

Bidirectional Transformer Coupled Hybrid Converter for Battery Energy Storage System

Monisha¹, Sandhiya², Suruthi³, Arul Doss Adaikalam⁴

U.G[B.E] Students, Department of EEE, TJS Engineering College , Chennai, Tamil Nadu, India ^{1,2,3}

Assistant Professor, Department of EEE, TJS Engineering College , Chennai, Tamil Nadu, India ⁴

ABSTRACT :The proposed system aims to satisfy the low demand, manage the power flow from different sources, inject surplus power into the grid and charge the battery from grid as and when required. A transformer coupled boost half-bridge converter is used to harness power from wind, while, by bidirectional buck-boost converter is used to harness power from PV along with battery charging or discharging control. A single-phase full-bridge bidirectional converter is used for feeding AC loads and interaction with grid. This improves the efficiency and reliability of the system.

I. INTRODUCTION

Photovoltaic (PV) is the field of technology and research related to the application of solar cells for energy by converting sunlight directly into electricity. Photovoltaic are generally known as a method for generating solar power by using solar cells packaged in photovoltaic modules, often electrically connected in multiples as solar photovoltaic arrays to convert energy from the sun into electricity. In the simple words the photons from sunlight knock electrons into a higher state of energy, creating electricity. The term photovoltaic denotes the unbiased operating mode of a photodiode in which current through the device is entirely due to the transducer light energy. Virtually all photovoltaic devices are some type of photodiode. Solar cells produce direct current electricity from light, which can be used to power equipment or to recharge a battery lead acid. PV cells have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. These values correspond to a particular resistance, which is equal to V/I as specified by Ohm's Law. A PV cell has an exponential relationship between current and voltage, and the maximum power point (MPPT) occurs at the knee of the curve as shown in Figure 1.0, where the resistance is equal to the negative of the differential resistance ($V/I = -dV/dI$).

II. LITERATURE SURVEY

H. Wu, K. Sun, S. Ding, and Y. Xing, “**Topology derivation of nonisolated three-port dc-dc converters from DIC and DOC,**” *IEEE Trans. Power Electron.*, vol. 28, no. 7, pp. 3297-3307, July 2013.

The power flow in a TPC is analyzed and compared with that in a DIC or a DOC, respectively. Beginning with building the power flow paths of a TPC from a DIC or a DOC, the general principles and detailed procedures for the generation and optimization of TPC topologies are presented. Based on these works, a family of nonisolated TPC topologies is developed.

J. Zeng, W. Qiao, L. Qu, Member, and Y. Jiao, “**An isolated multiport DC-DC converter for simultaneous power management of multiple different renewable energy sources ,**” *IEEE Trans. Emerg. Sel. Topics Power Electron.*, vol. 2, no. 1, pp. 70-78, Mar. 2014.

The dc-dc converter only uses one controllable switch in each port to which a source is connected. Therefore, it has the disadvantage of more number of power switches while compared with proposed system. The converter is applied for simultaneous maximum power point tracking (MPPT) control of a wind/solar hybrid generation system consisting of one wind turbine generator (WTG) and two different photovoltaic (PV) panels.

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F. Nejabatkhah, S. Danyali, S. Hosseini, M. Sabahi, and S. Niapour, "Modeling and control of a new three-input DC-DC boost converter for hybrid PV/FC/battery power system," *IEEE Trans. Power Electron.*, vol. 27, no. 5, pp. 2309-2324, Feb. 2014.

The converter interfaces two unidirectional input power ports and a bidirectional port for a storage element in a unified structure. This converter is interesting for hybridizing alternative energy sources such as photovoltaic (PV) source, fuel cell (FC) source, and battery. Supplying the output load, charging or discharging the battery can be made by the PV and the FC power sources individually or simultaneously.

R. Wandhare and V. Agarwal, "Novel integration of a PV-wind energy system with enhanced efficiency," *IEEE Trans. Power Electron.*, vol. 30, no. 7, pp. 3638-3649, Jul. 2015.

The proposed scheme uses both the grid- and rotor-side power converters of doubly fed induction generator to inject PV power into the grid. The system is able to feed significantly large PV power into the grid compared to an equivalent rating inverter used in the conventional PV-grid system.

L. Kumar and S. Jain, "A multiple input dc-dc converter for interfacing of battery/ultracapacitor in EVs/HEVs/FCVs," in *Proc. IEEE IICPE, 2012*, pp. 1-6.

A non-isolated bidirectional multiple input dc-dc converter is presented to interface a battery and an ultracapacitor for vehicular applications. The proposed converter is capable of drawing power from multiple energy sources to supply the demand of vehicle loads. The presented converter has bidirectional capability.

III. PROPOSED SYSTEM

The proposed converter consists of a transformer coupled boost half-bridge bidirectional converter and voltage doubler fused with bidirectional buck-boost converter and a three-phase full-bridge inverter. The proposed converter has reduced number of power conversion stages with less component count and high efficiency compared to the existing grid-connected schemes. The topology is simple and needs only four power switches. The boost half-bridge converter and voltage doubler has two dc-links on both sides of the high frequency transformer. Controlling the voltage of one of the dc-links ensures controlling the voltage of the other. Moreover, additional converters can be integrated with any one of the two dc-links. A bidirectional buck-boost dc-dc converter is integrated with the primary side dc-link and three-phase fullbridge bidirectional converter is connected to the dc-link of the secondary side. The input of the half-bridge converter is formed by connecting the PV array in series with the battery, thereby incorporating an inherent boosting stage for the scheme. The boosting capability is further enhanced by a high frequency step-up transformer. The transformer also ensures galvanic isolation to the load from the sources and the battery. Bidirectional buckboost converter is used to harness power from PV along with battery charging/discharging control. The unique feature of this converter is that MPP tracking, battery charge control and voltage boosting are accomplished through a single converter. Transformer coupled boost half-bridge converter is used for harnessing power from wind, voltage doubler is used doubling the voltage and a three-phase full-bridge bidirectional converter is used for feeding ac loads and interaction with grid. The proposed converter has reduced number of power conversion stages with less component count and high efficiency compared to the existing grid-connected converters. The power flow from wind source is controlled through a unidirectional boost half-bridge converter. For obtaining MPP effectively, smooth variation in source current is required which can be obtained using an inductor. In the proposed topology, an inductor is placed in series with the wind source which ensures continuous current and thus this inductor current can be used for maintaining MPP current. When switch T₃ is ON, the current flowing through the source inductor increases. The capacitor C₁ discharges through the transformer primary and switch T₃. In secondary side capacitor C₃ charges through transformer secondary and anti-parallel diode D₅. When switch T₃ is turned OFF and T₄ is turned ON, initially the inductor current flows through antiparallel diode of switch T₄ and through the capacitor bank. During this interval, the current flowing through diode decreases and that flows through transformer primary increases. When current flowing through the inductor becomes equal to that flowing through transformer primary, the diode turns OFF. Since, T₄ is gated ON during this time, the capacitor C₂ now discharges through switch T₄ and transformer primary. During

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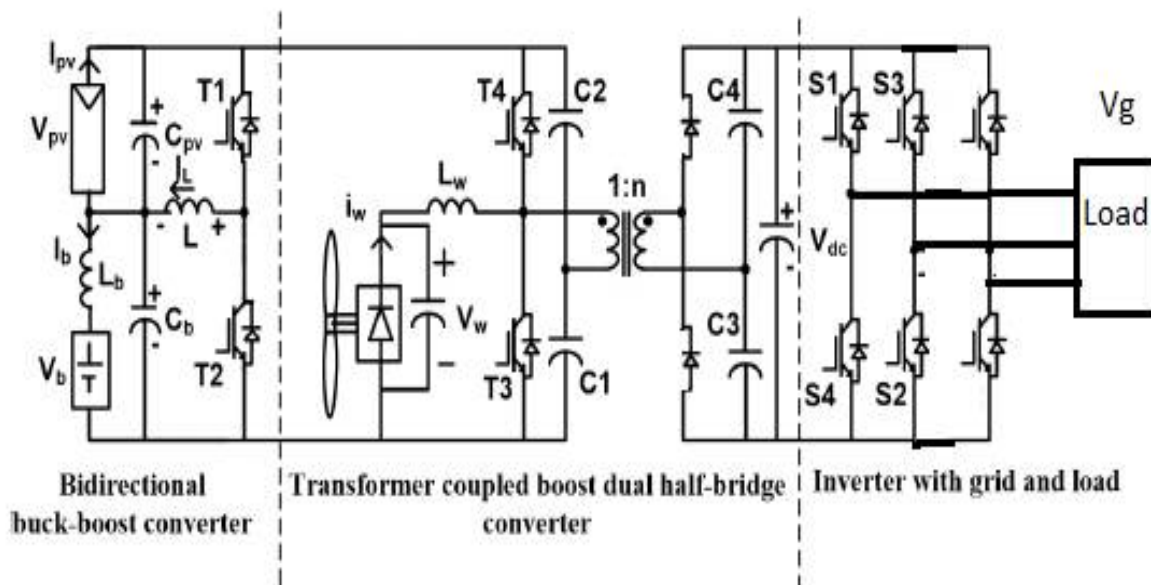
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the ON time of T₄, anti-parallel diode D₆ conducts to charge the capacitor C₄. The path of current flow is shown in Fig. 2(d). During the ON time of T₃, the primary voltage $V_p = -VC_1$. The secondary voltage $V_s = nV_p = -nVC_1 = -VC_3$, or $VC_3 = nVC_1$ and voltage across primary inductor L_w is V_w . When T₃ is turned OFF and T₄ turned ON, the primary voltage $V_p = VC_2$. Secondary voltage $V_s = nV_p = nVC_2 = VC_4$ and voltage across primary inductor L_w is $V_w - (VC_1 + VC_2)$. It can be proved that $(VC_1 + VC_2) = V_w(1 - D_w)$. The capacitor voltages are considered constant in steady state and they settle at $VC_3 = nVC_1$, $VC_4 = nVC_2$.

Therefore, the output voltage of the secondary side dc-link is a function of the duty cycle of the primary side converter and turns ratio of transformer. In the proposed configuration as shown in Fig. 2(a), a bidirectional buck-boost converter is used for MPP tracking of PV array and battery charging/discharging control. Further, this bidirectional buck-boost converter charges/discharges the capacitor bank C₁-C₂ of transformer coupled half-bridge boost converter based on the load demand. The half-bridge boost converter extracts energy from the wind source to the capacitor bank C₁-C₂. During battery charging mode, when switch T₁ is ON, the energy is stored in the inductor L. When switch T₁ is turned OFF and T₂ is turned ON, energy stored in L is transferred to the battery. If the battery discharging current is more than the PV current, inductor current becomes negative. Here, the stored energy in the inductor increases when T₂ is turned on and decreases when T₁ is turned on. It can be proved that $V_b = D_1 - DV_{pv}$. This voltage is n times of primary side dc-link voltage. The primary side dc-link voltage can be controlled by half-bridge boost converter or by bidirectional buck-boost converter. The relationship between the average value of inductor, PV and battery current over a switching cycle is given by $I_L = I_b + I_{pv}$. It is evident that, I_b and I_{pv} can be controlled by controlling I_L . Therefore, the MPP operation is assured by controlling I_L , while maintaining proper battery charge level. I_L is used as inner loop control parameter for faster dynamic response while for outer loop, capacitor voltage across PV source is used for ensuring MPP voltage.

Circuit Diagram :



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IV. INTRODUCTION TO MATLAB TOOL

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include

- Math and computation
- Algorithm development
- Data acquisition
- Modeling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics
- Application development, including graphical user interface building

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar non interactive language such as C or Fortran.

The name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects. Today, MATLAB engines incorporate the LAPACK and BLAS libraries, embedding the state of the art in software for matrix computation

MATLAB has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science. In industry, MATLAB is the tool of choice for high-productivity research, development, and analysis.

MATLAB features a family of add-on application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow you to learn and apply specialized technology. Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, and many others.

V. THE ROLE OF SIMULATION IN DESIGN

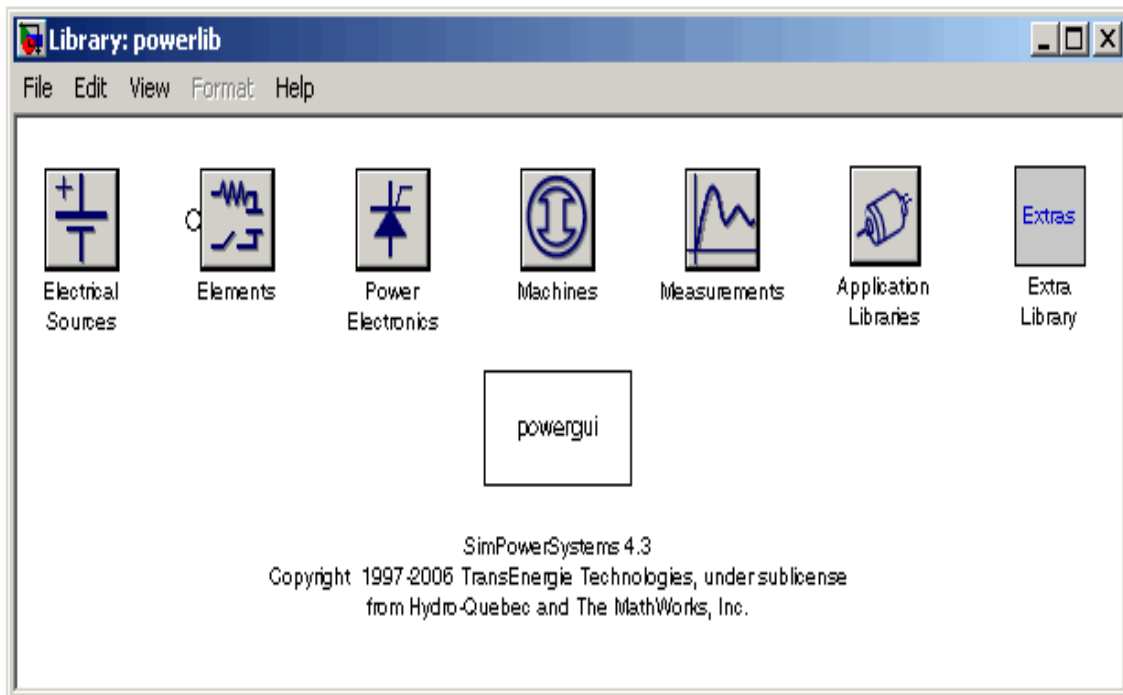
Electrical power systems are combinations of electrical circuits and electromechanical devices like motors and generators. Engineers working in this discipline are constantly improving the performance of the systems. Requirements for drastically increased efficiency have forced power system designers to use power electronic devices and sophisticated control system concepts that tax traditional analysis tools and techniques. Further complicating the analyst's role is the fact that the system is often so nonlinear that the only way to understand it is through simulation. Land-based power generation from hydroelectric, steam, or other devices is not the only use of power systems. A common attribute of these systems is their use of power electronics and control systems to achieve their performance objectives. SimPower Systems is a modern design tool that allows scientists and engineers to rapidly and easily build models that simulate power systems. SimPower Systems uses the Simulink environment, allowing you to build a model using simple click and drag procedures. Not only can you draw the circuit topology rapidly, but your analysis of the circuit can include its interactions with mechanical, thermal, control, and other disciplines. This is possible because all the electrical parts of the simulation interact with the extensive Simulink modeling library. Since Simulink uses MATLAB® as its computational engine, designers can also use MATLAB toolboxes and Simulink blocksets. SimPower Systems and Sim Mechanics share a special Physical Modeling block and connection line interface.

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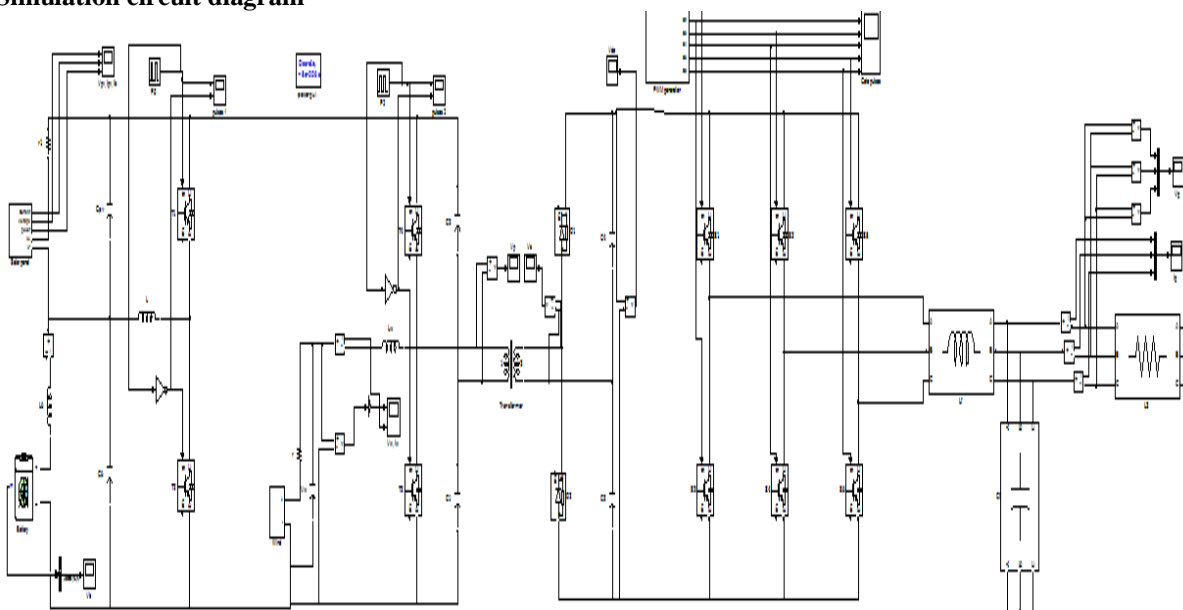
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Proposed simulation results Mode - 1 Simulation circuit diagram



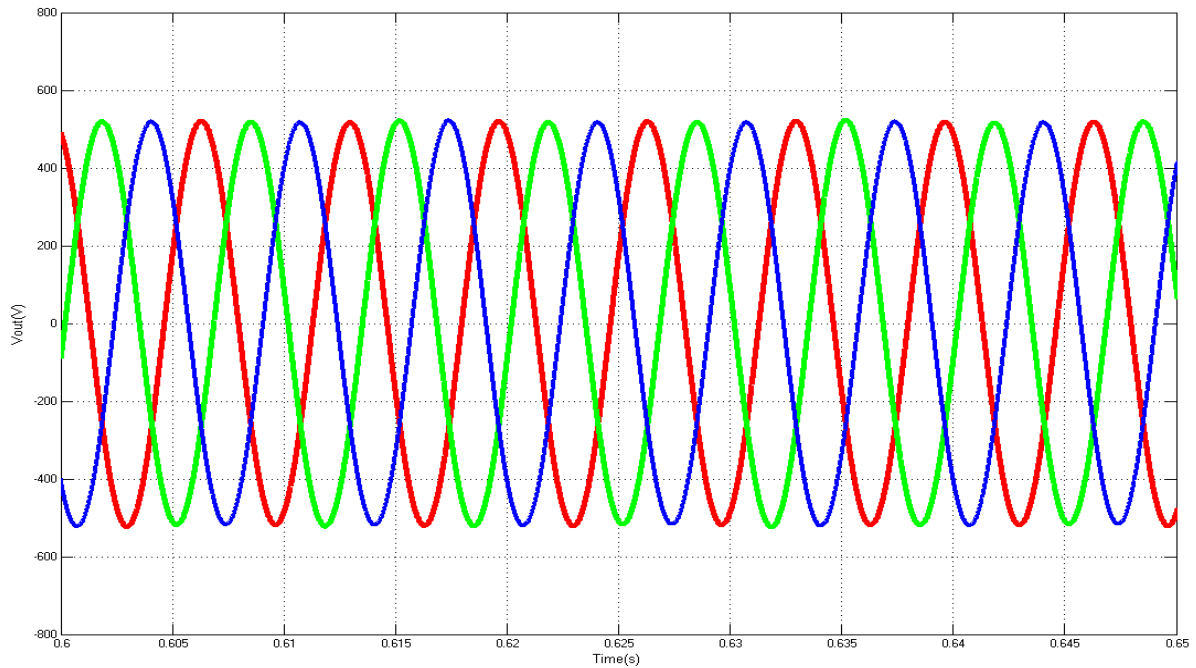
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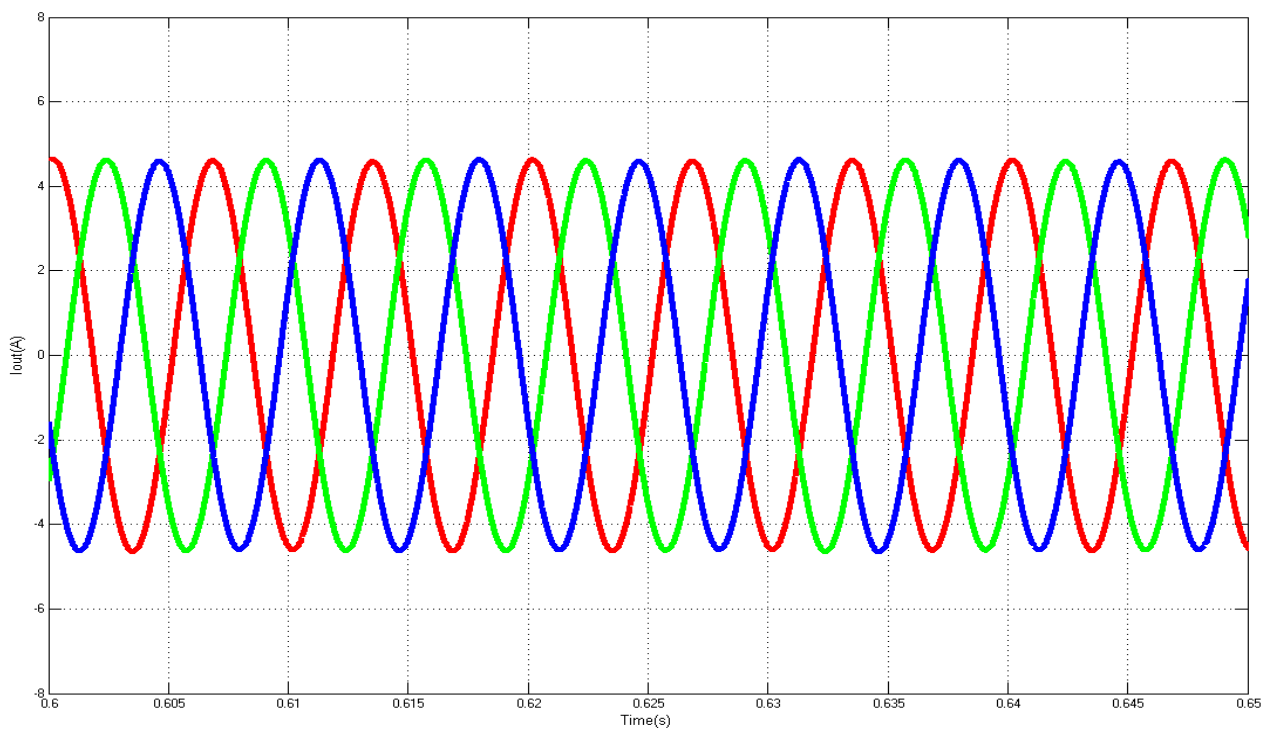
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Output voltage



Output current



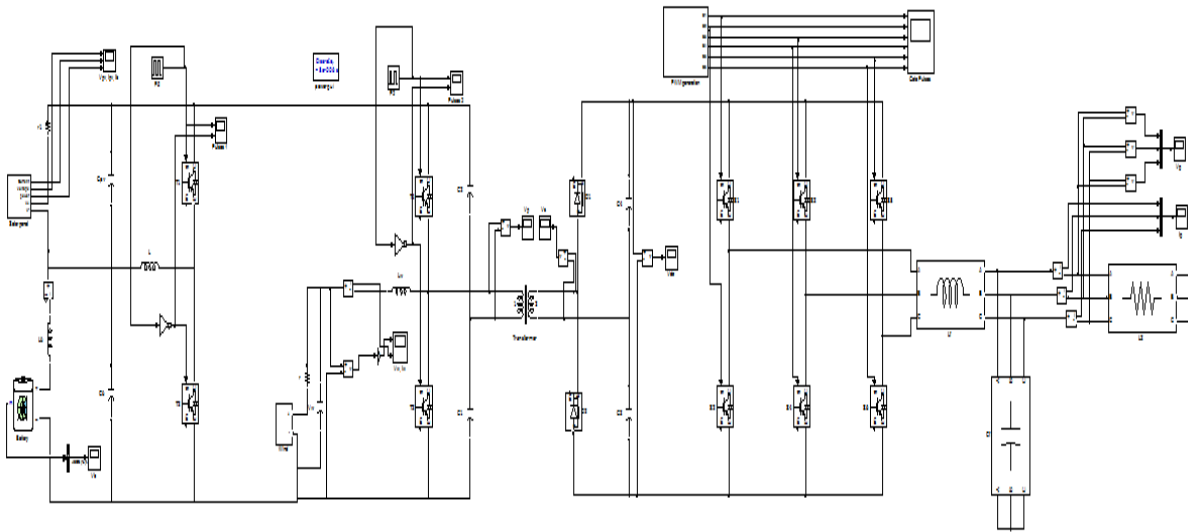
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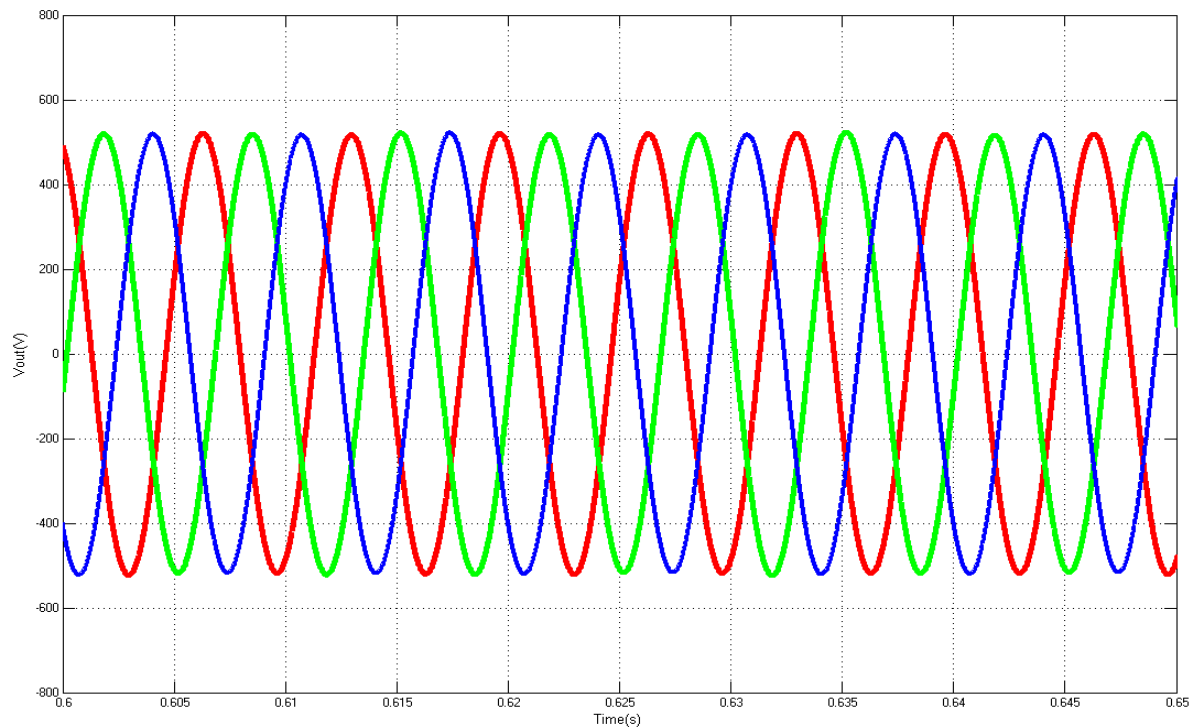
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Mode – 2 Simulation circuit diagram



Output voltage



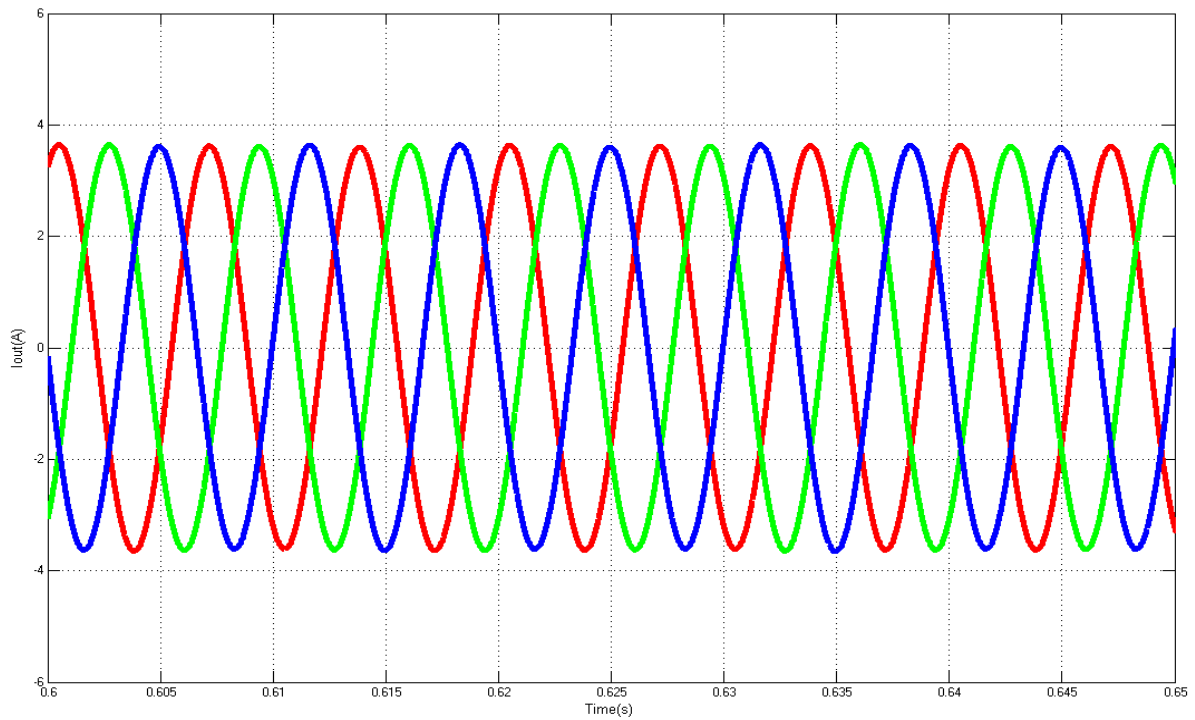
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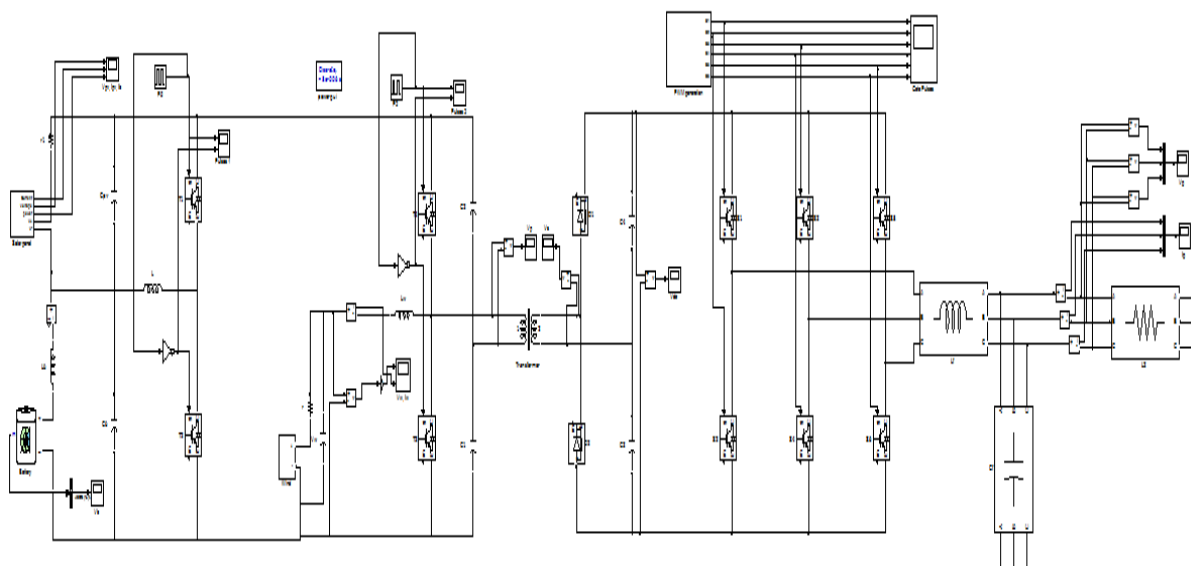
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Output current



Mode - 3 Simulation circuit diagram



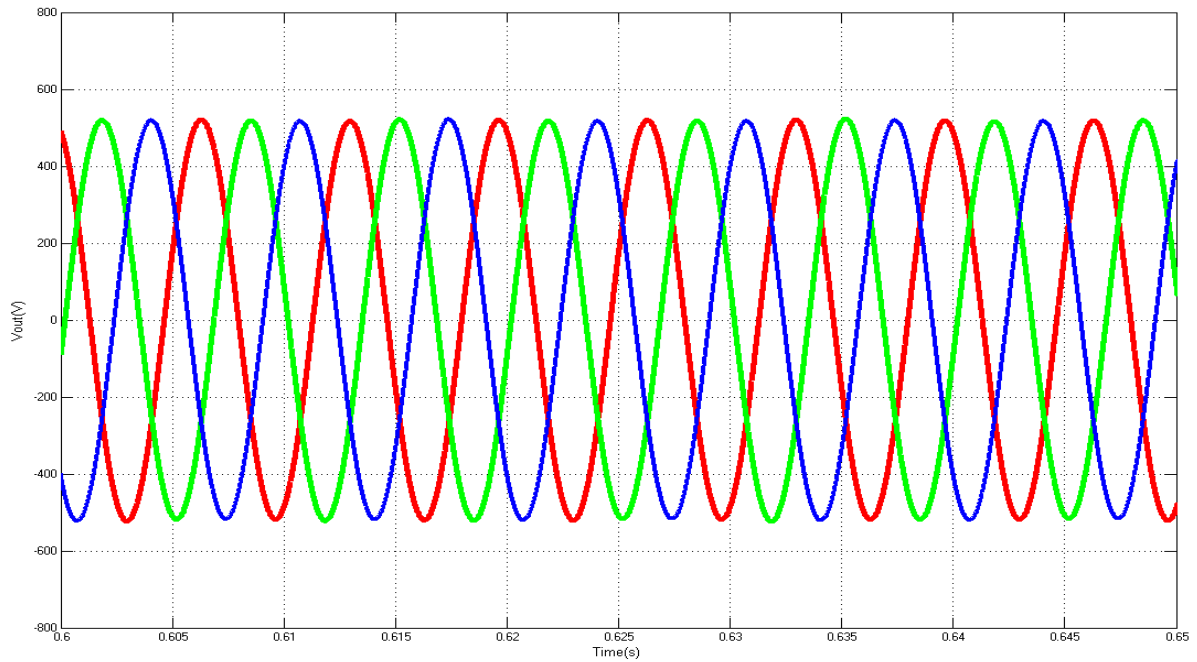
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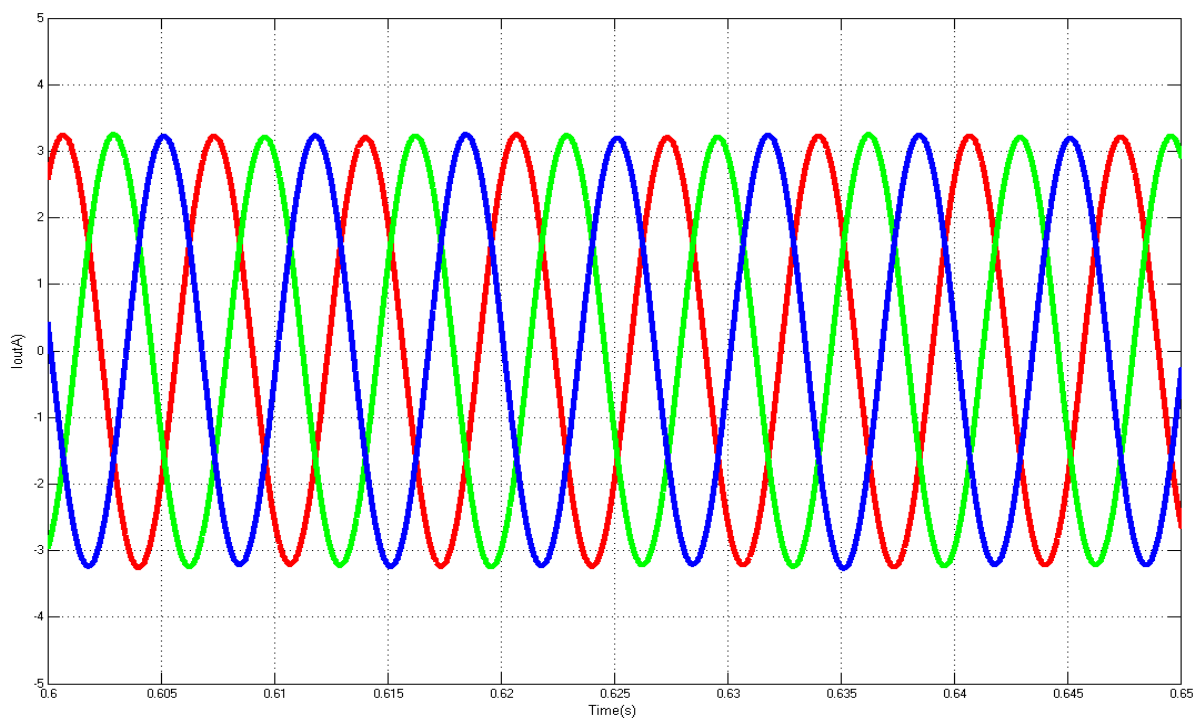
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Output voltage



Output current



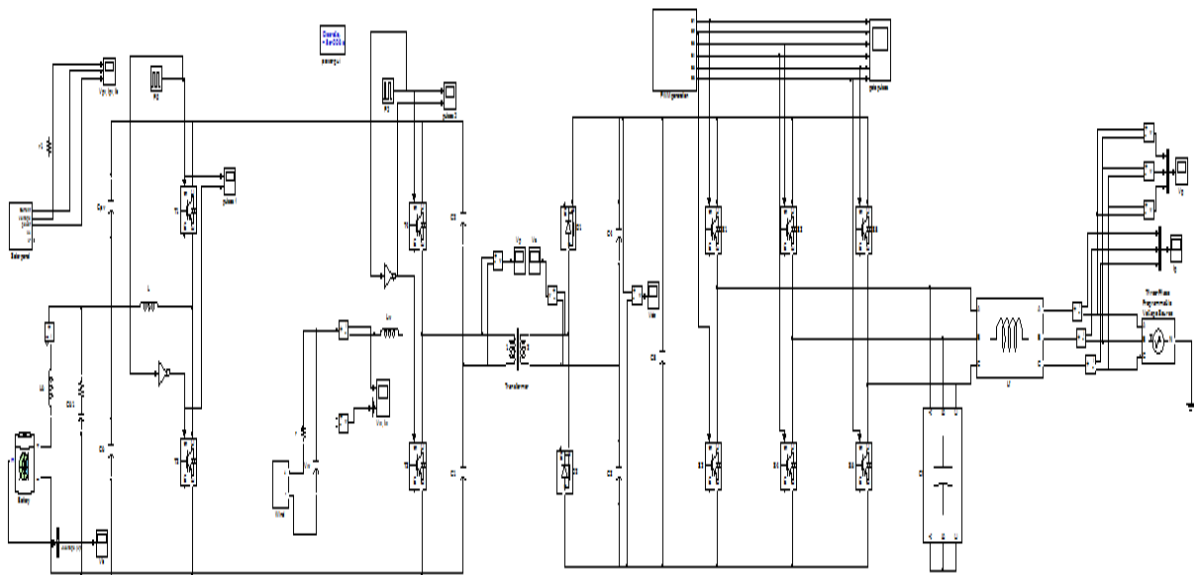
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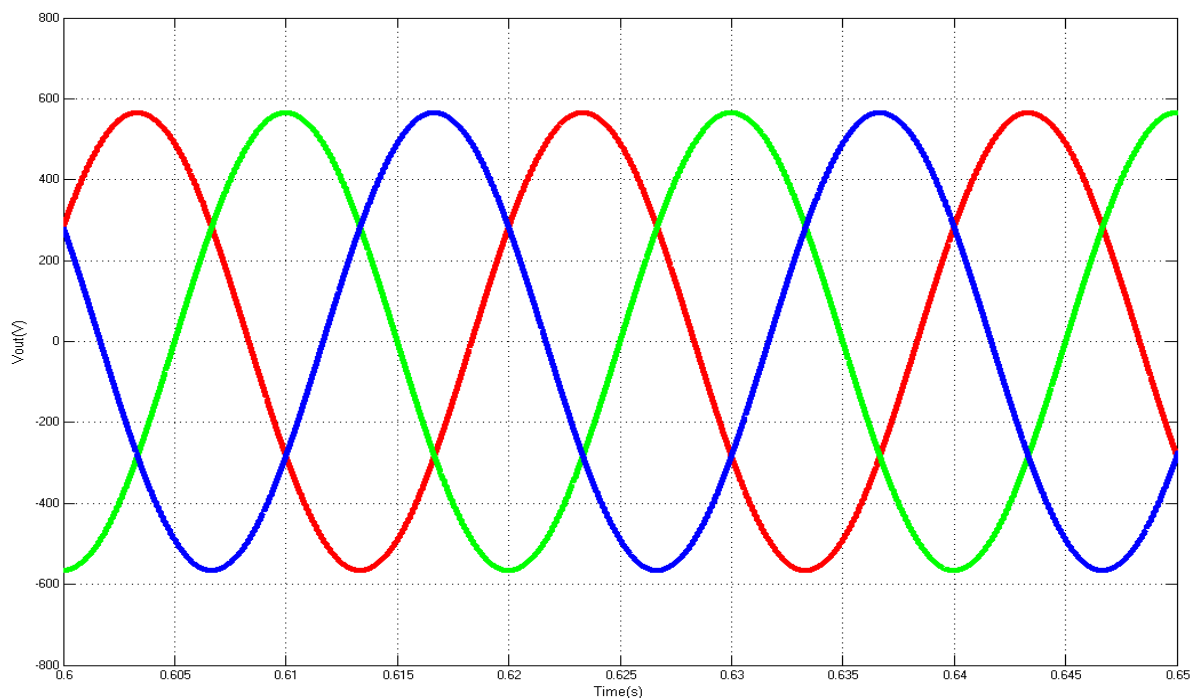
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Mode – 4 Simulation circuit diagram



Output voltage



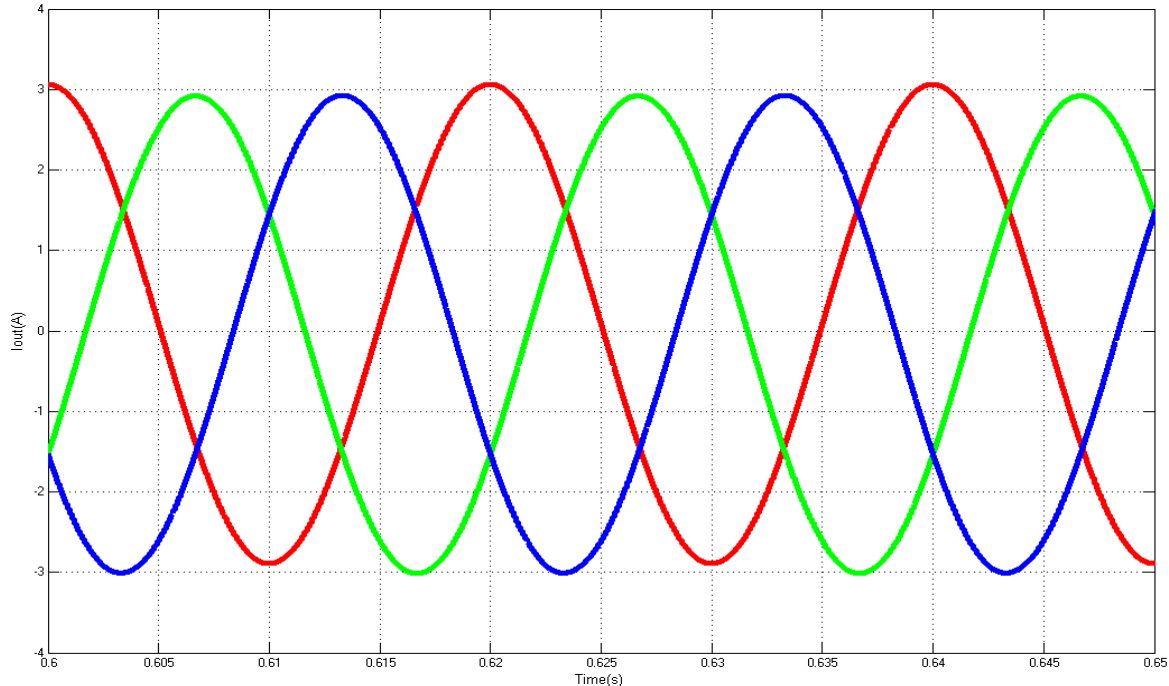
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Output current



VI. CONCLUSION

A novel 3phase-inverter, which consists of multiple distributed BBCs and a Voltage Doubler using PV and wind source , for the battery energy storage system has been proposed in this paper. The proposed 3phase-inverter has individual power control capability for each battery module while fulfills the functions of battery charging and discharging by using pulsating current. Eventually, the equalization, lifetime extension, and capacity flexibility of the battery energy storage system can be achieved. According to the developed mathematical equations, the power control capability of each individual battery module can be achieved without the need of input current sensor. Also, with the interleaved operation, the current ripple of the output inductor can be reduced significantly. A design guide line of the proposed 3phase-inverter is presented. Finally, matlab simulations and hardware measurements are shown to verify the validity of the proposed 3phase-inverter.

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