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Research Article

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

Multiport converters 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

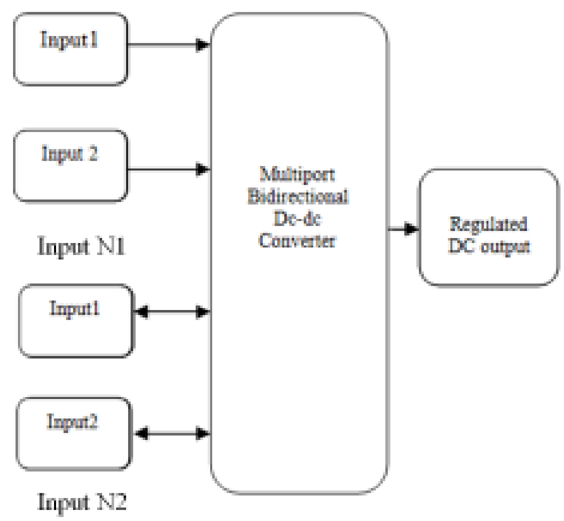

Fig. 1: Multiport system structure

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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 entired 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):

$$P_v = \frac{1}{2} . \rho_a \cdot A_v \cdot u^3 \quad (1)$$

where, ρ_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 (Cp) of the wind turbine, as it shows the Eq. (2):

$$P_m = P_v \cdot C_p(\lambda) \quad (2)$$

Is the tip speed ratio λ, given by Eq. (3):

$$\lambda = \frac{r.\omega_m}{n} \quad (3)$$

where, r is the length of the wind turbine spade and ω_m is the angular rotor speed. The variation of the C_p with λ 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 λ 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 of 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:

$$T_m = \frac{P_m}{\omega_m} \tag{4}$$

$$T_m = \frac{1}{2}.\rho_a \cdot A_v \cdot \frac{C_p\, r.}{\lambda} \cdot u^2 \tag{5}$$

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.

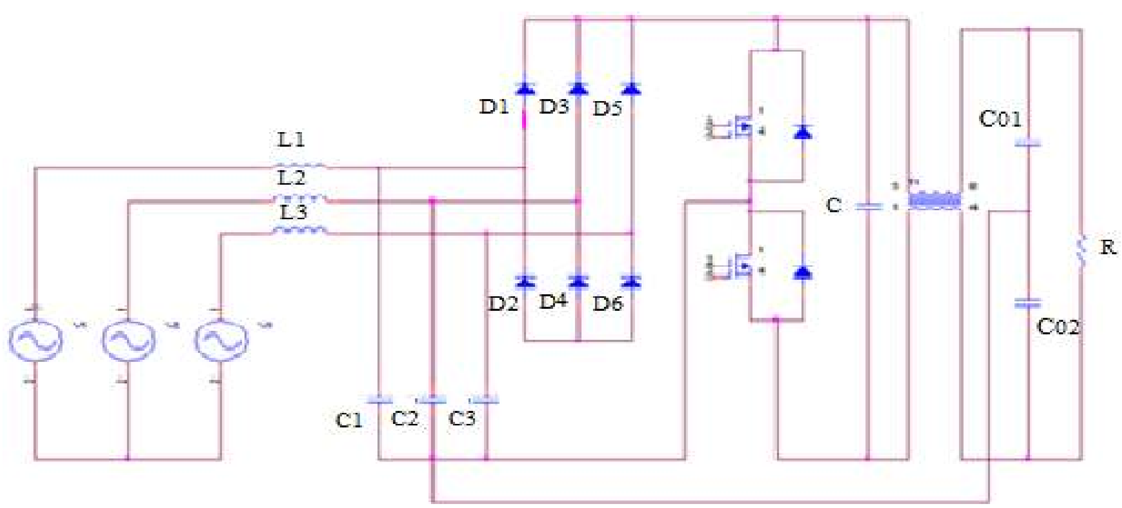

Fig. 2: PFC boost converter

PFC rectifier operation and control: The first part of the PFC boost converter is describes 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 LM and leakage inductances L_{LK1} and L_{LK2}.

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 VO, voltage VCR across capacitor CR can be considered constant and equal to V_0:

$$V_0 = V_{01} + V_{02} \tag{8}$$

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° 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 L1, L3 with winding ratios $n1$ and $n2$ 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 $d1$ and $d2$. 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.

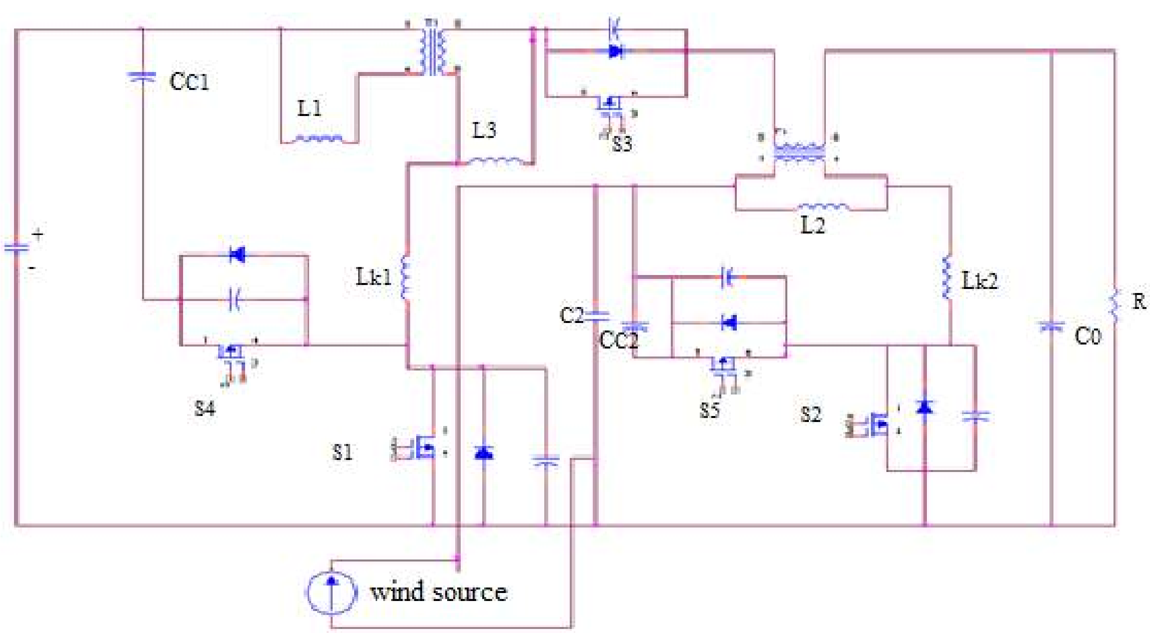

Fig. 3: Dc-Dc multiport converter

Similarly, S_5 is driven in a interrelated manner to switch S_2. The duty cycle d1 and d2 are driven by 180° phase shift between in it. The wind power system, which has operated by four operating periods based on availability of wind energy. Operating period1 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 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:

$$P_{Load} = P_{Wind\_WVC} + P_{bat-WVC} \quad (9)$$

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:

$$P_{Load} = P_{wind\_BVC} + P_{Bat\_BVC} \quad (10)$$

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, $vC2$ 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: $t_0 \le t < t$: At the time $t0$, switch $S1$ and auxiliary switches $S4$ and $S5$ are turned OFF, while the primary switch S_2 is turned ON. Although $S1$ is in the off state, resonant inductor $Lk1$ resonates with capacitors $Cr1$ and $Cr4$ are. In this period, $Cr1$ is discharged to zero and $Cr4$ is utilized to the period and charged to Vbat+$VCc1$. 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 $Vwind$-$L2$-$Lk2$-$S2$ loop. In order to achieve the ZVS feature for S_1, the energy stored in resonant inductor $Lk1$ should satisfy the following inequality:

$$L_{K1} \geq \frac{[(C_{r1}||C_{r4})(V_{ds}(t_0)]^2}{[i_{LK1}(t_0)]^2} \quad (11)$$

Mode 2: t1≤t<t2: 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 $iLk1$ is increased towards zero. $L2$ is still linearly charged in this period.

Mode 3: t2≤t<t3: In mode 3 switch $S1$ begins to conduct current at $t2$ and the battery port current follows the path Vbat-$L1$-$Lk1$-$S1$. $S2$ 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: t3≤t<t4: 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 $Lk2$, $Cr2$ and $Cr5$ releases the energy stored in $Lk2$. Resonant capacitor $Cr2$ is quickly charged to V_{wind}+ $VCc2$, while

Table 1: Circuit parameters for wind side PFC converter

Parameter	Value
L	200 uH
C	2.2 uF
C_R	3 uF
Lm	1.7 mH
L_{lk}	145 uH
C_1, C_2	270 uF

Table 2: Circuit parameters for multi-port 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
C0	47 uF

*Cr*5 is discharged to zero. In order to achieve the ZVS feature for *S*5, the energy stored in resonant inductor *Lk*2 should satisfy the following inequality:

$$L_{K2} \geq \frac{[(C_{r2}||C_{r5})(V_{ds}(t_3))]^2}{[i_{LK2}(t_3)]^2} \tag{12}$$

Mode 5: t4≤t<t5: At the interval *t*4, V_{Ds5} reaches zero and the body diode across the auxiliary switch *S*5 is turned ON. Therefore, a ZVS condition for *S*5 is established. Given that the *Cr*5 is much smaller than *Cc*2, almost all the magnetizing currents are recycled to charge the clamp capacitor *Cc*2. Furthermore, *VCc*2 is considered as a constant value since the capacitance of *Cc*2 is large enough. This interval ends when inductor current i_{LK2} drops to zero.

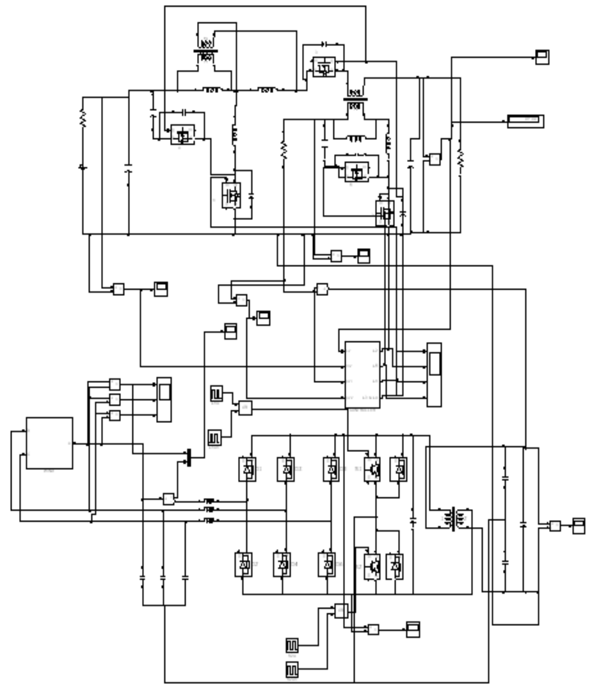

Fig. 4: Proposed multiport circuit

Mode 6: t5≤t<t6: At the interval of *t*5, the current of *Lk*2 is reversed in direction as the result the achieved energy stored, this interval is released through the

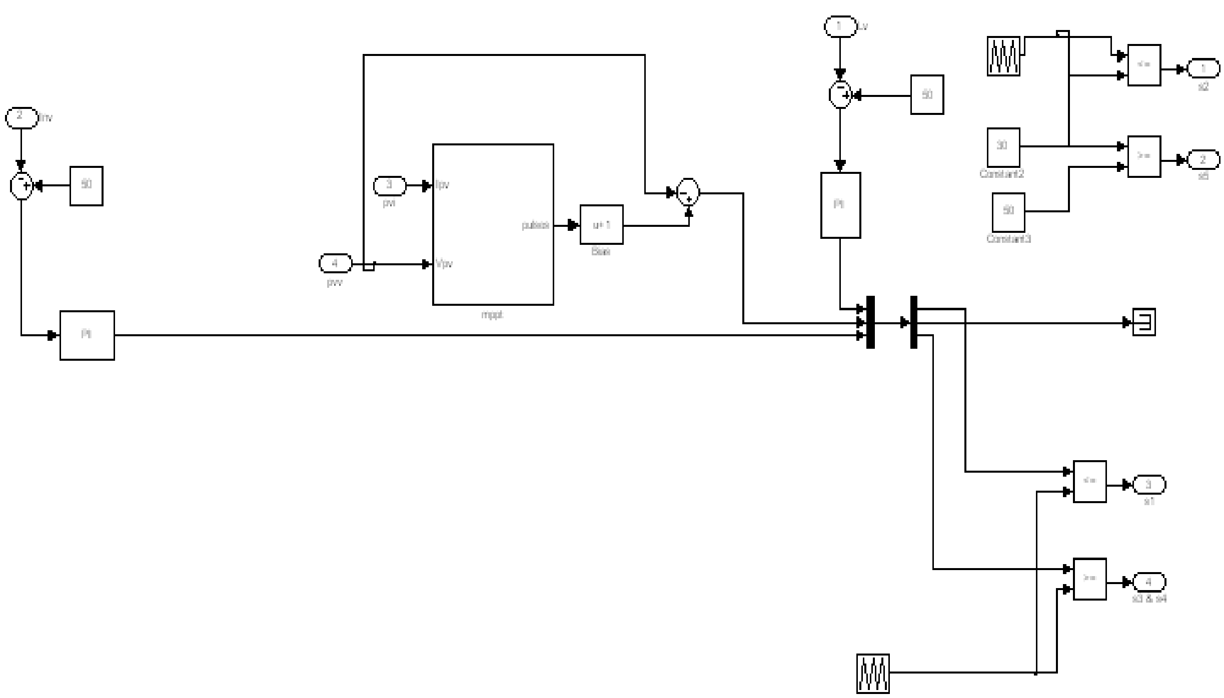

Fig. 5: Controller circuit for multi-port converter

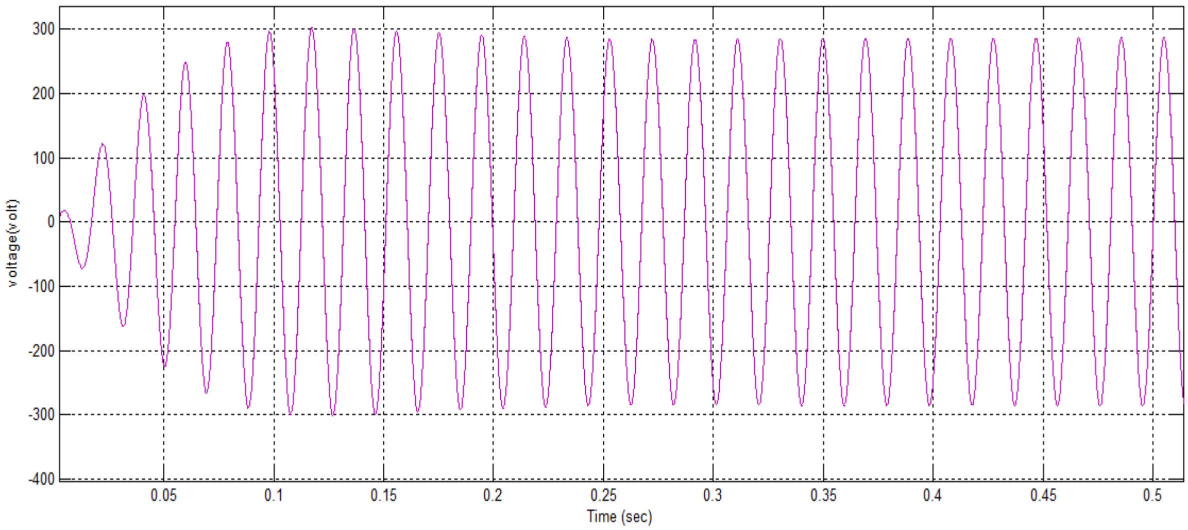

Fig. 6: Wind voltage

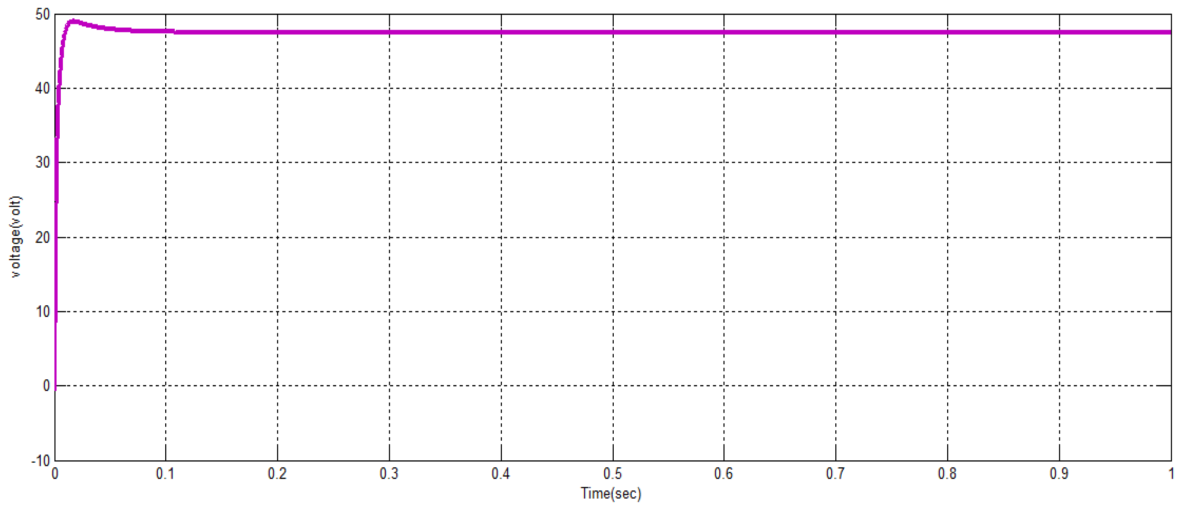

Fig. 7: Output voltage

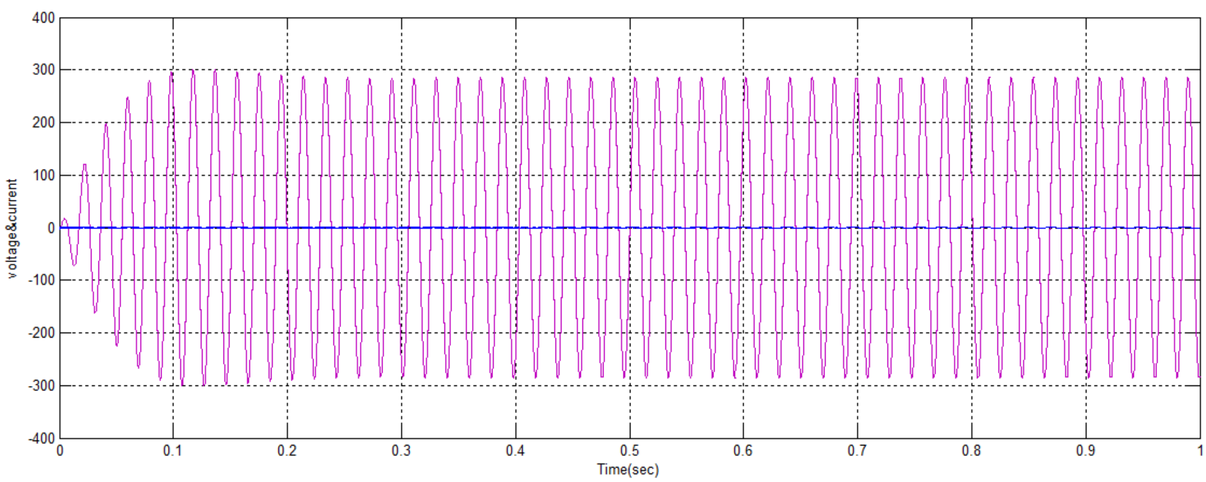

Fig. 8: PFC

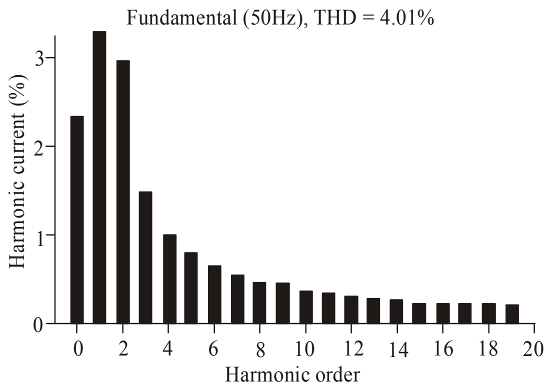

Fig. 9: THD

*Cc*2-*S*5-*Lk*2-*L*3 loop. End of the mode 6 Switch *S*5 is turned OFF.

Mode 7: t6≤t<t7: Duration of t6, both *S*2 and *S*5 Switches are in the OFF state. A resonant circuit is formed by *Lk*2, *Cr*2 and *Cr*5. During this interval, *Cr*2 is discharged to zero and *Cr*5 is charged to V_{wind} th+ *VC*2. To ensure the ZVS switching of *S*2, the energy stored in *Lk*2 should be greater than the energy stored in parasitic capacitors *Cr*2 and *Cr*5 (Table 1 and 2):

$$L_{K2} \geq \frac{[(C_{r2}||C_{r5})(V_{ds}(t_6)]^2}{[i_{LK2}(t_6)]^2} \quad (13)$$

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.

REFERENCES

Danyali, S., S.H. Hosseini, F. Nejabatkhah, S.M. Niapour and M. Sabahi, 2008. Modeling and control of a new three-input DC-DC boost converter for hybrid WIND/FC/battery power system. IEEE T. Power Electr., 23(2): 782-792.

Huang, A.Q., Y.M. Chen and X. Yu, 2013. High step-up three-port DC-DC converter for stand-alone WIND/battery power systems. IEEE T. Power Electr., 28(11): 5049-5061.

Huusari, J., J. Lepp¨aaho, L. Nousiainen and T. Suntio, 2010. Issues on wind generator interfacing with current-fed MPPT-tracking converters. IEEE T. Power Electr., 25(9): 2409-2419.

Jang, Y. and M.M. Jovanovic, 2013. The TAIPEI rectifier-a new three-phase two-switch ZVS PFC DCM boost rectifier. IEEE T. Power Electr., 28(2): 686-694.

Jung, J. and A. Kwasinski, 2011. A multiple-input SEPIC with a bi-directional input for modular distributed generation and energy storage integration. Proceeding of 26th Annual IEEE Applied Power Electronics Conference and Exposition (APEC, 2011), pp: 28-34.

Kolar, J.W. and T. Friedli, 2011. The essence of three-phase PFC rectifier systems. Proceeding of IEEE 33rd International Telecommunications Energy Conference (INTELEC, 2011), pp: 1-27.

Li, W. and X. He, 2011. Review of nonisolated high-step-up DC/DC converters in photovoltaic grid-connected applications. IEEE T. Ind. Electron., 58(4): 1239-1250.

Silva, C.E.A., R.T. Bascope and D.S. Oliveira, 2008. Three-phase power factor correction rectifier applied to wind energy conversion systems. Proceeding of 23rd Annual IEEE Applied Power Electronics Conference and Exposition (APEC, 2008), pp: 768-773.

Solero, L., A. Lidozzi and J.A. Pomilio, 2004. Design of multiple-input power converter for hybrid vehicles. Proceeding of 19th Annual IEEE Applied Power Electronics Conference and Exposition (APEC '04), pp: 1145-1151.

Wu, T.F., Y.S. Lai, J.C. Hung and Y.M. Chen, 2008. Boost converter with coupled inductors and buck-boost type of active clamp. IEEE T. Ind. Electron., 55(1): 154-162.