Multi Port Single Stage Power Electronics Converter and Wind PFC Converter for DC Micro Grid Applications

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Abstract: In this study multi port AC/DC-DC single stage power electronics converter proposed for grid power supply. The topology includes reduced number of active element and passive element. Passive element is used to provide to achieve improved voltage gain and to reduce the voltage stress of input side switches. The active-clamp circuits are used to recycle the energy stored in the leakage inductors and to improve the system performances. Here two input port (wind and battery unit) and output port connected to dc grid, battery act as charge unit and source. Efficient wind power conversion is achieved by PFC boost dc-dc converter. Controlled and high step up voltage is supplied to multi-port converter from wind source.

Keywords: Battery voltage control, multi-port dc-dc converter, PFC boost ac-dc converter, PWM modulator, wind generation

INTRODUCTION

Multipro converter interfacing with several power sources and storage devices are widely used in recent trends. Independent power converters used for each of the energy sources, common high-voltage or low-voltage DC bus is used to interconnect multiple sources are considered essentially need several conversion stages in conventional method. Existing multiport structure is inherently complex also has more priced due to the multiple conversion stages and communication devices between individual converters.

Proposed multiport converters have more merits including less components, lower price, more compact size and good dynamic characteristics in Huang et al. (2013) Energy storage device should be incorporated in many patients. For sample, in electric vehicle application acceleration or startup period the regenerative breaking should occurred. Consequently, the port connected to the energy storage to allow bidirectional power flow is very important one. Multiport system structure shown in Fig. 1.

Additionally battery unit is used as a both storage and source unit. It is deliberate effort that for the AC-dc converters connected to the wind arrangement, as the result the PFC boost converter is coupled with battery source based converter, as the proposed event is made by voltage gain extension battery system with such as coupled inductors, transformer unit and capacitors are often to employed and achieve high potential conversion gain ratio and the reduce the voltage stress on input side switches described in Li and He (2011). Accordingly, conduction losses are reduced which can choosing the power switches with lower voltage rating and lower turn-on resistance for the converters. Coupled inductors are relatively as good as compared to isolation transformers. Since the coupled inductors have simple structural windings also have less conduction losses in Wu et al. (2008). However, the leakage inductors of the coupled inductors used to consume great energy for a large winding ratio. Where the voltage stresses and the losses of the switch will both be
increased in such a case. A boost converter with coupled inductor and active-clamp circuit is proposed in Wu et al. (2008). These types of boost converters can yield a high step-up voltage gain, reduce the voltage stresses on switch and recycle the energy in the leakage inductor.

A multi port-input converter based on a boost topology is presented in Solero et al. (2004) that have lower input current ripples. Therefore, it is suitable for the large current applications such as hybrid vehicles. Another two-input port boost converter that interfaces two unidirectional input ports and one bidirectional port is presented in Danyali et al. (2008) for a hybrid WIND/battery system. The two types of decoupling networks are introduced based on the utilization stage of the battery. A multi-input single-ended primary-inductor based converter with a bidirectional input is proposed in Jung and Kwasinski (2011). This converter system is suitable for the hybrid system that incorporates energy storage elements like as ultra capacitors. However, lack of voltage gain extension cells makes the converters in Solero et al. (2004) and Jung and Kwasinski (2011) difficult to be used in a high step-up application. Moreover, for the converters presented in Danyali et al. (2008) and Jung and Kwasinski (2011), the operation mode has to be changed after a transition between charging and discharging occurs. This would increases the complexity of the control scheme and also reduces the reliability of the system.

The three-phase Power-Factor-Correction (PFC) rectifiers with three or more active switches exhibit superior power factor and input-current Total Harmonic Distortion (THD) compared with those implemented with a fewer number of switches (Kolar and Friedli, 2011). However, because the simplicity and low cost of single- and two-switch rectifiers are so attractive, they are increasingly employed in cost-sensitive applications such as three-phase battery chargers.

In this study a new, three-phase, two-switching, Zero-Voltage-Switch (ZVS), Discontinuous-Current-Mode (DCM), PFC boost rectifier is introduced in wind generation. The proposed rectifier unit has achieves less input-current THD over the entire input range and above 20% load and features of ZVS for all the switches without need of additional soft-switching circuit arrangement. Moreover, the proposed rectifier is automatically achieves the balancing between voltage of the two output capacitors connected in series. In addition, the common-mode Electromagnetic Interference (EMI) of the proposed rectifier is quite low. Proposed rectifier system provides dynamic generation capability for wind energy source.

The proposed Multi-port AC/DC-DC converter for the Hybrid wind/battery system is achieved the following advantages:

- High step up voltage conversion ratio and coupled inductors are used to reduce the input side switching losses.
- The simple converter topology which has reduced number of the switches and associate circuits.
- Simple control strategy which does not need to change the operation mode after a charging/discharging transition occurs unless the charging voltage is too high.
- In all modes of operation output voltage is always regulated.

The MPPT-tracking converters are noted and the operating range of the voltage has to be limited less than the MPP voltage when the output voltage or current control is active described in Huusari et al. (2010). This issue could be addressed by limiting the operating range of the converter in the voltages higher than MPP.

**WIND POWER GENERATION**

The basic principle of wind turbine, which is convert the linear motion of the wind into rotational energy. A 1310 L-L voltage, 2.6 W of power and 50 Hz induction generator is used for generation purpose. It is interface with proposed rectifier for efficient generation. The basic principle of wind turbine is linear motion into rotational energy. An electrical generator is performed by rotational energy, allowing the wind kinetic energy to be turned into electric power presented in Silva et al. (2008).

The captured power of the wind ($P_v$) for wind turbine is given by Eq. (1):

$$P_v = \frac{1}{2} \rho_a A_v u^3$$

where, $\rho_a$ is wind velocity, $u$ is wind speed and $A_v$ is wind turbine area of swept. The mechanical Power ($P_m$) is generated by the wind turbine from the capture power of wind depends of the power Coefficient ($C_p$) of the wind turbine, as it shows the Eq. (2):

$$P_m = P_v C_p(\lambda)$$

Is the tip speed ratio $\lambda$, given by Eq. (3):

$$\lambda = \frac{r \omega_m}{n}$$

where, $r$ is the length of the wind turbine spade and $\omega_m$ is the angular rotor speed. The variation of the $C_p$ with $\lambda$ depends on the aerodynamic characteristics of the wind turbine. The $C_p$ equation is provided by the
turbine manufacturer. In the quality of illustration, an optimum value of \( \lambda \) for which the conversion of the captured wind power in mechanical power is maximum.

**PMSG wind model:** The proposed Permanent Magnet Synchronous Generator (PMSG), which is constructed by using number of poles to avoid the availability of gearbox, presents PMSG have some advantages when compared with the DFIG in Wind Energy Conversion Systems (WECS) (Silva et al., 2008). External excitation current is not required; such as light weight, compact size, more reliability, good efficiency. Effective mechanical Torque \( (T_m) \) is applied to the PMSG is given by:

\[
T_m = \frac{p_m}{\omega_m} \tag{4}
\]

\[
T_m = \frac{1}{2} \rho_a A_v \frac{C_o}{\lambda} \cdot u^2 \tag{5}
\]

Using the following torque equation again, the electromagnetic Torque \( (T_e) \) of the PMSG is given by:

\[
T_e = \frac{E_{a} I_a + E_{b} I_b + E_{c} I_c}{\omega_m} \tag{6}
\]

where, the \( E_{a,b,c} \) and \( I_{a,b,c} \) are represented by the induced instantaneous voltages and currents through PMSG windings. If friction is not considered, the variation of the angular mechanical speed of the rotor with the time:

\[
\omega_m = \frac{1}{j} (T_m - T_e) \tag{7}
\]

The power converter rectifier stage used to must presents to produces high boost up voltage with power factor and harmonic distortion in the current and voltage of PMSG’s systems such as shown in Fig. 2.

**Wind generator side converter:**

**PFC boost converter:** Proposed three-phase two-switch soft switch PFC boost rectifier provided effective neutral potential balance the three Y-connected capacitors, \( C_1, C_2 \) and \( C_3 \), are used to create virtual neutral \( N \), i.e., same potential there is no physical connection in three-wire power systems. Since the effective neutral is connected to the midpoint between two switches \( S_1 \) and \( S_2 \) and capacitor voltage is same as in neutral point of three phases. In addition, by connecting virtual neutral \( N \) directly to the midpoint between switches \( S_1 \) and \( S_2 \), decoupling of the three input currents is achieved. In each decoupled inductor circuit current depends on each phase voltages, current reduces which reduces the THD and increases the PFC (Jang and Jovanovic, 2013).

In Fig. 2 diodes \( D_1-D_6 \) allow only the positive phase voltage. Deliver the current to \( S_1 \) and \( S_2 \) when \( S_1 \) on and \( S_2 \) on, respectively. During \( S_1 \) off periods stored inductor energy connected with positive phases and delivered the energy to CR. During \( S_2 \) off periods stored inductor energy connected with negative phase and delivered the energy to capacitor CR. LC inductor circuit and it is connected with capacitor CR. It can produces high EMI current in conventional. Proposed coupled inductor \( LC \) the midpoint of output capacitors \( C_{01} \) and \( C_{02} \) can be directly connected to virtual neutral \( N \), which makes the output common-mode noise very low. Furthermore, because of the presence of coupled inductor \( LC \), a parallel operation of multiple rectifiers is also possible.
**PFC rectifier operation and control:** The first part of the PFC boost converter is described in the basic function and modulation of three-phase PFC rectifier systems. In order to complete the overview, typical control structures of the system constructed by the input and output filter capacitors which is used to neglecting ripple voltages. It is assumed that in the ON state, semiconductors are exhibit zero resistance and those are short circuits. Then the output capacitances of the switches are not neglected in this analysis. And the two-winding ideal transformer with magnetizing inductance $L_{LM}$ and leakage inductances $L_{L1K1}$ and $L_{L2K2}$.

It should be noted that the average voltage across capacitor CR is equal to output voltage. Assumed rectifier the ripple voltage of capacitor CR is much smaller than output voltage $V_0$, voltage $VCR$ across capacitor CR can be considered constant and equal to $V_0$:

$$V_0 = V_{o1} + V_{o2}$$

Rectifier unit D1, D2 and D3 conduct only when their corresponding phase voltage is positive and rectifier D4, D5 and D6 conduct only when their corresponding voltage is negative, the Simplified circuit diagram of the rectifier along with the reference directions of currents and voltages. However, the same model is applicable to any other $60^\circ$ segment during which the phase voltages do not change polarity. Whereas the switching interval, the S1, S2 switches operate in a complementary fashion with approximately 50% duty cycle and with a short dead time between the turn OFF of switch S1 and the turn ON of switch S2 and vice versa.

At the time both switches can achieve ZVS. Regulation of the output voltage and ZVS are maintained simultaneously with respect to input voltage and load current variations. This type of control strategy has been routinely employed to bridge-type resonant converter (Jang and Jovanovic, 2013). As the result Soft switching topology is operating under continuous conduction modes of operation.

During the switching period $T_S$, switch S1 is turn OFF and switch S2 is turn ON. Since the effect of the dead time is neglected. Under ZVS condition PFC is achieved and wind generation is improved during these modes.

**PROPOSED MULTIPORT CONVERTER OPERATION AND CONTROL**

**Multiport converter operation:** This converter section which is introduces the topology of non-isolated three-port AC/DC-DC converter is proposed, as shown in Fig. 3. The converter switches $S_1$ and $S_2$ are composed with two main ports battery and wind. Bidirectional power flow of the battery port is achieved by driven of synchronous switch $S_3$ and corresponding to switch $S_1$. The two coupled inductors $L_1, L_3$ with winding ratios $n_1$ and $n_2$ are used to maintain voltage gain ratio. Active clamped circuits formed by $S_4, Lk1, Cc1$ and $S_5, Lk2, Cc2$. The both sets are used to recycling the leakage energy, two switch based two port converter is allow to controlled by duty cycles $d_1$ and $d_2$. The fixed-frequency driving signals of the auxiliary switches $S_3$ and $S_4$ are interrelated to primary switch $S_1$, switch $S_3$ provides bidirectional path for the battery port.

![Fig. 3: Dc-De multiport converter](image)
Similarly, $S_5$ is driven in an interrelated manner to switch $S_2$. The duty cycle $d_1$ and $d_2$ are driven by $180^\circ$ phase shift between in it. The wind power system, which has operated by four operating periods based on availability of wind energy. Operating period 1 is considered, the battery will serve as the main power source. The wind starts to generate and the initial to medium wind speed is enough for supplying part of the load demand, the operation period is changed to period 2. The load is supplied by both wind turbine and battery source in this period. In period 3 the increasing isolation makes the wind power as large as the load demands. After rectification process the battery will conserves the extra wind power for backup use. During period 4, the charging voltage of the battery reaches the preset level and can avoid the overcharging. As claimed period 4, the charging voltage of the battery reaches the battery port is mainly used to maintain the power at balancing and storing the unconsumed wind power source in this period. In period 3 the increasing isolation makes the wind power as large as the load demands. After rectification process the battery will conserves the extra wind power for backup use. During period 4, the charging voltage of the battery reaches the preset level and can avoid the overcharging. As claimed by the load demand, the proposed two-port converter is operating under two modes. One is battery balancing mode (mode 1), another one is Maximum Power Point Tracking (MPPT), is always operated for the wind port to draw maximum power from the wind port. The battery port is mainly used to maintain the power at balancing and storing the unconsumed wind power during light-load condition, else provides power at demand of heavy-load condition. The following statement can be represented by power sharing of the inputs:

$$P_{Load} = P_{Wind,wvc} + P_{bat-wvc}$$  \hspace{1cm} (9)

where, $P_{Load}$ is represented by load demand power, $P_{Wind,wvc}$ is the wind power under Wind Voltage Control (WVC) and $P_{bat-wvc}$ is the battery power under WVC. In mode 1, maximum power is drawn from the WIND source. The battery may produce or store the power depending on the load demand. As the result, $P_{bat-wvc}$ could be either positive or negative. When compared to the battery charging voltage as high as the maximum setting voltage, the converter section will be switched as the battery management mode (mode 2). According to the mode 2, MPPT will be disabled; therefore, only part of the wind power is drawn. However, the battery voltage could be controlled to avoid the battery from overcharging. The power sharing of the input ports (wind, battery) can be represented as:

$$P_{Load} = P_{wind,BVC} + P_{Bat,BVC}$$  \hspace{1cm} (10)

where, $P_{wind,BVC}$ is defined as wind power under Battery Voltage Control (BVC) and $P_{Bat,BVC}$ is named by battery charging power under WVC. Whereas the load demand is increased and the battery side voltage is decreased, the Converter is operated in mode 1.

### Multiport converter battery balancing modes:

In battery balancing mode, $i_{L1}$ and $i_{L2}$ are named by magnetizing inductor currents, $V_{C2}$ is wind side voltage, $V_o$ is output voltage, all values are selected to derived from mode of small-signal model. Switching period should be divided into four kinds of main circuit levels depending of the two main switches such as ON-OFF states. The state equations of each stage can be developed based on Kirchhoff’s Current Law and Kirchhoff’s Voltage Law. Battery balancing and efficient power flow management from wind side port to load performance derived fully by this operation.

### MODES OF OPERATION

There are around seven various modes of operation as explained below.

#### Mode 1: \(0\leq t < t_1\): At the time \(0\), switch \(S1\) and auxiliary switches \(S4\) and \(S5\) are turned OFF, while the primary switch \(S2\) is turned ON. Although \(S1\) is in the off state, resonant inductor \(L_{k1}\) resonates with capacitors \(C_{r1}\) and \(C_{r4}\) are. In this period, \(C_{r1}\) is discharged to zero and \(C_{r4}\) is utilized to the period and charged to \(V_{bat+V_{Cc}1}\). For the Wind port, \(S2\) is turned ON, the wind generator is utilized the period and generates the wind power, then allows to deliver the wind current flows through \(V_{wind-L2-Lk2-S2}\) loop. In order to achieve the ZVS feature for \(S1\), the energy stored in resonant inductor \(L_{k1}\) should satisfy the following inequality:

\[
L_{k1} \geq \frac{[|c_{r1}|c_{r4}|V_{dc}(t_0)|^2}{i_{Lk1}(t_0)^2} \hspace{1cm} (11)
\]

#### Mode 2: \(t_1\leq t < t_2\): This mode starts when \(V_{ds1}\) is down to zero. The body diode of \(S1\) is forward biased so that the ZVS condition for \(S1\) is established. The resonant current \(i_{Lk1}\) is increased towards zero. \(L2\) is still linearly charged in this period.

#### Mode 3: \(t_2\leq t < t_3\): In mode 3 switch \(S1\) begins to conduct current at \(t_2\) and the battery port current follows the path \(P_{bat-L1-Lk1-S1}\). \(S2\) is also turned ON in this interval. As the result, both \(L1\) and \(L2\) are linearly charged and energy of both input ports is stored in these magnetizing inductors. Auxiliary switches \(S3\), \(S4\) and \(S5\) are all turned OFF.

#### Mode 4: \(t_3\leq t < t_4\): In this interval, \(S2\) starts to be turned OFF and the auxiliary switch \(S5\) remains in the OFF state. However, a resonant circuit formed by \(Lk2\) and \(Cr2\) and \(Cr5\) releases the energy stored in \(Lk2\). Resonant capacitor \(Cr2\) is quickly charged to \(V_{wind} + V_{Cc}2\), while
Table 1: Circuit parameters for wind side PFC converter

| Parameter | Value |
|-----------|-------|
| L         | 200 uH |
| C         | 2.2 uF |
| C_a       | 3 uF   |
| L_m       | 1.7 mH |
| L_k       | 145 uH |
| C_1, C_2  | 270 uF |

Table 2: Circuit parameters for multiport converter

| Parameter     | Value |
|---------------|-------|
| Bat_V         | 48 V  |
| Wind_Power,V  | 520 W/1300 V |
| n1, n2        | 4.44  |
| f_sw          | 50 kHz |
| L_1, L_2     | 52 uH  |
| L_k1, L_k2   | 1 uH   |
| C_c1, C_c2   | 470 uF |
| C_0          | 47 uF  |

Cr5 is discharged to zero. In order to achieve the ZVS feature for S5, the energy stored in resonant inductor Lk2 should satisfy the following inequality:

\[
L_{k2} \geq \frac{[G_{r2} |V_{dS}(t_3)|^2]}{|L_{k2}(t_3)|^2} \tag{12}
\]

Mode 5: \( t_4 \leq t < t_5 \): At the interval \( t_4 \), \( V_{DS} \) reaches zero and the body diode across the auxiliary switch S5 is turned ON. Therefore, a ZVS condition for S5 is established. Given that the \( C_{r5} \) is much smaller than \( C_{c2} \), almost all the magnetizing currents are recycled to charge the clamp capacitor \( C_{c2} \). Furthermore, \( V_{c2} \) is considered as a constant value since the capacitance of \( C_{c2} \) is large enough. This interval ends when inductor current \( i_{L,k2} \) drops to zero.

Mode 6: \( t_5 \leq t < t_6 \): At the interval of \( t_5 \), the current of \( L_{k2} \) is reversed in direction as the result the achieved energy stored, this interval is released through the

Fig. 4: Proposed multiport circuit

Fig. 5: Controller circuit for multi-port converter
Fig. 6: Wind voltage

Fig. 7: Output voltage

Fig. 8: PFC
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**Mode 7: t6≤t<t7:** Duration of t6, both S2 and S5 switches are in the OFF state. A resonant circuit is formed by Lk2, Cr2 and Cr5. During this interval, Cr2 is discharged to zero and Cr5 is charged to $V_{\text{wind}}$ + $V_{C2}$. To ensure the ZVS switching of S2, the energy stored in Lk2 should be greater than the energy stored in parasitic capacitors Cr2 and Cr5 (Table 1 and 2):

$$L_{k2} \geq \frac{[G_{c2}][G_{r2}](V_{\text{dis}}(t_o))^2}{[L_{k2}(t_o)]^2}$$  \hspace{1cm} (13)

**SIMULATION RESULTS**

Simulation result of multiport single stage converter and PFC wind and battery arrangement with boost converter using power generations with R load performances is verified and shown in Fig. 4. Proposed controller arrangement is shown in Fig. 5. Wind voltage and output voltages shown in Fig. 6 and 7. THD = 4.01% is shown in Fig. 8 and 9.

**CONCLUSION**

Multi port dc-dc converter integrated with wind and battery unit proposed. Double inductor based boost conversion is taken. Achieved of the desired voltage range is proved by battery charging and its control based on generation capacity of wind with active clamp circuit. MPPT is presented to improve the generation of wind through Multi-port converter. Wind generation and quality of power deliver to multiport side is improved by proposed PFC converter. MATLAB (SIMULINK) Result shows the entire performance of proposed unit and verified.

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