Implementation of Reduced Switch Modular Inverter for Hybrid of Solar Photovoltaic and Wind Energy System

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Abstract- To fulfill the challenging demands of the growing grid, new concepts of the inverters are needed. In this project a reduced switch modular inverter design is detailed. A reduced switch modular inverter design is presented for a modern power system which inputs power from both AC and DC Renewable Sources. The modular inverter is the combination of both three phase inverter and three phase inverter with the neutral point and it supports both symmetrical and asymmetrical loads. Power Electronics Inverter is the key component to couple the two different renewable energy sources such like solar and wind. The converter is the combination of Cuk – SEPIC converters, the input from the source can be either buck or boost or stabilized at a particular value, the inductor in those converters provides the function filter reducing harmonics.

Index Terms- Hybrid Power, Interconnected Power System, Power Conversion, Power Generation Reliability, Designing Method, System Analysis and DC- AC Power Conversion.

I. Introduction

Recently, a combination of PV and Wind source forming a good pair with promising features for distributed power energy system applications. This means now a day a large power systems are replaced by a renewable energy sources. Applications with the Photovoltaic (PV) and wind energy have been increased significantly due to the rapid growth of power electronic techniques [1][2]. Generally PV power and wind power are complementary since sunny days are usually calm and strong winds occurred at the cloudy days or at night time. Hence, therefore the Hybrid PV/Wind power system has a higher reliability to deliver a continuous power than the individual sources [3]. Traditionally, a sub sequential energy storage banks is used to deliver the reliable power and to draw the maximum power from the PV arrays or wind turbines for either one of them has an intermittent nature [4].

Usually, two separated inverters for the PV array and wind turbine are used for the hybrid PV/Wind power system [5]. An alternative approach is to use the modular inverter for combining these renewable energy sources. Because of the complementary feature of solar and wind energy, the power rating of the modular inverter will be smaller than the total power rating of the two individual inverters. It can simplify the power system and reduced costs.

Several hybrid PV/Wind energy system use a separate DC/DC converter connected in parallel in the rectifier stage to perform MPPT control for the each renewable energy sources [3][4]. The structure proposed by [7] is a fusion of buck and buck-boost converter. The systems in literature require a passive input filters to remove the high frequency current harmonics injected into the wind turbine generators [8]. The harmonic content in the generator decreases the life span and increases the power loss by heating [8].

The objective of this paper is to propose a reduced switch modular inverter for a hybrid of solar photovoltaic and wind energy system. The proposed system design is a fusion of Cuk and SEPIC converters and inverters are switched automatically according to the load. The features of the proposed system topology are: 1) The inherent nature of these converters eliminates the need for separate input filters for PFC 2) it can support both step up/down operations for renewable sources 3) Systems works on the presence of both or any one of the renewable energy sources 4) Individual and simultaneous operations is supported 5) A large range of input voltage variation caused by different insolation and wind speed is acceptable 6) power rating of the inverter can be reduced.

II. THE PROPOSED MULTI INPUT RECTIFIER

A system diagram of the proposed rectifier stage of the hybrid energy system is shown in Fig. 1, where one of the inputs is connected to the output of the PV array and other inputs is connected to the output of the generator output. The fusion of the two converters is achieved by reconfiguring the two existing diodes from each converter and the shared utilization of the cuk output inductor by the sepic converter. This configuration allows each converter to operate normally individually in the event that one source is unavailable. Fig. 2 illustrates the case when only the wind source is available. In this case, D1 turns off and D2 turns on; the proposed circuit becomes a sepic converter and the input to output relationship is given by equation (1). On the other hand, if only the PV source is available, then D2 turns off and D1will be always on and circuit becomes a cuk converter as shown in Fig. 3. The input to output voltage relationship is given by equation (2). In both cases, both the converters have step up/down capability, which provides more design flexibility in the system if the duty ratio control is utilized.

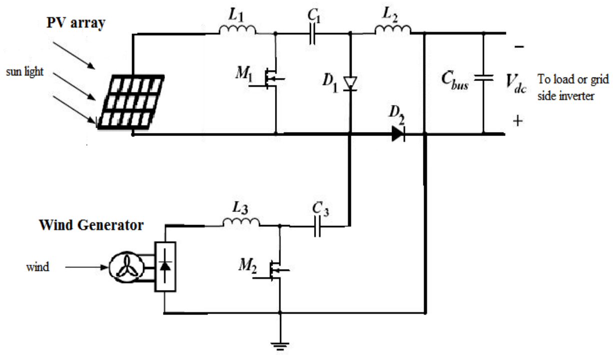


Fig.1 cuk sepic based converter on source side

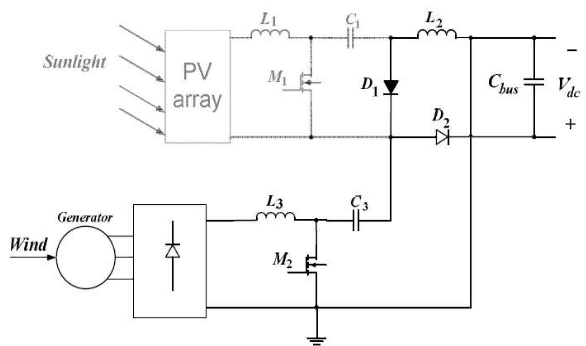


Fig.2 Sepic Converter (Wind source is available)

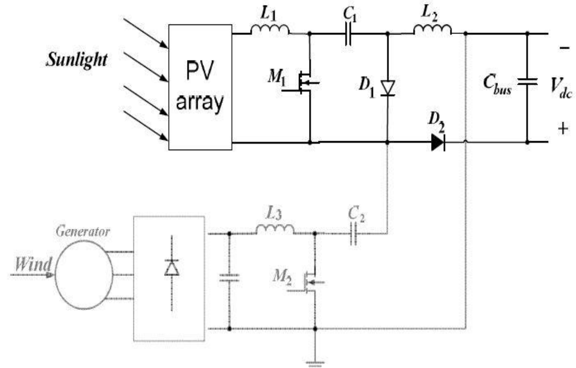


Fig. 3 Cuk Converter (PV source is available)

$$\frac{V_{dc}}{V_W} = \frac{d_2}{1-d_2} \tag{1}$$

$$\frac{V_{dc}}{V_{PV}} = \frac{d_1}{1-d_1} \tag{2}$$

In the both cases, the input to output voltage relationship is given by equation (3)

$$V_{dc} = \left(\frac{d_1}{1-d_1}\right) v_{PV} + \left(\frac{d_2}{1-d_2}\right) v_W \tag{3}$$

The PV array

The PV array is constructed by many series or parallel connected solar cells. Each solar cell is form by a PN junction semiconductor, which can produce currents by the photovoltaic effects. The equivalent circuit of the PV array is shown in Fig. 4, where I_{ph} is the generated current by the photovoltaic effect, Rs is the internal equivalent series resistance, I_{pv} is the PV array output current, and V is the PV array output voltage.

Usually, R_{sh} is very large and R_s is very small. Both of them can be neglected in order to simplify the solar cell model. Typical output power characteristic curves for the PV array under inslolation are shown in Fig. 5.

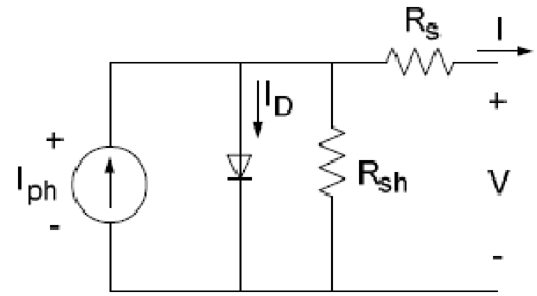


Fig. 4 Equivalent circuit of the PV array

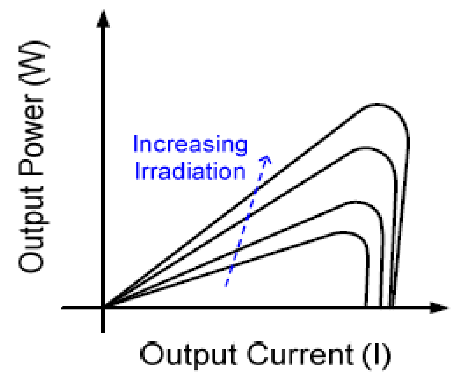


Fig. 5 PV array output power characteristic curve

The resultant ideal voltage-current characteristic of the photovoltaic array is given by equation (4) and (5);

$$I = I_{ph} - I_D \tag{4}$$

$$I = I_{ph} - I_0\left(\exp\left(\frac{qV}{kT}\right) - 1\right) \tag{5}$$

The Wind Turbine

Among the various types of wind turbines, The permanent magnet synchronous variable speed wind turbine, which has higher reliability and efficiency. The power of the wind can be derived as equation (6);

$$P_{wind} = \frac{1}{2}\rho A V_{wind}^3 \tag{6}$$

where ρ is the air density (kg/m^3), A is the area (m^2) swept by wind blades, and V_{wind} is the wind speed (m/s). The ratio of the energy extracted by the wind turbine $E_{turbine}$ to the total energy of the air-stream E_{wind} flowing through the area swept by the wind turbine blades is defined as the coefficient of performance is given by (7):

$$C_p = \frac{E_{turbine}}{E_{wind}} \times 100\% \quad (7)$$

It has been proved that the maximum value of C_p is 59.26%, which is called the Betz limit. The coefficient of performance will always less than the Betz limit. The below Fig. 6, shows the power coefficient of the typical wind speed.

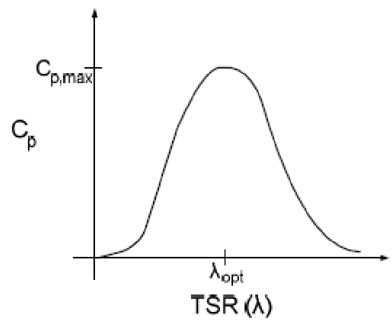


Fig. 6 Power Coefficient curve for typical wind speed

III. DESIGN OF MODULAR INVERTER WITH REDUCED SWITCH

Signification

Conventional three phase inverter system structures are fixed in size and function and offer only limited flexibility demands and to be more versatile in production and development, a new standardized system concept with modular structure is needed. Modularity basically means a segmentation of the complex structures into functional groups. In this way the main components of an inverter structure can be subdivided and the resulting modules can be treated as standalone systems. By use of standardized interfaces these separated modules can be scaled independently. The result is an inverter system that is completely adaptive regarding size, components, configuration and the operating control. The system is flexible to be quickly adapted and optimized for any application demands. Modularity or modular design is the subdivision of a complex system into smaller units (modules) with basic functionalities. These modules can then be used in different systems with multiple functionalities. A module pool keeps different discrete modules that can perform defined discrete tasks or functions. To connect any modules in a free selectable order and topology, standardized interfaces have to be defined to react on linked neighbor modules and hand over information to them. Production costs are reduced by completely independent manufacturing of the various modules. Furthermore, modular design offers additional benefits such as augmentation and exclusion. An existing system can be enlarged, updated, modified or pared down in functionality by adding or excluding new sub functional modules.

Principle to Design Modular Inverter

The basic principle of modularity can be applied to the two main fields of inverter design, the hardware and the software design. Although these design fields are functional closely related to each other, they can be more or less decoupled in design by standardized interfaces or e.g. by the use of per unit (pu) or standardized values for communicated data. In the underlying project, the modular approach has been applied to the design of an exemplary inverter system the applied modularity will now be detailed. At this point it has to be mentioned that the level and depth of modular design applied to inverters, but also to any other system, always depends on the product range of the manufacturer and the applications to be covered by the designed systems. The more complex a system is and the more functions it has to perform, the higher the level of modularity should be. The characteristic of the inverter load regarding the symmetry is one of the main influencing factors of the desired power electronic inverter topology.

The inverter topologies for symmetrical loads are shown in Fig. 7. This modular inverter is built of two MOSFET legs and with one split capacitor legs. Each of the legs is generating the voltage for one grid phase by pulsing the intermediate circuit voltage. For asymmetrical loads two strategies are commonly applied. The three leg inverter with a neutral point Fig. 8 is a combination of three single phase inverters sharing a common neutral line. The neutral line is connected to the mid –point of a common intermediate circuit built by two capacitors these characteristics lead to different hardware topologies and also different control modes that have to be implemented regarding to the environment conditions of the inverter on its primary and secondary side. As stated in the introduction, most of the inverters are fixed in their power rating and functionality. Further inverters, however, need to be able to adapt changing source and situations.

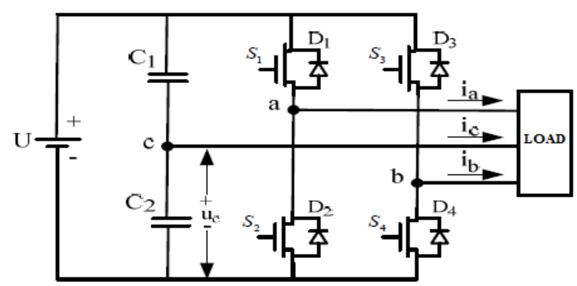


Fig.7 Inverter topology for symmetrical load

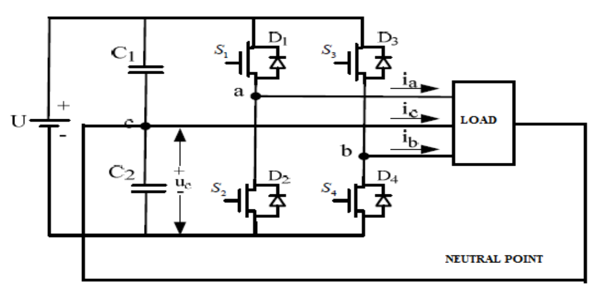


Fig. 8 Inverter topology for asymmetrical load

C. Modular Inverter Specification

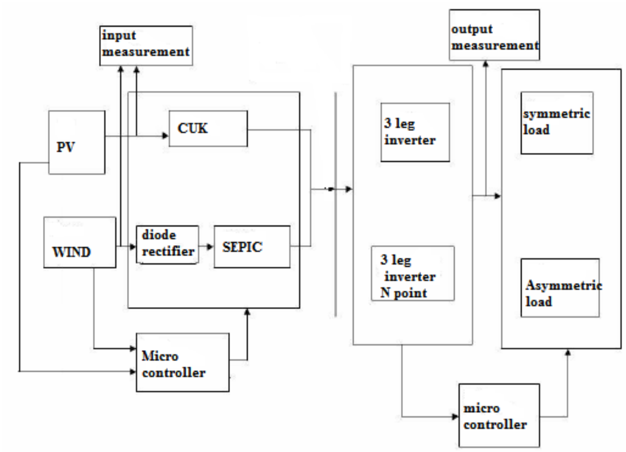


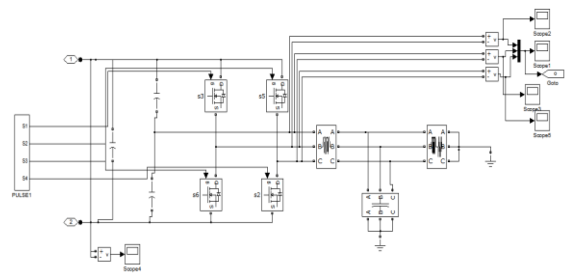
Fig. 9 Modular Inverter Blocks With input converter blocks

All basic inverter topologies are built of a couple of main functional elements. The selection and Composition of these elements is mainly based on the type and behavior of the ECS as well as the grid which the inverter is connected to. The basic components needed to operate any ECS and grid type are shown in Fig. 9 Three main module pools can be built. These are the converter, the intermediate circuit and the switch topology module pool. By selection of modules from these three module pools any typical basic inverter topology can be set up in hardware. The converter module pool itself contains DC/DC converters to adjust the voltage level of DC ECS to the intermediate circuit voltage and to actively control the DC sources. Passive and active rectifiers of this pool are able to connect AC sources to the intermediate circuit. The intermediate circuit pool keeps two different module types the circuits are the standard two level intermediate circuits built by one capacitor and the three level intermediate circuits with divide the intermediate circuit voltage in halves by the use of two series capacitors. The third wire in this case is connected to midpoint between the two capacitors. A chopper circuit is available for all intermediate circuit modules. It is closely linked to the intermediate circuit and will not be treated as separated module because of security aspects. The inverter topology for symmetrical loads is this basic inverter is built of two MOSFET legs and with one split capacitor legs either three leg inverter or three leg inverter with neutral point.

IV. SIMULATION AND RESULTS

Inverter system was simulated using MATLAB/SIMULINK. The system was finally tested under common ECS and with different loads. The designed inverter is able to handle AC and DC sources as inputs. Symmetrical and Asymmetrical load situations were successfully handled by application of three legs and three legs inverter with NP.

The test installation is set for a three phase system with a frequency of 50Hz; the applied switching frequency was 10 KHz, normal pulse generators providing switching pulses to the MOSFET switches with respect to time instant. Balanced load with resistance of 1000 ohms at all phases. The inverter output voltages are near undistributed three phase signal in amplitude and phase while the current is increased in phase ‘a’, due to load step. In this case unbalance resistive-inductive load was placed. All Phases were set to 1000 ohms initially, while phase ‘a’ includes a 1mH inductance is series as well. An unsymmetrical load step from 500 ohms to 1000 ohms in phase “a” was performed. The quick reaction of modular inverter control to the load step can be seen.



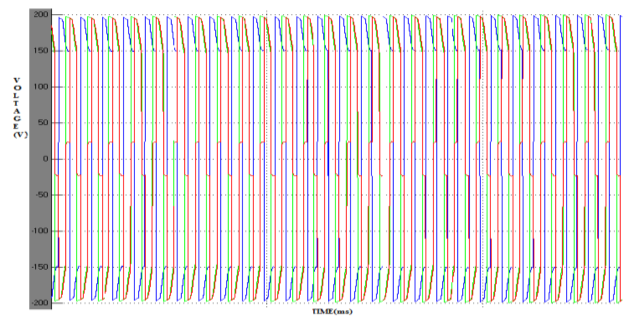
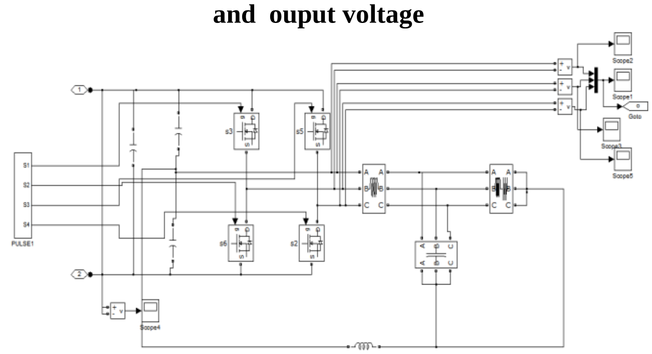


Fig. 10 Symmetrical load modular inverter simulation circuit and ouput voltage



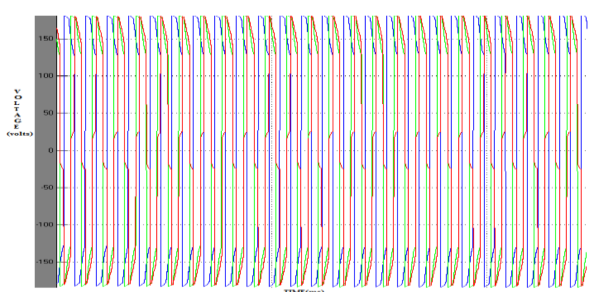


Fig. 11 Asymmetrical load modular inverter simulation circuit and output voltage

V. CONCLUSION

Cuk - Sepic converter design methodology based modular inverter with four switches and two fixed capacitors were proposed. Hence it is clear from the simulation results by reducing the number of switches in the modular inverter; it is able to get a desired simulation output as shown in simulation results, Due to the design of Cuk-SEPIC converter there is no need for additional Filter components in the proposed circuit; the features of the proposed system are (1) possible to work on both or any one of the renewable sources; (2) reducing the switches in the inverter side will leads to improve performance and efficiency; (3) so conduction losses and switching losses will had been reduced; (4) size of the component and cost are reduced. CUK - SEPIC Converter and modular inverter performance for the proposed system is analyzed through MATLAB software simulations.

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