Study on Wind and PV Hybrid Renewable Energy Systems

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***Abstract*—** Depletion of conventional energy sources such as fossil fuel has led to the increased usage of renewable energy sources to meet the ever-growing demand in the energy sector. However utilisation of the alternate energy sources to their maximum efficiency is a challenge to the power sector. Hybrid power systems are power systems in which more than one renewable energy source is used to supply power to the grid. This paper provides an overview of the technology being utilized in the hybrid power systems involving wind and solar energy as sources. The paper presents a survey of the various topologies available for DC-DC conversion and DC-AC conversion for both standalone and grid-connected applications.

***Keywords*—** **Inverter, Hybrid Renewable Energy system, Wind, Photovoltaic energy, Survey.**

I. INTRODUCTION

Conventional energy sources are fast depleting thus paving the way for alternate energy sources such as solar energy, wind energy, fuel cell, etc. Total installed capacity of power in India is about 330.26 GW of which 57.26 GW amounts to renewable energy sources. (Source: NREL, All India Installed Capacity of Power stations). Energy from these sources is not reliable as they do not provide energy continuously. Sun, the source of energy for Photovoltaic system is abundant in nature. However it cannot produce reliable energy due to its intermittent nature. On the other hand, the output from wind mills will be high during windy days and less on other days.

Thus it is seen that alternate energy sources fail to provide continuous and reliable energy when utilised individually. Combination of two or more alternate energy sources not only helps in improving reliability of the power system but also maximizes the utilisation of the sources. Hybrid Photovoltaic and Wind energy system combines the solar photovoltaic system and wind energy system. In a hybrid system, if one energy source is unavailable, then the other source provides energy thereby maintaining continuity of power supply. During daytime, power from solar panels is higher than that of the wind system. During night, in the absence of sunlight, the power from the wind source is higher. Thus the combination helps in improving the reliability and efficiency of the power system.

Hybrid Renewable Energy system consist of ac-dc rectifier in case of wind energy, dc-dc converters to control the dc bus voltage and to supply dc loads and dc-ac inverters to inject sinusoidal current into the grid for grid-connected system or to supply ac loads in a standalone system. Suitable MPPT control technique is required to track the maximum power point in order to obtain maximum efficiency. This paper presents an overview of the different topologies available for hybrid renewable energy system.

II. DC-DC CONVERTERS

A double-input PWM DC-DC converter for high and low voltage sources is proposed by Yaow-Ming Chen et al [1]. With PWM control, the proposed converter can draw power from two different voltage sources simultaneously or individually. Only one DC-DC converter is connected to both the sources and is used for step-up and step-down operations thereby reducing the size of the system. By using a single passive lossless soft-switching cell, switching losses of all power switches can be reduced significantly. The same converter is implemented for a grid connected hybrid PV/Wind power system in [2] with the realization of Perturb and Observe MPPT feature for both the sources. The double-input converter is also implemented using Incremental Conductance algorithm by Yuvaraj V et al [3].

Joanne Hui et al. [4] has proposed a new topology by the fusion of Cuk and SEPIC converters. The advantage of these converters is the inherent nature to eliminate the need for separate input filters. They also support wide ranges of PV and wind input and can operate individually and simultaneously.

A new three-input dc–dc boost converter that interfaces two unidirectional input power ports and a bidirectional port for a storage element in a unified structure is proposed by Farzam Nejabatkhah [5]. Alternate energy sources such as Photovoltaic system (PV), wind energy and Fuel cells are used as input sources. The proposed structure utilizes only four power switches that are independently controlled with four different duty ratios. Utilizing these duty ratios, tracking the maximum power of the PV source, controlling the battery power, and regulating the output voltage are provided. Due to interactions of converter control loops, decoupling network is used to design separate closed-loop controllers.

Chih-Lung Shen et al [6] presents a dual – input power converter (DIPC) with six modes of operation for a hybrid photovoltaic – wind power system. Leakage energy present in the system is completely recycled to improve the conversion efficiency and both the input energy can be processed separately or simultaneously. Even if either of the input energy sources shut down, the proposed DIPC can still keep providing sufficient power for output. It has the advantages such as lower transform turns ratio, sharing a common output inductor and smaller volume.

Sungwoo Bae et al [16] have proposed a current-source interface multi-input dc – dc converter to deliver a micro grid powered by wind and photovoltaic energy. The dynamic modelling and operation strategy for the micro grid is discussed. The variations in wind, power dispatched to the grid and ac loads are taken into account and the model is found to be reliable for a sustained micro grid making the CSI MI Cuk converter suitable for this application.

III. MAXIMUM POWER POINT TRACKING

Maximum Power Point Tracking Algorithms are used to track the operating point of the panel where the efficiency is maximum. There are many algorithms namely, Hill Climbing method, Perturb and Observe, Incremental Conductance, Fractional Open Circuit voltage method, Fractional short circuit current method, Fuzzy Logic Control, Neural network, Ripple Correlation Control, Linear Current control, Current sweep, etc. The methods vary in complexity of the algorithm, number of sensors required, convergence speed, cost, range of effectiveness, hardware implementation, popularity, and in many other aspects. In PV applications MPP of a solar panel varies with irradiation and temperature, so the use of MPPT algorithms is required in order to obtain the maximum power from a solar array.

David Sanz Morales [7] in his thesis presents various algorithms for Photovoltaic Applications. Comparison of Perturb and Observe method, Incremental Conductance and Fuzzy logic based MPPT Algorithms is done. As the first two algorithms suffer from the disadvantage of poor performance under changing irradiance, modified algorithms are proposed. The modified algorithms give better results when compared to Fuzzy Logic controller. Due to its simplicity, Perturb and Observe method is preferred.

Trisham Esram et al [8] also deal with the various algorithms used for tracking the maximum power point. Comparison among the different algorithms is based on subsystems namely Implementation, Costs, Sensors required, occurrence of multiple local maxima and Applications.

Jogendra Singh Thongam et al [17] present a study of the MPPT Algorithms for wind energy conversion systems. Tip-Speed ratio control, Power signal feedback control and Hill-Climbing search control is studied for PMSG, SCIG, DFIG based Wind Energy Conversion Systems.

Ameni Kadri et al [18] study the tip-speed ratio control and hill-climb search algorithm for DFIG based wind energy conversion system.

IV. INVERTER DESIGN

Various topologies of single-stage and multiple-stage single-phase inverters appropriate for small Distributed Generation systems are studied and compared by Yaosuo Xue et al [9]. Conventional buck inverters can be used combined with line-frequency voltage step-up transformers, which add to the size, weight, and cost of a small DG system. Multiple-stage inverters can reduce the system size and boost the dc-link voltage with dc–dc converters or high-frequency transformers. Although additional power conversion stages can usually achieve a high power and voltage range with flexibilities, in certain cases, a single-stage boost or buck-boost inverter represents more compact and efficient design with low component counts and advanced control techniques. However, the ideal buck-boost topology has yet to be found. This provides motivation for research into high efficiency, low cost inverters for DG applications.

Soeren Baekhoej Kjaer et al [10] present the various inverters topologies available for Photovoltaic applications. The comparisons are made and valuated against demands, lifetime, component ratings, and cost. The classification of inverters is based on number of power processing stages, type of power decoupling between the PV module and the grid, transformers and types of interconnections between the stage, and types of grid interfaces. Based on the study, in the case of ac modules, dual stage inverters with decoupling capacitor in the dc link and high frequency transformers for voltage amplification are preferable. Line-frequency CSIs are suitable for low power, e.g., for ac module applications, whereas high-frequency VSI is suitable for both low- and high-power systems, like the ac module, the string, and the multi string inverters.

A single-stage inverter which has a single power circuit and a One-Cycle Control along with MPPT feature is proposed by Yang Chen et al in [11]. The proposed circuit has a control circuit which is simple and comprises of an integrator, clock, flip-flop, comparator and a PI compensator. The output current of the inverter is adjustable based on the voltage of the PV array and is sinusoidal in natures that it can be connected to the grid. It also lowers the cost increases the reliability of the system.

V. GRID CONNECTED SYSTEMS

Yaow-Ming Chen et al [12] proposes a novel multi-input inverter design for the grid connected hybrid wind/PV system. The converter can deliver sinusoidal current to the grid from both the sources simultaneously if power is available or from individual sources if power is available from only one source even when large input voltage variations is present. This converter uses a Buck and Buck-Boost converter which necessitates the use of power factor correction. Perturb and Observe algorithm is used for maximum power point control due to its simplicity.

Mangu B et al [13] propose a control strategy for power flow management of a grid-connected hybrid PV-wind-battery based system. The proposed system is a multi-input transformer coupled bidirectional dc-dc converter which satisfies the load demand, manage the power flow from different sources, inject surplus power into the grid and charge the battery from grid.

A bidirectional buck-boost converter is used to harness power from PV along with battery charging/discharging control while a transformer coupled boost half-bridge converter is used to harness power from wind. The converter reduces the number of conversion stages by using less number of components and losses when compared to the existing systems.

VI. STANDALONE SYSTEMS

A bidirectional DC-DC converter for wind-PV hybrid standalone energy system with battery backup is proposed in [14] by Siddharth Joshi et al. Battery is used for charging and discharging the battery and DC link voltage. DC link voltage is regulated using a bidirectional DC-DC converter. Only DC loads are considered to evaluate the performance of the converter and hence an inverter is not used. The results convey that the system has increased efficiency.

Siavash Taghipour Broujeni et al [15] propose a paper which analyzes the various control strategies available for hybrid PV/wind power systems. The main objective of the paper is to extract maximum power from the input renewable energy sources under different conditions and to regulate the output voltage. After analysing various circuits, a hybrid double-input power converter is proposed. The system consists of a DC/DC converter, PV arrays and Wind Energy Conversion (WEC) systems. Perturbation and Observation algorithm is used for maximum power point tracking and PI controller is used for voltage regulation.

VII. SUMMARY

The following table, Table I is concluded from the literature survey.

TABLE I

SURVEY ON VARIOUS CONVERTERS FOR HYBRID RENEWABLE ENERGY SYSTEM

Paper Title	Author	Journal and Year	Proposed	Remarks
Topologies of Single – Phase Inverters for Small Distributed Power Generators – An Overview	Yaosuo Xue, Liuchen Chang, Josep Bordonau, Toshihisa Shimizu	IEEE Transactions on Power Electronics, September 2004	Comparison of various single phase inverters	Additional power conversion stages – high power and voltage range Single stage
Review of single-phase grid-connected inverters for photovoltaic modules	Soeren Baekhoej Kjaer, John K. Pedersen, Frede Blaabjerg	IEEE Transactions on Industry applications, September/ October 2005	Comparison of various inverters for PV applications	Line frequency – CSI–low power. High frequency – VSI – low/high power.

Paper Title	**Author**	**Journal and Year**	**Proposed**	**Advantages**	**Disadvantages**
Grid-Connected PV-Wind-Battery based Multi-Input Transformer Coupled Bidirectional DC-DC Converter	B. Mangu,, S. Akshatha, D. Suryanarayana, and B. G. Fernandes	IEEE Journal of Emerging and Selected Topics in Power Electronics, 2017	Multi-input transformer coupled bidirectional dc-dc converter	1) Reduced no. of power conversion stages 2) Reduced losses and Improved efficiency	Transformer coupling makes the power circuit bulkier
Paper Title	**Author**	**Journal and Year**	**Proposed**	**Advantages**	**Disadvantages**
Hybrid Wind Photovoltaic Standalone System	Siddharth Joshi, Vivek Pandya, Bhavesh Bhalja	IEEE , October 2016	Bidirectional DC-DC converter with battery as backup source	Battery back-up provided with PV source	1)Only DC loads are considered 2) Individual MPPT controller
Multi-Input Inverter for Grid-Connected Hybrid PV/Wind Power System	Yaow-Ming Chen, Yuan-Chuan Liu, Shih-Chieh Hung, Chung-Sheng	IEEE Transactions on Power Electronics, May 2007	Multi-input converter with a full bridge DC-AC inverter	1)Power delivered individually or simultaneously 2)Input voltage variation is acceptable	MPPT – P&O - oscillations
A Hybrid Wind-Solar Energy System: A New Rectifier Stage Topology	Joanne Hui, Alireza Bakhshai and Praveen K. Jain	IEEE, March 2010	Front-end rectifier – Cuk converter and SEPIC converter	1)Input filters are not necessary 2)Renewable sources can be stepped up/down	1)Dedicated single input converters 2)MPPT is realized individually for each source
Hybrid PV/Wind Power System Control for Maximum Power Extraction and Output Voltage Regulation	Siavash Taghipour Broujeni, Seyed Hamid Fathi	International Conference on Control, Instrumentation and Automation, December, 2013	Multi – input converter with output voltage PI controller	1)Extracting maximum power 2)Output voltage regulation	Individual MPPT Controllers – P&O
Modeling and Control of a New Three-Input DC–DC Boost Converter for Hybrid PV/FC/Battery Power System	Zhicheng Wang, Fuxin Liu	IEEE Transactions on Power Electronics, May 2012	DC-DC converter with four power switches operated in four different duty ratios	Control the power flow among the input sources and the Load	High voltage stress leading to conduction losses

VIII. CONCLUSION

Various topologies which were proposed for DC-DC conversion and DC-AC conversion for both grid-connected and stand-alone applications were discussed. Different papers put forth different topology based on the requirement and application. Some papers propose individual DC-DC converter for wind and photovoltaic system, while some propose a single converter. Separate MPPT algorithms are used to track the maximum operating point of the renewable sources. As the sources are renewable, hybrid power systems can be termed as the future. By implementing appropriate MPPT algorithms, the operating point is maintained at its maximum point, thereby improving the performance of the system.

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