International Journal of Power Electronics and Drive Systems (IJPEDS)
Vol. 3, No. 4, December 2013, pp. 444~449
ISSN: 2088-8694

Model of Bi-directional Flyback Converter for Hybrid AC/DC Distribution System

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Article Info

Article history:

Received Aug 19, 2013
Revised Oct 2, 2013
Accepted Oct 28, 2013

Keyword:

bi-directional
DC/DC converter
galvanic isolation
hybrid distribution system
simulation model

ABSTRACT

In this article, a simulation model and concept of two switch bi-directional isolated DC/DC converter is presented. Converter is based on flyback converter type. Also control method for voltage regulation with bi-directional power transfer is presented. Target application of the proposed converter was selected to be a hybrid AC/DC distribution system concept of which was briefly described. The requirement of galvanic isolation in the hybrid AC/DC concept comes from use of shared neutral wire; DC current runs with unbalanced part of AC current in neutral wire. Without galvanic isolation grounded neutral would cause short circuit if DC/DC converter is connected to three phase rectifier or inverter. Simulation was carried out with PSCAD electromagnetic transient simulator.

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1. INTRODUCTION

Power electronics are a key part in integration of renewable energy to power grids. DC/DC converters are needed when two systems with different DC voltage levels need to be connected. Galvanic isolation is a desired feature so that faults on one side do not affect the other side of the converter. Here a simulation model of a bi-directional isolated converter is presented and analysed for voltage regulation control method.

Target application for the converter is a hybrid AC/DC distribution system where galvanic isolation allows DC to run on neutral wire shared with AC system. Design approach selected for the converter is to use only two switching components with single level DC for simplistic design. The design of this converter is a modification from flyback converter. Target application for the converter is hybrid AC/DC distribution system where galvanic isolation allows DC to run on neutral wire shared with AC system. Figure 1 represents the general concept of hybrid AC/DC distribution system.

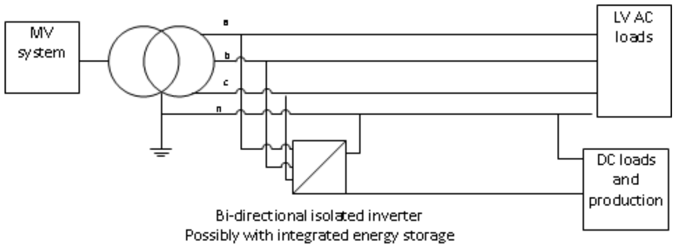

Figure 1. Hybrid AC/DC distribution system concept

As mentioned in the previous chapter, the converter is based on flyback converter and realization that it can be modified to to create two switch isolated bidirectional converter. Figure 2 displays schematic of a flyback converter.

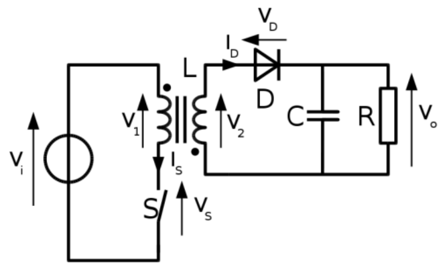

Figure 2. Schematic of a flyback converter [1]

A flyback converter has a transformer inside to provide galvanic isolation but also help voltage conversion between the sides. A diode takes care of converting AC from transformer to DC for the load side with capacitor providing smoothing to the voltage. Figure 3 displays a schematic of the proposed converter.

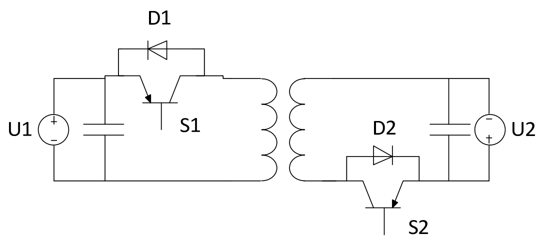

Figure 3. Schematic of bi-directional flyback converter

Modifications to flyback converter are an added diode in parallel of the switch and a second switch in parallel to diode on load side. Also a second capacitor is added to source side of the converter. Converter on the Figure 3 is also an inverting converter; voltage polarity is reversed on the other side of the converter. With these modifications both sides of the converter can operate either as a load or as a source. Bi-directional flyback converter has been previously investigated in publications [2] and [3] to name a few.

2. SIMULATION MODEL

Simulation tool selected for the converter is PSCAD. PSCAD is electromagnetic transient simulation software developed by Manitoba HCDC Research Center. Calculations in PSCAD are made in instantaneous values and resulted differential equations are solved numerically. PSCAD can also be used for power flow calculations although large networks could be more easily solved with software that can use state vectors for finding the solution. Solution time step is set to 5 µs and simulation time to 11 s. Circuit diagram of the converter model is presented in Figure 4.

Converter is designed for 700 V at left side and 230 V on the right side. IGB transistors and diodes are modeled with default values of PSCAD. Capacitor at 700 V side was set to 250 µF and capacitor on 230 V side to 50 mF. The UMEC transformer model [4] was selected for the transformer, which is available in the base library of PSCAD. Parameters for transformer are presented in Table 1.

Converter control system is configured so that it maintains 230 V DC voltage at right side of the converter displayed in Figure 4. Control method is called current-mode which is presented in [5]. In this control method output current is compared to calculated reference current and difference of these is given to switch drive circuitry. Figure 5 displays the control system.

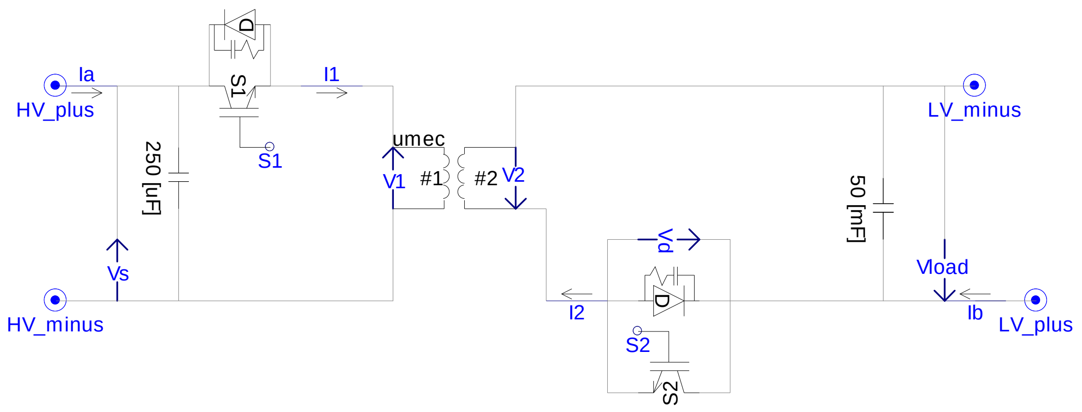

Figure 4. Circuit diagram of the converter model

Table 1. Transformer values

Transformer size (kVA)	Primary voltage(kV)	Secondary voltage (kV)	Base operation frequency (kHz)	Leakage reactance (pu)	No load losses (pu)	Copper losses (pu)	Model saturation	Tap changer winding
60	0.7	0.23	20	0.05	0.0015	0.01	No	None

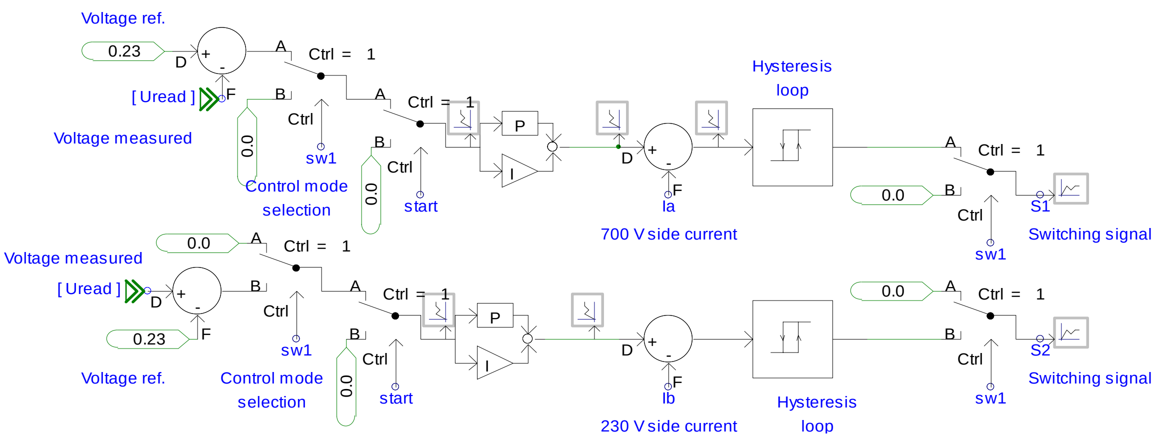

Figure 5. Control system

Measured voltage is compared to reference (230 V) and difference is connected to PI-controller. Input of the PI-controller is switched to zero when particular switch is not operating. This makes sure that PI controllers start from zero position when operation mode is changed. S2 Switch is used when power flows from 230 V side to 700 V and S1 when Power flows to 230 V side from 700 V side. The output of the converter is compared to DC side currents, Ia for S1 and Ib for S2. In this case switching signal is generated by two level hysteresis loop width of which is set to 1 A. This means that signal oscillates between ON and OFF when current is more than 1 A from the reference. Operation mode is selected by measuring output voltage and comparing it to reference with PI controller. Control mode selection logic is displayed in Figure 6.

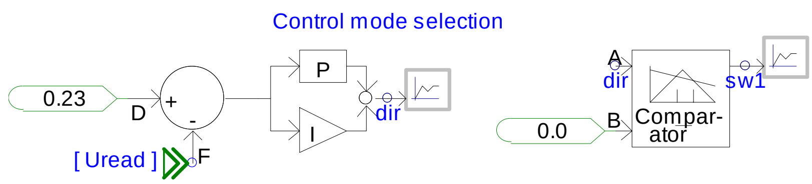

Figure 6. Operation mode selection logic

PI controller in the Figure 6 basically calculates the direction of the current reference and outputs 1 for S1 to be active and -1 for S2 to be active. Comparator converts S2 signal to 0. (S1 remains at 1) Parameters for PI controllers are displayed in Table 2.

Table 2. Parameters for PI controllers

Switch name of the PI controller	Gain	Integral time constant (ms)	Current limit / Max. value (A)	Min. value (A)
S1	2	2	100	0
S2	2	2	305	0

3. RESULTS AND ANALYSIS

Simulation model of the converter is built as module to PSCAD and voltage source is connected to to each side of the module. A 700 V DC source with 0.5 Ohm series resistance is on the primary side and controllable voltage source with series resistance of 0.1 Ohm is added to the secondary side. Figure 7 displays converter module with the voltage sources.

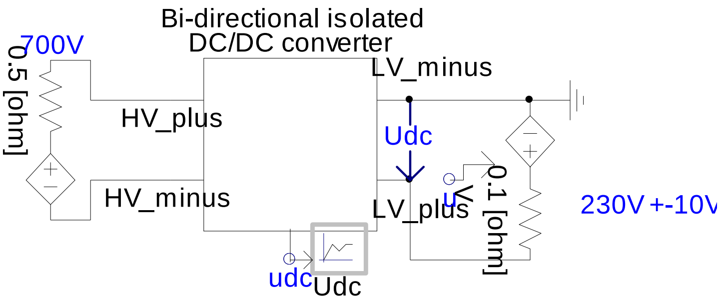

Figure 7. Converter module connected to voltage sources

Converter operates so that voltage remains at 230 V on the secondary side. By adjusting the voltage source after the 0.1 Ohm impedance, power demand for the converter is generated when converter reacts to the change in voltage. Figure 8 displays the voltage reference in kV respect to time in s.

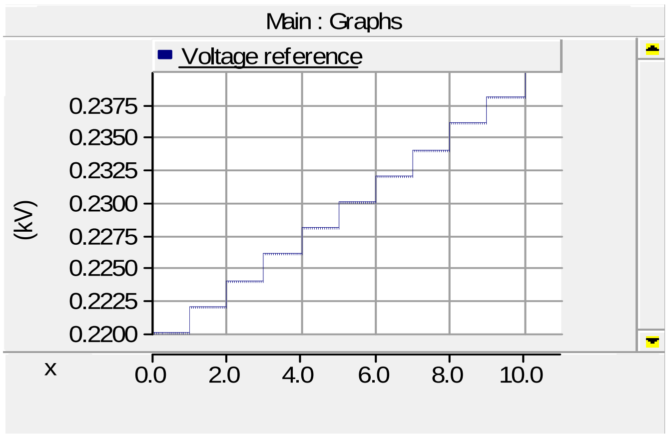

Figure 8. Voltage reference for the “230 V” source

Power output of the converter is displayed in Figure 9.

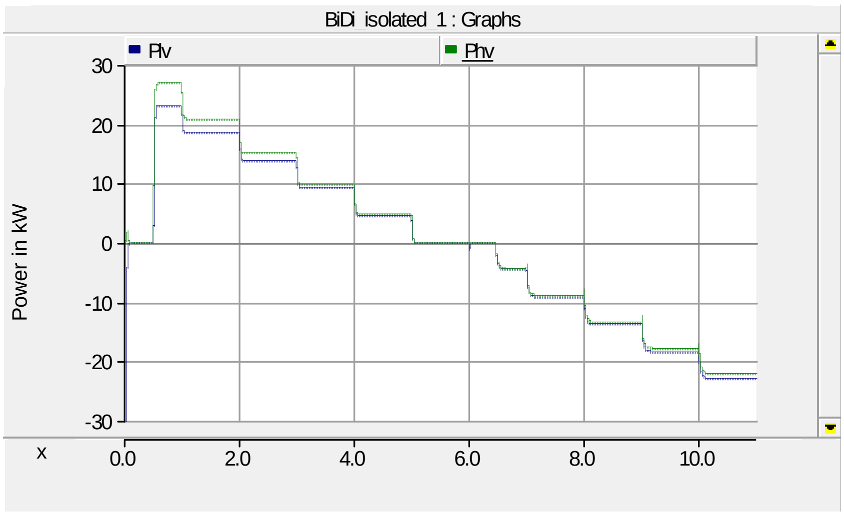

Figure 9. Power output (input) of the converter. Green is power coming from 700 V side and blue power coming to 230 V side

Positive power means power is flowing from 700 V side to 230 and negative from 230 V side to 700 V side. Figure 10 displays voltage at 230 V side.

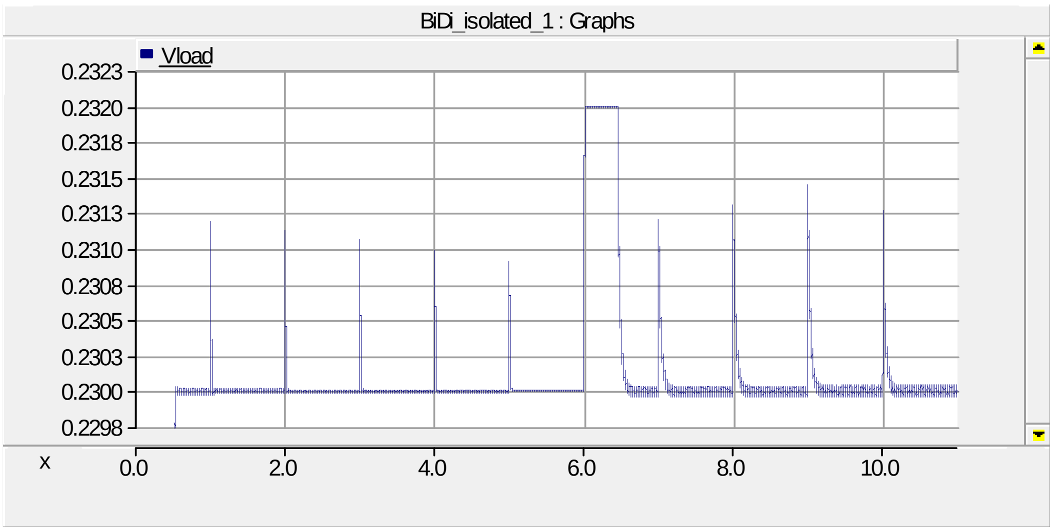

Figure 10. Voltage at 230 V side during the simulation in kV

Voltage errors in load steps are about 1.25 V. Converter starts at 0.5s therefore output voltage is not up in the beginning. At 6.0 s converter shuts down and voltage error is larger, about 2 V. This is because width of the hysteresis loop was set to 1 A and this voltage error generates smaller current error than 1 A. Shape of current from both ends of converter is displayed in Figure 11.

Primary current has more spikes when power flow is reversed to flow from secondary side to primary side. This can also be seen in Figure 10 where output voltage has more noise in same situation.

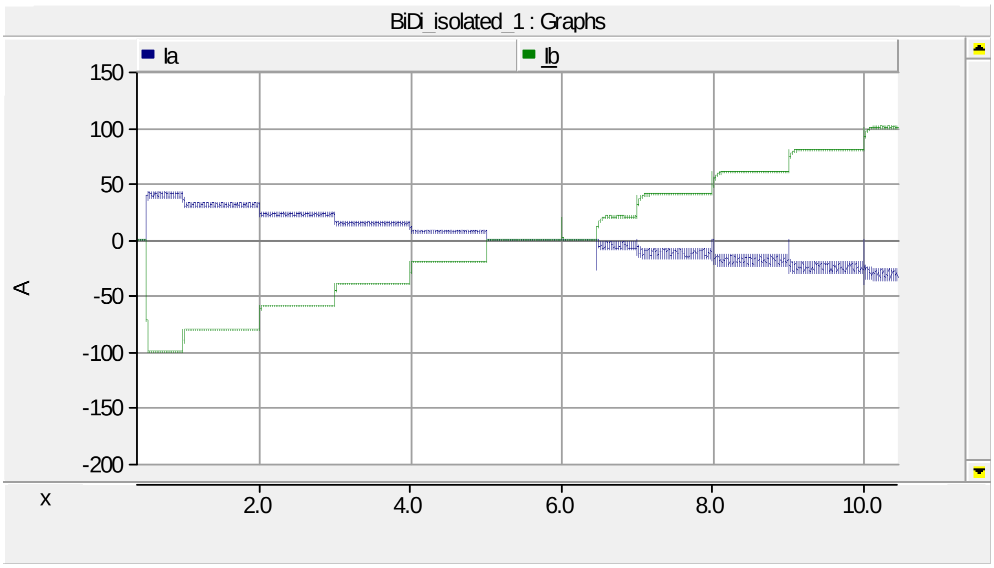

Figure 11. Current at primary side (blue) and secondary side (green)

4. CONCLUSION

Bi-directional flyback converter model with galvanic isolation was investigated with PSCAD/EMTDC software. Application in mind for the converter was a hybrid AC/DC distribution system. Concept is based on modifying flyback converter type with additional components to allow bidirectional operation. Converter was configured to convert 700 V to 230 V so that target was to have stabile 230 V side voltage and adjust power accordingly. Voltage source with series resistor was used to make a voltage error in steps and converter corrected it back to 230 V. Results show that proposed converter successfully manages to keep output voltage error under 2 V in the simulation.

In continuation of this research a suitable grid tie inverter model will be developed together with concept for the control system. Main point of the proposed concept is to maximize power flow in neutral connector with the Hybrid system. One of the problems using neutral connector for DC current flow is that it must be controlled so that it won’t disturb AC power system operation and take capacity from normal AC current. One option could be use some means to communicate with DC loads to manage the demand. Other option could be just to use DC system as backup when there is fault in AC distribution. Other related research could include investigation on integration of renewable generation and storage systems with the concept and finding out practical limitations with the concept when integrated to typical Nordic LV distribution system. Of course topic of LV distribution itself is interesting and a lot of research has been done in this field and incorporating this to AC/DC hybrid concept will be one of the main tasks for the continuation of this work.

ACKNOWLEDGEMENTS

Work for the converter model and AC/DC hybrid distribution system concept was carried out in the Smart Grids and Energy Markets (SGEM) research program work package 5.3 coordinated by CLEEN Ltd with funding from Tekes – the Finnish Funding Agency for Technology and Innovation.

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