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Converter Analysis for Small Wind Turbine Applications

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Abstract. Current environmental concerns and expensive infrastructure costs have a significant impact on the adoption of wind turbine technology. Research on the technologies of small wind turbines, which are much smaller in size and capacity, has increased recently. These Small wind turbines have a minimal influence on the environment and require less infrastructure. They have a limited capacity for power generation, necessitating the connection of several turbines to generate usable power. Numerous topologies have been proposed by researchers to combine the power of several wind turbines, but these conventional topologies were primarily developed for high-power wind turbines and cannot be used to connect very small wind turbines because a sizable portion of the generated power would be lost in driving the sophisticated electronic components

1 INTRODUCTION

There is a rapid rise in energy demand due to development of technology and standards in human life over the last decade. Generation of energy to satisfy the increasing demand through conventional methods like fossil fuels is not a permanent solution and also causes heavy damage to the environment.As that the need for clean energy sources in the rise and a great deal of researches have been undertaken to discover new technologies which can satisfy the present damage demand.

At present solar and wind energy are the major source of clean energy generation and many researches are still being done to develop the existing technologies into a more-optimal ones. wind energy is one of the major energy sources with huge to potential to develop and play a key role in satisfying the rapid rise of energy demand. High intial-cost, heavy infrastructures and large area requirements are some of the major constraints to develop the wind energy fields in urban areas and maximizing the wind energy applications.

Researchers proposed many topologies for smooth energy conversions of wind turbines bur these are suitable for large energy stations which are not suitable for small wind turbines as there will be high energy losses in driving the electronic components. This can be avoided by designing a non-isolated DC-DC converter for small energy ratings which is suitable for

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small wind turbine applications in urban areas or where large areas are not available. By using these topologies maximum potential of wind turbines can draw foe energy production.

The DC-DC converters can be classified into linear and switched. Switched converters are highly used as they provide high power conversion efficiency. They can both step-up or step-down the output voltage based on the requirement while the linear converters can only act as buck converters and cannot be used to step up the input voltage. Based on the characteristics & configuration, they are majorly classified into non-isolated, isolated, hard switched, Resonant, Continuous, Discontinuous, Bi-directional, etc which have buck, boost, buck-boost, SEPIC, Cuck, Forward, Push-Pull, Flyback converters, etc. Among the many topologies mentioned, we discuss about buck and buck boost converter in this paper and their performances for varying duty cycles.

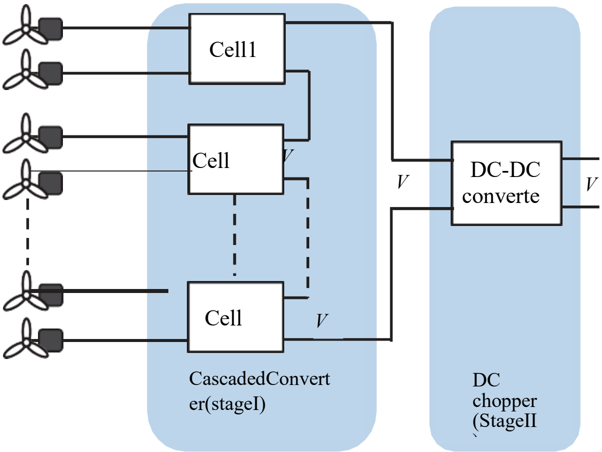

Fig 1. Typical structure of cascade connected multiple small wind turbines

2 LITERATURE SURVEY

The authors of the literature have provided many DC-DC converters like non-isolated, partially isolated and fully isolated converter topologies for various applications. The key characteristic that sets apart the non-isolated converters from the other two types is the absence of a transformer. The voltage gain of non-isolated converters with a single inductor is constrained. Cascaded & multilayer converters can produce high boost voltage gains, and they can also produce converted power with less distortion when compared to conventional converters. It has been demonstrated that a series of PV panels could be powered by high voltage generated by cascading non-isolated converters connected in serial.

Despite the fact that numerous DC-DC converters have been described in the literature, none of the topologies were intended to gather energy produced by a grid of extremely small wind turbines, as was explained above. This research presents a converter for series-connected, extremely small wind turbines in an effort to close this gap. The direct connection of several turbines in series or parallel is inefficient for wind turbines that are connected in series. The generated current from all linked turbines can be added if and only if all connected turbines generate the same voltage level (spinning all connected turbines at the same speed), which is practically impossible because the wind turbines are not all identical.

$$\boxed{P = 1/2C_p \rho v3A}$$

Where, Cp= coefficient of rotor power,
ρ=density of air
v= velocity of wind to the turbine
A= area of rotor swept

Different levels of generated voltages will be present in the grid if each turbine is powered by a wind speed that is not the same as the others. The turbine with the lower voltage will act as a load on the turbine with the higher voltage, using up the electricity produced inside the grid in the process. The generated voltage from each wind turbine is frequently too low, and using merely diodes to connect them together is not an efficient solution because most of the generated power will be lost due to the voltage drop across each diode. Special electronic circuits that are lacking in the literature must be added to the system in order to connect these incredibly small wind turbines and produce enough power.

The objective of this research is outlined as:

- We offer a non-isolated multi-input DC-DC converter to capture power produced by a cascade of extremely small wind turbines. The converter that is being suggested uses the fewest parts possible and uses very little power. Additionally, its terminal voltage has a very minimal amount of ripple.

3 PROPSED CONVERTER

In the DC-to-DC converters, magnetic fields in inductors or transformers regularly store and release energy, usually between the frequencies of 300 kHz and 10 MHz. The amount of power transmitted to a load can be more easily regulated by modifying the charging voltage's duty cycle (i.e., the ratio of on/off times), though this control can also be used to regulate the input current, the output current, or to keep the power constant. Converters built on transformers might isolate the input and output. Typically, a switching converter is referred to as a DC-to-DC converter. A switched-mode power supply's brain is made up of these circuits.

The majority of DC-to-DC converters are made to transfer power from a certain input to an output solely in one direction. However, by substituting all diodes with individually controlled active rectification, all switched regulator topologies can be rendered bidirectional and capable of moving power in either direction. For instance, applications needing regenerative braking of automobiles, where power is given to the wheels when driving and yet delivered by the gears when braking, can benefit from the usage of a bidirectional converter.

A. Converter Topologies

[i]Buck Converter:

A buck converter can said to be a typical step-down converter which is used to step down the input voltage and give reduced output voltage levels. It’s operation mainly relies on the ON and OFF states of the MOSFET's conduction state. Numerous power semiconductor devices, including power BJTs, power MOSFETs, IGBTs, and GTOs, among others, function as switches in chopper circuits. Because a thyristor requires an external commuting circuit to be commutated, which adds to the circuit's complexity, the usage of thyristors is typically not permitted in chopper circuits. During power-saving mode, MOSFET or IGBT can also be switched off sustaining a zero voltage between the IGBT's gate to collector terminal and the MOSFET's gate to source terminal. Here, MOSFET is taken into account for circuit operation. The key benefits of buck converters include improved transient performance, increased efficiency due to lower transitional losses, lower output ripple voltage, and lower need of the input capacitor's ripple-current rating

[ii]Buck-Boost Converter:

The input voltage can be stepped up or down using a Buck-Boost. It can be compared to a Fly-back converter that uses a single inductor rather than a transformer. Knowing that V out is truly negative in relation to supply potential when a buck-boost converter is used can complicate some designs. Although buck-boost converters offer many benefits, they also demand more expensive parts since they must resist both high Vin max voltage and high input current at Vin min. It can be said to be a combination of both buck and boost converter and can be used in place of both of them for simple circuit operations. It is mainly used for applications where sensitive power control is required. A general application of buck-boost is for high power effulgent lighting and can also be used in wind turbine applications.

B. Operating principle

[i]Buck converter:

A buck converter can be said to be operated on two modes namely continuous conduction mode and discontinuous conduction mode. When switch is turned ON it can be said to be continuous conduction mode and when switch is turned OFF it can be said to be in discontinuous method of conduction. Typically, the CCM approach is employed for effective power conversion, whilst the DCM is utilized for stand-by and lower power applications. Because an inductor is linked in series to the power supply, the CCM's inductor current never approaches zero during a single switching cycle and has a steady input current.

OPERATION MODE 1(SWITCH 'S' IS ON):

When main Switch 'S' is turned on, input current IL travels through the components of the load resistor R, filter capacitor, and inductor L. The inductor voltage VL is determined by applying Kirchhoff's voltage law, which is

$$VL = Vs - V \qquad (1)$$

This mode is mainly used for effective power transmission and the switch will be turned ON in this mode. In this mode there will be uninterrupted flow of power from source to load and freewheeling diode don't participate in this mode.

OPERATION MODE 2(SWITCH 'S' IS OFF):

When switch, 'S' is OFF it goes into the discontinuous conduction mode. In this mode there will be no current flow from source to load as the switch will be in OFF state blocking the current flow. Then the freewheeling diode gets into conduction state using the energy stored in inductor then there will be flow of current to the components R, L, C and D.

$$VL = -Vc = -V\mathrm{o} \qquad (2)$$

[ii]Buck-Boost converter:

A buck-boost converter converts a input positive DC voltage to a output voltage. A buck-boost converter can be used to both step0up and step-down the input voltage depending on the requirements of the application. The main advantage of using buck-boost converter is its capability to perform both step-up and step-down operations with minimum number of negative components.

OPERATION MODE 1:

when operating in this manner, switch ‘S’ is in ON condition and inductor starts to get charged by the source voltage. Diode will be in blocking mode in this period. Voltage across the inductor can said to be equal to source voltage which can described as,

$$VL = Vs \tag{3}$$

OPERATION MODE 2:

when operating in this manner, both switch ‘S’ will be blocked and inductor starts to get discharged. The discharged inductor current flows through resistor and capacitor. Diode D will be in conducting state during this period. There will be no conductivity between source and load. Load will be supplies through the energy stored in inductor during mode 1. Capacitor charges through its lower plate as positive.

OPERATION MODE 3:

In this mode of operation both switch ‘S’ and diode D will be in OFF condition. Now, output voltage flowing through the load is same as capacitor voltage. We can observe that output voltage will be in negative form. So, Buck-boost regulator is also called as inverting regulator.

C. Circuit Analysis

[i] Buck Converter:

In a buck converter during Continuous Conduction Mode (CMM), Output voltage can be calculated by

$$V\ out = Vin*D \tag{4}$$

Duty-cycle can also be used to represent the charging and discharging time of the inductor as

- Charging Time= $I1(t) = D*T*(V\ out-Vin)/L$ (5)
- Discharging Time= $I2(t) = (D-1)*T*V\ out/L$ (6)

Duty-cycle of the buck converter is calculated using,

$$D=Ton/T \tag{7}$$

[ii]Buck-Boost Converter:

In mode 1, When switch is ON and diode is OFF,

Time period, $T=Ton + Toff$ (8)

And switching frequency: $f\ switching = 1/T$ (9)

By applying KVL,

$Vin = VL$

$VL = L\ di\ L/dt = Vin$

$di\ L/dt = \Delta\ I\ L/DT = Vin/L$ (10)

In mode 2, when switch is OFF and diode is ON,

$Toff = T\text{-}Ton = T\text{-}DT = (1\text{-}D)\ T$ (11)

By applying KVL we get.

$VL = Vo$

$VL = L\ di\ L/dt = Vo$

$di\ L/dt = \Delta\ IL/\Delta\ t = Vo/L$ (12)

4SIMULATION RESULTS

After With reference to Fig.1, The input voltage from the wind turbines are fed to the given topology as shown in fig.2 where we can observe the stepping down of given voltage to give the output voltage. As we said earlier, we are considering two types of converters for this operation to compare their performance. From Fig.3 we can observe the connection and operationpf buck-boost converter. Here, we can observe the operational performance of both converters in varying duty- cycle.

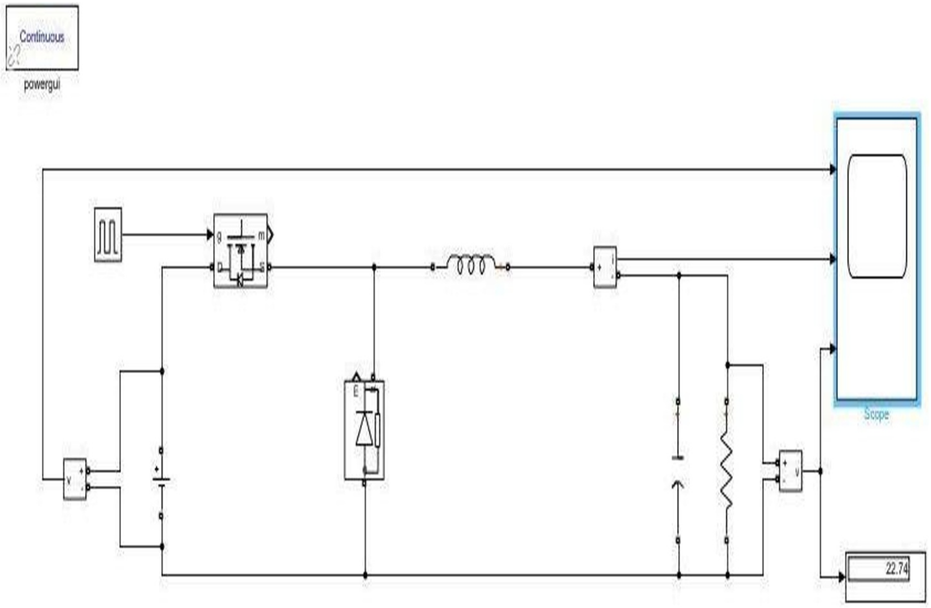

Fig.2.Simulation of Buck Converter

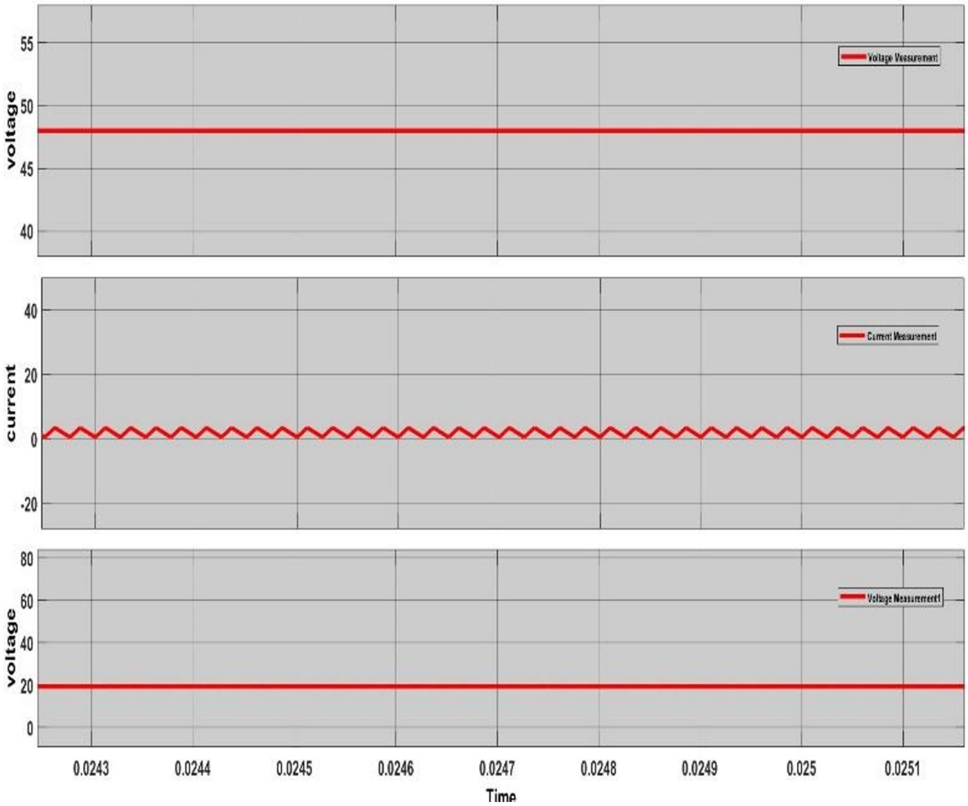

Fig.2(a)Vin, V out &currentat 40%dutycycle

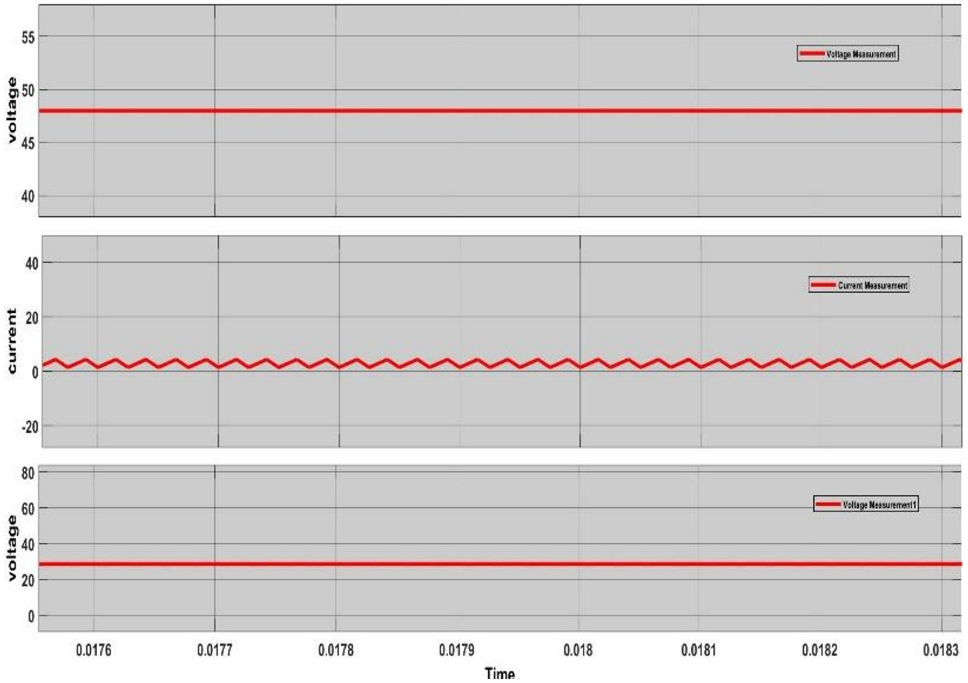

Fig.2(b)Vin, V out &currentat 60%dutycycle

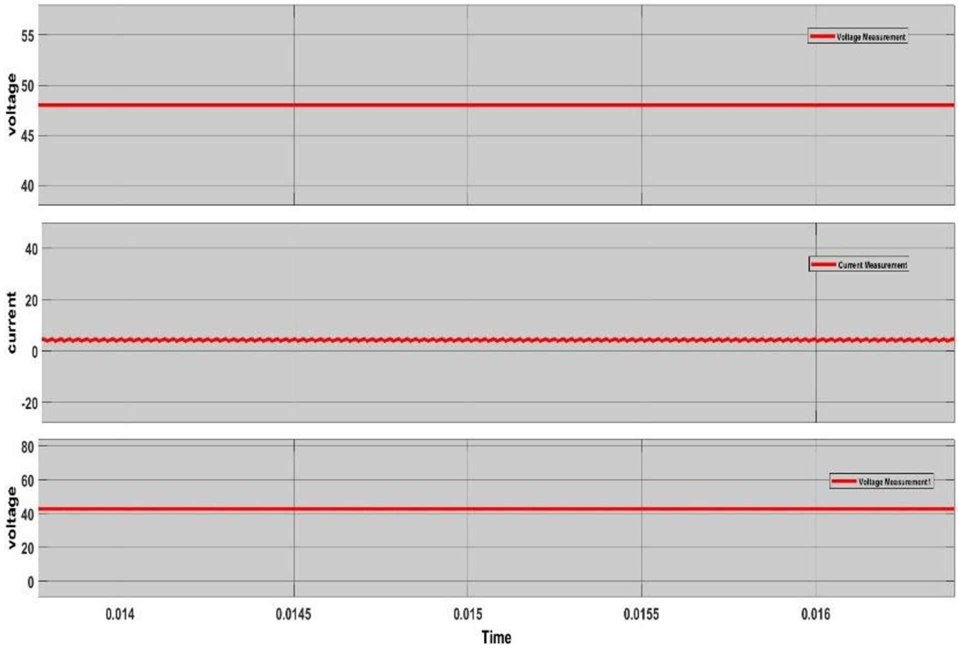

Fig.2(c)Vin, V out &currentat 90%dutycycle

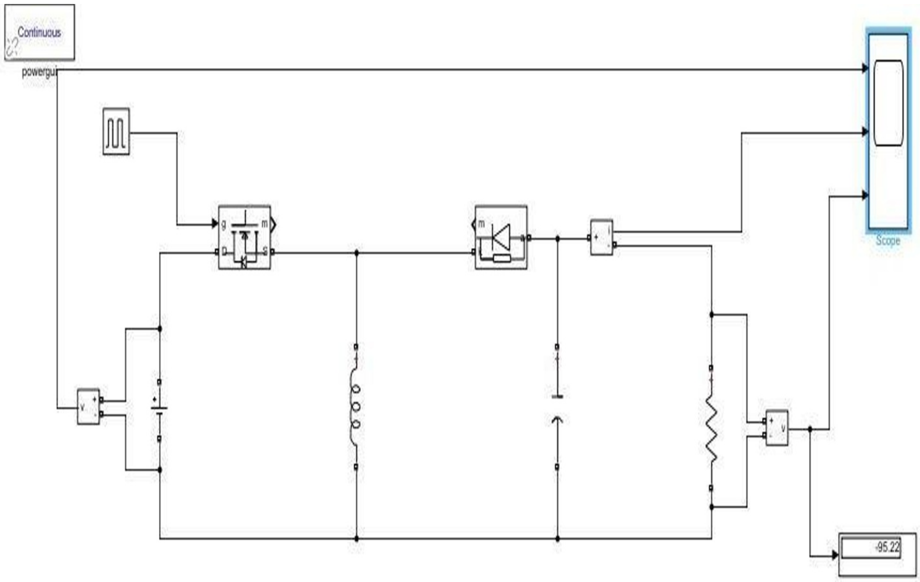

Fig.3.Simulation of Buck-B**oost** Converter

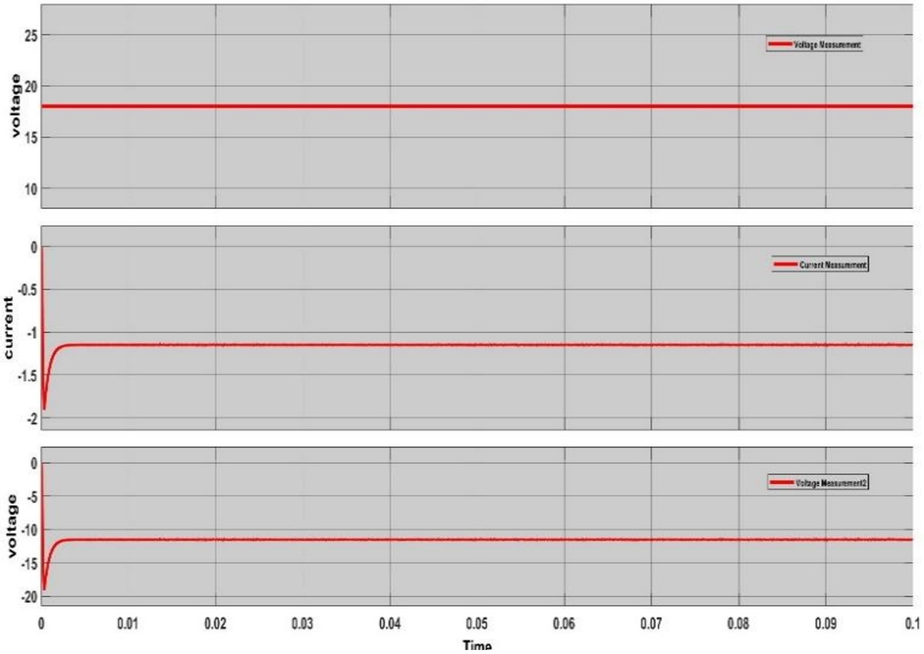

Fig.3(a)Vin, V out &currentat 40%dutycycle

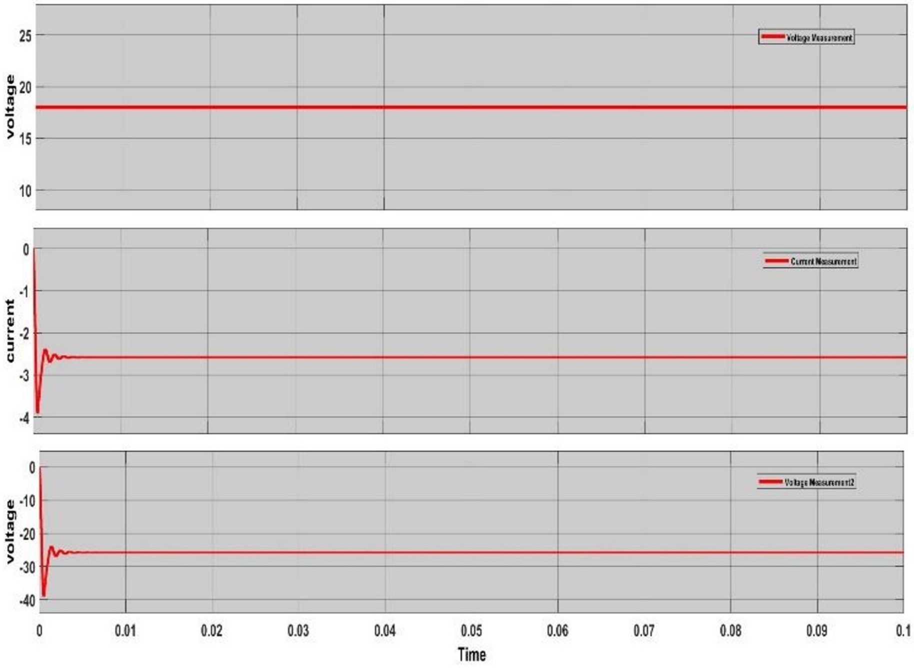

Fig.3(b)Vin, V out &currentat 60%dutycycle

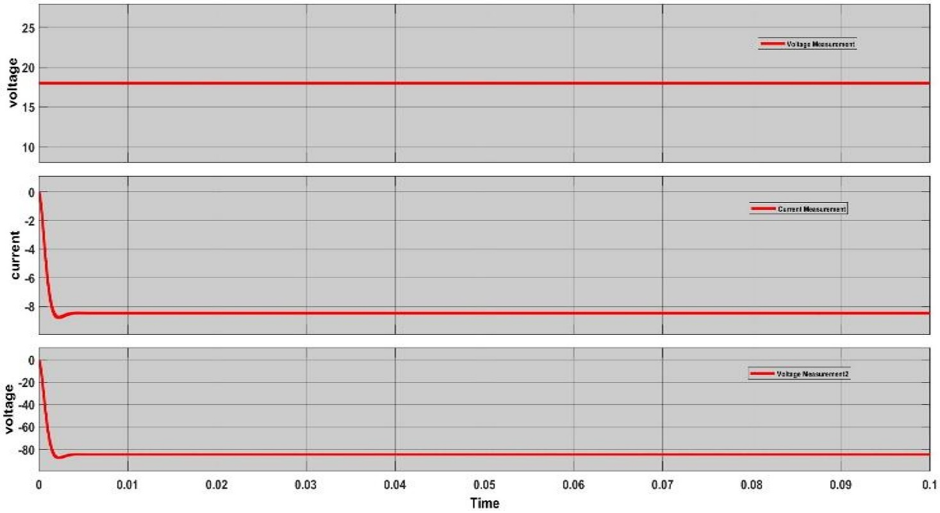

Fig.3(c)Vin, V out &currentat 90%dutycycle

TABLE I. VARIATION OF VOLTAGE AND CURRENT W.R.T DUTYCYCLE

[i]Buck Converter:

Duty-cycle	**Voltage(V)**	**Current(A)**
40%	19.17	0.442
60%	28.69	1.396
90%	42.83	3.73

[ii] Buck-Boost Converter:

Duty-cycle	**Voltage(V)**	**Current(A)**
40%	-11.55	-1.55
60%	-25.97	-2.597
90%	-85.65	-8.635

TABLE II. DESIGN SPECIFICATION OF CONVERTER

[i] Buck Converter:

Duty-cycle	**Voltage(V)**	**Current(A)**
40%	-11.55	-1.55
60%	-25.97	-2.597
90%	-85.65	-8.635

[ii] Buck-Boost Converter:

Components	**Value**
Input Voltage	20V
Time period	1/40ks

Inductor	45µH
Capacitor	100µF
Resistor	10Ω

CONCLUSION

This work shows the variation in voltage levels for small wind turbine applicationsdepending on the type of converter employed. We primarily discussed secondary part namely DC-DC converter which will soothe and modulate the output from cascaded wind turbines. We mainly concentrated on two converters namely buck and buck-boost converters in this paper. We simulated the operation mechanism of both buck and buck-boost converters using matlab software. We simulated both the converters and observed its output voltage levels depending on the varying duty-cycle. From the above mat lab simulations, we can observe that there will a significant fall in output voltage with respect to rise in duty-cycle while using buck-boost converter whereas there will be increase in output voltage with respect to duty-cycle which is desirable for small wind turbine applications.

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