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A Comparative Assessment of the Performance of Frequency Converters Used with Renewable Energy Systems

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Abstract

Renewable energy systems usually produce electricity power in a form which does not fit with the load in terms of voltage and frequency. Therefore, it is necessary to use different types of converters to adjust the available renewable energy with the load requirements which leads to increased usage of medium sized PV arrays and wind turbine in homes and businesses applications. This paper reviews and assesses the performance of various types of frequency converters which may be used with renewable energy systems to match the load requirements. Firstly, the state of the art in converters, used with renewable sources either with grid connected or standalone power systems, is presented. The conditions required for converters, used with a renewable energy sources, are discussed with respect to various types of converters. A comparative assessment between two types of converters used with a photovoltaic system is presented as an example. Consequently, the importance of selecting the suitable converter with renewable energy sources is highlighted. Finally, the results of the comparative assessment are presented, forming a useful guidance to power system engineers for selecting the suitable converter when a renewable energy source is considered.

Keywords: power electronics converters; renewable energy sources

1. Introduction

There is a worldwide agreement on the need to reduce greenhouse gas emissions, and different policies are implemented both internationally and locally regarding this matter [1-12]. One of the vital components in the achievement of this goal is the intention to provide a high share of energy obtained from renewable sources worldwide. Also, the limited amount of conventional energy and the ever-increasing energy consumption renders the search for new sources of energy. Due to the limited amount of fossil energy, it is believed that between the years 2020 and 2030, a major “energy gap” will arise between the required amount of energy and what can be produced from fossil fuels. To resolve this energy gap, new energy sources will be needed. The most promising types of renewable energy source are that obtained from solar and wind sources. However, energy obtained from these sources does not match completely with the load requirement, especially voltages and frequencies. These renderers the needs for frequency converters to match the load requirements with the produces renewable energy. Subsequently, this paper reviews frequency converters that normally used with renewable energy systems and assesses their performances.

Last century, renewable energy sources (solar panels and rotating turbine) were mainly being used in small-scale devices independent or remote from the grid, or for large-scale power generation. In the last few years, [1-11]. Renewable energy has been increasingly used in medium sized grid connected photovoltaic (PV) systems and wind turbine (WT). These are now being purchased by households or by private

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companies to supply power to their buildings.

The photovoltaic technology gained recognition and was considered an electric source for non-space applications after the oil crises in 1973. Early PV started with the production of a high cost single junction solar cells and efficiency less than 1% efficiency. Intensive research plans financed by photovoltaic authorities and incentive programs, to encourage the use of photovoltaic energy over the past 20 years, led to a substantial reduction in solar cell production cost and enormous increase in the solar cell efficiency [5]. Cell efficiency increased from about 6% in the early 70^s to more than 20% at present [6]. Also solar cost is reduced from 28 $/ Wp (peak power) in the early 80^s to about 5$/Wp at present. The idea of producing a photovoltaic plant generating megawatts seemed unlikely to the majority until the late 90^s. However, by the year 2008, there were around 1000 plants worldwide rated at ≥ 1 MW_p [9]. The great driver of this revolution has been the generous financing of photovoltaic electricity at certain countries [13-19]. This is an indication that a new era of clean, reliable and unlimited source of energy is just started. Specifically, there has been extraordinary research and development activities by teams in universities, government institutes, and PV companies over the past 20 years, leading to a substantial improvement in PV technology. This appeared in: introduction of new types of solar cells [2], improvement in system components in reliability[20 - 22], enormous reduction of cost and high increase in solar cell efficiency [23-28]. Moreover, the present development in PV industry initiated an international awareness of PV systems and studies for a very large scale PV project (VLS-PV) including Egypt [29].

There are two major sectors for the use of photovoltaic systems, grid-connected and the so-called stand-alone systems [30-35]. The former delivers power directly to the grid as the DC current from the solar modules is converted into AC by an inverter. The latter supplies power to decentralized systems and small-scale consumer products. Over the years, it has been customary for books on PV to describe stand-alone systems first. However, the market has shifted towards PV power plants and installations on buildings connected to an electricity grid since the late 90's . By the year 2000, grid-connected PV had overtaken stand-alone systems in global market share and by 2009 more than 95% of solar cell production was being deployed in grid-connected systems [35-39].

Most of these PV systems are arranged in a series string of PV modules to generate a usable amount of voltage, as otherwise they would generate very low voltages. Generally, PV arrays have a converter that handles the entire string and does not have a maximum power point track (MPPT) for individual modules in the array [8, 37-41].

Usually, photovoltaic and wind systems are the source of energy in stand- alone systems. Efficient use of energy is very important since there is no utility line; a battery set becomes essential because energy power is provided in an irregular way from the renewable source; leaving aside this issue, a power conversion stage is required in order to ensure a good output power quality [1-7].

This paper presents the state of the art in converters used with renewable systems, either grid connected or stand-alone power systems, types of converters to be used with renewable energy source and the importance of selecting the suitable converter with renewable energy sources are presented. This is described subsequently.

2. State of The Art in Converters Used with Renewable Systems

Converters normally reported in the literature used with renewable energy sources, either connected to the grid or as stand-alone systems.

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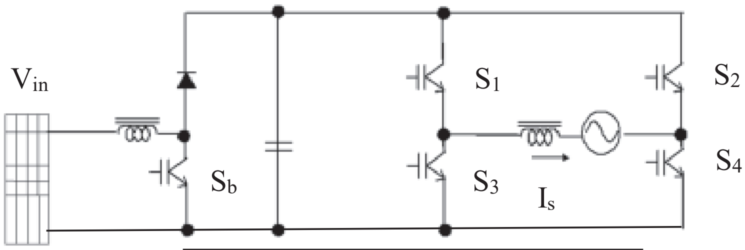
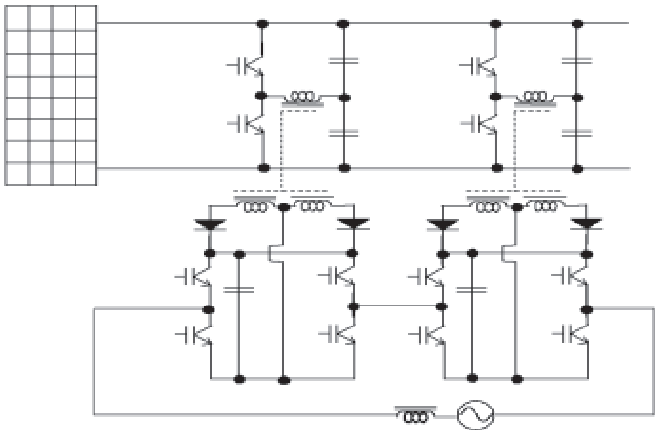
This section describes some topologies reported in the literature for renewable systems dealing with photovoltaic and wind systems [12-26].

2.1 Grid connected systems

Grid connected systems deliver the maximum obtainable power to the ac mains from the photovoltaic (PV) and/or wind system [12]. However, this power depends on weather conditions which means that such energy varies from time to time. To solve this problem, control strategies are usually used to track the maximum power point (MPP) [8 and 18]. Moreover, to increase the system's efficiency with the fact that renewable energy sources generate power at relatively low voltage, the use of boosting type converters becomes necessary. Figure 1 shows different topologies that provide current to the grid [12-26].



(a) DC/DC converter and inverter



(b) Multiple dc/dc converters and multilevel inverter

Figure 1. Topologies to inject current to the ac mains

It is normally found in literature systems that combine the power of two or more sources. Kobayashi et al. [19-23] suggested a converter which is able to obtain energy from a PV array and the utility mains for telecommunication applications. Particularly in this case, there is not energy injected into the AC mains. Walker et al. [23-26] proposed a cascade connection of a dc/dc converter when multiple photovoltaic panels are employed, with a single converter for each panel, also different dc/dc converters can be taken into account. In a system which uses photovoltaic panels and a wind turbine as main inputs, the photovoltaic voltage is higher than the output voltage, and the wind turbine voltage is lower than the output voltage [12-17].

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Figure 2 shows converters that are able to handle photovoltaic arrays and/or wind systems. They are multiple input DC/DC converters, and they have the purpose of increasing the output power or deliver energy from different renewable sources [15].

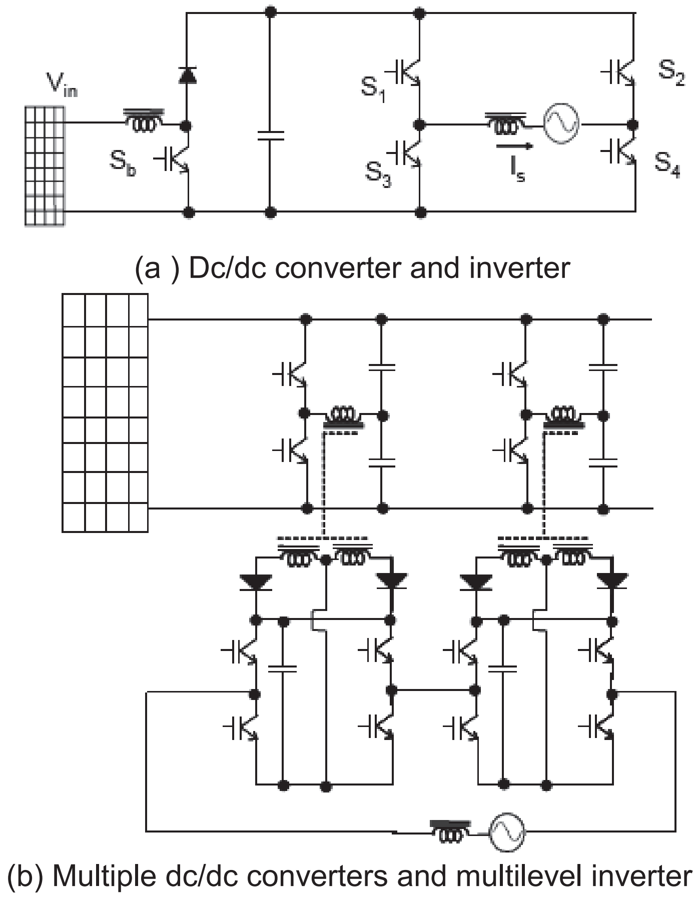

Figure 2. Topologies to inject current to the ac mains

2.2 Stand-alone systems

Stand-alone systems are not connected to the utility grid, and for this type of system, it is compulsory to use a battery set in order to provide energy due to weather conditions. Energy is stored in the battery set, and when it is completely charged, it is ready to feed the load. Traditionally, at this time, the energy available from the PV system is not used until the battery set is charged again. Figure 3 shows a converter that consist of two stages, proposed in [16]. The first stage is a dc/dc boost converter that increases the input voltage, but also charges the battery set. Figure 4 illustrates a dc/dc converter for stand-alone applications based on the integration of different dc/dc converters [24]. Energy, which can be administrated by having control on the switches, is delivered in three modes: the first one feeds the load and charges the battery set simultaneously from the renewable source, the second one delivers energy from the sources to the load, and finally, the last one when the battery set provides all the energy to the load.

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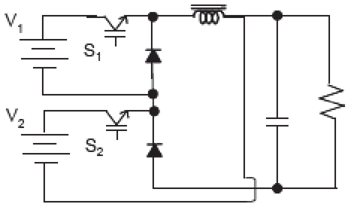

Figure 3. Buck converter and buck-boost converter

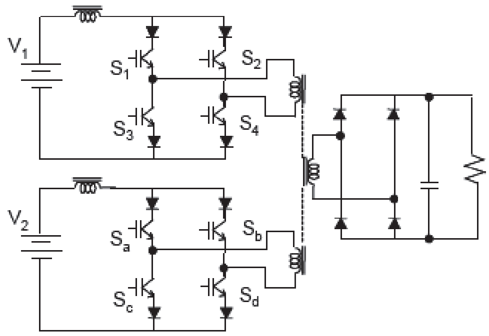

Figure 4. Isolated converter

3. State Of The Art In Power Electronics Technology

As the technology for power semiconductor devices and integrated circuits develops, the potential for applications of power electronics becomes wider. There are already many power semiconductor devices that are commercially available for the use with renewable energy sources, which is described subsequently [1-7].

3.1 Switching devices

- Uncontrolled turn on and off (Power Diode)
- Controlled turn on uncontrolled turn off (Thyristors)
- Controlled turn on and off characteristic (Power Transistor, BJT,
- MOSFET, GTO, IGBT)
- Continuous gate signal requirement (BJT, MOSFET, IGBT)
- Pulse gate requirement (SCR, GTO)
- Bipolar voltage-withstanding capability (SCR, GTO)
- Unipolar voltage-withstanding capability (BJT, MOSFET, GTO, IGBT)
- Bidirectional current capability (TRIAC)
- Unidirectional current capability (SCR, GTO, BJT, MOSFET, IGBT)

3.2 Static Converters

Figure 5 shows the static converter that 1. isbeing used in one form or another [1-11]. It can be summarized as follows:

1. AC to DC Converter:

An AC to DC converter circuit can convert AC voltage into a DC voltage. The DC output voltage can be controlled by varying the firing angle of the thyristors. The AC input voltage could be a single or three phase(half/full wave).

2. DC to DC Converter:

These converters can converter a fixed DC input voltage into variable DC voltage or vice versa. The DC output voltage is controlled by varying of duty cycle. In many industrial application , DC-DC converter are required to convert a fixed-voltage DC source into a variable-voltage DC source. Like a transformer, DC-DC converter can be used to step down or step up a DC voltage source.

3. AC to AC Converter:

This converters can convert from a fixed AC input voltage into variable AC output voltage. The output voltage is controlled by varying firing angle of TRIAC. These type of converters are known as AC voltage regulator.

4. DC to AC Converter (Inverter):

These converters can converter a fixed DC input voltage into variable AC output voltage. The output voltage is controlled by varying firing angle of TRIAC.

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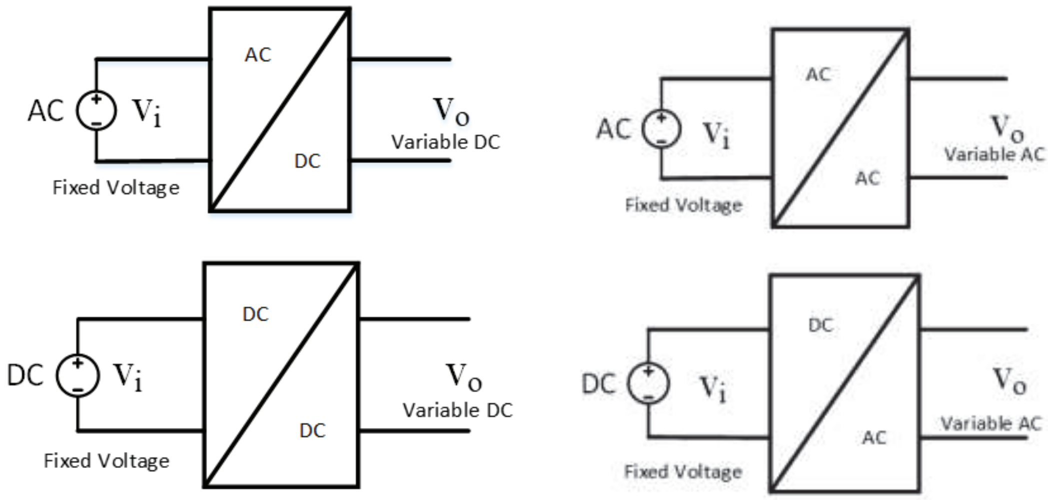


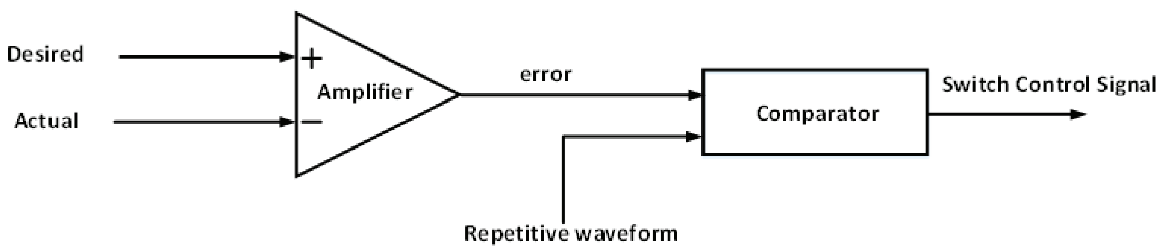
Figure 5. Types of converters.

3.3 The pulse-width modulator

In a converter with a given input voltage, the average output voltage is controlled by controlling the switch on and off durations (t_{on} and t_{off})[11-14]. One of the methods for controlling the output voltage employs switching at constant frequency (hence, a constant switching time period $\tau = t_{on} + t_{off}$) and adjusting the on-duration of the switch to control the average output voltage is called Pulse-Width Modulation (PWM) switching. In this method the switch duty cycle D, which is defined as the ratio of the on-duration to the switching period, is varied. The other control method is more general, where both the switching frequency (and hence the time period) and the ON-duration of the switch are varied. This method is utilizing forced-commutated thyristors.

In the PWM switching at a constant switching frequency, the switch control signal, which controls the state (on and off) of the switch, is generated by comparing a signal level control voltage V_c with a repetitive waveform as shown in figure 6-a. The control voltage signal generally is obtained by amplifying the error, or the difference between the actual output voltage and its desired value. The frequency of the repetitive waveform with a constant peak, which is shown to be a sawtooth, established the switching frequency. This frequency is kept constant in a PWM control and is chosen to be in a few kilohertz to a few hundred kilohertz range. When the amplified error signal, which varies very slowly with time relative to the switching frequency, is greater than the sawtooth waveform, the switch control signal becomes high, causing the switch to turn on. Otherwise, the switch is off. In terms of V_c and the peak of the sawtooth waveform E_{st} in figure 6-b, the switch duty cycle can be expressed as

$$D = {t_{on}}/{\tau} = {V_c}/{E_{st}} \quad (1)$$



(a) Block diagram

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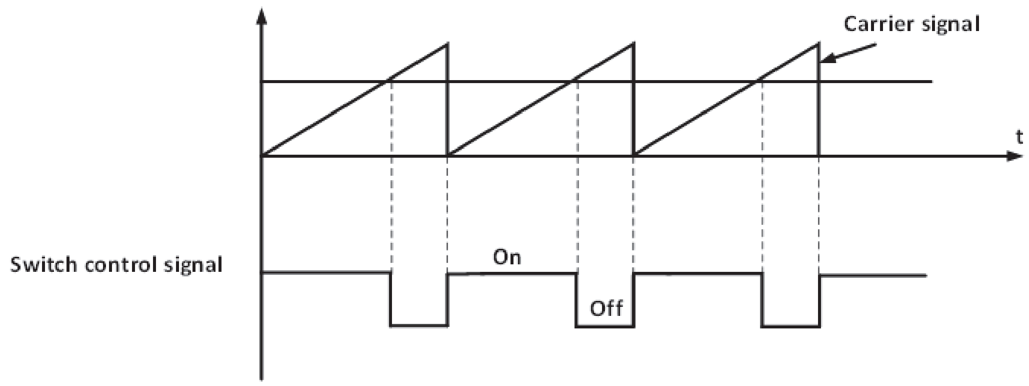

(b) Comparator Signal

Figure 6. Pulse Width Modulator

4. Problems of Renewable Energy Sources and relevant Converters

4.1 Problems with Photovoltaic sources

PV modules are set of photovoltaic cells in series and have a maximum power point (MPP). The MPP is the voltage point where a photovoltaic cell, module or array will generate the maximum electrical energy for a given illumination level. In practice the MPP is not always obtained [4,8,18,28,38].

Most PV arrays are arranged in a series string, the modules connected in series one after another. This is done to generate higher voltages better matched to grid connection. This means that according to Kirchhoff's current law, the modules will all experience the same current running through them. If the modules are all generating the same amount of power, then this poses no problem. However, when modules are generating different amounts of power then some modules will be operating away from their MPP. This can be due to panel mismatch, where panels in an array are generating different amounts of energy due to manufacturing tolerances or temperate differences. Another cause is due to orientation mismatch, where panels are placed on a roof at different angles to the sun, so they generate different amounts of power. Finally, even shadows reducing the sunlight being received by a single panel can reduce the power produced by the entire array. The energy lost when mismatched power output occurs is surprisingly large. When a module is partially shaded not only does it cause other modules to deviate from their maximum power point, but it can also become reverse biased. When this happens, the shaded module begins acting as a load, dissipating the energy generated by all the other modules in the string. It has been observed, from the shading experiments, that in the worst-case scenario the energy reaching the cells was reduced by 4.16% [3]. However, the power output was reduced by 48.2% [3]. Cell and module shading exhibit similar behavior, and it can be expected that an experiment with module shading would yield similar results.

4.2 Problems of Wind Energy Systems

The rotating turbine is characterized by no dimensional curves of the power coefficient (Cp) as a function of both the tip speed ratio (λ) and the blade pitch angle (β). In order to fully utilize the available wind energy, the value of (λ) should be maintained at its optimum value. Therefore, the power coefficient corresponding to that value will become maximum. The model is based on the steady-state power characteristics of the turbine. The stiffness of the drive train is infinite, and the friction factor and the inertia of the turbine must be combined with those of the generator coupled to the turbine. Suitable converters must be selected to match the wind

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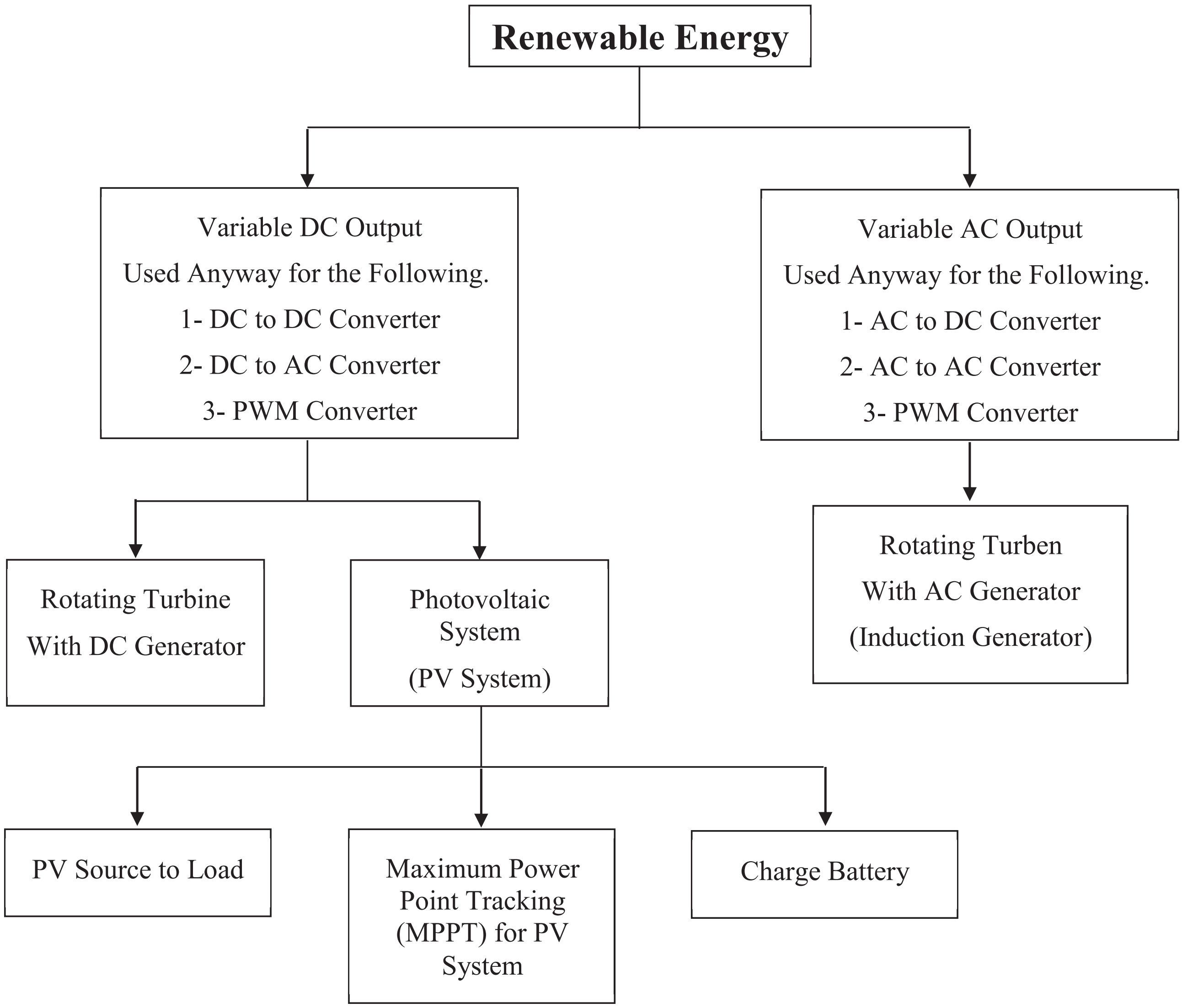
system output with the grid connected or the stand-alone system used [13-26].

4.3 Converters

The following diagram summarizes types of converters used with renewable energy sources:



4.4 Converters Requirements

The problem with renewable energy systems is that the output voltage exhibits high nonlinear characteristics and output voltages depend on whether condition. To solve these problem suitable converters must be chosen. Subsequently, the following criteria is essential in the choice of converters for renewable energy sources:

- The converter should have a step up/down Characteristics.
- The converter should perform well over a wide range of operating conditions in both steady state and transient condition.

The above criteria are important to ensure constant voltages at the load terminals when closed loop systems are being considered and also to track maximum power operating point. The commonly converter well-known topologies are step-down (buck converter), step-up (boost converter), step-down/step-up (buck-boost converter), cûk converter, and sepic converter [11, 27-40].

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4.4.1 Buck Converter

The buck converter is known as a dc-dc step down converter. The di/dt of the load current is limited by an inductor. However, the input current is discontinuous and a smoothing input filter is normally required. It requires a protection circuit in case of possible short circuit across the diode path. The step-down (buck converter) is used to drive a low voltage load from a high voltage. It operates efficiently at most radiation levels with a simple design and inexpensive cost. Therefore, step-down topology is used in this work.

4.4.2 Boost Converter

A boost regulator can step up the output voltage without transformer. The input current continuous. However, a high peak current must flow through the power switch . The output voltage is very sensitive to change in duty ratio and it might be difficult to stabilize the regulator. The step-up (boost converter) is used to drive a high voltage load from a low voltage. It is more efficient at high radiation levels.

4.4.3 Buck-Boost Converter

A buck–boost regulator provides voltage polarity reversal without a transformer under fault condition of the transistor and has a step up / down capability. However, the di/dt of the load current is limited by an inductor Output short circuit protection would be easy to implement . However, the input current is discontinuous and a high peak current flows through the power switch. Both the input and output current are highly discontinuous which Leads to large external filtering requirements. The step-down/step-up converter can drive a high or low voltage load from a low or high voltage, respectively. However, this type is more expensive and complicated.

4.4.4 Cúk Converter

The Cúk converter is a type of dc-dc that has step up/down capabilities with an inverted output. The Cúk converter is based on the capacitor energy transfer. As a result, the input current is continuing. The circuit has low switching losses and has high efficiency. the output voltage is reverse (opposite of the input voltage). The output voltage may be more or less than the input voltage. thus it operates in both buck and boost mode which depends upon the duty –ratio . the advantage of the Cúk circuit is that both the input current and the current feeding the output stage are reasonably ripple free. This advantage translates in terms of low filtering requirement s on both sides. The Cûk converter has the same characteristics of the buck-boost type. In addition, the main special merit of Cûk converter is ass smooth input and output currents. However, it is also more expensive and complicated.

4.4.5 Sepic Converter

It is also known as Single-ended primary-inductor converter which is a type of dc-dc converter similar to the Cúk converter but has advantages of having non-inverted output i. e. the output voltage is of the same polarity as the input voltage [11, 41-65].

4.5 Analysis and operation

The objective of this study is to assess the performance of Cúk and Sepic converters when operating with a photovoltaic system. Modeling of these two converters is described subsequently.

4.5.1 Principle of Step-Down Converter

4.5.1.1 Static Analysis

In a buck converter Fig. 7, the average output Va is less than the input Vs. The circuit diagram of a buck converter using a power transistor is shown in figure (7-c). The circuit operation can be divided into 2 modes:

Mode 1 begins when transistor Q is turned on at t = 0. The input current, which rises, flows through a filter inductor L, a filter capacitor C, and a load resistor RL.

Mode 2 starts when transistor Q is turned off at t=t_{on}. The freewheeling diode D_f conducts due to energy stored in the inductor and the inductor current continues to flow through L, C, load, and D_f. i_L falls until Q is turned on again in the next cycle. The waveforms for the voltages and currents are shown in figure (6-b) for a continuous current flow in the inductor L. Depending on the switching frequency. f_s, L, and C, the i_L could be discontinuous.

The voltage across the inductor L is, in general.

$$e_L = L\, {di}/{dt} \qquad (2)$$

Assuming i_L rises linearly from I_1 to I_2 in time t_{on} ,

$$V_s - V_a = \mathrm{L}(I_2 - I_1) / t_{on} = \mathrm{L}\Delta\mathrm{I} / t_{on} \qquad (3)$$

Or

$$t_{on} = \Delta\mathrm{I}\ \mathrm{L} / (V_s - V_a) \qquad (4)$$

Also, i_L falls linearly from I_1 to I_2 in time t_{off},

$$V_a = \mathrm{L}\ \Delta\mathrm{I} / t_{off} \qquad (5)$$

Or

$$t_{off} = \Delta\mathrm{I}\ \mathrm{L}/V_a \qquad (6)$$

Where ΔI is the peak-to-peak ripple current of L.

As the ratio of the onetime to the switching period τ is the duty cycle D. therefore, substituting t_{on} = D τ and t_{off} = (1-D)τ in equations (4, 5, 6) yields the average output as

$$V_a = D\, V_s \qquad (7)$$

Assuming a lossless converter, $V_s\ I_s = V_a I_a = D V_s I_a$. Therefore, the average input current is

$$\mathrm{I_s} = \mathrm{DI_a} \qquad (8)$$

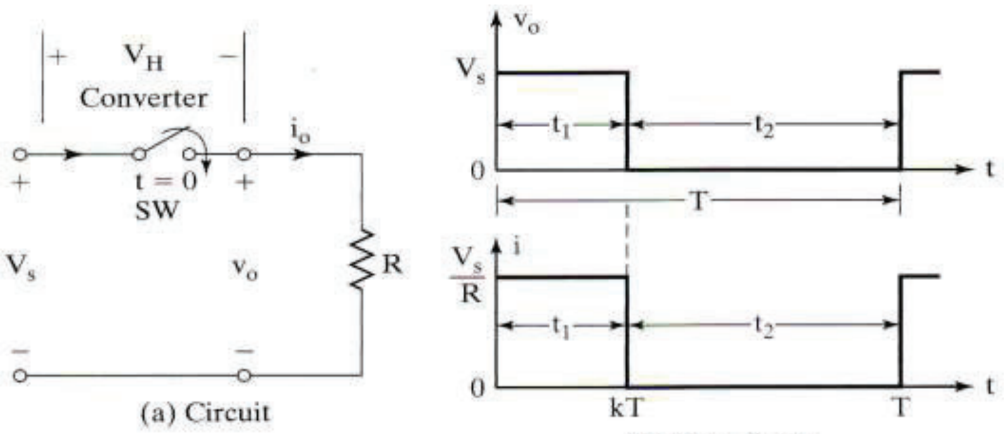
Therefore, from equations (7, 8) the effective input resistance seen by the source can be expressed in terms of the load resistance R_L

$$= R_L / D^2 \quad R_{eq} \qquad (9)$$

The duty cycle can be varied from 0 to 1 by varying t_{on} , τ , or f_s. Therefore, R_{eq} can be varied from R_L to ∞. Now the switching period τ can be expressed as

$$\tau = \frac{1}{f_s} = \Delta\mathrm{I}\ \mathrm{L}\frac{V_s}{V_a(V_s - V_a)} \qquad (10)$$

The Buck converter requires only one transistor and has a high efficiency. The di/dt of the load current is limited by inductor L. However, the input current is discontinuous, and a smoothing input filter is normally required. It provides one polarity of voltage and unidirectional output current. It requires a protection circuit in case of possible short-circuit of the diode path.



(a) Circuit

(b) Waveforms

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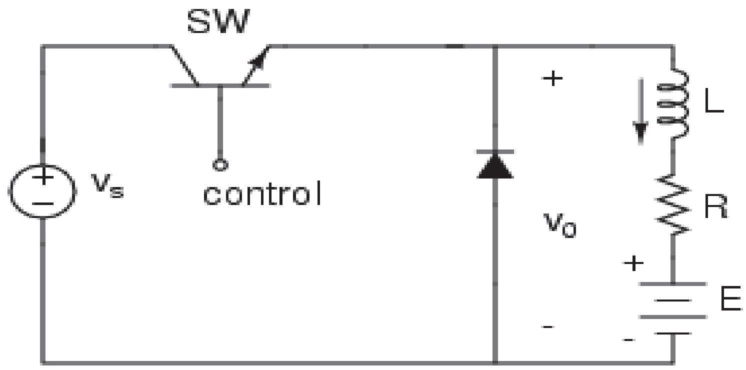

(c) Circuit

Figure 7. Buck converter.

4.5.1.2 Dynamic Analysis

The circuit diagram of the step-down converter is shown in figure (8.a). The circuit operation is divided into two modes. First, the MOSFET is turned on, while the power diode is reversed biased. Second, the MOSFET is turned off, while the power diode is forward biased. Figures (8.b) and (8.c) show these two modes [1-11].

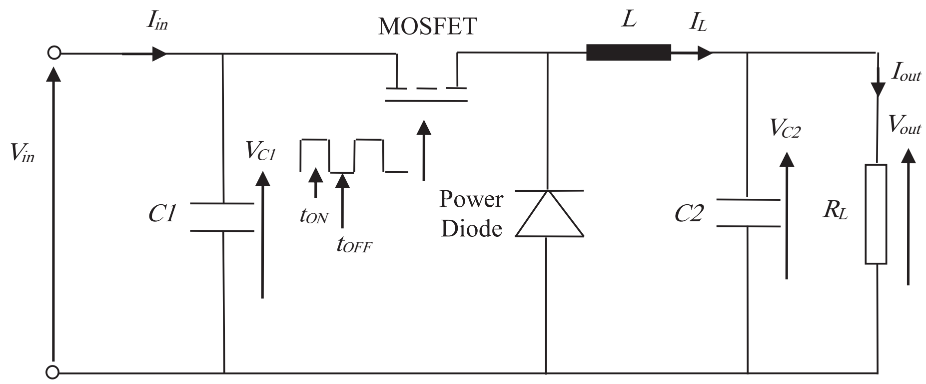

Figure 8.a. The circuit diagram of the step-down converter.

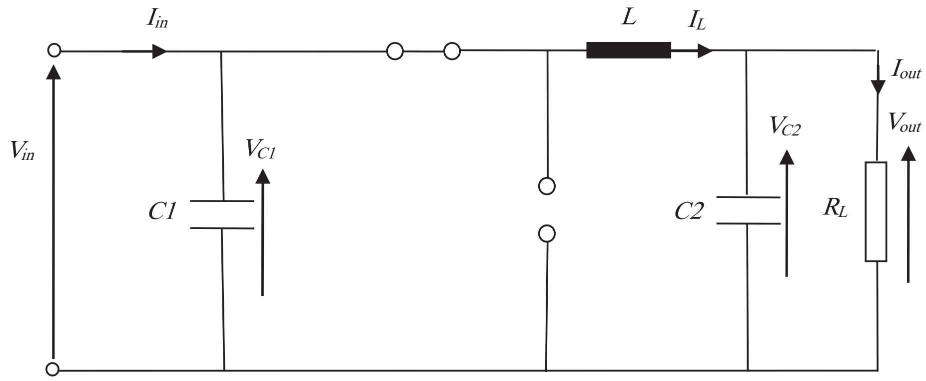

Figure 8.b. Equivalent circuit of the first mode.

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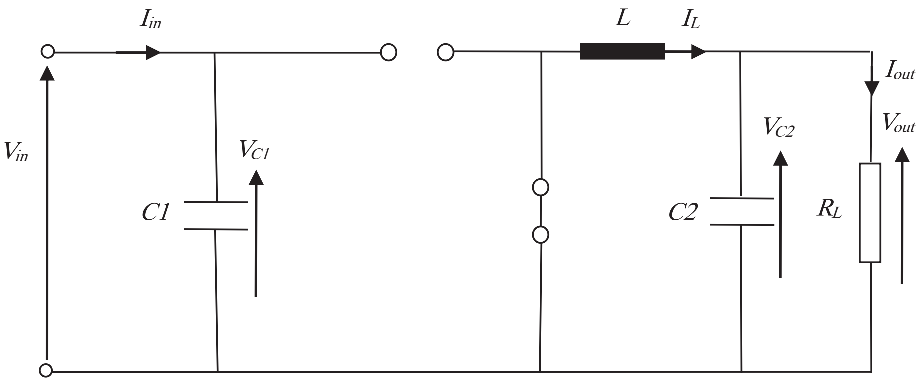

Figure 8.c. Equivalent circuit of the second mode.

The function of the input and output filters is to absorb the voltage variations and to support current smoothing and boosting.

For the first mode: the following equations are valid.

$$I_{in} = C1\dot{V}_{C1} + I_L \qquad (11)$$

$$V_{in} = L\dot{I}_L + V_{C2} \qquad (12)$$

$$I_L = C2\dot{V}_{C2} + \frac{V_{C2}}{R_L} \qquad (13)$$

The above three equations can be rearranged to give the state form:

$$\begin{bmatrix} \dot{V}_{C1} \\ \dot{I}_L \\ \dot{V}_{C2} \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{C1} & 0 \\ 0 & 0 & -\frac{1}{L} \\ 0 & \frac{1}{C2} & -\frac{1}{C2R_L} \end{bmatrix} \begin{bmatrix} V_{C1} \\ I_L \\ V_{C2} \end{bmatrix} + \begin{bmatrix} 0 & \frac{1}{C1} \\ \frac{1}{L} & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} V_{in} \\ I_{in} \end{bmatrix} \qquad (14)$$

For the second mode: the following equations are correct

$$I_{in} = C1\dot{V}_{C1} \qquad (15)$$

$$0 = L\dot{I}_L + V_{C2} \qquad (16)$$

$$I_L = C2\dot{V}_{C2} + \frac{V_{C2}}{R_L} \qquad (17)$$

These three equations are rearranged to deduce the following state representation:

$$\begin{bmatrix} \dot{V}_{C1} \\ \dot{I}_L \\ \dot{V}_{C2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & -\frac{1}{L} \\ 0 & \frac{1}{C2} & -\frac{1}{C2R_L} \end{bmatrix} \begin{bmatrix} V_{C1} \\ I_L \\ V_{C2} \end{bmatrix} + \begin{bmatrix} 0 & \frac{1}{C1} \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} V_{in} \\ I_{in} \end{bmatrix} \qquad (18)$$

Thus, the step-down converter can be represented, during *ON* and *OFF* periods respectively, as follows

$$\dot{x}(t) = A_{ON}x(t) + B_{ON}u(t) \qquad (19)$$

$$\dot{x}(t) = A_{OFF}x(t) + B_{OFF}u(t) \qquad (20)$$

Defining the duty ratio D as:

$$D = \frac{t_{ON}}{t_{ON} + t_{OFF}} \qquad (21)$$

Therefore, we can represent the step-down converter in a final state form by combining the

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two state representations (14), (18), in terms of the duty ratio *D* that expresses the *ON* periods and *1-D* that expresses the *OFF* period. The final state form appears in equation 22.

$$\begin{bmatrix} \dot{V}_{C1} \\ \dot{I}_L \\ \dot{V}_{C2} \end{bmatrix} = \begin{bmatrix} 0 & -\frac{D}{C1} & 0 \\ 0 & 0 & -\frac{1}{L} \\ 0 & \frac{1}{C2} & -\frac{1}{C2R_L} \end{bmatrix} \begin{bmatrix} V_{C1} \\ I_L \\ V_{C2} \end{bmatrix} + \begin{bmatrix} 0 & \frac{1}{C1} \\ \frac{D}{L} & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} V_{in} \\ I_{in} \end{bmatrix} \tag{22}$$

4.5.2 Principle of Step-Up Converter

The circuit diagram of the step-up converter is shown in figure (9.a). When switch SW is closed for t_1, the inductor current rises and energy is stored in the inductor L. If the switch SW is opened for time t_2, the energy stored in the inductor is transferred to load through diode D_1 and the inductor current falls. Figures (9.b) show the current waveform [10].

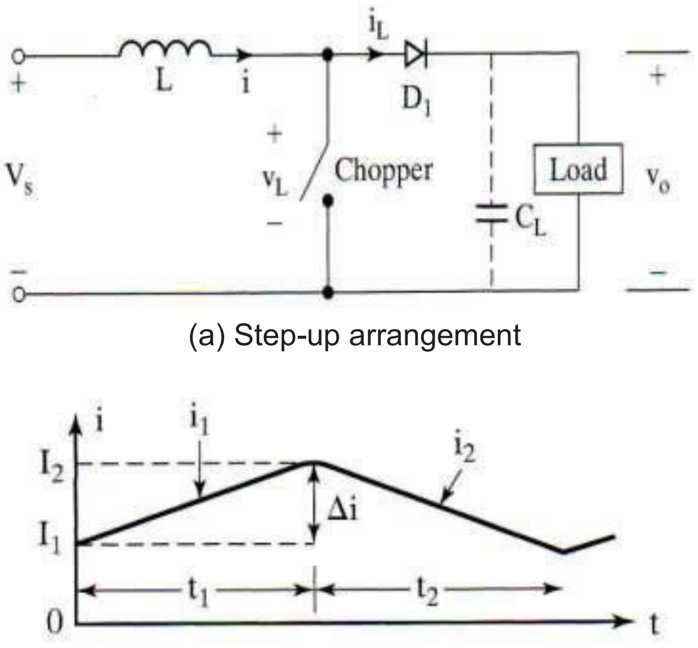
When this DC-to-DC converter is turned on " switch SW is closed, the voltage across the inductor L is : $V_L = L\frac{di}{dt}$ (23)

And this gives the peak-to-peak ripple current in inductor as:

$$\Delta I = t_1 \frac{V_s}{L} \tag{24}$$

The average output voltage is:

$$V_o = V_s + L\frac{\Delta I}{t_2} = V_s(1+\frac{t_1}{t_2}) = V_s\frac{1}{1-K} \tag{25}$$



(a) Step-up arrangement

(b) Current waveform

Figure 9. Step up converter

4.5.3 Principle of Buck-Boost Converter

A buck-boost regulator provides an output voltage that may be less than or greater than the input voltage-hence the name "buck-boost"; the output voltage polarity is opposite to that of the input voltage. This regulator is also known as an

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inverting resulator. The circuit arrangement of a buck-boost regulator is shown in figure (10) [10].

The circuit operation can be divided into two modes. During mode 1, transistor Q1 is turned on and diode Dm is reversed biased. The input current, which rises, flows through inductor L and transistor Q1. During mode 2, transistor Q1 is switched off and the current, which was flowing through inductor L, would flow through L, C, Dm, and the load. The energy stored in inductor L would be transferred to the load and the inductor current would fall until transistor Q1 is switched on again in the next cycle. The equivalent circuits for the modes are shown in figure (9.b). The wave forms for steady-state voltages and currents of the buck-boost regulator are shown in figure (9.c) for a continuous load current.

Assuming that the inductor current rises linearly from I_1 to I_2 in time t_1

$$V_s = L\frac{I_2 - I_1}{t_1} = L\frac{\Delta I}{t_1} \quad \text{Or} \quad t_1 = \frac{\Delta IL}{V_s} \qquad (26)$$

And the inductor current falls linearly from I_2 toI_1 in time t_2,

$$V_a = -L\frac{\Delta I}{t_2} \quad \text{or} \quad t_2 = \frac{-\Delta IL}{V_a} \qquad (27)$$

Where $\Delta I = I_2 - I_1$ is the peak-to-peak ripple current of inductor L. From (26) and (27).

$$\Delta I = \frac{V_s t_1}{L} = \frac{-V_a t_2}{L} \qquad (28)$$

Substituting t_1 = KT and t_2 = (1-K) T, in (28),the average output voltage is:

$$V_a = -\frac{V_s K}{1-K} \qquad (29)$$

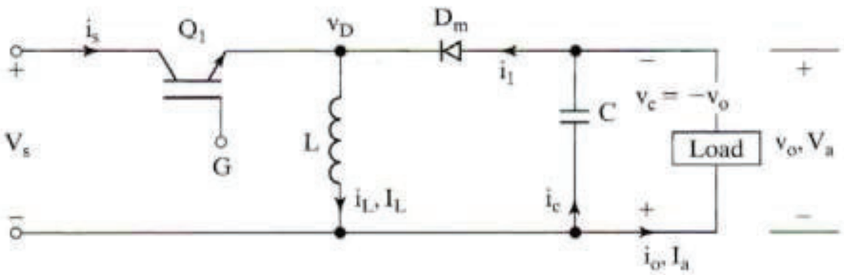
Substituting t_1 = KT and t_2 = (1-K)T, into last equation $(1-K) = \frac{-V_s}{V_a - V_s}$ (30)

Substituting t_2 = (1-K)T, and (1-K) from last two equations $t_1 = \frac{V_a}{(V_a - V_s)f}$ (31)

Assuming a lossless circuit, $V_s I_s = - V_a I_a = V_s I_a K / (1\text{-}K)$ (32)

and the average input current I_s is related to the average output current I_a by

$$I_s = \frac{I_a K}{1-K} \qquad (33)$$



(a) Circuit diagram

Figure. 10 Buck-Boost Converter

5. Results and Performance

5.1 Constant Load

The effects of varying the irradiation level on motor current, voltage and speed at 50% of motor load and different values of duty ratio are presented in figures 9 and 10 when using either cuck or sepic converters. Comparison of these results illustrate clearly that the cuck converter has a wider range of operation with respect to irradiation level and duty cycle for this type of load [13].

5.2 Pump load

The motor pump load torque is taken as [11, 50 and 51]:

$$T_L = 0.005 + 0.00004\,\omega + 0.0001\,\omega^{1.8}$$

The effects of varying the irradiation level on motor current, voltage and speed at different

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values of duty ratio are presented in figures 11, 12, 13 and 14 when using either cuck or sepic converters. Comparison of these results illustrates clearly that the cuck converter has a wider range of operation with respect to irradiation level and duty cycle in the case of pump load.

5.3 Photovoltaic Power

The output power derived from both photovoltaic systems when feeding a pump load are obtained as a function of the control voltage as shown in figures 15 and 16. Examining these results illustrates superior performance of the photovoltaic system with cuck converter rather than with sepic converter over a wide range of operation [36-54].

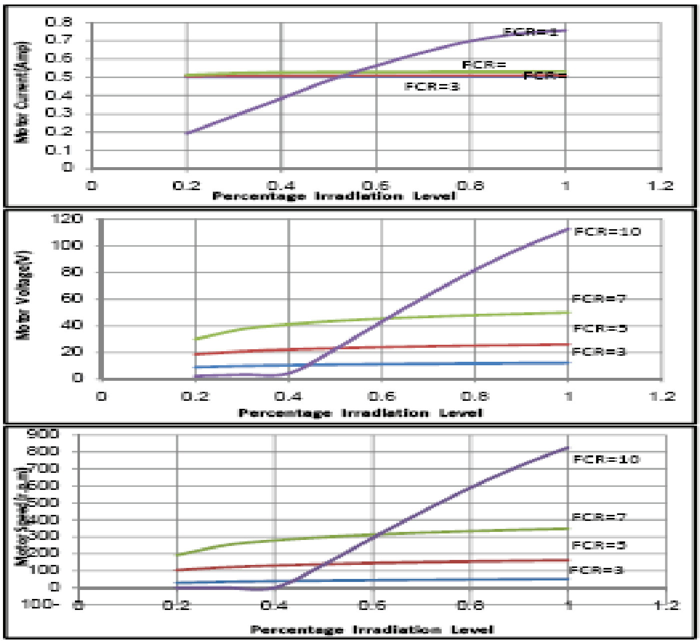

Figure 11. Varying solar irradiation levels, cuk converter

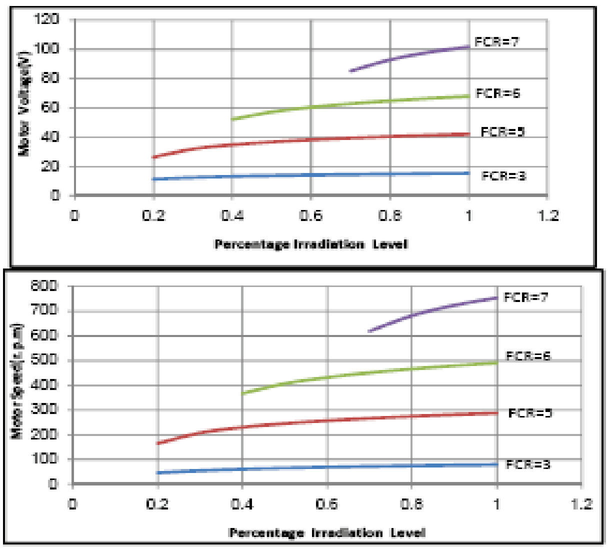

Figure 12. Effect of varying solar irradiation level, sepic converter

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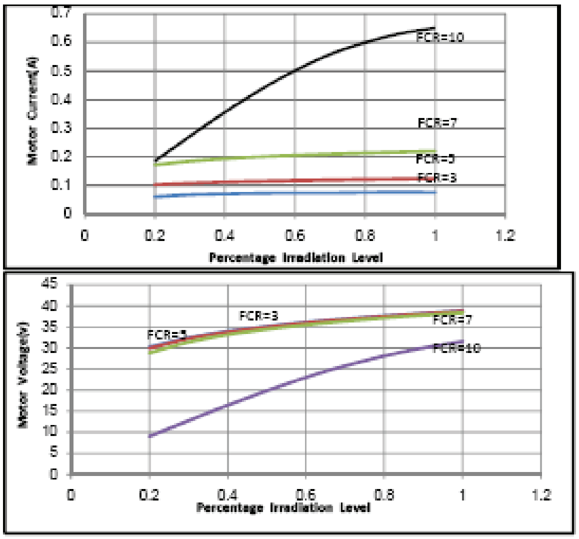

Figure 13. Effect of varying solar irradiation level, cuck converter(Pump load)

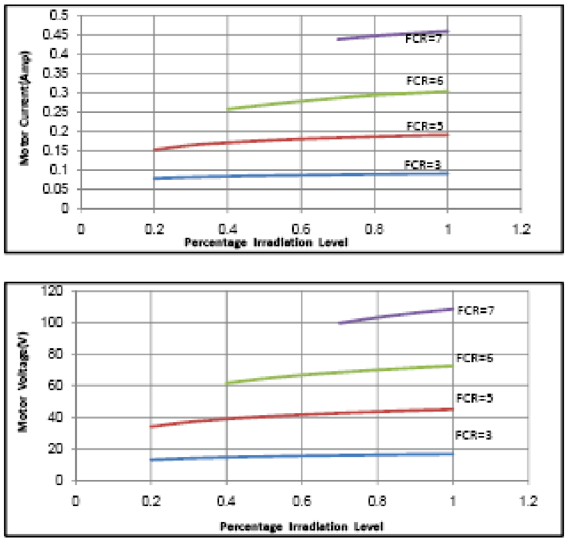

Figure 14. Varying solar irradiation level, sepic

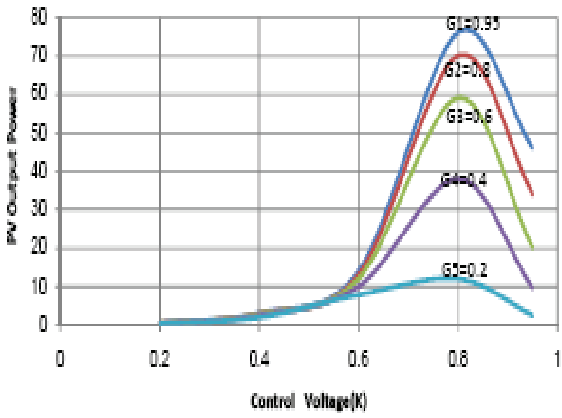

Figure 15. PV Power versus K, cuk converter

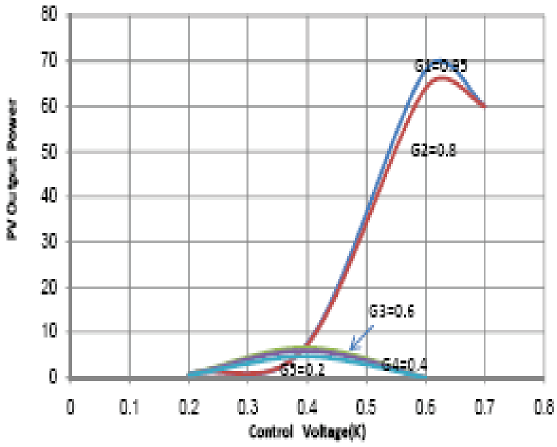

Figure 16. PV Power versus K, sepic

6. High Gain DC-DC converter:

The main concern in the renewable energy system as PV system and fuel cell is the output energy, as it known, the main problem in those systems is having a low output energy. The conventional boost converter topologies are considered as a simple and an efficient solution. However, in order to approach a high gain output voltage, the duty ratio must be increased which in turn leads to high power losses.

Therefore, many converters are modified to give a high voltage gain and a high efficiency while keeping the duty cycle as low as feasible, called, high gain DC-DC boost converter. which being an appropriate solution for the low output voltage of the renewable energy systems. Generally, this topology of converter is divided into two types as follow:

I. Isolated high gain DC-DC converter

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In this type of converter, a high frequency transformer is used to give isolation and higher output voltage, figure (17). The main benefit of transformer isolation is avoiding the high voltage interference happening in the input section and preventing the ripple current. However, the transformer in that structure increases the size and the prices of the system. In addition, the voltage stress of the converter's switches is increased by reason of the leakage inductance resulting in raising the converter's switching losses [46,47]. Figure (18) illustrates a topology of isolated converter.

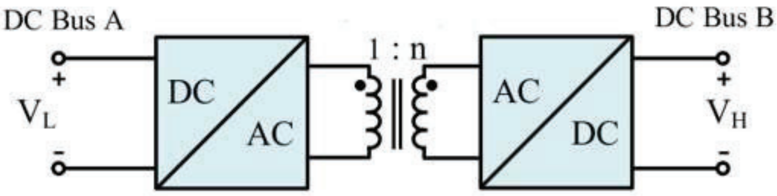

Figure 17. Isolated DC-DC Topology.

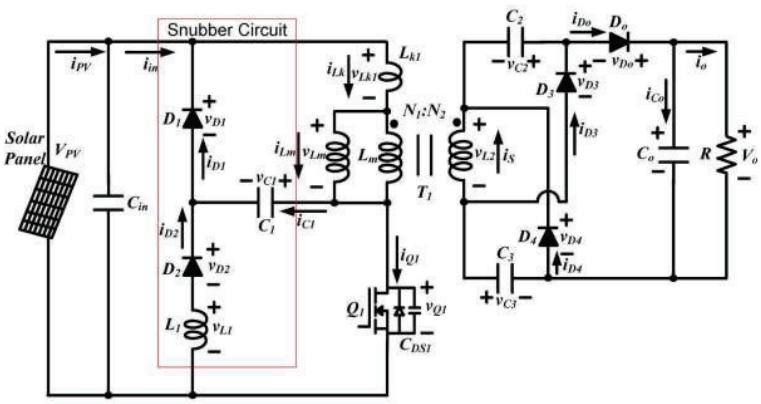

Figure 18. circuit

II. Non-isolated high gain DC-DC converter

For this topology, rather than using transformer, several techniques are used for increasing the output voltage. some of topologies depending on coupled inductors and the other depend on uncoupled inductors. For the coupled inductors, the turns ratio of the coupled inductor is increased in order to obtain high voltage gain. In addition, voltage multiplier circuits can be implemented to achieve this as well, shown in figure (19). The main drawback in this type is the high leakage inductance, resulting in increasing the losses of the circuit [48].

For the uncoupled type, higher voltage gain obtained by combining capacitors and inductors [49,50], such as gain voltage lift [51], switched inductor [52], switched capacitor [53], and hybrid switched capacitor, coupled inductors [53] and inductor[54]. The drawbacks of those topologies are voltage spikes on the switches besides using high numbers of elements. Figure (20) shows examples of uncoupled inductor.

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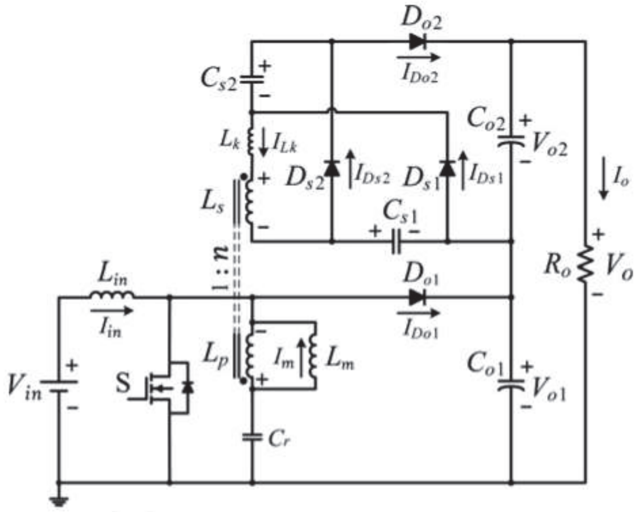
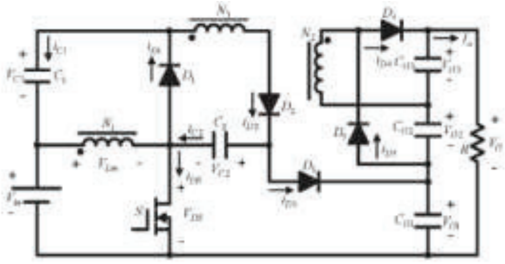
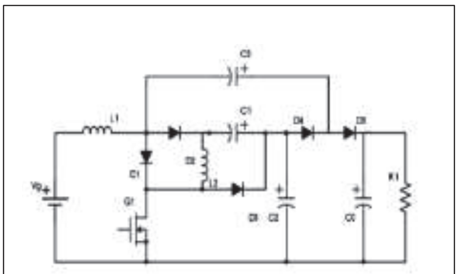


(a)

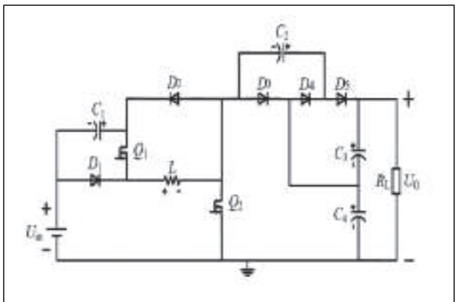


(b)

Figure 19. circuits for coupled inductor DC-DC Converter



(a)



(b)

Figure 20. High gain DC-DC converter circuits

8. Conclusion

The paper presented a comparative assessment of the performance of frequency converters used with renewable energy systems. The review of the state of the art in converters used with renewable sources either with grid connected or stand-alone power systems showed that a wide range of converters can be used with renewable energy sources. However, it has been concluded that the converters used with renewable energy sources should have a step up/down Characteristics to match the load/grid voltage requirements, especially if a control strategy to track MPP is being used. Moreover, converters used with renewable energy sources should perform well over a wide range of operating conditions in both steady state and transient condition. Also, the comparative assessment of the performance between two types of recommended converters indicated that the converter should be selected carefully for the optimum utilization of renewable energy systems. This also may help in producing a low-cost simple renewable source for remote areas and desert development applications. The discussions and results presented in this paper form a useful guide to power system engineers in development and planning of power systems when renewable energy sources are being considered.

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