Chapter

Implement Using KY Converter for Hybrid Renewable Energy Applications: Design, Analysis, and Implementation

Pushpavalli Murugan and Jothi Swaroopan Nesa Mony

Abstract

This chapter mainly focuses on meeting the energy demand and methodologies of renewable energy. Nowadays, researchers are mainly focusing on renewable energy from the sun, wind, biomass, etc. due to energy crises and the lack of non-renewable energy. The potential for solar energy is high and this demand can best be met with hybrid systems, which can provide an uninterruptible power supply. This chapter looks at the performance metrics of hybrid energy as well as the methodologies and various control techniques connected with power management. The chapter also defines the photovoltaic (PV)-based, novel, dual KY boost converter. Dual PV sources act as input for the dual KY boost converter to generate as much energy as possible from the dual PV system, using the inverter module to produce single-phase alternating current output. A dual KY boost converter can provide higher maximum power, a faster response, and smaller voltage ripple. KY boost converters are designed to generate stable output values according to various conditions because of various control techniques and the maximum power point tracking control algorithm.

Keywords: hybrid energy, grid system, control techniques, dual KY converter

1. Introduction

In India 53% of energy is produced from thermal power stations. The major problems with thermal energy are lack of coal, ash production, fuel emission, high running costs, and disruption to the ecology. This chapter mainly focuses on renewable energy sources like photovoltaic (PV), wind, and stable conversion using a hybrid system. In this introduction, the focus is on wind energy-related challenges because wind energy is not a linear energy. Wind is always fluctuating in nature so an appropriate controller is always required for optimal power. Here, an appropriate controller for an induction generator to achieve steady-state output will be described. An induction generator acts as a drive and a neural network controller is introduced with an ant colony optimization method. The controller is intended to drive a turbine to extricate extreme power from the wind. This strategy is dependable and reliable [1].

A wind energy system requires constant power at the conversion stage, and to avoid this variable, a frequency transformer technique is adopted. This methodology proposed in this chapter is a standalone wind system. The suggested strategy is modest, and has basic control with no harmonics [2]. The system consists of solar power, wind power, a diesel engine, and an intelligent power controller. To attain an active and balanced response for active power control, the controller consists of a radial basis function network and an improved Elman neural network for maximum power point tracking (MPPT). The pitch angle of the wind turbine and the PV system uses a radial basis function network, where the output signal is used to control the DC/Elman neural network DC boost converters to achieve MPPT [3]. Different types of permanent synchronous generator with various power capacity wind farms are connected to the common grid. This setup has three collected models of variable wind speed fitted with permanent magnet synchronous generator (PMSG) wind turbines for dynamic investigation [4].

This chapter mainly targets a suitable converter for a renewable energy system. It discusses the KY converter, which is suitable for hybridizing the energy. The KY converter gets its name from a paper titled "KY converter and its derivatives" by K.I. Hwu and Y.T. Yau (KY converter). A dual KY boost converter is presented, which is a KY converter combined with a normal synchronously rectified boost converter. The input and output inductor currents are continuous, with a higher voltage conversion ratio suitable for low-ripple applications. By using soft switching with the surge current suppressed the device can be used in high-power applications. The KY converter has better performance than a boost converter [5] and provides a fast response to reach the maximum power point compared to a boost converter. A novel voltage-bucking/boosting converter is called a KY buck-boost converter. It has fast transient responses, synchronous rectification, load regulations, and low-output voltage ripples. Cuk, Sepic, Zeta, and Luo converters could also be considered but they possess right half-plane zeroes, thereby causing system instability and slow load transient responses [6]. The operation of KY converters is also given, along with experimental results to verify ideal line and load regulations, and low output voltage ripples due to non-pulsating output currents.

Most solar panel energy efficiency ratings range from 15 to 20% [7]; therefore, various MPPT algorithms have been introduced. Numerous controllers are utilized to find MPPT and the efficiency is increased [8]. Power from any renewable energy source can be delivered to the grid individually or a balanced MPPT feature can be realized for renewable energy, power converters, and control algorithms along with purposeful energy resources for efficient operation of the microgrid. The proposed microgrid, based on hybrid energy resources, operates in autonomous mode and has an open architecture platform for testing multiple different control configurations. AC/DC, DC/AC, and DC/DC converters are integrated with the distributed energy system due to different types of output voltages [9]. Several algorithms that are used to operate DC/DC converters around the MPPT are reported in the literature. Comparing all algorithms, a fuzzy logic controller coupled to other controllers works well under partial shading conditions. There is also a newly designed fuzzy logic controller coupled to a Hopfield neural network maximum tracking technique [10]. The MPPT technique is very important because it increases the energy efficiency of a renewable energy system.

Another major challenge is hybrid renewable energy. The configuration of the hybrid renewable energy system and interfacing power converters for connecting the energy sources to the AC bus is extensively discussed. An outline of the control process in a hybrid renewable energy system and the application of the relevant control methods for system stabilization, effectively inducing real power and proper load-sharing methods, are available. Different approaches for hybrid renewable energy system design and control methods for power converters in the recent research literature are also briefly discussed. The AC bus-linked hybrid renewable energy system configuration reduces the number of power conversion stages and losses in power transferred to the load/utility. The master/slave control with the droop concept does not require a communication link and provides good load sharing, such as the flexibility, expandability, and modularity of the hybrid renewable energy system. Both single-master and multimaster approaches are used in the inverter control strategies [11]. In addition, a multi accumulated model utilizing comparable wind speed display has excellent similarity to the total model in transient and steady states and it also expends less time in reproduction when contrasted with the entire model [12]. Finally that the hybrid control system challenges not so distant future with its very own potential which clears another time with powerful and proficient energy balance. Globally, renewable energy has a green future and will undoubtedly become a credible alternative to fossil fuels [13, 14].

In conclusion, hybrid energy devices combining a variable velocity wind turbine and PV array-generating device could deliver a non-stop power to weight ratio to produce a viable hybrid controller. The hybrid controller manages the strength flow between the system's additives such that the cost is minimized and load necessities might be met throughout the year [15]. Hybrid renewable energy's main challenges are energy storage capacity and energy management. To utilize 100% renewable energy, the design requires intelligent charge control, battery state of charge, and estimation of the impact of various working routines on battery life. Different architectures of energy sources and power management on peak load sharing are analyzed with a reduction of varying losses [16].

The next important analysis concerns a multi-input system. A novel multi-input inverter is used for the grid-connected hybrid solar/wind power system to simplify the power system and reduce the cost. The multi-input inverter is designed with a buck/buck–boost fused to a multi-input DC/DC converter and a single-phase bridge-type DC/AC inverter [17]. A semi-isolated multi-input converter for a hybrid PV/wind power charger system that can simplify the power system, reduce cost, deliver continuous power, and overcome high-voltage-transfer ratio problems is proposed [18].

Various literatures on the use of hybrids with renewable energy systems for uninterrupted power supply to the load have been analyzed. Another requirement is the MPPT algorithm along with the multi-input converter, which is used to reduce the volume of the system. Hybrid renewable energy systems in combination with existing setups are presented to investigate the possibility of specialized aggressiveness [15]. In this chapter, the operational principle of the proposed semi-isolated multi-input converter is explained: a novel, executed multi-input KY boost converter for hybrid systems associated with the grid. The control parameters are reliant on the wind, sun, storage, and grid conditions and checked under dynamic conditions. DC bus voltages are used to deal with the contribution of various working mode controls amid different working conditions [19, 20].

2. Hybrid energy system methods

2.1 Types of integration system

There are numerous approaches to coordinate distinctive alternative energy to form the integration of hybrid systems. For the most part, strategies can be arranged into three classes: DC coupled, AC integrated, and hybrid integrated. The AC-integrated system can be grouped into power-frequency AC-integrated and high-frequency AC-integrated systems. The strategies of a DC-coordinated setup are shown in **Figure 1**.

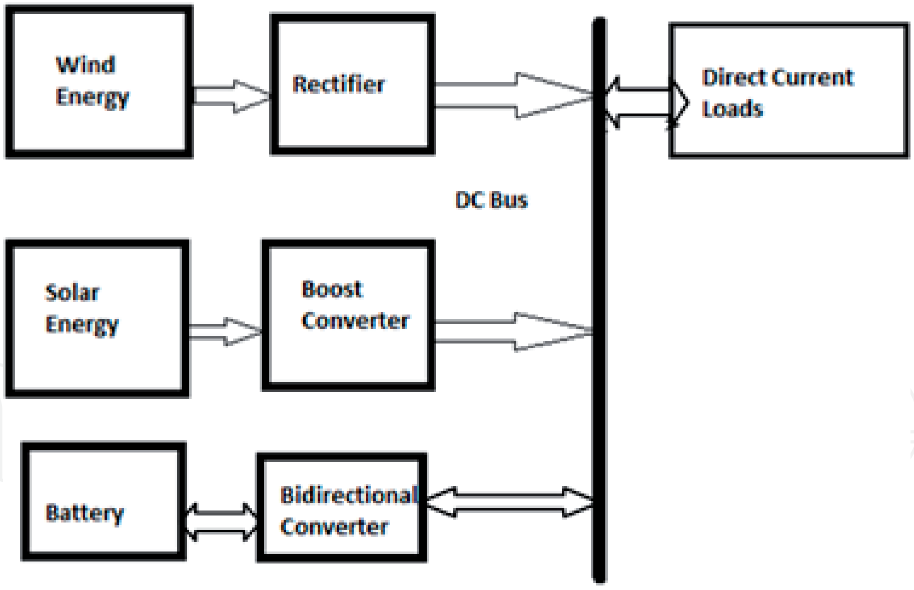

Figure 1.
Block diagram of a DC-coupled integration system.

2.1.1 DC-coupled integration system

The DC sources may be associated with the DC bus directly if they are suitable. If there are any DC loads, they can be clearly related to the DC bus, or through the DC/DC converters, to fit DC voltages to DC loads [21].

2.1.2 AC-coupled integration system

AC coupling can be split into two further categories: power frequency AC-coordinated and high-frequency AC-coordinated systems. An AC-coordinated system is shown in **Figure 2**, where diverse energy sources are coordinated through their control switching interfacing circuits to a power recurrence AC bus. Inductors may likewise be required between the control switching circuits and the AC bus to accomplish the desired control through the board.

2.1.3 Hybrid-coupled integration system

Rather than interfacing all the distributed generation sources to only one DC or AC bus, as already discussed, the distinctive distributed generation sources can be associated with the DC or AC bus of the mixture system. **Figure 3** demonstrates a hybrid-coupled coordinated system, where distributed generation assets are associated with the DC bus as well as the AC bus. In this arrangement, energy sources can be coordinated specifically without any additional circuits. Therefore, the framework can have higher energy effectiveness and diminished cost. Meanwhile, control and power flow management may become increasingly difficult compared to DC and AC bus-coordinated systems [22].

2.2 System arrangement

The system comprises renewable energy and alternative energy. The renewable energies are wind, solar, and biomass. Alternative energies are a diesel generator and a storage system. In a storage system, a battery, fuel cells, supercapacitors, and aqua electrolysis are used [23]. The level of dependability of a PV and wind-coordinated framework to suit a specific load can be given by a mix of

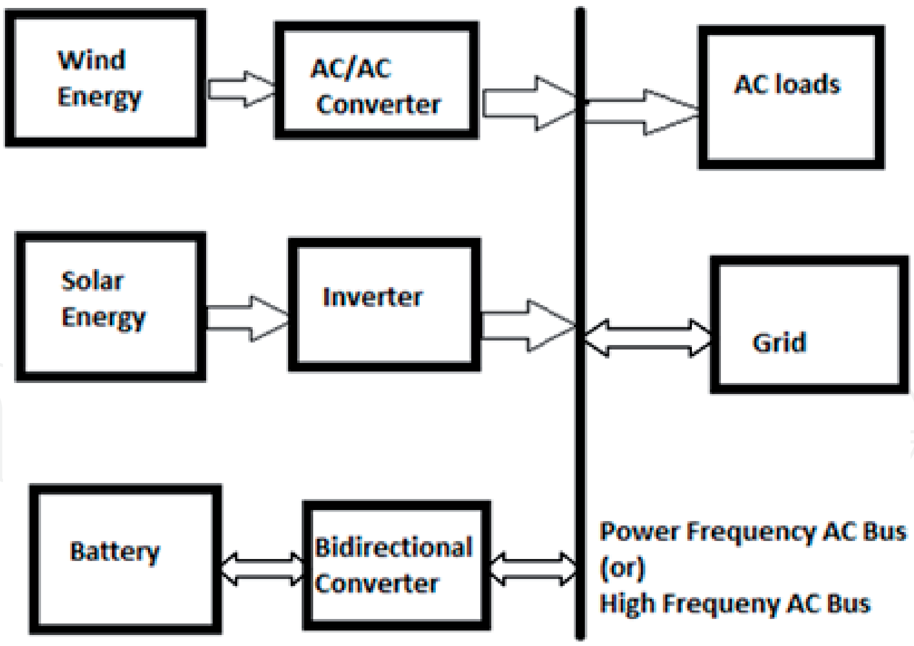

Figure 2.
Block diagram of an AC-coupled integration system.

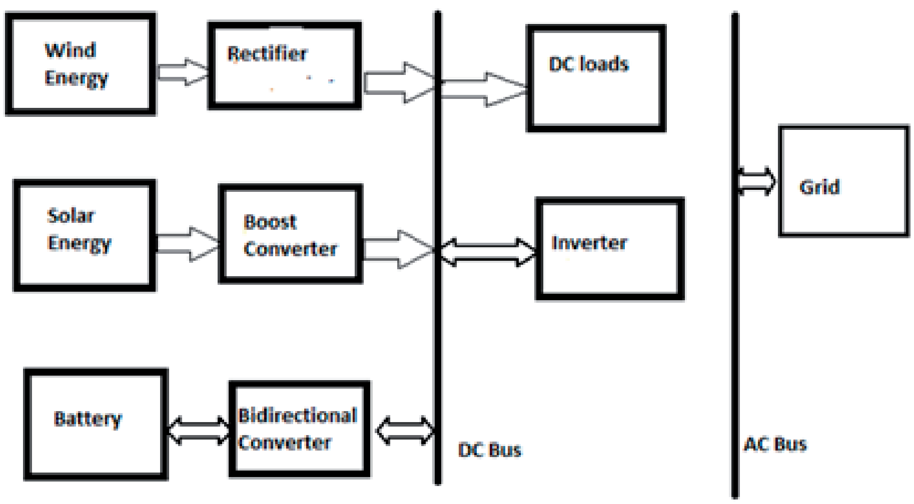

Figure 3.
Block diagram of a hybrid-coupled integration system.

appropriately estimated wind energy, PV, battery units, and alternative sources. In atmospheres, alternative sources are expected to be highly dependable also, keep away from gross over-plan of the sunlight based and wind framework. In other words, an assistant energy provider can be viewed as an optional technique for proposing an alternative energy source fused into the framework compared to expanding equipment sizes unnecessarily for those periods when energy generation is reduced [24]. The PMSG-based wind turbine works at the greatest power point following the MPPT mode to extract power from the wind, although wind power may need to be reduced under specific conditions. Wind reduction can be accomplished by utilizing the turbine's capacity and pitch control systems [25].

The execution of crystalline silicon PV modules limits the physical elements of the PV cell material, the temperature of PV array cells and the sun situated irradiance revealed on the sun's situated cells. One solved proper model for the most outrageous power yield of PV modules is used [4–7, 12, 19, 20, 22–24, 26–30].

Changes in wind speed and sunlight-based illumination are associated with the wind turbine generator, and PV can recreate a variety of intensities of AC and DC sources and test the MPPT control calculation [28].

Regarding the size of the battery bank to use for these sorts of uses requires examination of the battery's charge and discharge capabilities, including burden, yield, and in the case of sunlight-based or elective critical sources, the working temperature and capability of the charger and other parts of the structure. By and large, problems occur while charging the battery bank and its capability drops when the battery ages or is misused. At the point when the aggregate yield of solar and wind energy is more than the energy requested, the storage unit is charged. Two properties of the battery are associated with the hybrid system's execution, i.e. the state of charge and the charge voltage [29].

The hybrid system grid plays a vital role and can work in two modes. Grid Tied mode the power converters to produce constant voltage to a DC bus and exchange of power can be accomplished using DC and AC buses, while the grid working as an autonomous mode storage unit plays a vital role in balancing voltage and power.

2.3 Expert control

2.3.1 Intelligent controller

The control framework for hybrid energy system designs should limit fuel utilization by expanding energy from inexhaustible sources. Nonetheless, there are control changes by which the sustainable power source can change, which causes unsettling influences that can influence the nature of the energy conveyed to the heap. To deal with the stream of energy effectively, with fewer harmonics, a controlling strategy should be developed.

The energy sources are modeled from PV, wind, and battery. To coordinate all the converters used in the hybrid system, intelligent controllers are essential. A proportional-integral controller, fuzzy logic controller, neural network, and genetic algorithms are used as an intelligent controller [7].

2.3.2 Control methods

- The hybrid system has three types of controller. The controller used in PV and wind is said to be a generator side converter to obtain maximum power point tracking from solar and wind.

- A grid side converter is used to sustain constant voltage in a DC bus and frequency in an AC bus, to control the exchange of reactive power in the AC bus.

- A storage side converter maintains constant DC voltage and state of charge of the battery.

These converters will coordinate the entire hybrid system.

2.3.3 Power management

Power management is categorized as two types: rule based and optimization based. Rule based mainly depends on real-time applications. Depending on the grid requirements, power flow will be controlled from source to grid. Optimization based depends on the cost of energy. Its main focus is to minimize cost.

As the arrangement of hybrid renewable energy and alternative energy systems as a microgrid expands, so does the necessity for continuous energy for such systems. Powerful correspondence between the separate energies of the microgrid is imperative and merits further consideration. In addition, efficient methodologies and institutionalization are required for the production and safe organization of such systems.

2.3.4 Grid-connected mode

At the point where the hybrid grid works in islanding mode, the boost converter and the consecutive AC/DC/AC converter of the doubly-fed induction generator may work in on-MPPT or off-MPPT mode depending on framework control equality and criticality goals. The essential converter is a voltage source that gives a consistent voltage that repeats for the AC framework and works either in inverter or converter mode for smooth power exchange between the AC and DC link. The battery converter works either in charging or discharging mode and is reliant on the power balance in the framework. DC interface voltage is maintained by either the battery or the boost converter and is reliant on structure working conditions. Forces under different load and supply conditions should be adjusted.

When the hybrid system works in grid-connected mode, the goal of the boost converter is to pursue the MPPT of the PV display by coordinating its terminal voltage. The sequential AC/DC/AC converter of the doubly-fed induction generator is controlled to guide the rotor side current to achieve MPPT and to synchronize with the AC framework. The energy overflow of the hybrid grid framework can be sent to the utility framework. The activity of the battery for energy stockpiling is less imperative since the power is adjusted by the utility framework. For this situation, the fundamental purpose of the battery is to eliminate customary control trade between the DC and AC link. The DC/DC converter of the battery can be controlled as an energy pad using this strategy. The principal of converter is intended to work bidirectionally to fuse corresponding normal for wind what's more, sun-powered sources. The goals of the primary converter are to maintain a steady DC-connected voltage for the variable DC stack and to synchronize with the AC connection and utility framework.

3. Design of a dual KY boost converter

3.1 Working of a dual KY boost converter

Figure 4 demonstrates the proposed dual KY boost converter built using the KY converter joined with the boost converter. The dual KY converter is made using four switches M1, M2, M3, and M4, one diode D, one output inductor Lo, two input inductors Li1, Li2, a support capacitor Cs, and one output capacitor Co. The depository capacitor Cs is a support between the KY converter and the conventional synchronously rectified boost converter. The multi-input DC voltage is 12 V and 110 V are obtained at the yield. Because of the conduction status of the switches the dual KY converter has two modes of operation. **Figure 5** shows mode 1 operation of the dual KY boost converter. M1 and M4 are turned off and M2 and M3 are turned on. The diode D is forward biased and begins to conduct, and Cs is released. In this manner, the voltage across Li1 is V1, making Li1 charged, while the voltage across Lo is Vo minus VCs, subsequently making Lo demagnetized. Additionally, the current flowing through Co is equivalent to ILo minus the current moving through RL.

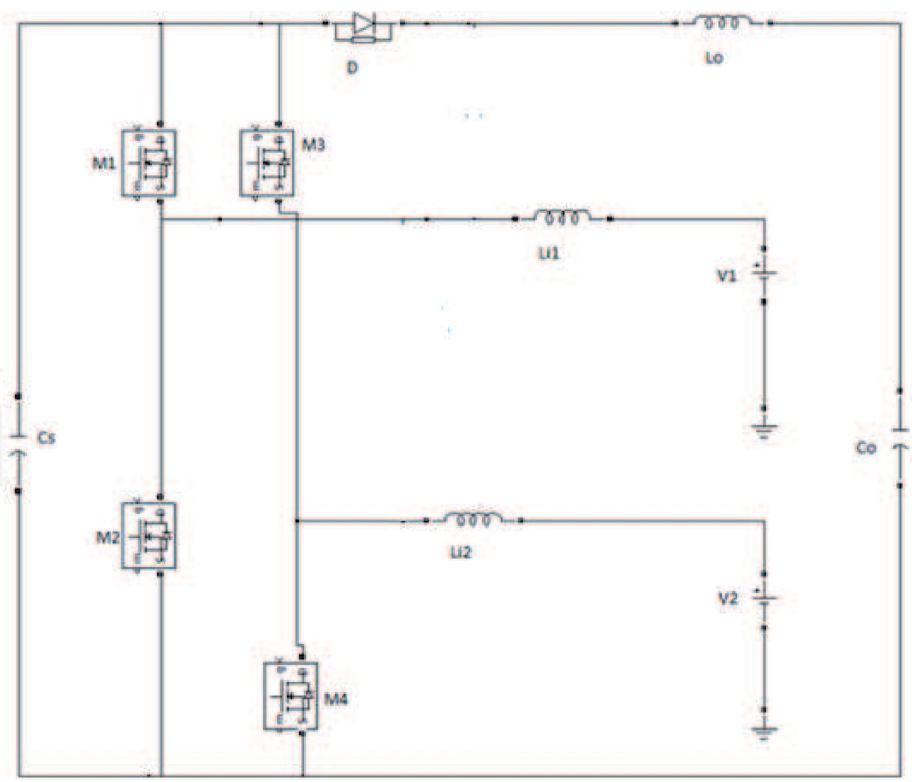

Figure 4.
Dual KY boost converter connected to DC input.

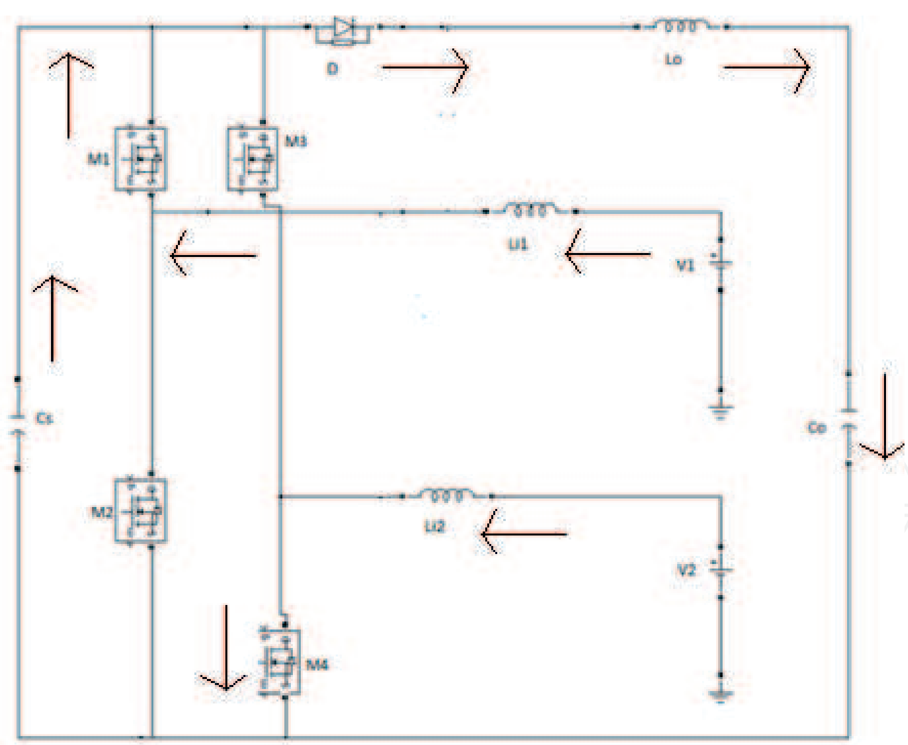

Figure 5.
Mode 1 operation of the dual KY boost converter.

Figure 6 shows mode 2 operation of a dual KY boost converter. M2 and M3 are turned on and M1 and M4 are turned off. Consequently, the voltage across Li1 is VCs subtracted from voltage source V1, subsequently making Li1 demagnetized, while the voltage across Lo is Vo subtracted from 2VCs making Lo polarized. Additionally, the current flowing through Co is equivalent to ILo minus the current moving through RL, while the current moving through Cs is equivalent to the total of ILi1 and −ILo.

DOI: http://dx.doi.org/10.5772/intechopen.90755

The input voltage V1 = V2 = 12 V and the input power of 12 W is made up from each source of 6 W. **Figure 8** shows the output power of a dual KY boost converter of 22 W with output voltage of 110 V. The results are shown in **Figures 7** and **8**.

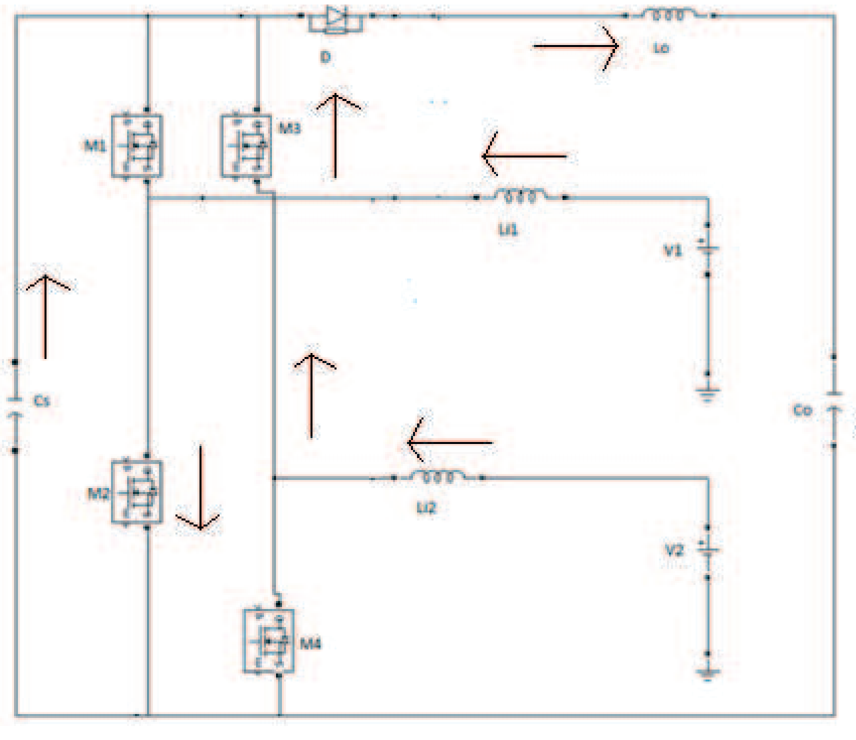

Figure 6.
Mode 2 operation of a dual KY boost converter.

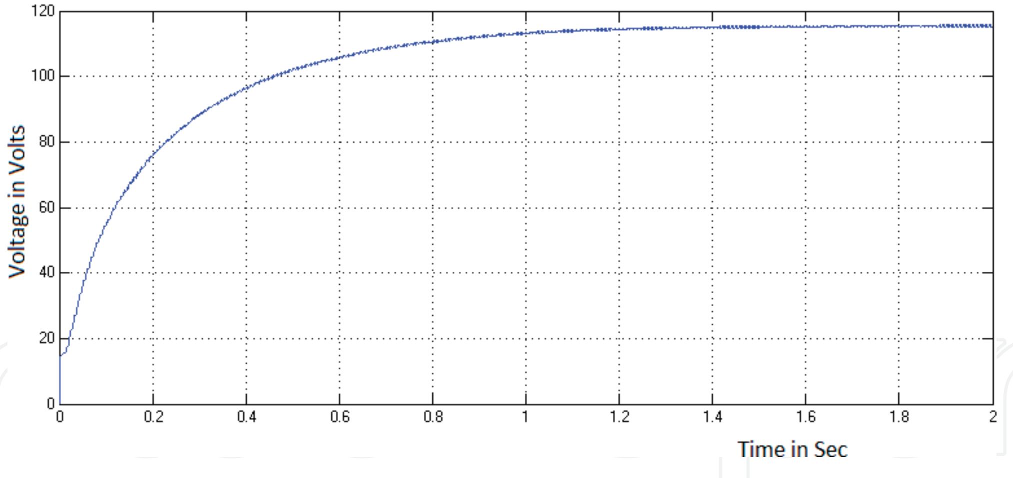

Figure 7.
Dual KY boost converter output voltage is 110 V.

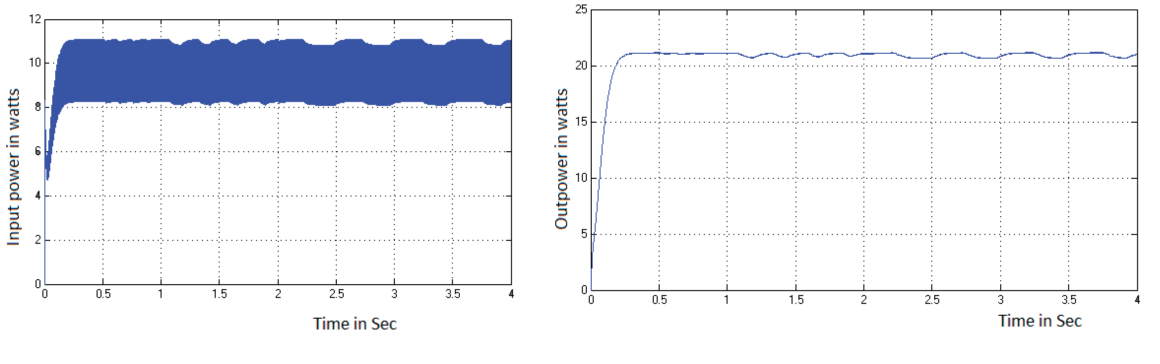

Figure 8.
Total input power = 12 W and dual KY converter output power = 22 W.

3.2 Disadvantages of the existing method

Regular converters for interfacing numerous sustainable sources utilize a typical DC connection or normal AC recurrence interface, which has disadvantages like the necessity for increased bundling, and expanded switches over the ordinary structure becoming delineated [31]. The multiport converter has numerous points of interest compared to the traditional structure regarding the number of energy gadgets and transformation steps that can enhance system cost. Certain non-segregated voltage-bucking/boosting converters make the system cost effective. The interleaved converter can likewise be utilized. It comprises two single-stage support converters in parallel.

3.3 Advantages of the proposed method

This dual KY support converter topology highlights higher proficiency with less powerful hardware gadgets and fewer power change processes. The proposed dual KY support converter has the benefits of basic topology and the least number of energy switches. The dual KY support converter has persistent data and yields inductor streams and high-voltage proportions. The dual KY support converter structure is promising from the perspectives of minimal effort, concentrated control, and small size [27].

4. Dual KY boost converter connected to inverter

The dual KY converter is connected to a single-phase inverter. Analysis is done for a PV array input of 18 V given to V1 and V2 and the KY converter voltage is 230 V with a current of 3.5 A. The dual KY boost converter output is connected to a single-phase inverter. The single-phase inverter output voltage is 230 V and the total harmonic distortion (THD) value is nearly 8.22%.

4.1 Dual KY boost converter connected to PV array input

Table 1 listed the design value of PV array.

Parameters	Values
Isc	5.96 A
Voc	6.2 V
Series resistance	0.18 ohm
Parallel resistance	2 ohm
No. of modules connected in series	4
No. of modules connected in parallel	4
Irradiance	1000 W/m^2
Temperature	25°C

Table 1.
Design value of PV array.

DOI: http://dx.doi.org/10.5772/intechopen.90755

4.2 Simulation results of dual KY boost converter connected to inverter

The above design values of PV arrays are connected as input and the waveforms are obtained. The analysis is done for a PV array input of 18 V shown in **Figures 9** and **10** and an output of 230 V obtained across the load resistance shown in **Figure 11**. The component determinations are given as follows: (1) evaluated PV array input voltage is 18 V; (2) DC voltage is 110 V; (3) exchanging recurrence is 2 kHz; (4) estimation of Li1 and Li2 is 400 µH and the estimation of Lo is the same as that of Li; (5) one 1 µF capacitor is decided for Cs; (6) one 470 µF capacitor is decided for Co; and (7) parameters of the PI controller, kp and ki, are set to 1 and 10 individually. These outputs are replicated using the simulation shown in **Figures 12** and **13**.

Figure 14 shows the perturbation and observation algorithm used to generate the duty ratio for switches. The simulation also shows a dual KY boost converter connected to battery terminals and the state of charge is checked. The dual KY boost converter output is connected to a single-phase inverter. The single-phase inverter output voltage is 230 V and the THD value is nearly 8.22%.

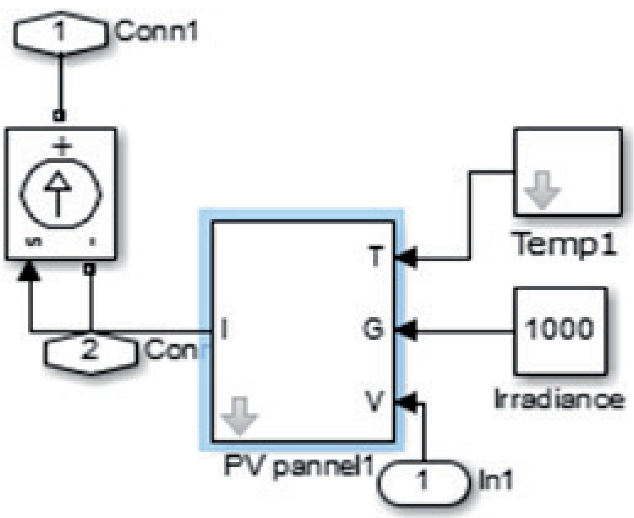

Figure 9.
Dual KY boost converter connected to PV array input.

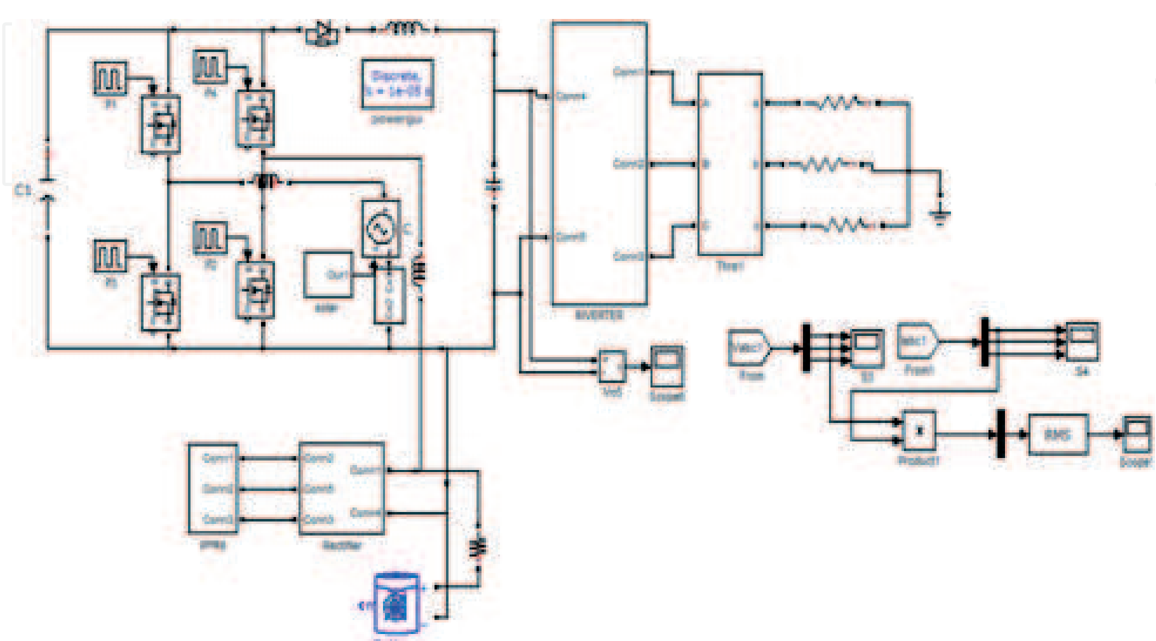

Figure 10.
Dual KY boost converter connected to single-phase inverter output.

The corresponding waveforms are shown in **Figures 15–18**. **Table 2** shows the output values of KY boost converter. **Table 3** shows the comparison of KY boost and boost converter.

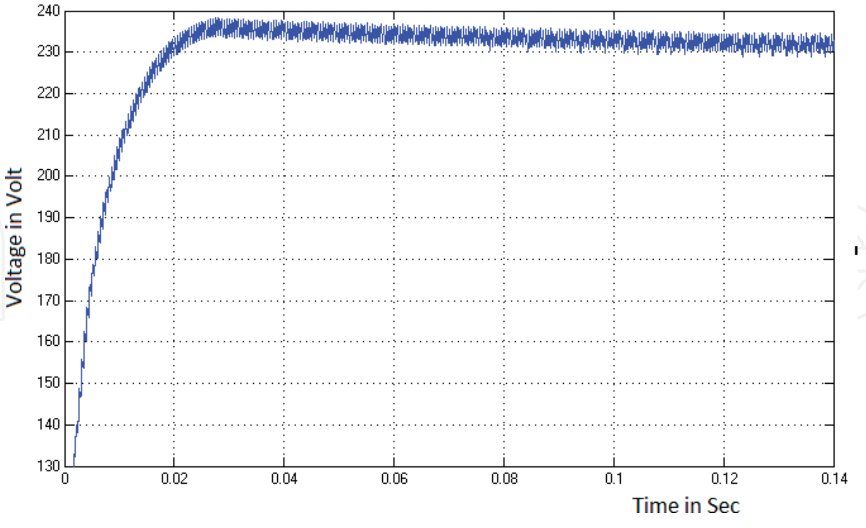

Figure 11.
Dual KY boost converter DC output voltage of 230 V.

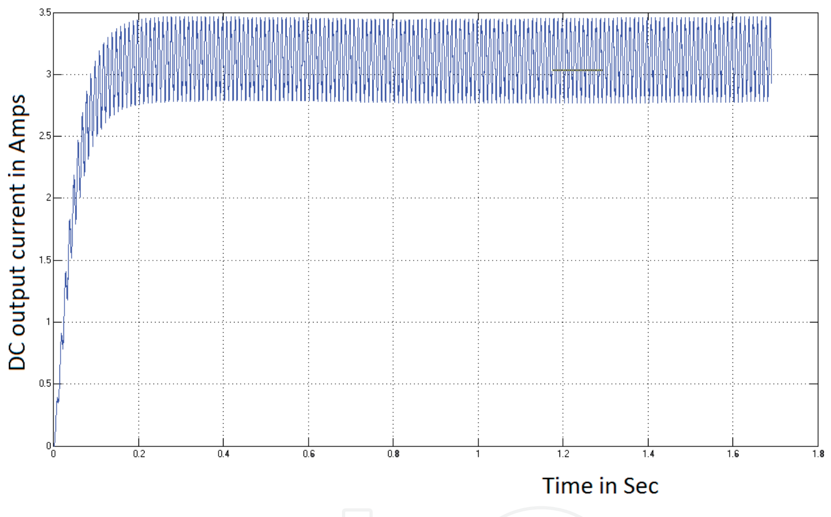

Figure 12.
Dual KY boost converter DC output current of 3.5 A.

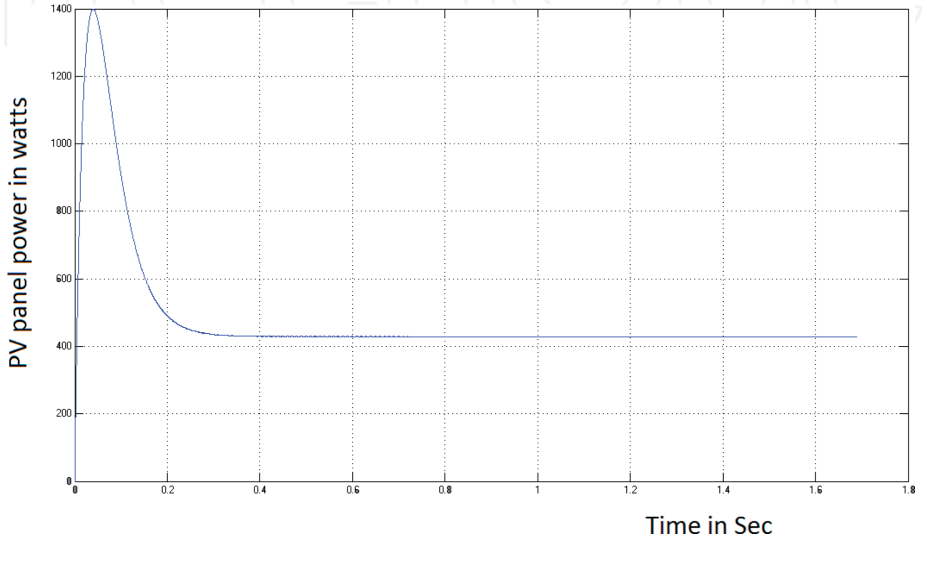

Figure 13.
Ppv = 450 W.

DOI: http://dx.doi.org/10.5772/intechopen.90755

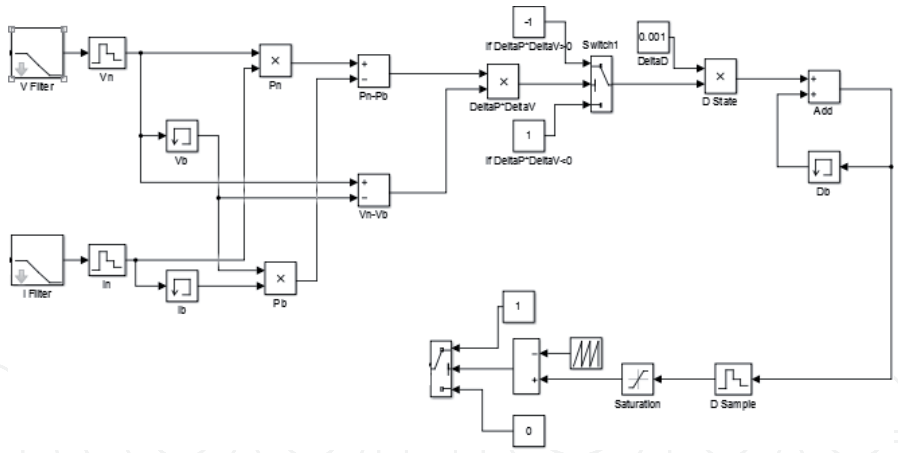

Figure 14.
Perturbation and observation algorithm for generating pulses.

Parameters	Values
Isc	26.3 A
Voc	19.5 V
PV panel voltage	18 V
PV panel current	25A
PV panel power	450 W
KY boost converter voltage	230 V
KY boost converter current	3.5 A
Inverter AC output voltage	230 V
Inverter AC output current	5 A
Power factor	0.93

Table 2.
Output of KY boost converter.

Converter	Vin	Vo	THD (%)
KY boost converter	18 V	230 V	6.58
Boost converter	18 V	110 V	10

Table 3.
Comparison of output voltage and THD.

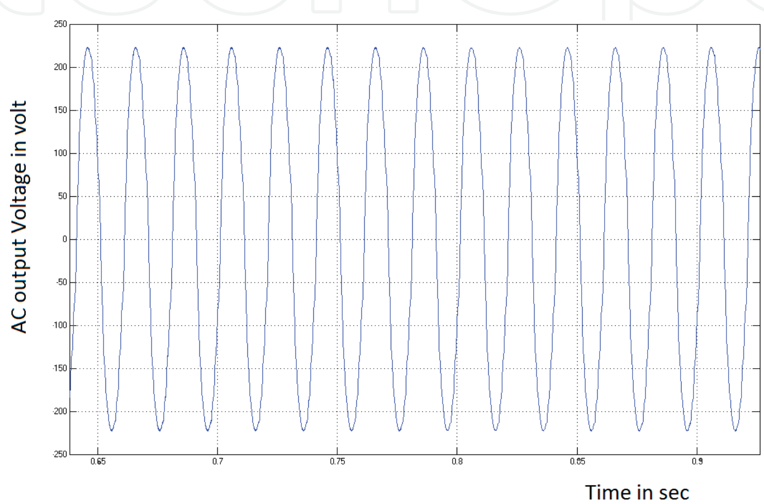

Figure 15.
Inverter AC output voltage is 230 V.

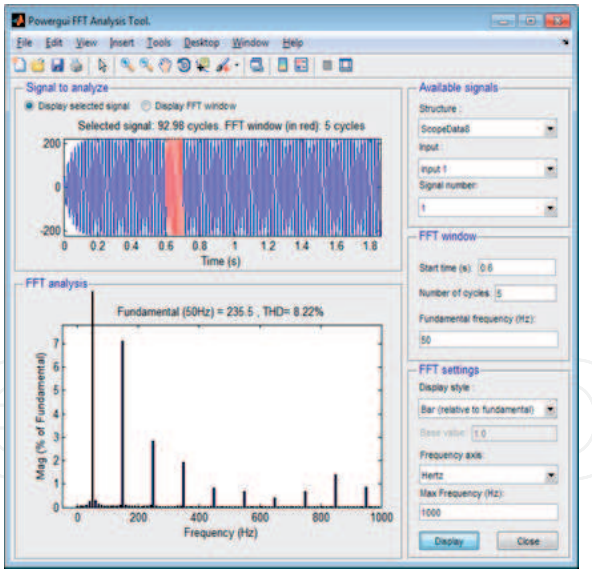

Figure 16.
THD = 8.22% for single-phase inverter output voltage.

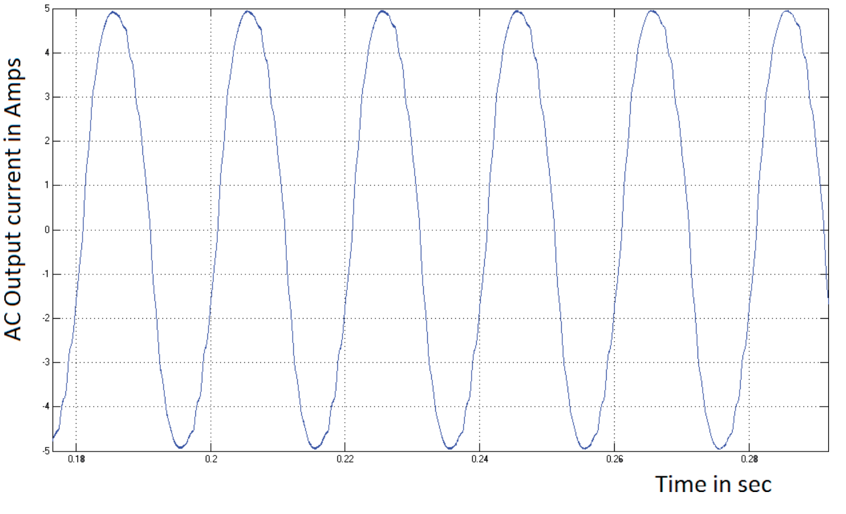

Figure 17.
Single-phase inverter AC output current is 5 A.

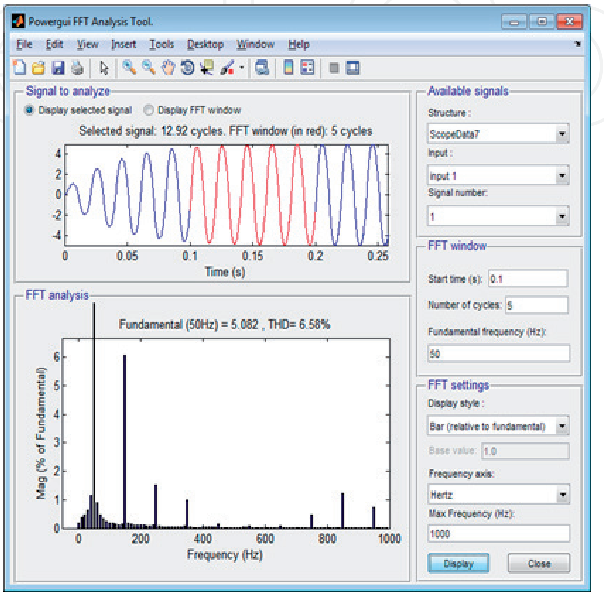

Figure 18.
THD = 6.58% for single-phase inverter output current.

5. Conclusion

Because of fast improvements in the field of sustainable power sources and expanding costs of ordinary items like oil and gas, the use of sustainable power sources has turned out to be exceptional in hybrid systems. Solar PV and wind systems have been promoted around the globe on a comparatively large scale. This chapter proposed a hybrid energy system consisting of a wind turbine and a PV source to supply continuous power to the load. A controller is used to track the maximum power from renewable sources. Simple and economic control with a KY converter, which is a DC/DC converter, is used for maximum power extraction from the wind turbine and PV array. Power from the dual PV array can be transported to the utility grid. At the same time, the MPPT attribute can be acknowledged for the dual PV system. The substantial range of PV array voltage, current, and temperature variations was caused by various insolations. This solitary dual generation system can adequately separate extremes of power from the two PV sun-oriented energy sources. Boosting the DC voltage (18–230 V) to an adequate level utilizing the dual KY boost converter and obtaining pure AC voltage (230 V) from the inverter are key to understanding the above targets. A model of a hybrid dual solar system arrangement utilized with a control strategy has therefore been created. The KY converter will offer low THD (6.58%), high power factor under nonlinear stacking conditions, and pronounced unique reactions under transient stacking conditions.

Author details

Pushpavalli Murugan[1*] and Jothi Swaroopan Nesa Mony[2]

1 Research Scholar/EEE, Sathyabama Institute of Science and Technology, Chennai, India

2 Professor/EEE, RMK Engineering College, Chennai, India

*Address all correspondence to: pushpavalli.eee@sathyabama.ac.in

References

[1] Hong C-M, Cheng F-S, Chen C-H. Optimal control for variable-speed wind generation systems using general regression neural network. International Journal of Electrical Power & Energy Systems. 2014;**60**:14-23

[2] Bakhsh FI, Khatod DK. A new synchronous generator based wind energy conversion system feeding an isolated load through variable frequency transformer. Renewable Energy. 2016;**86**:106-116

[3] Lin WM, Hong CM, Chen CH. Neural-network-based MPPT control of a stand-alone hybrid power generation system. IEEE Transactions on Power Electronics. 2011;**26**(12):3571-3581

[4] Badr MA, Atallah AM, Bayoumi MA. Comparison between aggregation techniques for PMSG wind farm. Energy Procedia. 2015;**74**:1162-1173

[5] Hwu KI, Yau YT. Two types of KY buck–boost converters. IEEE Transactions on Industrial Electronics. 2009;**56**(8):2970-2980. DOI: 10.1109/TIE.2009.2023100

[6] Hwu KI, Yau YT. Topology exchange between KY converter and its derivative. In: 2008 Twenty-Third Annual IEEE Applied Power Electronics Conference and Exposition. Austin, TX, USA: IEEE; 2008. pp. 1675-1678

[7] Deshmukh MK, Deshmukh SS. Modeling of hybrid renewable energy systems. Renewable and Sustainable Energy Reviews. 2008;**12**(1):235-249

[8] Ponkarthik N, Kalidasa Murugavel K. Performance enhancement of solar photovoltaic system using novel maximum power point tracking. International Journal of Electrical Power & Energy Systems. 2014;**60**:1-5

[9] Anbarasi Jebaselvi GD, Paramasivam S. Analysis on renewable energy systems. Renewable and Sustainable Energy Reviews. 2013;**28**:625-634

[10] Subiyanto S, Mohamed A, Hannan MA. Intelligent maximum power point tracking for PV system using Hopfield neural network optimized fuzzy logic controller. Energy and Buildings. 2012;**51**:29-38

[11] Senjyu T, Nakaji T, Uezato K, Funabashi T. A hybrid power system using alternative energy facilities in isolated island. IEEE Transactions on Energy Conversion. 2005;**20**(2):406-414

[12] Rolan A, Luna A, Vazquez G, Aguilar D, Azevedo G. Modeling of a variable speed wind turbine with a permanent magnet synchronous generator. In: 2009 IEEE International Symposium on Industrial Electronics. Seoul, South Korea: IEEE; 2009. pp. 734-739

[13] Ekren BY, Ekren O. Simulation based size optimization of a PV/wind hybrid energy conversion system with battery storage under various load and auxiliary energy conditions. Applied Energy. 2009;**86**(9):1387-1394

[14] Yang H, Lu L, Zhou W. A novel optimization sizing model for hybrid solar-wind power generation system. Solar Energy. 2007;**81**(1):76-84

[15] Nema P, Nema RK, Rangnekar S. A current and future state of art development of hybrid energy system using wind and PV-solar: A review. Renewable and Sustainable Energy Reviews. 2009;**13**(8):2096-2103

[16] Bocklisch T. Hybrid energy storage systems for renewable energy

applications. Energy Procedia. 2015;**73**:103-111

[17] Chen YM, Liu YC, Hung SC, Cheng CS. Multi-input inverter for grid-connected hybrid PV/wind power system. IEEE Transactions on Power Electronics. 2007;**22**(3):1070-1077

[18] Chen CW, Chen KH, Chen YM. A semi-isolated multi-input converter for hybrid PV/wind power charger system. In: 2014 International Power Electronics Conference (IPEC-Hiroshima 2014-ECCE ASIA). Hiroshima, Japan: IEEE. pp. 3592-3597

[19] Pushpavalli, M. Swaroopan NJ. Maximum power tracking for PV array system using fuzzy logic controller. In International Conference on Intelligent Computing and Applications. Springer: Singapore; 2019. pp. 337- 348

[20] Pushpavalli M. Harmonic reduction study in KY boost and single phase AC converter. International Journal of Applied Engineering Research (IJAER). 2015;**10**:3549-3558

[21] Xu L, Chen D. Control and operation of a DC microgrid with variable generation and energy storage. IEEE Transactions on Power Delivery. 2011;**26**(4):2513-2522

[22] Adhikari S, Li F. Coordinated V-f and P-Q control of solar photovoltaic generators with MPPT and battery storage in microgrids. IEEE Transactions on Smart Grid. 2014;**5**(3):1270-1281

[23] Nehrir MH, Wang C, Strunz K, Aki H, Ramakumar R, Bing J, et al. A review of hybrid renewable/alternative energy systems for electric power generation: Configurations, control, and applications. IEEE Transactions on Sustainable Energy. 2011;**2**(4):392-403

[24] Lau KY, Yousof MFM, Arshad SNM, Anwari M, Yatim AHM. Performance analysis of hybrid photovoltaic/diesel energy system under Malaysian conditions. Energy. 2010;**35**:3245-3255

[25] Jaramillo-Lopez F, Kenne G, Lamnabhi-Lagarrigue F. A novel online training neural network-based algorithm for wind speed estimation and adaptive control of PMSG wind turbine system for maximum power extraction. Renewable Energy. 2016;**86**:38-48

[26] Ramaprabha R, Balaji M, Mathur BL. Maximum power point tracking of partially shaded solar PV system using modified Fibonacci search method with fuzzy controller. Electrical Power and Energy Systems. 2012;**43**:754-765

[27] Pushpavalli M, Jothi Swaroopan NM. Performance analysis of hybrid photovoltaic/wind energy system using KY boost converter. International Journal of Power Electronics and Drive Systems (IJPEDS). 2019;**10**(1):443

[28] Murtaza A, Chiaberge M, De Giuseppe M, Boero D. A duty cycle optimization based hybrid maximum power point tracking technique for photovoltaic systems. Electrical Power and Energy Systems. 2014;**59**:141-154

[29] Dali M, Belhadj J, Roboam X. Hybrid solar-wind system with battery storage operating in grid-connected and standalone mode: Control and energy management—Experimental investigation. Energy. 2010;**35**(6):2587-2595

[30] Kim HS, Kim JH, Min BD, Yoo DW, Kim HJ. A highly efficient PV system using a series connection of DC–DC converter output with a photovoltaic panel. Renewable Energy. 2009;**34**(11):2432-2436

[31] Liu X, Wang P, Loh PC. A hybrid AC/DC microgrid and its coordination control. IEEE Transactions on Smart Grid. 2011;**2**(2):278-286