ISSN (Print) : 0974-6846
Indian Journal of Science and Technology, Vol 9(38), DOI: 10.17485/ijst/2016/v9i38/101956, October 2016 ISSN (Online) : 0974-5645

A Control Methodology of Bidirectional Converter for Grid Connected Systems

Sarat Kumar Sahoo[1]*, Dhaval Patel[1], M. Balamurugan[1] and Ashwin Kumar Sahoo[2]

[1]School of Electrical Engineering, VIT University, Vellore - 632014, Tamil Nadu, India; sksahoo@vit.ac.in, dhavelele@gmail.com, balamurugan.mano@vit.ac.in
[2]Department of EEE, SSN College of Engineering, Chennai - 603110, Tamil Nadu, India; ashwinsahoo@ssn.edu.in

Abstract

Objectives This paper proposes a control methodology of bidirectional Converter for grid connected systems. **Methods/ Statistical Analysis**: The bidirectional converter is used for converting the DC-AC power by using decoupled current control strategy in stationary reference frame. The simulations of the proposed system are carried out in PSIM software. An experimental prototype of Bidirectional converter has been built in the laboratory. A TMS320F28335 digital signal processor (DSP) is used for generating the control pulses for the Converter. **Findings:** The control of grid converter along with battery backup would provide support to the grid. Thus the proposed control strategy could independently control active and reactive power and also able to avoid grid failures. **Application/Improvements:** Reduction of operating switching frequency, improved dynamics as well as robustness against grid impedance variation are some of the improvements of proposed system.

Keywords: Battery, Bidirectional Converter, DSP, Grid, PSIM

1. Introduction

The solar and wind based power plants are increased in exponential manner. The biggest disadvantage of renewable energy sources is unexpected changes in output. The output of these sources particular wind output changes with weather and available wind speed. This change in output effects on the frequency and voltage variation of the grid load bus. For that reason there is a challenge in connection of these renewable energy sources to the grid system[1]. There is one solution this problem is to make this wind farm output smooth for throughout the time. The output could be smooth with use of battery based large energy storage system. This system works as source/ sink and helps to the grid for its stability and makes grid power quality battery. This system will work as source when there is demand of power from the grid side and it will work as sink when there is excess power is available in the grid. This is complementary and available optimal solution for high efficiency and high power demand of the grid with it is able respond rapidly to the changes in grid side[2,3]. For connection of large battery based system to the grid there are different converter topologies[4]. These converter topologies basically divided into two parts. One is directly connected one stage conversion topology and other is two stage based converter topology. In two stage topology there is use of dc to dc converter which works as battery charger and discharger, but use one extra converter efficiency of the overall system gets reduced[5]. For low voltage application there is two- level H-bridge inverter is used as single stage converter[6,7]. This converter topology improves system efficiency, but due to variations in output voltage of the battery there is variation in DC-link voltage of the converter. To maintain battery voltage minimum more than grid voltage so it could feed power to the grid up to its gets discharged[8,9]. This grid converter single stage operation works as PWM rectifier in charging mode and as inverter in battery discharging mode. The Circuit diagram of the classical two level bidirectional grid converter is shown in Figure 1. The

*Author for correspondence

converter with switching and control methodology works as inverter as well as rectifier. In rectification mode it will work as boost rectifier which will boost output DC-link voltage across the battery.

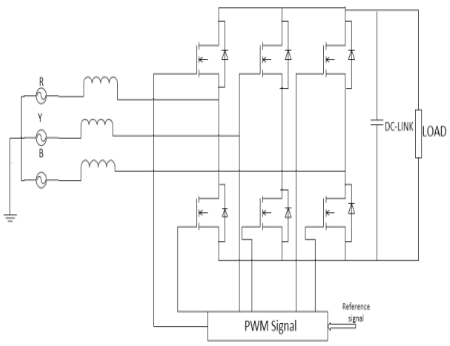

Figure 1. Bidirectional grid converter.

Grid converter's current control technique is the base of overall control of the converter. There are different current control strategies available for control of grid converter. These techniques are classified as Natural Frame control, Synchronous Frame based control, and Rotating Frame based control, Hysteresis control and Direct Power control[10,11].

2. System Description

The system description involves explanation of the system block diagram and about design of Passive components of the system. The block diagram of the system is shown in Figure 2. The circuit diagram shows L-C-L filter with bidirectional converter and also shows the controller side consists of DSP based controller for overall control of the system. The inrush current protection circuit with the single switch based brake system which is essential in

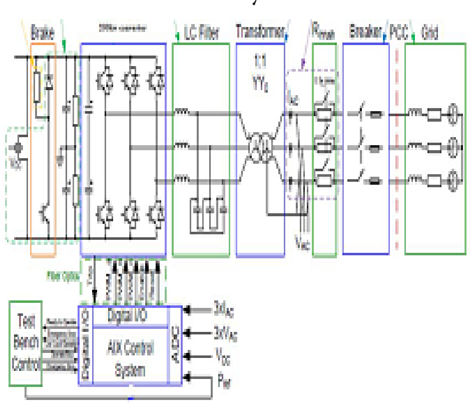

Figure 2. Circuit diagram of the proposed system.

protection of battery. This will stop flowing of more current into the battery while it is getting charged.

Design of different parameters is the essential part of converter based system. For this converter system there are few parameters which are need to address before its application, those are selection of DC-link Voltage, design of DC-link Capacitor and design of L-C-L filter for smooth output/input current flowing from the converter.

2.1 Selection of DC Link Voltage

In single converter based static energy storage system the DC link voltage of converter gets fluctuates according to the battery state of charge condition and battery charge or discharge mode. For that purpose DC-link has to withstand this wide range of fluctuating voltage.

For lead acid battery there is 15% variation in the battery voltage according to its SOC. For the converter operation minimum battery voltage must be selected which is sufficient to inject current into the grid while its get discharged. For that minimum dc-link voltage is selected as per given in (1).

$$V_{\min} = \sqrt{2} * V_{LL,PCC} = 585V \qquad (1)$$

The voltage drop on coupling transformer as well as on the grid filter side has to be considered while deciding DC link voltage of the converter. The battery voltage when its gets charged at 15% higher than nominal then 10% safety margin for the converter operation is considered as per the maximum DC-link voltage shown in (2).

$$V_{DC,\max} = 1.25 * \sqrt{2} * V_{LL,PCC} \qquad (2)$$

2.2 Selection of DC Link Capacitor

The sizing of DC-link capacitor is an important aspect of converter operation. In single stage conversion DC-link will get large variation in input DC voltage so the Capacitor value must be designed as per the condition. The general approach for design of DC-link capacitor value includes ripple in charge of capacitor and ripple in voltage across DC-link is shown in (3).

$$C_{\min} = \frac{\Delta Q_{c\max}}{\Delta V_{dc\max}} = 9.8mF \qquad (3)$$

2.3 Design of LCL Filter

The L output filter design is considered to maintain output current ripple must be maintaining within 5% THD limit. In this section involves design of the L-C-L filter for the switching frequency of and grid frequency. For design of filter the converter has to maintain voltage drop should not be exceed 12%. The following equations for the design of filter components. The design of total inductance required for filter is shown in (4).

$$L_{TOTAL} = \frac{V_r * (voltagedropofinductor)}{\sqrt{3} * I_r * 2 * 3.14} \quad (4)$$

Here V_r = rated voltage of system, I_r = rated rms of the system

From the rated voltage drop of the system one could decide how much smooth output current feed or draw from the grid. With more voltage drop output current will get smooth but it will increase the system losses. To find optimize solution to get smooth current with optimize voltage drop. Grid side chock (L_g) is directly connected to the converter side which will have more harmonics in the output side. Its value should select between 60% to 80%. and decoupling (L_d) choke is connected to the grid side and its value should select between 40% to 20%. Equation for the design of filter capacitor is shown in (5).

$$C_f = \frac{(L_d + L_g)}{((f_r * 2\pi)^2 * L_d * L_g)} \quad (5)$$

C_f=filter capacitor, L_d=decoupling choke, L_g=grid chock, F_r=ringing frequency.

Here ringing frequency must be selected between 10 times more than fundamental frequency and it should not more than half of the switching frequency. This ringing frequency selection will decide the size of the filter capacitor, and also decide how much higher frequency components are removed from the system.

3. Control Strategy of Grid Converter

The control strategy for the control of grid converter in both rectifier and inverter mode is based on the stationary reference frame (d-q)[12] is shown in Figure 3.For the testing of the converter the reference power is to which is following in or out from the battery. This will decide on the basis of battery state of charge and voltage balance and grid monitoring system output condition. To maintain dc link voltage constant so one parameter is used for the current flow from the converter which will control the operation of the converter.

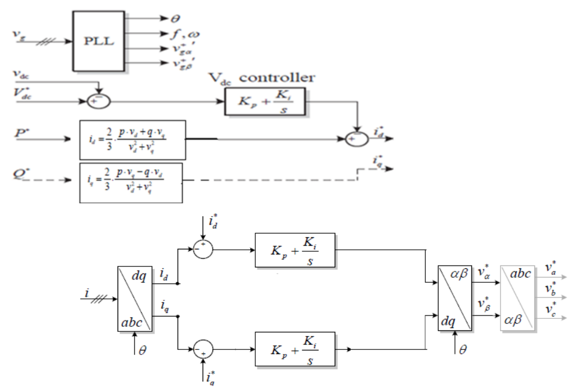

Figure 3. Control strategy of grid converter.

The reference dc link voltage which acts on the active Current exchange with the grid while the active power reference given by the reference control improves the controller transient response. In the control structure PLL (phase lock loop) will give control over converter's synchronization with the grid which will give phase synchronization angle (θ).which will use in different reference frame transformation[13].

In the operation of converter the reference active and reactive power will decide the mode of operation. From Figure 3 the equation can be written which will decide the reference current for the different mode of operation. The reactive current could be controlled with the feed-forward term. This reactive current control would support to maintain grid voltage within the predefined limit. For the current control there are several possibilities with respect to the chosen reference frame in the case of linear controllers, hysteresis control or predictive control. The synchronous frame control (d-q) was used in this work since it provides the following advantages. In the synchronous reference frame we would get independent control over active and reactive components[14]. This will allow us to control quantities in dc quantities which will very easily controllable with use of PI controller. The mean part of control strategy is to get Id and Iq components from the reference active and reactive power which will decide flow of current from the converter.

$$I_d = \left(\frac{2}{3}\right) * \frac{PV_d + QV_q}{V_d^{\,2} + V_q^2} \tag{6}$$

$$I_q = \left(\frac{2}{3}\right) * \frac{PV_q + QV_d}{V_d^2 + V_q^2} \tag{7}$$

where P&Q are reference values. V_d and V_q are grid side voltage d-q components.

From (6) & (7) the reference current has decided from that the control system current has been able to follow that value.

4. Simulation Results

The control strategy in Figure 3 was implemented in PSIM software tool. The results are presented for simulation parameters given into the Table1. The whole system is simulated in PSIM software tool environment and the simulation diagram is shown in Figure 4. The simulation circuit shows grid converter with L-C-L filter to the grid. This system includes three current sensors f or sensing of grid current and three voltage sensors for sensing of grid voltage and one voltage sensor for sensing of DC-link voltage.

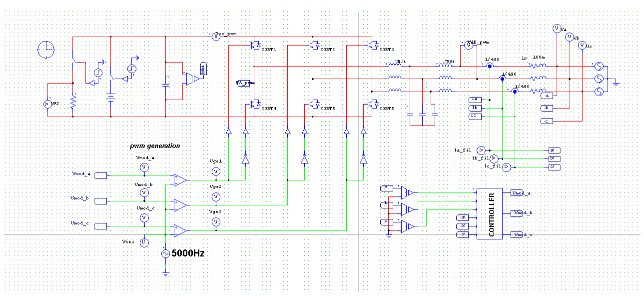

Figure 4. Simulation diagram of proposed system.

Table 1. Simulation parameters

S.No	Parameters	Values
1	Load Voltage	415 V
2	Output Frequency	50 Hz
3	DC Link Voltage	720 V
4	Converter side Inductor (L_d)	78.5 uH
5	Filter Capacitor (C_f)	104 uF
6	Grid side Inductor (L_g)	107.1 uH
7	Carrier Frequency	5000 Hz
8	DC Link Capacitor	9.8 mF

The sensors output are converted into the per unit system, and then given to the controller for implementation of control strategy for converter operation. In the converter operation first task of controller to converts grid parameters into the rotating frame based d-q components and then process further for implementation of control logic.

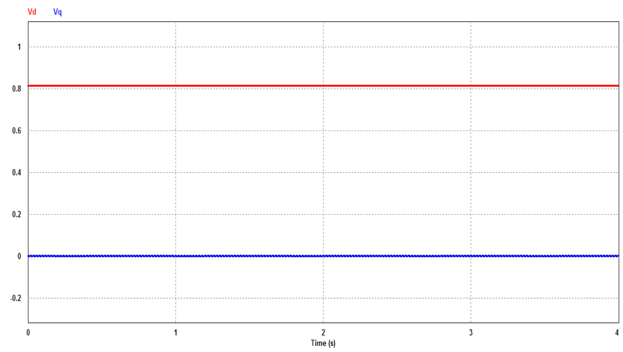

Figure 5. Voltage d-q component.

d-q components of grid voltage sensing transformation is shown in Figure 5. which are used for controlling of the output power flow in or out from the dc link side. The d component value is near equal to the unity value and q-component value is near to the zero value.

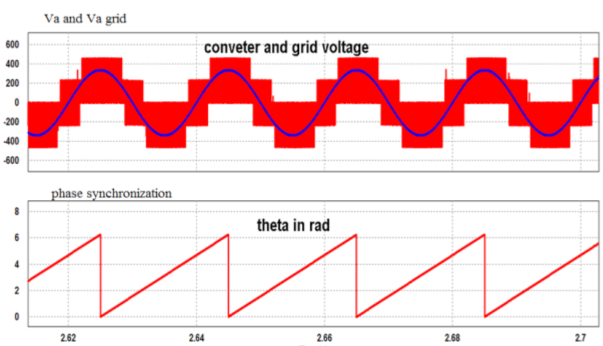

Figure 6. Grid synchronization.

Output theta (θ) in radian which used for synchronization is shown in Figure 6. Converter with grid for inverter as well as rectification mode would see that synchronization of output voltage and grid voltage both are in phase with each other. With this method by using zero crossing detection for grid side sensing that will decide when the converter will get synchronized with grid. In this system this synchronization process gets happen within one cycle of operation. Current d-q components is shown in Figure 7. The tracking of output current d-q components with reference d-q. The active component get changed from negative value to the positive value which shows transformation of converter operation from rectifier mode to the inverter mode. And like that it also shows change in reactive current flow direction. From the waveforms it is clear that control strategy works perfectly and it follows whatever reference current and its direction change with requirement of charging/discharging of the battery.

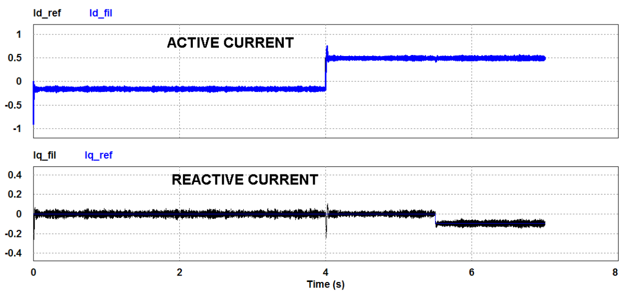

Figure 7. Active and reactive current.

Power flow of the whole system is shown in Figure 8. The reference power changes from negative to positive as per that our system or controller output also tries to follow that power reference. Active as well as whatever reactive power changes our system is capable of following to those changes with fast and accurate manner. So the output power will have minimum fluctuations in output power and current.

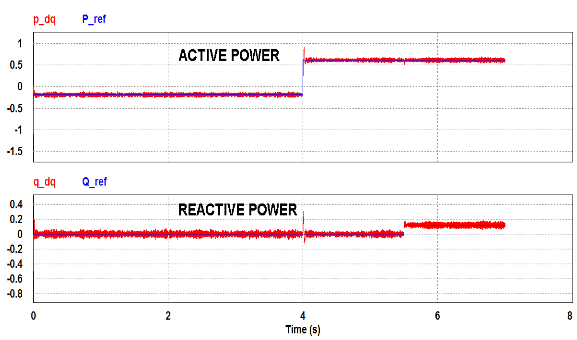

Figure 8. Power flow.

Converter output current and grid voltage waveforms for the operation of rectification and inversion is shown in Figure 9. In the rectification mode both voltage and current in the 180 degree phase shift and in the inverter mode both are in phase with each other.

Addition of reactive power to the system is shown in Figure 10. This reactive power compensation is additional feature of grid connected storage system.

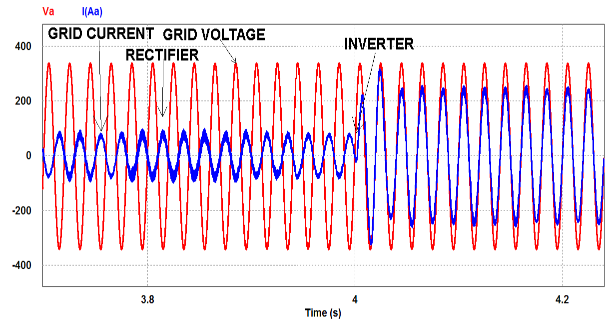

Figure 9. Grid voltage and current.

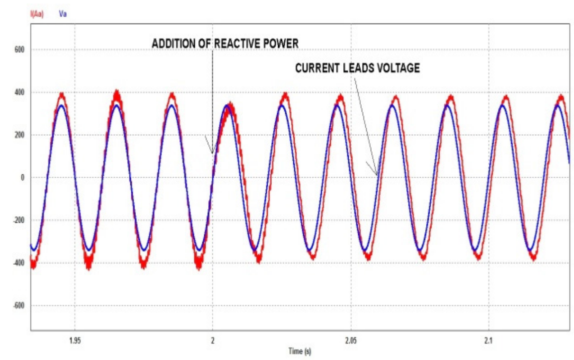

Figure 10. Addition of reactive power.

This will help in maintaining grid voltage and frequency within limits with works as reactive power source and sink.

5. Hardware Implementation

The grid connected energy storage system is implemented in hardware system, with use of Texas Instrument TMS320F28335 based controller system. The specifications are presented for following parameters is shown in Table 2.

Table 2. Hardware parameters

S.No	Hardware Components	Specifications
1	System Specification	Input Voltage=230 V Output Voltage=350 V System Current=50 A
2	IGBT	Mitsubishi IGBT Module CM400DY=24nF Rating-=200 V&400 A
3	LCL Filter	L_d=295uH, L_g=126uH, C_f=45uF

S.No	Hardware Components	Specifications
4	DC-Link Capacitor	9.8mF & 400 V

Hardware setup of grid tied bidirectional converter is shown in Figure 11.

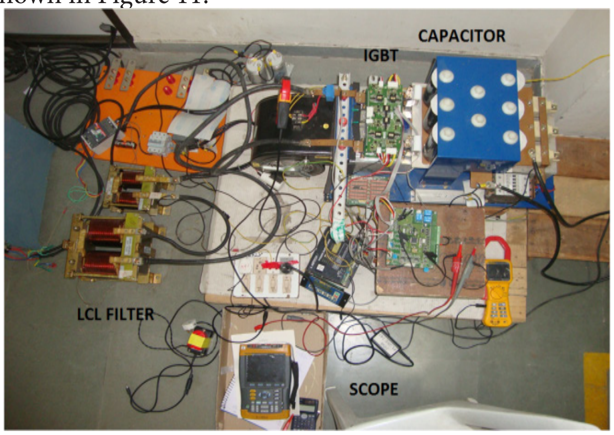

Figure 11. Hardware setup.

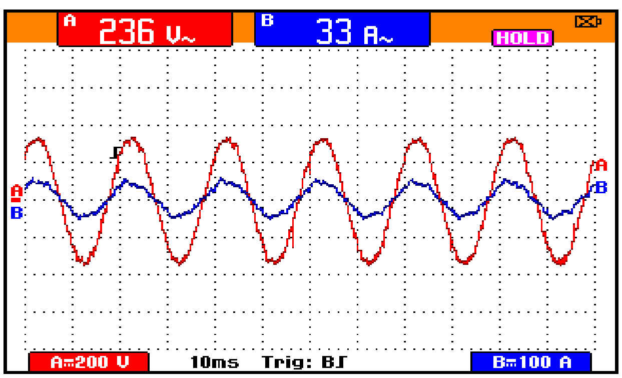

Figure 12. Rectification mode.

Rectification mode of operation of converter is shown in Figure 12. The waveform shows both current and voltage are in same phase with each other.

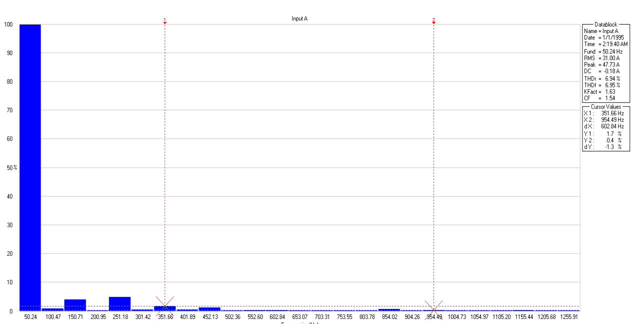

Figure 13. THD analysis.

THD analysis of current is shown in Figure 13. It shows current THD is within specified limits of standards. This shows output or input current from the grid side into the converter is sinusoidal. This will not create any distortions into the grid side supply system.

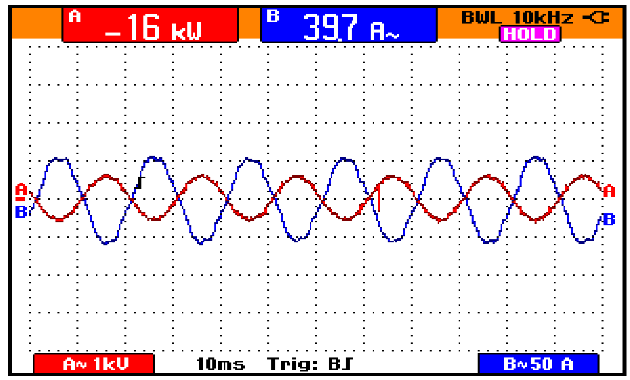

Figure 14. Inverter mode.

Current and Voltage waveform for the grid feeding mode of operation is shown in Figure 14. The waveform shows battery discharging mode operation when converter works as inverter and feed power to the grid side.

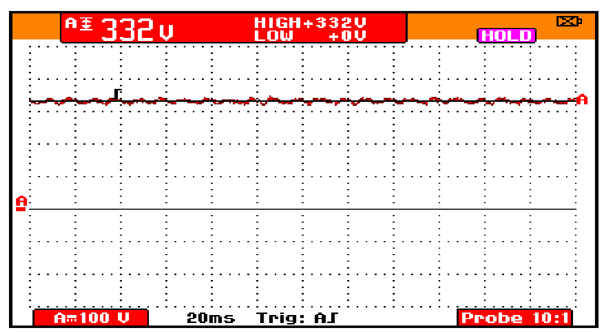

Figure 15. DC link voltage.

Voltage across DC-link side of the converter is shown in Figure 15. The voltage has to be maintaining constant to avoid switching stress on IGBT switches, because of variation in battery voltage form full charge condition to fully discharged condition.

6. Conclusion

In this paper the control strategy of bidirectional converter for grid connected system has been proposed. In order to inject a quality AC current into the grid, a bidirectional DC-AC converter was controlled in stationary reference frame. Simulation and experimental results shows that the control technique offers an excellent steady state response and low current harmonic distortion and also the current injected into the grid is in phase with the grid voltage.

7. Acknowledgement

The authors would like to acknowledge the financing support from Department of Science and Technology (DST), Government of India, Project No. DST/TSG/NTS/2013/59. This work has been carried out in Solar Energy Research Centre, School of Electrical Engineering, VIT University, Vellore, India.

8. References

1. Teodorescu R, Liserre M, Rodriguez P. Grid converters for photovoltaic and wind power systems. Wiley IEEE Press; 2011.
2. Teodorescu R, Blaabjerg F, Liserre M, Loh PC. Proportional resonant controllers and filters for grid-connected voltage-source converters. IEEE Proceedings on Electric Power Applications. 2006 Sep; 153(5):750–62.
3. Bavitra K, Sinthuja S, Manoharan N, Rajesh S. The high efficiency renewable PV inverter topology. Indian Journal of Science and Technology. 2015 Jul; 8(14):1–6.
4. Iov F, Blaabjerg F. Power electronics for renewable energy systems. Proceedings of International Conference on Power Engineering. Energy and Electrical Drives POWERENG; 2009. p. 9–12.
5. Sato Y, Ishizuka T, Nezu K, Kataoka T. A new control strategy for voltage type PWM rectifiers to realize zero steady-state control error in input current. IEEE Transactions on Industrial Applications. 1998 Jun; 34(3):480–6.
6. Trintis L, Nielsen SM, Teodorescu R. Single stage grid converters for battery energy storage. Proceedings of 5th International Conference on Power Electronics, Machines and Drives, UK; 2010 Apr. p. 1–6.
7. Pradeep M, Kumar MS, Sathiskumar S, Raja SH. Interleave isolated boost converter as a front end converter for solar/fuel cell application to attain maximum voltage in MATLAB. Indian Journal of Science and Technology. 2016 Apr; 9(16):1–5.
8. Trintis L, Nielsen SM, Teodorescu R. Cascaded H-bridge with bidirectional boost converters for energy storage. Proceedings of 14th European Conference on Power Electronics and Applications, Birmingham, UK; 2011 Aug–Sep. p. 1–9.
9. Prakash J, Sahoo SM, Sugavanam KR. Design of coordinated control scheme for hybrid resonant boost converter and multi level inverter. Indian Journal of Science and Technology. 2016 Mar; 9(11):1–11.
10. Zmood DN, Holmes DG, Bode GH. Frequency-domain analysis of three phase linear current regulators. IEEE Transactions on Industrial Applications. 2001 Apr; 37(2):601–10.
11. Babu PS, Ganesh C, Subbaiah PV. Improved droop control strategy for grid-connected inverters. Indian Journal of Science and Technology. 2015 Aug; 8(18):1–7.
12. Roiu D, Bojoi RI, Limongi LR, Tenconi A. New stationary frame control scheme for three-phase PWM rectifiers under unbalanced voltage dip conditions. IEEE Transactions on Industrial Applications. 2010 Jan; 46(1):268–77.
13. Timbus A, Teodorescu R, Blaabjerg F, Liserre M. Synchronization methods for three phase distributed power generation systems - An overview and evaluation. Proceedings of 36th Power Electronics Specialists Conferencce, PESC, Recife; 2005 Jun. p. 2474–81.
14. Ohnishi T. Three phase PWM converter/inverter by means of instantaneous active and reactive power control. Proceedings of IEEE International Conference on Industrial Electronics, Control and Automation IECON, KOBE; 1991 Oct–Nov; 1:819–24.