Control Of A Bidirectional Dc-Dc Converter To Interface Ultracapacitor With Renewable Energy Sources

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Abstract: The continual rise in electricity demand, combined with serious environmental problems created by traditional energy systems have been driving societies towards the use of renewable energy sources. However, the natural variability of some renewable sources due to their strong dependence on the weather conditions result to a high fluctuated output power, which impacts on the local loads that are sensitive to pulsating power. Hence, there is a need to support these sources by use of energy storage device, where it either injects its stored energy or absorbs the excess energy during the transients in the renewable source; resulting in a smooth output power to the load. In this paper, the control of a bidirectional converter to interface an ultra capacitor as storage device to renewable energy systems is discussed. The controller of the converter system has been designed and simulated based on the integration of both Current Mode Control (CMC) and Linear Quadratic Regulator (LQR) methods. The controller performance is tested under different modes of operating conditions in bidirectional converter using MATLAB/Simulink simulation.
IndexTerms- DC-DC converter, ultra capacitor, buck mode converter, boost mode converter, current mode control (CMC), linear quadratic regulator (LQR) control

I.INTRODUCTION

The pulsating power generated by the renewable sources results into a high fluctuated output power. Moreover, power generated from the renewable sources does not always match the demanded load power. Hence, there is a need to support these sources by use of energy storage device, where it either injects its stored energy or absorbs the excess energy during the transients in the renewable source; resulting in a smooth output power to the load.
The ultra capacitor is preferred due to its long life-time, good electrical behavior and to its relatively low initial cost in comparison with modern batteries. Connecting the renewable source and the ultra capacitor requires a power converter and a DC link. The converter must have the capability to allow both directions of power flow between the ultra capacitor and the DC link, and also the ability to increase or decrease the voltage level in each power flow direction; since the voltage level of the ultra capacitor and the DC link are different. Therefore, a bidirectional DC-DC converter is used. In bidirectional DC-DC converters, there are two modes of operation. The first mode is the boost mode, where the ultra capacitor is discharged to a higher voltage level at the DC link; in the second mode, namely the buck mode; here the excess power from the renewable source charges ultra capacitor.
This paper describes the design of a controller based on the current mode control (CMC) and linear quadratic regulator (LQR) control techniques. In the proposed controller, the outer loop of the CMC is modified to include the feedback gains of the LQR. The objective of the converter controller is to maintain the DC bus voltage at a relatively constant stream, regardless of the load switching and environmental changes.

A.BUCK CONVERTER STEP-DOWN CONVERTER

In this circuit the transistor turning ON will put voltage V_{in} on one end of the inductor. This voltage will tend to cause the inductor current to rise. When the transistor is OFF, the current will continue flowing through the inductor but now flowing through the diode. We initially assume that the current through the inductor does not reach zero, thus the voltage at $V_x$will now be only the voltage across the conducting diode during the full OFF time. The average voltage at V_x will depend on the average ON time of the transistor provided the inductor current is continuous.

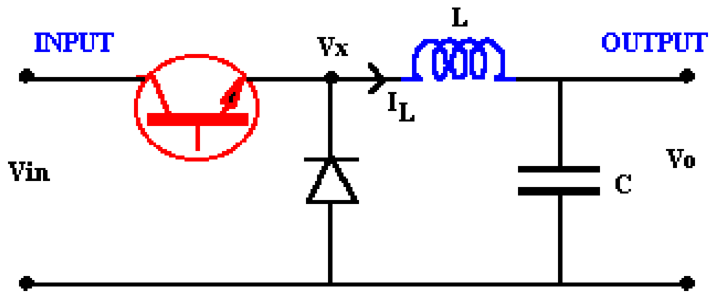


Fig 1: Buck Converter

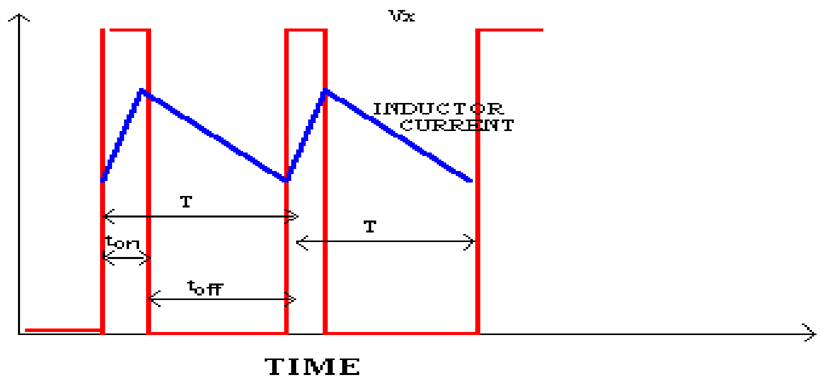


fig 2: Voltage and current changes

To analyze the voltages of this circuit let us consider the changes in the inductor current over one cycle. From the relation

$$\mathbf{V_x - V_o = L\frac{di}{dt} \ldots \ldots \ldots (1)}$$

The change of current satisfies

$$\mathbf{di = \int_{ON}^{OFF} (V_x - V_o)_x \, dt \ldots \ldots \ldots (2)}$$

For steady state operation the current at the start and end of a period T will not change. To get a simple relation between voltages we assume no voltage drop across transistor or diode while ON and a perfect switch change. Thus during the ON time V_x=V_{in} and in the OFF V_x=0. Thus

$$0 = di = \int_0^t (\mathbf{V_{in} - V_o})_x \, \mathbf{dt} + \int_{t_{on}}^{t_{on}+t_{off}} (\mathbf{-V_o})\mathbf{dt} \ldots\ldots\ldots\ldots (3)$$

This simplifies to

$$\mathbf{(V_{in} - V_o)t_{on} - V_o t_{off} = 0 \ldots\ldots\ldots\ldots (4)}$$

Or

$$\mathbf{\frac{V_o}{V_{in}} = \frac{t_{on}}{T} \ldots \ldots \ldots \ldots \ldots \ldots \ldots (5)}$$

And defining "duty ratio" as

$$\mathbf{D = \frac{t_{on}}{T} \ldots \ldots \ldots \ldots \ldots \ldots \ldots (6)}$$

The voltage relationship becomes Vo=D Vin Since the circuit is lossless and the input and output powers must match on the average V_o* I_o = V_{in}* I_{in}. Thus the average input and output current must satisfy I_{in} =D I_o These relations are based on the assumption that the inductor current does not reach zero.

B.BOOST CONVERTER

The schematic in Fig.3 shows the basic boost converter. This circuit is used when a higher output voltage than input is required.

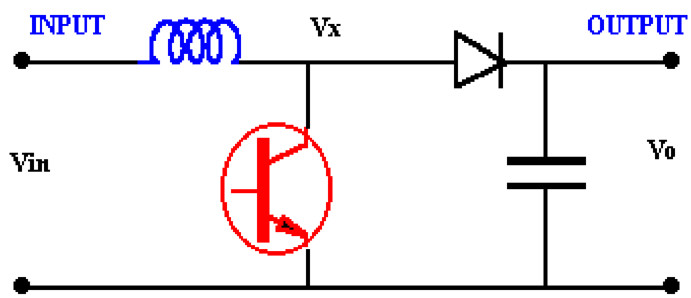


Fig.3: Boost Converter Circuit

While the transistor is ON $V_x = V_{in}$, and the OFF state the inductor current flows through the diode giving $V_x = V_o$. For this analysis it is assumed that the inductor current always remains flowing (continuous conduction). The voltage across the inductor is shown in Fig. 3 and the average must be zero for the average current to remain in steady state

$$\mathbf{V_{in} t_{on} + (V_{in} - V_o) t_{off} = 0} \ldots\ldots\ldots\ldots\ldots\ldots.(7)$$

This can be rearranged as

$$\frac{V_o}{V_{in}} = \frac{\mathbf{T}}{\mathbf{t_{off}}} = \frac{\mathbf{1}}{\mathbf{(1-D)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(8)$$

and for a lossless circuit the power balance ensures

$$\frac{I_o}{I_{in}} = \mathbf{(1-D)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(9)$$

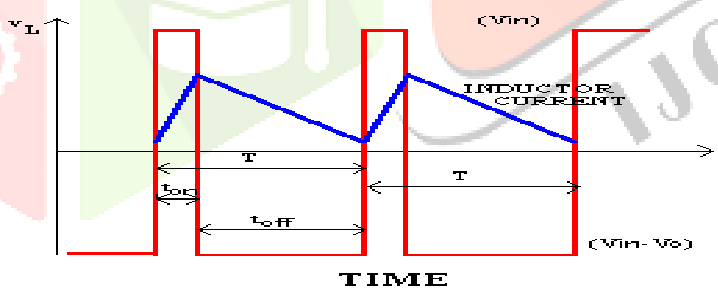
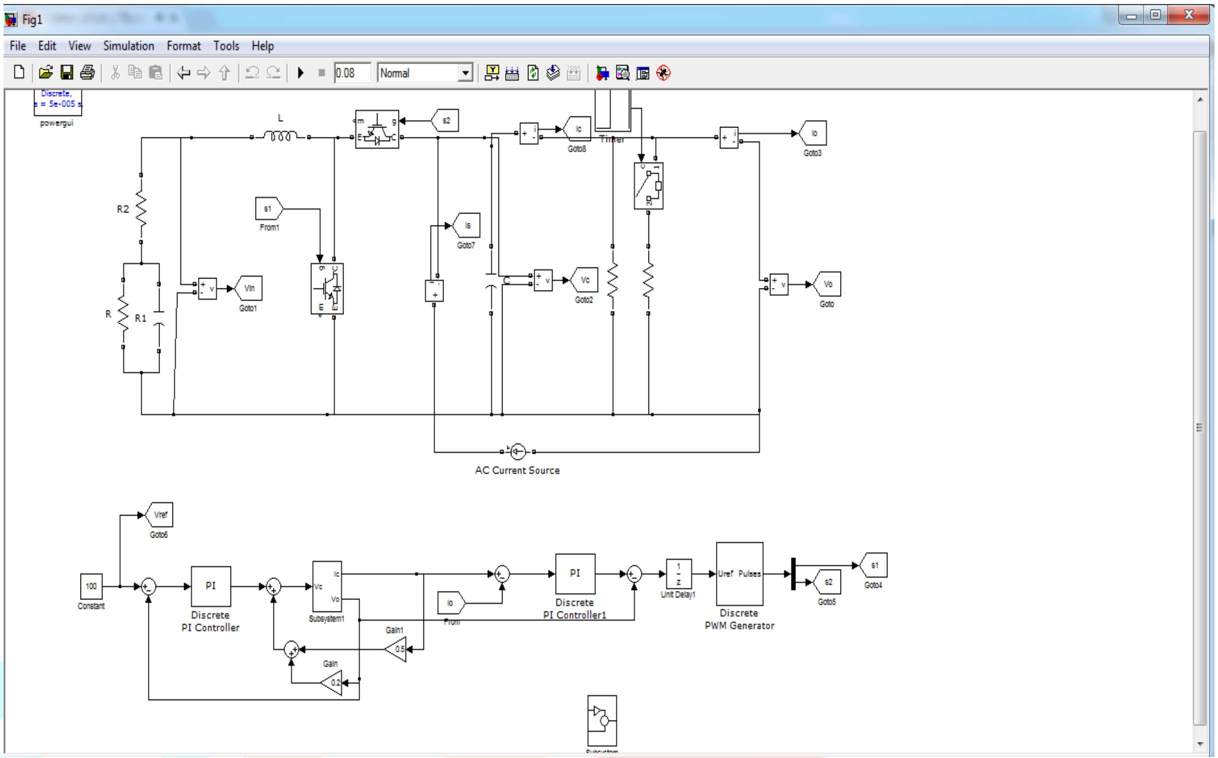


fig.4: Voltage and current waveforms (Boost Converter)

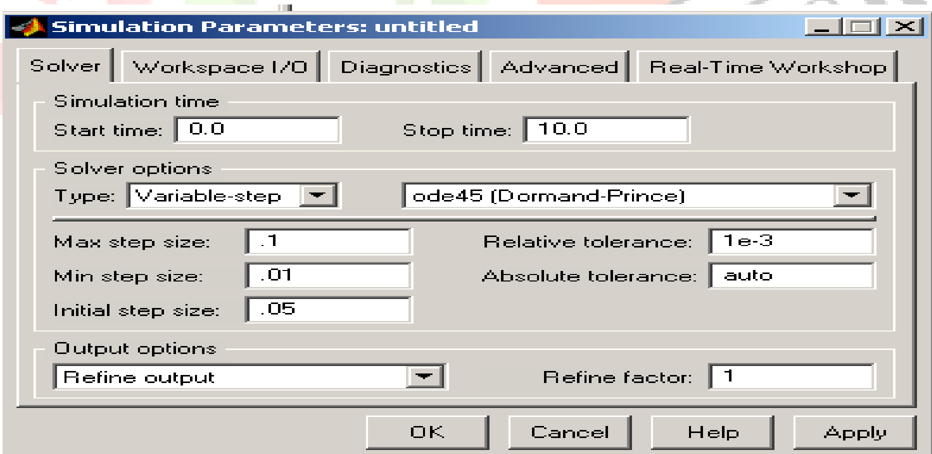
Since the duty ratio "D" is between 0 and 1 the output voltage must always be higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage.

II.Model



III. Setting simulation parameters

Running a simulation in the computer always requires a numerical technique to solve a differential equation. The system can be simulated as a continuous system or a discrete system based on the blocks inside. The simulation start and stop time can be specified. In case of variable step size, the smallest and largest step size can be specified. A Fixed step size is recommended and it allows for indexing time to a precise number of points, thus controlling the size of the data vector. Simulation step size must be decided based on the dynamics of the system. A thermal process may warrant a step size of a few seconds, but a DC motor in the system may be quite fast and may require a step size of a few milliseconds.



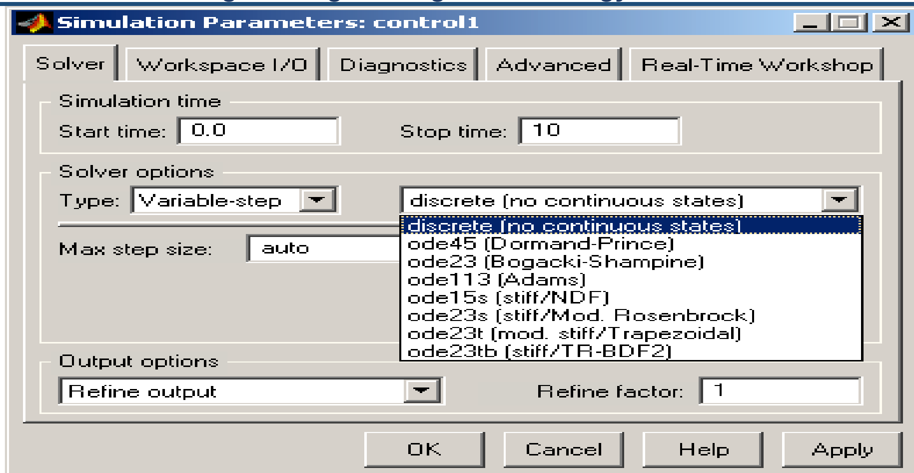


Fig.5: simulation parameters

IV. Results and analysis

The simulation results for the first case system test are shown, where the renewable source current was maintained fixed at 10 A while the load current was changed in steps from 5 A to 15 A and then to 5 A. In the first interval (between t=0 and t=0.02 s) the renewable source covered the load demand and injected its excess current to the ultra capacitor. In this interval, the bidirectional converter operated in a buck mode. However, when an additional 10 A was required by the load (between t=0.02 and t=0.05 s), the renewable source was not able to provide the full load demand. Thus, in this interval, the bidirectional converter switched to a boost mode to discharge the ultra capacitor and supply the extra load demand. When the load current returned to its initial value (between t=0.05 and t=0.08 s), the bidirectional converter softly changed its mode of operation into the buck mode. depicts the DC bus voltage. As can be seen, it was regulated at the desired value (100 V) regardless of the changes that happened in the load current. The figure clearly shows that the two modes of the converter operation altered softly.

Table 1: Paraemters of simulated system

L (mH)	C (µF)	R_o (Ω)	V_o (v)	C_{uc} (F)	R_s(mΩ)	R_P (Ω)
0.1	150	20	100	165	7	1×10^9

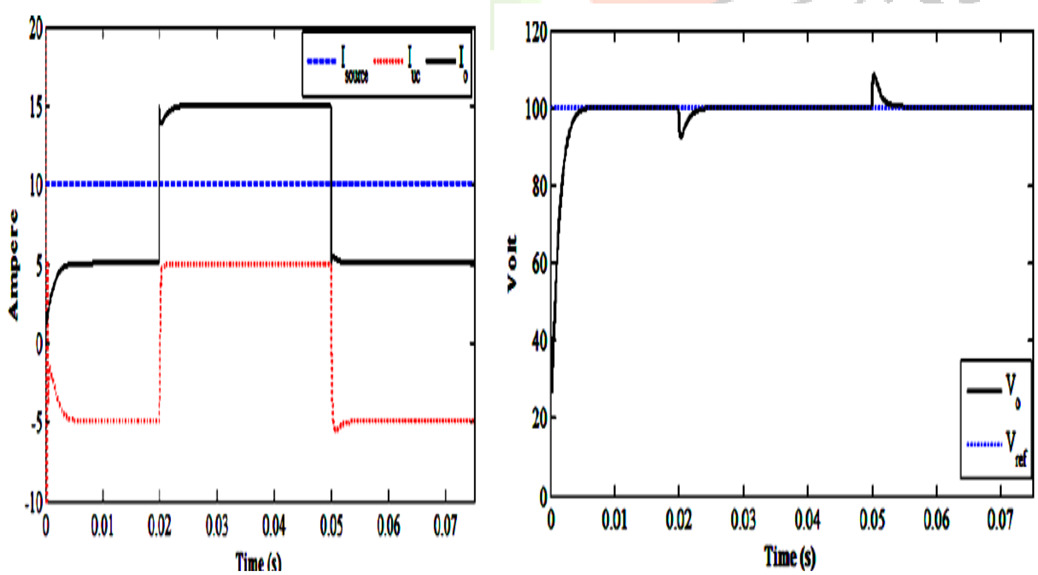


Fig.6:The responses of a step variation in the output voltage in buck mode operation

In the second case of simulation test, the output voltage reference was changed from 100 V to 110 V and back to 90 V. In addition, source I was changed from 0 A to 10 A at time of 0.04 s. Referring to the figures, it can be seen that before at t = 0.04 s the load current was completely provided by the ultra capacitor, and the converter was in the boost mode operation. Nevertheless, it was operating in the buck mode, by charging the ultra capacitor, during the remainder of the time. In both modes, the controller ensures good output voltage and current regulations . The output voltage tracked the reference accurately and smoothly. The transient time upon all changes was less than 7 ms, while the peak overshoot resulted from the current change was almost 8%.

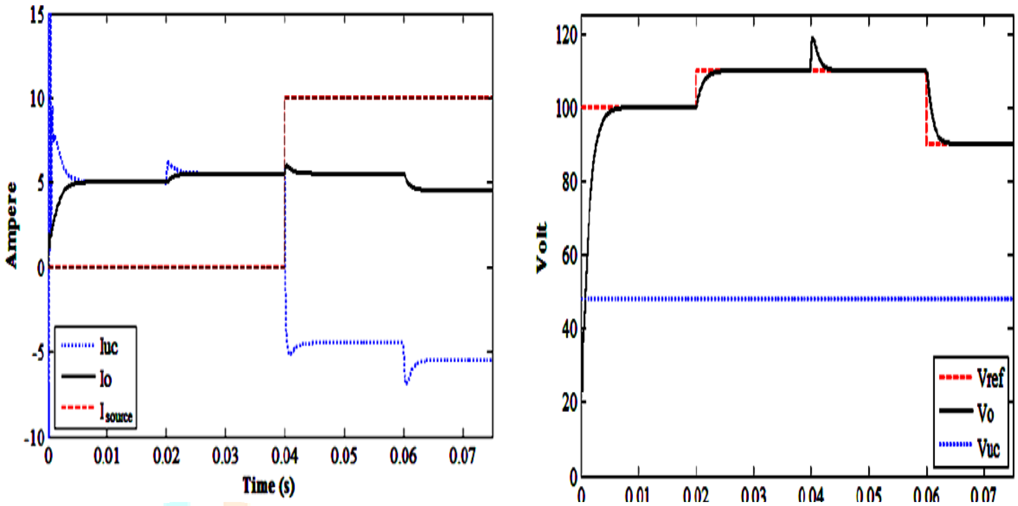


Fig.7: The responses of a step variation in the output voltage in boost mode operation

V.CONCLUSION

This paper has include the discussion of a new control method based on LQR and CMC control for a bidirectional DC-DC converter that interfaces ultra capacitor energy storage to a renewable energy system. The LQR-CMC method has been successfully applied to control the bidirectional converter in the case of boost and buck modes. The objectives of the controller were to regulate the output voltage and to achieve a smooth transition between the two operation modes of the bidirectional converter, namely buck and boost modes. In addition, the proposed controller ensures continuous power supply the load, regardless of the load and renewable energy power changes. In short, the proposed controller is capable of increasing the reliability and energy conversion efficiency of renewable energy systems.

REFERENCES

1. M. A. Abdullah, et al., "A study of maximum power point tracking algorithms for wind energy system," in 2011 IEEE First Conference on Clean Energy and Technology (CET), Kuala Lumpur Malaysia, 2011, pp. 321-326.
2. M. A. Abdullah, et al., "A review of maximum power point tracking algorithms for wind energy systems," Renewable andSustainable Energy Reviews, vol. 16, pp. 3220-3227, 2012.
3. M. A. Abdullah, et al., "Input Current Control of Boost Converters using Current-Mode Controller Integrated with Linear Quadratic Regulator," International Journal of Renewable Energy Research(IJRER), vol. 2 , pp. 262-268, 2012.
4. C. N. Bhende, et al., "Permanent Magnet Synchronous Generator- Based Standalone Wind Energy Supply System," IEEETransactions on Sustainable Energy, vol. 2, pp. 361-373, 2011.
5. M. Bottu, et al., "Design of a Conditioner for smoothing wind turbine output power," in North American Power Symposium(NAPS), 2010, 2010, pp. 1-6.
6. M. A. G. de Brito, et al., "Evaluation of the Main MPPT Techniques for Photovoltaic Applications," IEEE Transactions onIndustrial Electronics, vol. 60, pp. 1156-1167, 2013.
7. A. A. Hussein, et al., "Distributed Battery Micro-Storage Systems Design and Operation in a Deregulated Electricity Market," IEEETransactions on Sustainable Energy,,vol. 3, pp. 545-556, 2012.
8. M. H. Nehrir, et al., "A Review of Hybrid Renewable/Alternative Energy Systems for Electric Power Generation: Configurations, Control, and Applications," IEEE Transactions on SustainableEnergy, vol. 2, pp. 392-403, 2011.