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Performance Analyses of DC- DC Converter with Controller for PV Application

R. Padmavathi , R. Kalaivani

Abstract: The utility of electric power plays a major role in economic development of a country. However, the demand for electrical energy goes on increasing every day. In order to meet out the demand for electricity, Renewable Energy Source (RES) has been identified as the alternate for electricity generation. Among the various RES, PV system has added consideration throughout the world due to its easy accessibility, boundless nature and of low maintenance cost. Since the voltage obtained from PV is not suitable for high power applications, a DC/DC step up converter is introduced. This converter should have reduced output voltage ripple which is an important factor that influences the overall performance of PV system. Hence, this work studied about the different topology of converter suitable for PV systems to have a better efficiency.

Keywords : Maximum Power Point Tracker (MPPT), Photovoltaic cells (PV) and DC-DC converter.

I. INTRODUCTION

The power generation using PV has occupied a major role in world's power generation, because of its advantages like simplicity, longer life, high mobility and absence of release of pollution causing products[1]. In spite of its advantages, it also has some disadvantages like reduced conversion efficiciency and dependent of climatic conditions [2]. Countries around the world like China, New Zealand, Finland, South Korea, Spain etc., are depicting more funds to the projects over power generation using renewable energy sources [3-8]. Numerous publications have been made on this in the recent times. Yushchenko et al. [9] has valued the suitability factors of a land for grid-integrated solar power plants and also the PV systems well suited for rural areas in West Africa. Aleman Nava et al. carried out a study on eminence position of RES[10]. The problems and challenges faced in the Middle East region while implementing RES were estimated by Rawea & Urooj[11]. Honrubia-Escribano et al. [12] analysed the economical facts occurred while implementing PV plants.

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* Correspondence Author
R. Padmavathi*, Assistant Professor, Rajalakshmi Engineering College, Chennai. Tanilnadu, India. Email: padmavathi.r@rajalakshmi.edu.in
R. Kalaivani, Professor**,** Rajalakshmi Engineering College, Chennai, Tanilnadu, India

However, various steps has been taken to improvise the power generation from PV, the power produced by it varies with the impacts like temperature/load [13]. Thus it various in direct proportionate to irradiance and in inverse proportionate to temperature. Hence, the I/*V* characteristics is normally governed by load conductivity [14]. In order to grab constant current from the cell,

the level conductance has to be high, If

the conductance is vice versa, the cell performs as a constant voltage source. The block diagram presented in fig. 1 represents the methodology adopted for conversion of PV power to domestic/Industrial utilization.

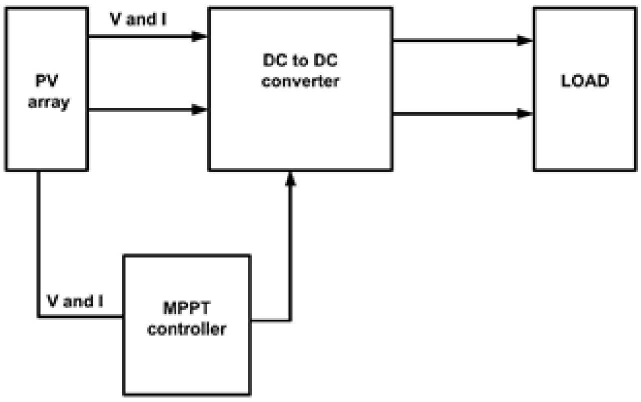

Fig 1. Block diagram of a PV system.

This work discusses about the basic details of a PV module, maximum power point tracking (MPPT) application and different converter topology applicable for the PV system.

II. METHODOLOGY

A. *Mathematical model of PV cell*

PV cell transforms light energy into electrical using PV effect. Whenever a photon emits energy higher than that of a band gap, electrons gets emitted and process a current.

PV module

PV module is obtained by interconnecting the solar cells. They are arranged either in parallel or in serial pattern. Various PV modules with different rating are commercially available in market (Generally the size may vary between 60 to 170W).

Modeling of PV Array

A PV array comprises a combination of series and parallel connections. Series connections results in increased voltage whereas the parallel connection increases the current.

Solar cell is always characterized using a current source with an inverted diode in parallel as represented in fig. 2. It has its own series (R_S) / parallel (R_{SH}) resistance. Thus R_S formulated due to the interruption occurred in the current and R_{SH} is mainly because of current leakage.

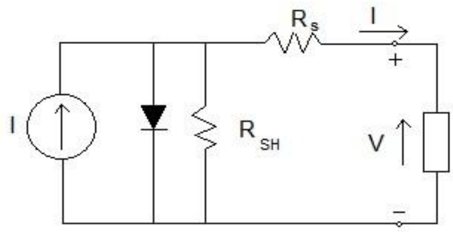

Fig 2. Modeling of PV cell

This model projected in figure 2 has greater $R_{SH\ and}$ does have any insignificant effect in the circuit. Hence it is neglected. Thus, the circuit with source (I), a diode and R_s was considered. Thus the output from the above model is calculated using conventional methods.

However, the output of the system is has the major impact with the variations in the weather condition of the environment. Thus, a constant active tracking system is mandatory to achieve the maximized power from PV array.

B. MPPT

A solar panel may not convert all the energy from the sun into electrical energy. Similarly, the both the insolation and load conditions also affects the operating points of a panel[15]. Hence to enrich the productivity of the panel, a novel technique called MPPT is employed.

This MPPT controls operative point of the modules accordingly to obtain maximum power. Thus a maximized output power is obtained from the panels. A current/voltage sensor is used at the output terminal to measure the PV output current and voltage. From the measured V/I, output power is calculated. Solar troubleshooting is the traditional method utilized for obtaining maximum power from PV [16, 17]. Then, MPPT is an alternate method implemented to obtain maximum power. In this topology, the MPP is detected using micro controller [18]. Using the detected MPP, controller triggers the converter switches. Thus its efficiency was verified by varying load impedance using duty ratio [19]. PV current is drastically affected with the variation in weather conditions. If the PV current is utilized as a reference variable, MPPT may be able to track an operating range of a PV and thus, the PV voltage is confined within 70–80% of V_{oc}. Hence, voltage is chosen as a control variable for PV system [20]. As the regulation of voltage is carried on the basis of power measurement, the input and output voltages ratio could be approximated by changeable duty cycle [21,22]. Thus, to track MPP of a PV system, numerous optimized techniques, including ACO, ANN, curve fitting, DC-link capacitor droop control, FFA, FSCI, FOCV, FL-MPPT, GA, HC, Inc-Cond, OCC, PSO, P&O, RCC and sliding-mode control have been introduced.

C. Converter Topologies

Mainly, DC/DC converters are introduced for an effective utilization of PV system [24]. Switching devices like MOSFET/IGBT are extensively implanted in converters. These switches exhibits a switching frequency (f_s) greater than 10 kHz and a voltage about 1.2 kV. But in HV converters fs is restricted to 1 kHz to minimize the switching loss. Author of [25] achieved a high power converter (Boost) by implementing SiC JFET as a switch which could accomplish upto 300 kHz. This results in reduction of the conduction loss with the application of MOSFET at low Rds source [26].

Hence while selecting converters for PV system care must be taken on efficiency, cost and its ability to sustain constant output regardless of variations in the input. At the same time, voltage ripple should be minimised [27].

The converters like SEPIC/ buck–boost/ / Cuk exhibits high ripple at the output. Hoewever, they has wide range of flexibility over an output voltage. Similarly, buck converter depicts high ripple current [28].

The features of buck / buck–boost/ boost / SEPIC and Cuk when implemented in PV systems is analysed in [29]. From this analysis, it was concluded that buckboost converter progresses a best performance in spite of variations in climate / load, along with high ripple input current and noise problems.

Progressive converters like Luo converter/ KY boost / quadratic (Boost) converters were also applied in PV applications [30].]. A NOELU converter PV system using Inc-Cond algorithm was studied by [31]. The stability analysis of quadratic double converter (Boost) integrated with MPPT was studied in [32].

The advancement of buck–boost/ Cuk/ SLLC, SEPIC, and ULLC converters for PV application using State-space modeling has been investigated [33]. From the results, it was proven that Luo converter based models suffers higher power loss over the other topologies.

Thus an analysis over highly-efficient converters for RES applications were done in [34]. Similarly a technical review over converters for PV system was made by [35].

Author of [36] analyzed the recent technological developments over mult-input converters along magnetic / electric coupling. A three-port topology converters with 2 inputs and 1 output was designed [37]. One input may be connected with solar panel and the other one with the battery. Similarly, the output is connected to the grid. This type of converters results in lower cost/ high reliability than that of the isolated converters.

Author of [38] discussed about the lower output gain and also the shoot-through condition occurrence in VSC / CSC. From the analysis, it is stated that an impedance based converters may resolve these problems. If an equivalent impedance lean towards an infinity, then it is observed as a CSC. Similarly, it is observed as a VSI if the equivalent impedance is zero.

III. ADVANCEMENT OF CONVERTERS (PV APPLICATIONS)

The advancement in converter topologies which are suitable for PV applications is discussed below.

A. Boost converter

In most applications, the voltage supplied to the load should be greater than the PV's output voltage. In order to achieve this, an MPPT controller should be integrated with the boost converter. Thus, various modifications have been introduced in boost converter to improve its efficiency. Huber [39] proposed a cascade arrangement of boost converter to maximize the voltage gain and for ripple reduction.

As an input voltage to the converter becomes low, then the 1st stage has reduced voltage stress and may operates at high fs. The second stage functions with lower fs and hence the switching loss gets reduced. However, the drawbacks include more number of components, less efficiency as well as EMI problem.

The performance of a 2 phase interleaved converter (step up) coupled under DCM was analysed [40].

A novel 2 phase converter with IBI-LLC was proposed by [41]. A fixed-frequency PWM topology is tailored to optimize a filter size/lower circulating current/ ripple free input current. In this mode, resonant frequency (fr) is tuned over f_s.

Hung et al. [42] formulated a novel topology to optimize PV system. It also reduces output voltage ripple. The operation of a converter under DCM was carried out using PFM. Thus the PV system implemented in this system is assumed to have low power/ irradiance. A minimization of the switching frequency results in a maximization of ripple current. This can adjusted by adjusting the peak value of the inductor current.

A cascaded connection of boost converters was studied by [43]. This was similar to that of two-stage approach with loss-free resistors. Transient stability is observed using a sliding mode control. An ideal reduced order sliding mode dynamics model is studied using non linearity characteristic of a PV unit and using an efficiency of a MPPT controller. From the analysis, it is concluded that the system was stable and has minimal settling time. When compared to that of the coupled inductor, it shows that any changes in the output voltage does not affect the input parameters/extracted power. The major disadvantages of this design is the addition of more control circuit.

A combined boost/ cuk converter (self lift) with greater voltage gain was modeled by [44] for a VSI designed without transformer. This allows the converter to have direct contact in between a PV and the grid. The inc- cond T algorithm was implemented to control the duty cycle, D.

A dual switch boost converter along with coupled inductor /voltage multiplier was formulated by [45]. This design exhibits high efficiency/ voltage gain and low voltage stress.

Buck/Boost converter

Compared to simple boost converters, buck–boost converters shown in figure 3 results in less ripple. Comparatively, the 2 switch buck/boost converters have minimized stress (both voltage/current) over the components.

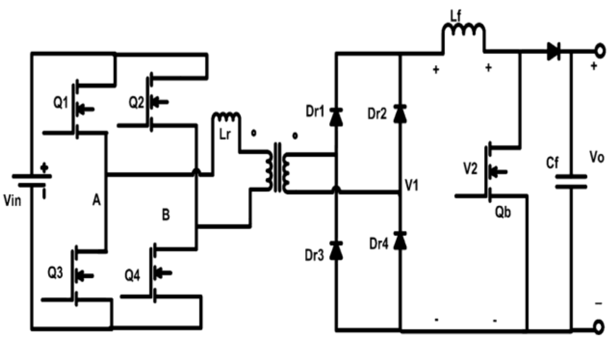

Fig 3. Buck/Boost converter.

A 2 switch NI converter (buck /boost) proposed by [46] has added current storage in it. In this, P&O was utilized to track the MPP. Fro the drawbacks include more number of components, less efficiency as well as EMI problem. m the experimental results, it is proven that this converter reveals enhanced efficiency under heavy loads. It can be operated as either buck or boost depending upon the output voltage condition.

An interleaved (Buck/ Boost) converter using a coupled inductor was designed by [47]. This system was analysed using SSA technique. In this topology, the interleaved techniques enhances the efficiency /power density of the converter. Simultaneously, the damping network minimizes voltage stress across the switches. The inductor current gradient and the capacitor voltage gradient are instigated to determine the ripple in the inductor current /capacitor voltage.

The effect of source resistance over Zeta/ SEPIC/ four switch synchronous converters using dynamic analysis was studied by [48]. A FLC was implemented to acquire maximum power from MPPT.

A new topology was proposed by [49] to enhance the efficiency of a converter by integrating a decoupling capacitor over a H bridge. Thus this circuit exhibits lower power loss/cost.

A scheme of 4 switch converter for PV system was formulated by [50]. It may operate in buck/ all three (buck boost /boost/buck) modes. Using SSA method, stability of this topology was analysed.

The performance of buck/ boost and buck boost converter topologies which performs MPPT tracking using DSP processor was studied by [51]. It combines discrete time control and proportional integral (PI) compensator. From the results, it was proven that Inc-cond exhibits higher tracking efficiency irrespective of environmental changes. In this topology, the buck converter reveals high efficiency.

B. Single-ended primary-inductance converter (SEPIC)

The SEPIC depicted in figure 4 exhibits both step up/ down principles.

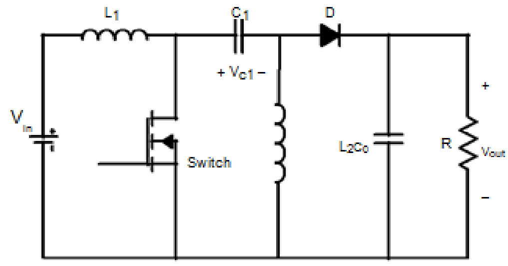

Fig 4. SEPIC converter.

A modified SEPIC with diode and capacitor is proposed by [52]. It reveals less ripple and hence used as a pre regulator. The converter operation under DCM results in reduced commutation losses. It also results in high efficiency with lower ripple current. In addition to that, the minimization of distortion in input current and low power factor were also discussed. An open loop control was carried out to reduce the 3rd harmonic distortion.

Harmonic balance techniques using Fourier analysis was applied to the converter model to predict its withstanding capability during transient periods [53].

A new modeling practice, which splits the converter into two parts (resonant inverter and rectifier) at the first stage for analysis and was again coupled together was introduced [55].

But the major drawback was that the system was considered linear.

The combination of Coupled inductor and auxiliary inductor may exhibit reduced ripple current. Hence, Do [54] formulated a modified voltage multiplier to reduce the high voltage stress problem of SEPIC.

A FLC based SEPIC converter to reduce THD level was formulated [56]. FLC controls a duty cycle according to output of P&O algorithm. Thus, triangular membership functions are implemented for the FLC.

C. Fly back converter (FBC)

The fly back converter is mainly implemented in PV systems where the power is very low power and is shown in figure 5[62]. When a converter with high gain is needed, the only solution is the fly back converters. While implementing in high power applications, the transformer results in large air gap. This large air gap will reduce the low magnetizing inductance. This in turn results in poor energy transfer efficiency. [57].

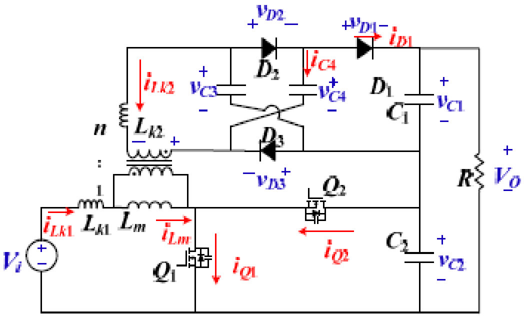

Fig 5. Flyback converter.

In this converter, possibility may arise for partial discharge over magnetizing inductance (transformer). So this converter can exhibits the characteristics of inverter. Hence its operation in CCM is not common [60]. A FBC which operates under BCM can provide high power and a large fs bandwidth[61]. Thus, efficiency of this converters may be enhanced in ZVS process [63]. Similarly, soft switching could be realized by clamp circuits [58]. Soft switching based dual FBC was proposed [59]. It reveals reduced ripple and higher efficiency. The ZVS is obtained using self driven synchronous rectifier (SR). Hence the losses are considerably reduced.

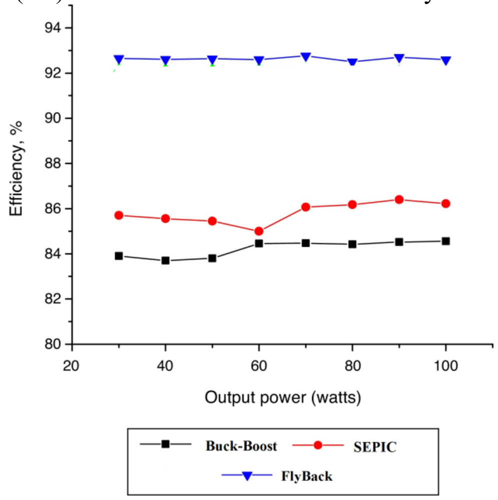

Fig 6. Efficiency of the studied converters.

Fig. 6 shows the efficiency of the various converters. The graph clearly shows that the fly back converter has more efficiency than the others.

IV. DESIGN OF CONTROLLERS FOR CONVERTERS

Several researchers have contributed in evolving PI controllers for DC-DC converters. Ref. [62] and [63] clearly explained the control of BDC for HEV applications with PI controller which in turn minimizes the switching losses. Thus the closed loop control of the converter using PID controller results in enhanced transient performance and steady state performance.

An auxiliary switch control using a lookup table based FPID, tuned using artificial intelligence proposed by [64] enhances the efficiency of a BDC. This depicts best response when compared with the performance of other controllers. The FPID controller with soft computing techniques enhances the flexibility and stability of converter.

Now-a-days, the techniques based on soft computing and computational intelligence becomes very popular because it provides fast response without overshoot. At the same time, SCT based controller has the ability of self-tuning process and are adaptive to uncertain systems. It also affords a promising option for any industrial applications with many desirable features. Hence SCT based controllers such as fuzzy and neural controllers are implemented for the converters.

The dynamic performance of the proposed converter by using fuzzy controller is better than the open loop performance in terms of steady state erro and t settling time. [65,66]. A BDC for hybrid power generators should hve low component rating/ / size/ weight and / cost [67]. The fuzzy logic controller for a BDC can also be used to interconnect a storage device to RES. This controller confirms the continuous supply of power to the load, irrespective of the changes in the power generation/load.

Therefore, the controller designed should be capable of enhancing the reliability and efficiency of RES. The FLC for hybrid system which utilizes multiple types of power sources such as PV, batteries and FC are found to produce accurate results with minimum distortion [68]. Thus the FLC with minimum number of membership functions and rules makes the design simple in both buck and boost stages.

Hence the implementation of FLC for output voltage regulation of BDC becomes more popular. (Stalin et al. 2016). A multiport converter (MPC) with optimized FLC results in high efficiency/ reliability. Thus, the control strategy based on fuzzy logic control technique avoids peak shoot through problem. Therefore the description of better linguistic rules depends only on the knowledge of the control expert and the conversion of these rules into fuzzy set is not formalized. Hence the performance of the fuzzy logic controller can be significantly exaggerated by the choice of MFs. Therefore, tuning methods are needed for the FLCs to acquire more accuracy. To tackle the proper selection of tuning techniques, neural controllers are adopted.

Thus the model of the DC/DC converter by using neural network emulator also implemented. Jose Quero et al. (2002) proposed a NN controller to control the resonant converters. Thus the characteristics of a feedback control and the optimal trajectory control law were analyzed. Sabura Banu et al. (2004) used NN for the identification of power converter behavior and acquired exact identification using 3 layer NN for quasi-resonant converter with 10 neurons in both input / hidden layer.

1 neuron in output layer. Javad Mahdavi et al. (2005) proposed an NN controller for the implementing sliding mode control using state space averaging method. Hsu et al. (2006) developed a new intelligent control system which comprises NN controller and a supervisory controller.

Chun Fei Hsu et al. (2006) focused the efficacy of the Adaptive Recurrent (AR) network implemented in a converter. By Lyapunov stability theorem, the control method was investigated and the stability of the system was guaranteed. Murphey et al. (2006) presented a new fault detection system in electric drives using machine learning. Weiming Li and Xiao Hua Yu (2007) formulated a NN to enhance the efficiency of a converter under dynamic condition.

A multi-layer feed forward NN controller can also be implemented for a converter. Yonis et al. (2018) presented a NN controller for converters. This system has the ability to track the output voltage accurately and ensures the stability of the system with faster response. Kuo Hsiang Cheng et al. (2007) formulated a fuzzy neural sliding mode control for converters.

Xinggui Wang et al. (2008) proposed NN with traditional PID controller. This system exhibits good dynamic performance.

Muhammad Sheraz et al. (2012) presented the neural network to track the maximum power from the photo voltaic system. Here the neural network based approach can track maximum power more accurately and much faster than the conventional methods.

V. CONCLUSION

This work analysed a different topology of converters (DC/DC) applicable for PV system. A detailed study was carried out to analyse the advantages and disadvantages of the above said converters. From this analysis, it is observed that the fly back converters exhibits better results comparatively than the other converter topology. Hence, FBC is adapted as a suitable converter for PV applications.

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AUTHORS PROFILE

R Padmavathi working in Rajalakshmi Engineering College in the Electrical and Electronics Engineering department with 12 years teaching experience. She has published papers in International conference and few journal papers .Her area of interest is power electronics and drives.

Dr. R Kalaivani is a Professor in the department of Electrical & Electronics Engineering having more than 18 years of eminent experience. She has several journal publications to her credit. She has authored textbooks on power systems. Her area of specialization is Power Systems.