being charged from the high voltage battery pack. In this research project, we will focus on creating a buck converter that is able to step down voltage from its input to its output. We will present the design and simulation of an open loop converter in MATLAB R2020a/Simulink and the calculations of various parameters such as fixed duty cycle, efficiency, output voltage, and power.

Basics of Open Loop:

Open loop provides a fixed duty cycle to obtain the theoretically calculated output voltage. Ultimately, there is no feedback from output to input opposed to closed loop that has one or more feedback loops. Buck converter is a DC-DC power converter and works by reducing the voltage at the endpoint. The circuit contains at least two semiconductors (MOSFET/Diode), two energy storage elements (inductor/capacitor), and a load (resistor). The purpose of the capacitor is to maintain a relatively stable output across the load resistor.

Simulink Buck Converter Model:

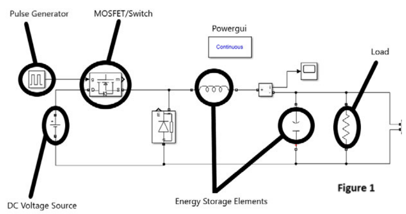

Figure 1

Settings:
DC Voltage = 12V
Duty Ratio = 41.67%
Determine Vout = Vin*D = 5V

Calculations:

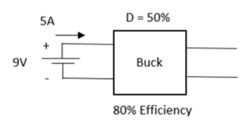

Figure 2

Pin = VI = 45W
Pout = 45W*80% = 36%
Vout = Vin*D = 9V*50% = 4.5V
Pout= VI
I = Pout/Vout = 36W/4.5V = 8A

Voltage Scope Measurement from Simulink Model:

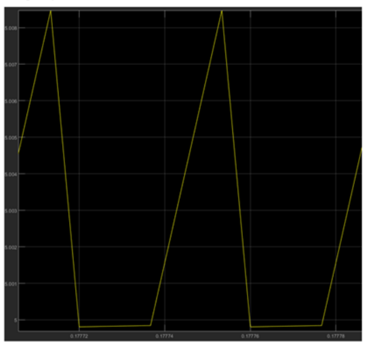

Figure 3

The scope displays an output voltage of 5V which is the same as the design and calculated value. Input and output voltage is linear.

Current Scope Measurement from Simulink Model:

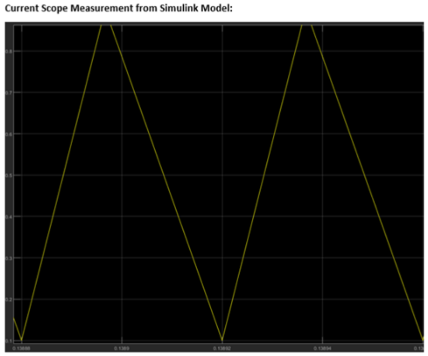

Figure 4

The open loop buck converter has a Continuous Conduction Mode (CCM) as shown in figure 5. In CCM, inductor current remains positive and continuous throughout the switching period and never falls to zero contrary to Discontinuous Conduction Mode (DCM) where inductor current drops to zero for some time during the switching period.

Selecting parameters/components and conducting analysis is crucial to designing an open loop circuit and delivering optimal results. The input voltage and fixed duty cycle varies and controls the output voltage at the load resistance. The ripple voltage and ripple current are not dependent on the load resistance; therefore, these parameters will remain constant as load varies.

Present, fuel cells are gaining ground and popularity because of their clean source of energy and ability to produce electricity directly from hydrogen and oxygen at low voltage.

Hardware-in-the-Loop (HIL) Real-Time Simulation of a Microgrid

A microgrid is a small-scale electric power distribution network. It is composed of various distributed electric power sources connected to the main bus through power electronics converters supplying various distributed loads. In this work, a microgrid model is simulated in consultation with OPAL-RT that is connected to a strong electric network. Hardware-in-the-loop (HIL) simulation is a type of real-time simulation. We were able to interact with the Simulated Microgrid Controller and perform testing on the model using the dashboard shown in Figure 6 in HIL environment. The microgrid is controlled by the Simulated Microgrid Controller dashboard and the user can manage the following tasks: switch to the main grid, battery energy storage system, PV generation system, wind turbine, diesel generator, critical load, shed-able load, and demand response. All these variables are interconnected through the microgrid bus.

Test Setup:

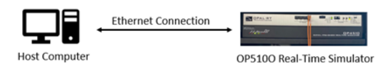

Figure 5

Lab View Panel Dashboard (User interface to control variables of the Simulated Microgrid Controller):

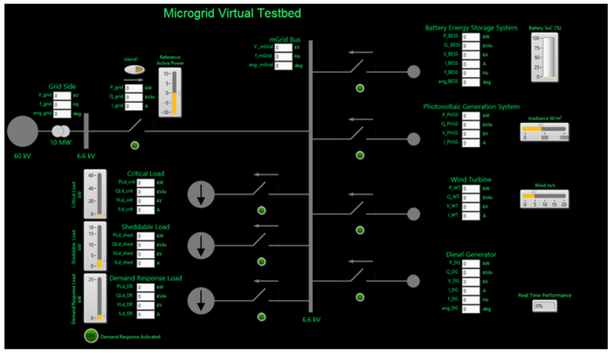

Figure 6

Grid Connected test:

1. Irradiance input of the PV generation system was changed to 1000 W/m2. The power generated by the PV system is 11.76kW.

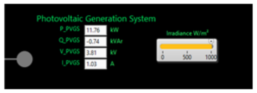

Figure 7

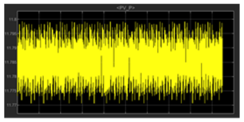

Figure 8

2. The wind speed input of the Wind Turbine system was changed to 11 m/s. The power generated by the Wind turbine is 9.99kW and the breaker was closed; the wind turbine is connected to the microgrid bus so is feeding the 9.9kW to the system.

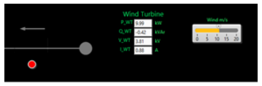

Figure 9

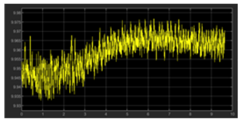

Figure 10

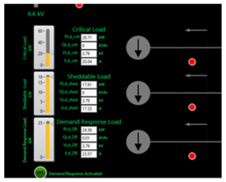

Figure 11

3. The critical load value was changed to 20kW, the shed-able load to 18kW and the demand response load to 25kW. By increasing the 3 different loads the 3 switches are closed and the microgrid bus is supplying the power requested by the loads.

References

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2. Selvam, Sivakumar, et. al. "An assessment on performance of DC-DC converters for renewable energy applications." Renewable and Sustainable Energy Reviews 58:1475-1485. doi: 10.1016/j.rser.2015.12.057.
3. OPAL-RT Technologies, "MicroGrid Test Bench FAT – Factory Acceptance Test" . September 25, 2020.