Converter for low voltage microgenerators engineering essay

Engineering

Abstract�" The conventional converters used in microgenerator is very inefficient due to many losses. Here the proposed converter directly boost the microgenerator low ac voltage to a usable higher dc voltage, and by that achieve higher efficiency than conventional power converters. The conventional converters have two stages: Diode Bridge Rectifier and a DC-DC converter. Here, the diode bridge rectification at the front end is not normally feasible due to the very low output voltage of the microgenerators. Even it is possible, the losses in the rectifier are very high, and this makes the conventional power electronic interfaces very inefficient. In this two types of direct ac-to-dc power electronics converter topologies are proposed for efficient and maximum energy taking from low voltage microgenerators. Here a direct single stage ac-to-dc electronic power conversion is succeeded by utilizing the bidirectional capability of MOSFETs, by this we can avoid the use of a front-end bridge rectifier. The energy harvesting can be successfully maximize by controlling the effective load resistance offered to the microgenerators. Simulation analysis and modelling in MATLAB of the proposed converters are presented in this paper. Index Terms�" AC-DC conversion, microgenerator, boost converter, low power, and low voltage. Advancements in low-power electronics have reduced the energy needs of analog and digital circuits. This gave rise to the development of self-powered wireless electronic devices that harvest ambient energy, such as mechanical energy, heat, light, etc. During the past two decades researchers have developed various microgenerators using different conversion mechanisms and associated electronics for energy recovery. Among them, microgenerators base vibrations, which harvest ambient energy mechanics, is currently the subject of numerous researchers. In this, electromagnetic microgenerators are considered for vibration based energy harvesting. The electromagnetic energy can be used to power a variety of applications such as sensor nodes wireless implantable medical devices, very low power portable electronic devices, etc. The electromagnetic microgenerators are spring damper system generally based on the mass, where the mechanical energy is converted into electrical energy by electromagnetic damping. The power level reported by electromechanical microgenerators is very low, ranging from microwatts to tensof milliwatts. Most of these are based on microgenerators resonance mass-spring system, which allows higher amplitude oscillation of the mass for low amplitude excitations Figure 1. The output of an inertial microgenerator, regardless of type, is an AC quantity. Therefore, the output of micro-generator has to be transformed by a power converter to create an output voltage appropriate to meet the requirements of the final application. Furthermore, in a microgenerator amount of energy conversion depends on the damping force whichacts on the microgenerator. For maximum energy recovery, the damping characteristics to be controlled to produce the optimum damping force. The damping force in an electromagneticgenerator can be changed by changing the effective resistance connected to the output the microgenerator. Power converters can be controlled to provide optimum damping resistance. Thus, in an energy harvesting power electronic converter has two main roles: first, to condition the ac output of the microgenerator to a suitable dc level as per requirements of theoutput load and second, to offer optimal damping resistance to the microgenerator for maximum energy harvesting. It should be noted that there could be two possible energy harvesting recovery. In one case, the converter is controlled to raise the amount of power required by the load. In the other case the converter is controlled to harvest maximum available power form microgenerator and storing in a memory buffer. One of the major aspects of electromagnetic microgenerators is that due to limitations of practical size, the output voltage is very low. Conventional power converters reported for vibration energy harvesting consist primarily a front end diode bridge rectifier followed by a boost converter Figure 2. But this transformation of two power stage has several drawbacks for electromagnetic microgenerators whose low output voltage must be strengthened to meet the load voltage (eg, hundreds of millivolts to 3. 3 volts) and current input is much higher than the output current. First, in the front end rectification diode bridge, the diode voltage drop and high input current amount causes high loss of power by converting ineffective. On the other hand, due to the diode bridge rectification the current drawn from the micro generator is unregulated, hence the resistance offered to the generator is not controllable. This prevents the implementation of maximum energy recovery. Recently dual polarity boost converter for power converter AC-DC is reported. In this it uses two inductors and the output bus DC is divided into two series connected capacitors. Eachof these capacitors are charged only to one half of the period of the alternating current of the microgenerator. However, capacitors meet the continuous load causing large voltage dropat the output. Therefore, to maintain the ripple voltage across the capacitor acceptable range of very high values are required, which is impractical. In addition, large capacitors will slow the response converter. In this work, two power converter topologies are selected for direct AC-DC conversion Figure 3 and Figure 4. These topologies use a single inductor and charge the output capacitorcontinuously. Bidirectional pulse switch (S1) is used in such converters. The bidirectional switch is realized using two MOSFETs connected in series (M1 and M2), and using their bidirectional conduction capabilities. In one proposed converters, two switches are used in the secondary circuit of boost converters (Figure 3). These switches are turned ON and OFF at a frequency equal to the frequency of the input voltage, which is very low (a few hundred Hz). This converter needs the detecting of inputvoltage polarity. In the other converter, an isolating capacitor topology is used in place of the two switches in order to avoid the input line voltage sensing. This topology uses capacitor charge recycling technique. Both converters are operated in discontinuous conductionmode (DCM) in order to reduce switching losses and easy implementation of the control system. The proposed converter can achieve greater efficiency than conventional converters and use very fewer components. PROPOSED CONVERTER TOPOLOGIESThe DCM operations of converter with two proposed topologies are presented here. It is followed by the analysis of converters. It is considered that the output voltage of the microgenerator is less than 500mV. It may be noted that this voltage is too small for conventional front end diode bridge rectification. SECONDARY SIDE SWITCH TOPOLOGYThe circuit diagram of the secondary side switch based converter is shown in Figure 3. A single inductor (L) is used for the boost operation. Two n-channel MOSFETs M1 and M2are connected in series and their two-way capability is used to achieve a bidirectional switch S1. This bidirectional switch is used for the boost operation in the positive and the negativehalf cycles of the input AC voltage. The MOSFETs of the bidirectional switch are driven by same pulse. When the gate pulse is high both channels MOSFET conduct. In each half cycle, a MOSFET conducts in the forward direction while the other MOSFET conducts in the reverse conduction. When the gate pulse is low, the MOSFET turns off, and the reverse connected body diodes blocks the input voltage to prevent any circulation current through the body diodes. Therefore, with this combination, a bidirectional switch is performed. During the period of turning on (decided by the duty cycle D), the inductor current and the energy stored in the inductor L will builds up. In the current topology, two secondary-side MOSFET, S3 and S4 are used appropriately to provide the discharge path for the energy stored in the inductance of output capacitor C1. These two switches are operated in a complementary manner. In this case, the upper switch (S4) is turned on only during the negative half of the microgenerator output voltage; whereas, the lower switch (S3) is turned on only during the positive half cycle. The energy stored in the inductor is discharged into the output capacitor C1, through the secondary switches (S3 or S4) and a secondary diode (D1 or D2). It may be noted that these secondary switches operate at a switching frequency very low, which is equal to the frequency of the input line voltage, which is much lower than the switching frequency of the converter. Thus the switching of the secondary switches are negligible. However, in this work, the polarity of the input voltage is detected to control the secondary switches. It may be notedthat these switches can be easily replaced by diodes to avoid the line voltage polarity sensing. However, replacement of secondary switches with diodes will cost more conductionoperating losses and therefore less efficient converter operation. The duty cycle, D, of the converter can be controlled to maintain the required output voltage under varying load. The converter is designed to operate in discontinuous mode to reduce the MOSFET switching losses and diode reverse recovery losses. The converter has four main modes of operation. The different operating modes are shown in the Figure 5. Mode I & II to the positive input voltage while the mode III and IV are for negative input voltage. Positive Half CycleMode I: In this mode, the two MOSFETs, M1 and M2, the bidirectional switch is activated simultaneously. The input voltage of positive polarity is applied across the inductor L and the inductor current built from zero. As this takes place during the positive half cycle, the secondary switch, S3, is held OFF while the other secondary switch, S4 is energized (ON). However, no current flows through S4. Mode II: This mode starts when the gate drive voltages of M1 and M2 goes low and turn the bidirectional switch OFF. The diode D1 is forward biased and the energy stored in the inductor charges the output capacitor through the diode D1 and the secondary switch, S4. It may be noted that the secondary switch, S4 is ON and the other secondary switch, S3, will be OFF for the entire positive half cycle. Negative half-cycleThroughout the duration of this half cycle S3 will be ON, and the switch S4 remains turned OFF. Mode III: This mode is similar to mode I, but the voltage applied across the inductor L is negative, and therefore the current in the inductor builds up in reverse. No current flows through the switch, S3. Mode IV: The bidirectional switch is disabled. The diode D2 is forward biased and the stored inductor current charges the capacitor, C, with the same polarity trough diode, D2 and switch

S3. Apart from these four modes of conduction, the converter is in discontinuous mode in which the currents of the diode goes to zero and bidirectional switch is disabled. SPLIT-CAPACITOR TOPOLOGYWe see that for the previous secondary switch based converter, the polarity of the output voltage of microgenerator is to be detected for switching the secondary side switches. To avoid this complexity detection of the polarity of the input voltage, in this section, a secondary side split-capacitor converter is proposed here. The topology diagram based single capacitor stage AC-DC converter is shown in Figure 4. The MOSFETs M1 and M2 are connected in the same manner as above, to achieve a bidirectional switch topology. The diodes D1 and D2 provide recovery path in each half cycle. Two equal capacitors, C2 and C3 are used for recycling charge and replace the secondary switches S3 and S4, the converter earlier. The output capacitor, C1, maintains the voltage required for the load. With an appropriate choice of spilt capacitors, the converter can operate at high efficiency. This converter also has four main modes of operation. Modes I and II correspond to the positive half cycle and modes III and IV are the negative input voltage (Figure 6). Positive Half CycleI Mode: In this mode, the MOSFET, M1 and M2 are turned ON, since the gate drive voltage becomes high. The current in the inductor built from zero. Mode II: In this mode, the MOSFET bidirectional switch are disabled. Here the inductor will forward biases the diode, D1, and charges the output capacitors. The currents of C1 and C2 are in the positive direction, but the direction of the current C3 is negative. Negative Half-CycleMode III: In this mode, the MOSFET, M1 and M2, of the bidirectional switch is activated. The voltage applied across Consider any kth switching cycle of the boost converter as shown in Fig 2. 3; where Ts is the time period of the switching cycle, D is the duty cycle of the converter, dfTs is the boostinductor current fall time (or the secondary diode conduction time), vi is the input voltage of the generator with amplitude Vp, and Vo is the converter output voltage. The converter switching frequency is much higher than frequency of the generator output voltage. Hence, Ts is much smaller than the time period of the input ac cycle (Ti). Ignoring the parasitic components of the circuit, at the kth switching cycle, the peak value of the inductor current (ipk) can be obtained as: ipk = m1DTs = vikDts= L (1)The inductor current fall time can be found as in (2). dfTs = ipk= m2 = ipkL1=(V0 ???? vik) (2)During this switching cycle, the energy (Ek) transferred from the input to the output can be obtained as: Ek = vik: ipk: Ts(D + df)= 2 (3)where, vik = Vpsin(2_: k: Ts= Ti). Defining total number of switching cycle in one input cycle as N= Ti/Ts, the average input power, Pi , of the converter can be obtained as in (4). Pi = (1= Ti): XNk= 1Ek = (1= Ti): vik: ipk: Ts:(D + df)= 2 (4)Furthermore, for large N, the summation in (4) can be approximated as integration. Based on these assumptions, the average input power, Pi, can be derived as in (5). It can be noted that in the above equation, (5), _ is constant for fixed Vp and Vo. Under steady state condition, the average input power and the average output power are equal. Therefore, neglecting losses in the converter, for a load resistance, R, the duty cycle of the converter (D) can be obtained as: The converter duty cycle can be calculated from the above equation. The above derived relations are further used to design the MOSFETs, inductor and diodes of the converter. IV. SIMULATION RESULTSA microgenerator with peak voltage 300mV sinusoidal output voltage at a resonant frequency of 100Hz is considered for the verification of the proposed converter topologies. Using the previous analysis sections, the converters are designed to stimulate the input AC voltage microgenerator to 3. 3V output DC voltage. The output load resistor is considered to be 200 ; therefore, the rated output power of the converter is about 54. 5mW. Considering the microgenerator to be an ideal voltage source AC, converters are simulated in MATLAB Simulink. The switching frequency of the converter is 25 kHz and the value of the inductor is designed 4. 7_H. Spice models of these devices are used for the simulation. The value of the output capacitor is 68_F. The simulation results of the two converters are presented as follows: A. SECONDARY SIDE SWITCH TOPOLOGYFigure 8, the input voltage, input current, and waveforms of output voltage are presented. It may be noted that the converter operates in DCM at a constant duty cycle, the input current profile follows the profile of the input voltage proportionally. Closed loop simulation of the converter is carried out while setting the output voltage of reference 3. 3V. Cycle steady state operating duty is constant around the value of D = 0. 67. The output ripple voltage is _0. 16V. B. SPLIT-CAPACITOR TOPOLOGYThe value of capacitor elements C1 and C2 are selected to be 33_F. The input voltage waveform and the input current are shown in Figure 9(a) and Figure 9(b), respectively. As expected, as the previous converter, the input current is proportional to the input voltage. A reference output voltage of 3. 3V carries out closed-loop simulation. The duty cycle of the converter is approximately D = 0. 68. The terminal voltage of the split capacitors (C2 and C3) and the output capacitor C1, are shown in Figure 9(c). These waveforms show the charge recycling operation of split capacitors. V. CONCLUSIONTwo converter topologies are introduced for the direct conversion of AC-DC power for low voltage applications of energy harvesting applications. Both proposed converters avoid conventional front-end diode bridge rectification and by that achieve greater efficiency. The proposed converter uses a single inductor and MOSFET based bidirectional switches for the boost operation. Operating principle and its analysis are discussed in detail. The simulation results show that the proposed converter can be used effectively for the effectiveness of low voltage energy harvesting.