Solar Energy Conversion Using Soft Switched Buck Boost Converter for Domestic Applications

Vidhya S. Menon
Dept. of Electrical and Electronics Engineering
Govt. College of Engineering, Kannur
Kerala

Sukesh A.
Dept. of Electrical and Electronics Engineering
Govt. College of Engineering, Kannur
Kerala

***Abstract*—Dependence on renewable energy systems is the best solution available that caters to both the increasing energy demand and the maintenance of a clean environment. Out of the renewable energy sources available, solar energy is a promising candidate for tropical regions since the availability is abundant. This paper considers a stand alone PV system with a dc-dc converter that uses the dc generated from the solar panel and processes this to a required dc level to cater to various dc loads. The converter works in the buck boost mode with a partial resonant circuit that conditions the power output of the panel to suit the load requirements.**

Hourly cloudless solar radiation data has been used to provide insolation data in the model which is calculated from geographic location data. The MPPT technique considered in the work is the Perturb and Observe (P&O) algorithm. Soft switching technique, which provides an appreciable increase in the efficiency has been utilized in the converter.

***Keywords*-Solar radiation modeling, buck boost converter, soft switching, MPPT.**

I. Introduction

With the alarming rate of depletion of the major energy resources worldwide, it has become an urgent necessity to seek for renewable energy resources that will power the future. According to the world market economy, the increasing demand for energy had forced to put a huge price tag on natural combustible sources of energies. In fact, it has been predicted that in the near future the demand of energy will grow in such a rate that it will be completely impossible to find out or meet the demand with the resources that we had been using for so long, such as oil, gas, coal, etc. This issue throws a positive challenge to the scientific community as more and more funds are being allocated for the research and development of new alternatives.

In this context we have concentrated our focus on the research of renewable energy. Among these renewable energy resources solar energy is one of a kind. In today's world there is a growing demand to find greener ways to power the world and minimize greenhouse gas emission. Solar power (photovoltaic) systems are a sustainable way to convert the energy of the sun into electricity [1]. As long as our earth exists, the sun is there to give us unlimited solar energy. It is completely up to us how we are going to utilize this abundant energy.

The output of solar panel is efficiently conditioned by power converters. The power converter must have high switching frequency in order to achieve small size, light weight, and low noise. However, the switches in the converter are subjected to high switching power losses and switching stresses. As a result,efficiency decreases. To improve the system efficiency, soft switching is employed nowadays [7].

The work has successfully developed the model of a stand-alone PV system which tracks the maximum power from the panel and converts it using a soft switched buck boost converter to be used by the dc loads at home.

II. Solar Radiation

Solar irradiance is defined as the intensity of solar radiation received on a surface at a given time and is usually expressed in Watts per square meter [W/m^2], and insolation is defined as the amount of solar energy received on a surface over a period of time and is expressed in units of kilowatts-hours per square meter [kWh/m^2]. Solar radiation are affected by many factors such as weather conditions (e.g., cloud cover, haze, seasonal ground effects, and water vapor), inclination of the surface, time of day, effects of local features (shading, topographical features, and urban landscapes), ecological and biological processes and human activities. To design and analyze solar systems, we need to know how much sunlight is available. A fairly straightforward, though complicated-looking, set of equations can be used to predict where the sun is in the sky at any time of day for any location on earth, as well as the solar intensity (or insolation: incident solar Radiation) on a clear day. To determine average daily insolation under the combination of clear and cloudy conditions that exist at any site we need to start with long term measurements of sunlight hitting a horizontal surface. Another set of equations can then be used to estimate the insolation on collector surfaces that are not on the ground. Solar flux striking a collector will be a combination of direct beam radiation that passes in a straight line through the atmosphere to the receiver, diffuse radiation that has been scattered by molecules and aerosols in the atmosphere, and reflected radiation that has bounced off the ground or other surfaces in front of the panel.

A. Solar Radiation Model Description

The general form of the model is given as follows [2]:

$$G_{TP} = G_{BP} + G_{DP} + G_{RP} \tag{1}$$

where G_{TP} is the total radiation on a tilted flat - panel, G_{BP} is the direct solar beam on the panel, G_{DP} is the diffuse radiation on the panel, and G_{RP} is the ground reflected irradiance on the tilted panel.

1) Direct solar beam radiation: The expression of the direct beam radiation is given as follows:

$$G_{BP} = G_B \cos\theta \tag{2}$$

where G_B is the direct beam radiation at the surface of the earth and θ is the angle of incidence between the normal to the panel face and the incoming direct beam.

2) Diffuse radiation: The model of diffuse component of radiation on a flat-panel is given by,

$$G_{DP} = CG_B \left(\frac{1+\cos\epsilon}{2}\right) \tag{3}$$

$$C = 0.095 + 0.04\sin\left[\frac{360}{365}(n-100)\right] \tag{4}$$

where C is a sky diffuse factor, n is the day number with January 1 as 1 and December 31 is the day number 365 and ϵ is the panel tilt angle.

3) Reflected radiation:

$$G_{RP} = \rho G_B (\sin\beta + C)\left(\frac{1-\cos\epsilon}{2}\right) \tag{5}$$

where ρ is the ground reflectance, β is the altitude angle of the sun, ϵ and C are the variables as already defined.

III. PHOTOVOLTAIC MODULE

Figure 1 shows the equivalent circuit of PV module. Leakage current due to recombination is neglected. The PV

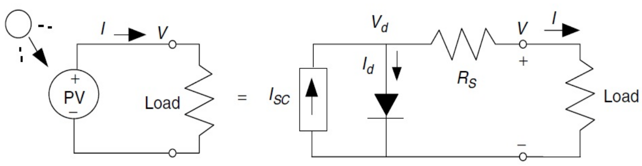

Figure 1. A PV equivalent circuit with series resistance.

module modeling equations are given by the following [1] :

$$I = I_{SC} - I_d \tag{6}$$

$$I_d = I_0\left(e^{qV_d/kT} - 1\right) \tag{7}$$

$$V_d = V + IR_s \tag{8}$$

The current-voltage and power-voltage characteristics of a PV module is shown below.

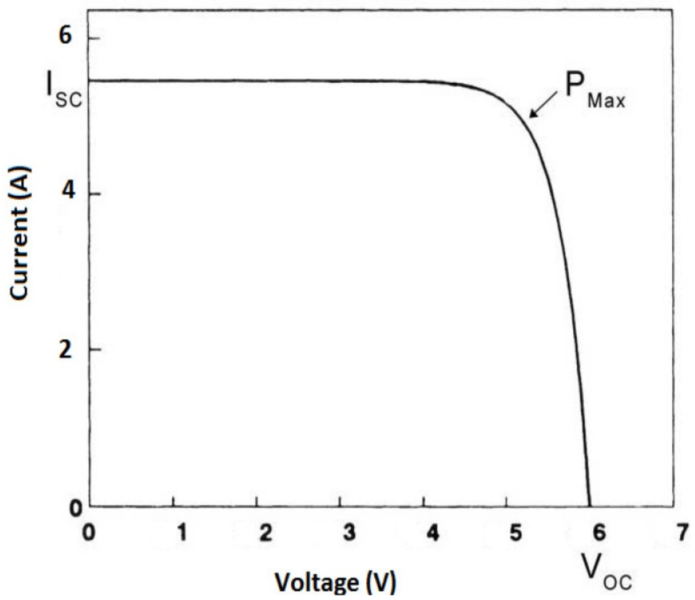

Figure 2. I-V characteristics of a solar panel

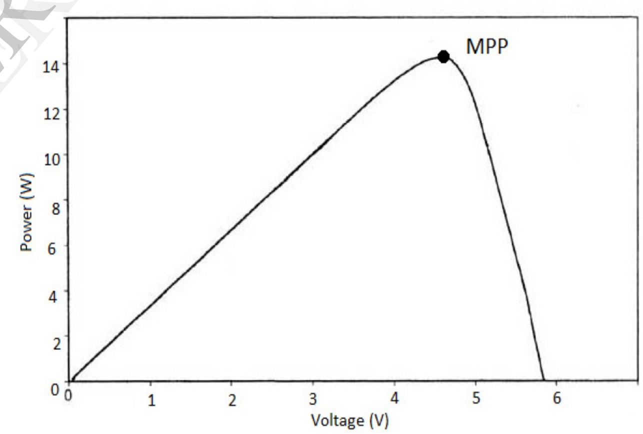

Figure 3. P-V characteristics curve of photovoltaic cell

IV. MAXIMUM POWER POINT TRACKING

Perturb and observe algorithm is used for MPP tracking. P&O algorithm is easy to implement compare to other algorithms [3],[5]. The most basic form of the P&O algorithm operates as follows. Figure 4 shows a PV module's output power curve as a function of voltage (PV curve), at the constant irradiance and the constant module temperature, assuming the PV module is operating at a point which is away from the maximum power point.

In this algorithm the operating voltage of the PV module is perturbed by a small increment, and the resulting change of power, ΔP, is observed. If ΔP is positive, then it is supposed that it has moved the operating point closer to the maximum power point. Thus, further voltage perturbations in the same direction should move the operating point toward the maximum power point. If the change in P is negative, the operating point has moved away from the MPP, and the direction of perturbation should be reversed to move back toward the maximum power point. Figure 5 shows the flowchart of this algorithm [4].

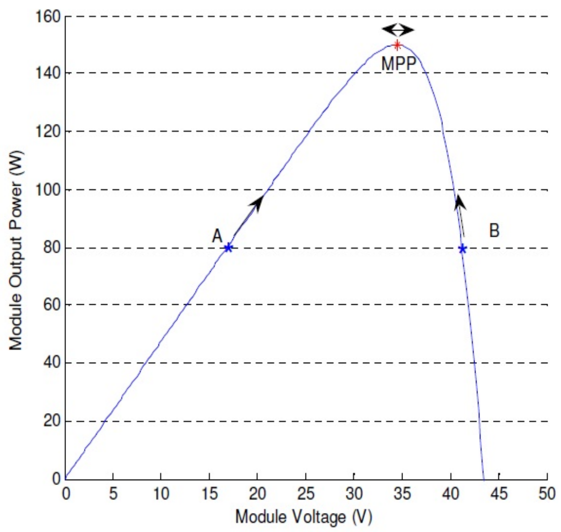

Figure 4. Plot of power vs. voltage

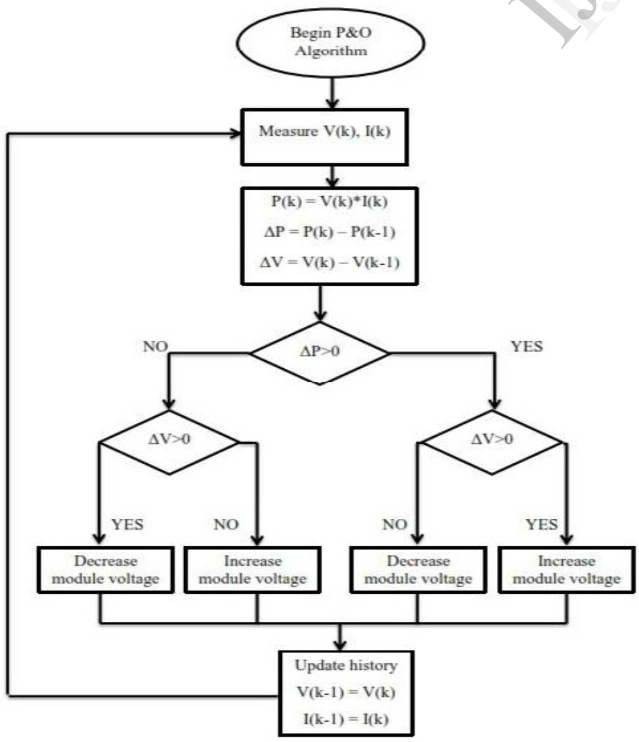

Figure 5. Flowchart of the P&O algorithm

V. Converter Choice for MPPT

Usually, the MPPT is achieved by interposing a DC/DC converter between the photovoltaic generator and the load, thus, acting on the converter duty cycle (D) it is possible to guarantee the operation point as being the MPP. Buck and boost are the converters mostly used. However, satisfactory results in tracking applications require converters with buck and boost characteristics simultaneously [6]. The operation point of the simplified system is defined by the generation and load curves intersection, as shown in figure 6 where the

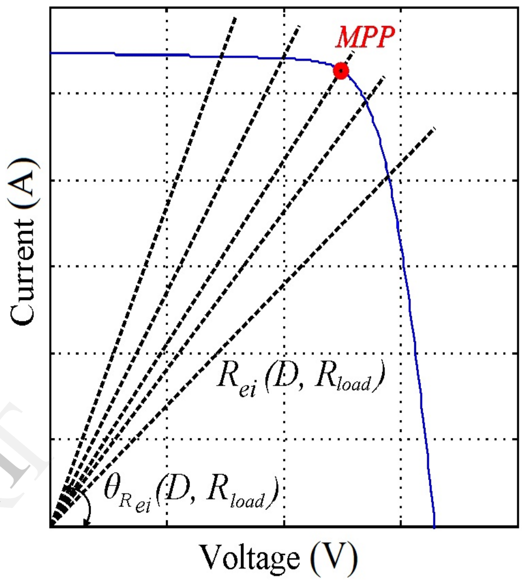

Figure 6. Generation curve and some load curves.

inclination angle θ_{Rei} and the effective input resistance R_{ei} expresses a relation between duty ratio (D) and the load, (R_{load}) .

Hence, acting on duty cycle, the inclination angle can be changed in order to allow the intersection of both (generation and load) curves exactly on the MPP, according to figure 6. Since the duty cycle is theoretically limited between 0 and 1, the effective inclination angle will be restricted by the following limits for a buck converter :

$$0^0 < \theta_{Rei}(D, R_{load}) < atan\left(\frac{1}{R_{load}}\right) \tag{9}$$

For a boost converter the range of inclination angle is

$$atan\left(\frac{1}{R_{load}}\right) < \theta_{Rei}(D, R_{load}) < 90^0 \tag{10}$$

Whereas for a buck boost converter range of θ_{Rei} is

$$0^0 < \theta_{Rei}(D, R_{load}) < 90^0 \tag{11}$$

VI. Soft Switching

A power converter can be operated with high switching frequencies only if the problems of switching losses can be overcome; this can be done using soft switching techniques.

This term soft switching refers to various techniques that make the switching transitions more gradual than just simply turning a switch on or off (which is referred to as hard switching in the power electronics literature) and that force either the voltage or current to be zero while the switching transition is being made.

A. Buck Boost Converter with Partial Resonant Circuit

A already mentioned, buck boost converter has an operational range that includes both of the operational regions of buck and boost converter. Hence the choice of buck boost converter to condition the power from the PV panel to meet the load requirements is out of question. In addition, a soft switched buck boost converter will increase the efficiency of the overall system.

The buck boost converter with partial resonant circuit is shown in figure. 7 [7]. It has four modes of operation. It is composed of controlling devices, a step up-down inductor L_r, and a snubber capacitor C_r. The partial resonant circuit consists of a series connected switch-diode pair with a resonant capacitor, which is operated to a loss-less snubber capacitor. The switching devices in the this converter are operated with the soft switching by partial resonance and with constant switching frequency.

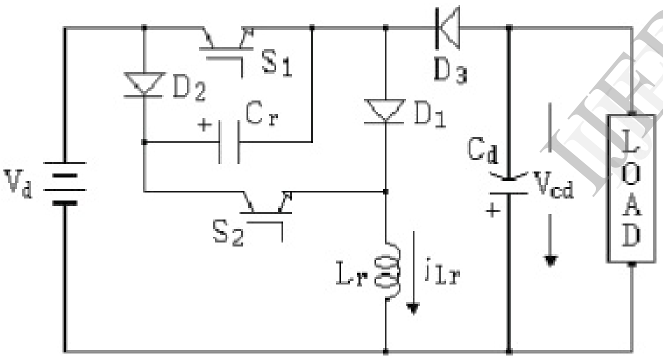

Figure 7. Buck boost converter with partial resonant circuit.

VII. Simulation Results

A 100W load supplied from a 150W solar panel was designed and simulated in MATLAB/SIMULINK. Specifications of the PV panel used for simulation [8], having 72 cells connected in series is given in table I. Figures 8 and 9 show PV and IV curves of the panel at different temperature and G=1kW/m^2 respectively. As can be seen from the results, voltage at which maximum power point occurs (V_{MPP}) changes as the temperature is varied.

IV and PV curves at different radiation and T=25^{0}C are shown in figures 10 and 11. In the equivalent circuit, the ideal current source delivers current in proportion to the solar radiation to which it is exposed. So as the radiation varies, panel current also varies. When radiation reduces, power reduces. The results indicates that for different irradiation,

Table I
PV PANEL SPECIFICATIONS.

Parameter	Variable	Value
Maximum Power	P_{MPP}	150W
Voltage at P_{max}	V_{MPP}	34.5V
Current at P_{max}	I_{MPP}	4.35A
Short Circuit Current	I_{SC}	4.75A
Open Circuit Voltage	V_{OC}	43.5V
Temperature Coefficient of I_{SC}	α	0.065%/^0C
Temperature Coefficient of V_{OC}	β	-160mV/^0C

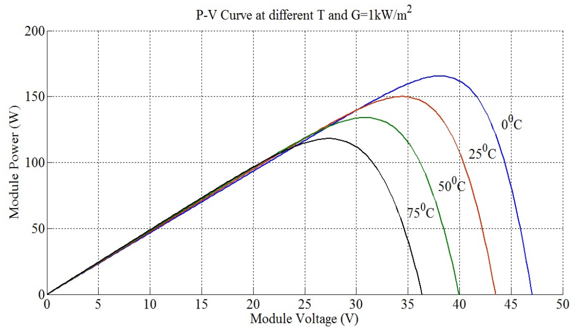

Figure 8. PV curve at different temperature and G=1kW/m^2

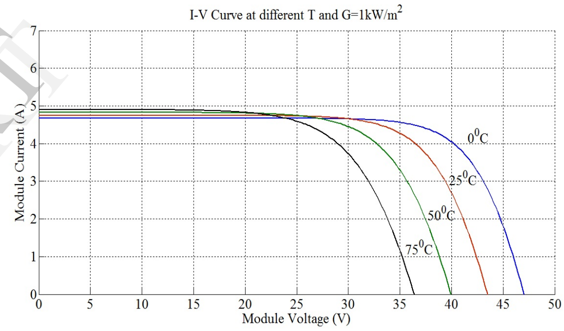

Figure 9. IV curve at different temperature and G=1kW/m^2

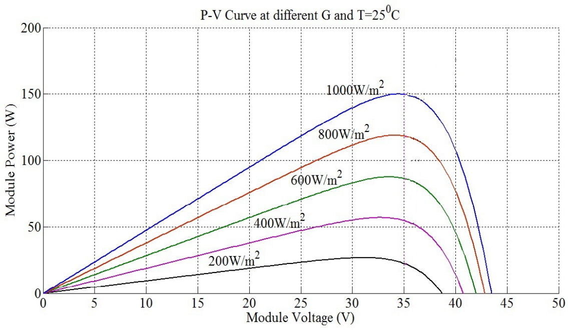

Figure 10. IV curve at different irradiation and T=25^{0}C

V_{MPP} remains the same but it changes as temperature vary. Thus the above results shows that MPPT algorithm extracts maximum power possible from the panel at different conditions of temperature and irradiation.

Simulation results of buck boost converter with partial resonant circuit for the design values mentioned above is

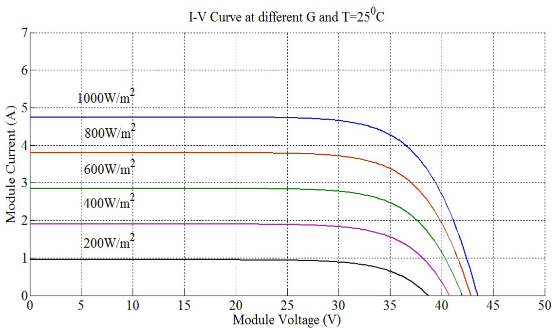

Figure 11. PV curve at different irradiation and T=25^{0}C

shown in figure 12. Closed loop operation of the converter was achieved by PWM switching and PI controller. The output voltage was compared with a reference voltage and the error was given to a PI controller whose output is compared with a triangular waveform to produce the switching pulses.

As shown in the figure when voltage across capacitor becomes zero switch is turned off and switch turns on when inductor current is zero, thus enabling soft switching. The resonant capacitor voltage is 36V which is the sum of input voltage and desired output. The inductor current, as shown is discontinuous. The switch voltage is equal to the capacitor voltage during mode (c) whereas during the mode (d) it has the value same as that of the output voltage. During mode (a) switches passes full current, while during mode (b), current splits through two paths and thus switch current reduces. All these are clear from the simulation waveforms shown.

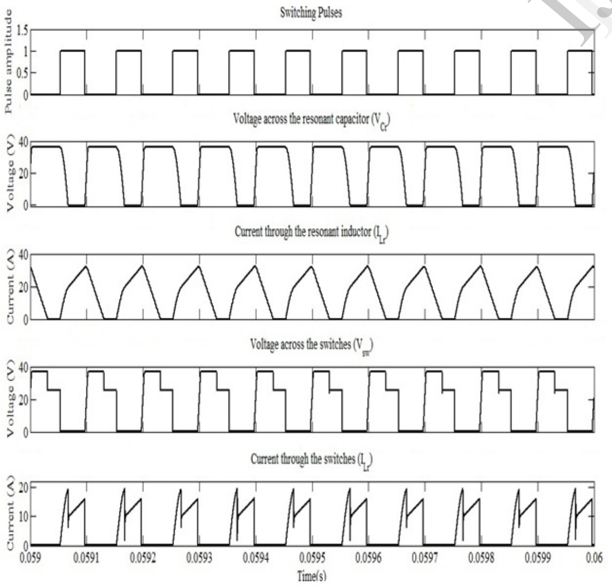

Figure 12. Simulation waveforms of buck boost converter with soft switching circuit

The output voltage is shown in figure 13. As per the design when the inductor value L_r>3.2$\times$10^{-5}, the converter operates in the continuous mode. The simulation waveforms for continuous mode with L_r=6 $\times$ 10^{-5} is shown in figure

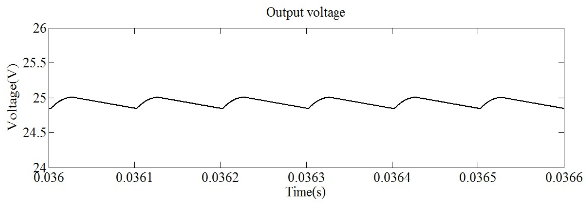

Figure 13. Output voltage of the complete system

14. Converter is not soft switched if it works in continuous conduction mode as the inductor current will never be zero. The system waveforms when the load is reduced to half

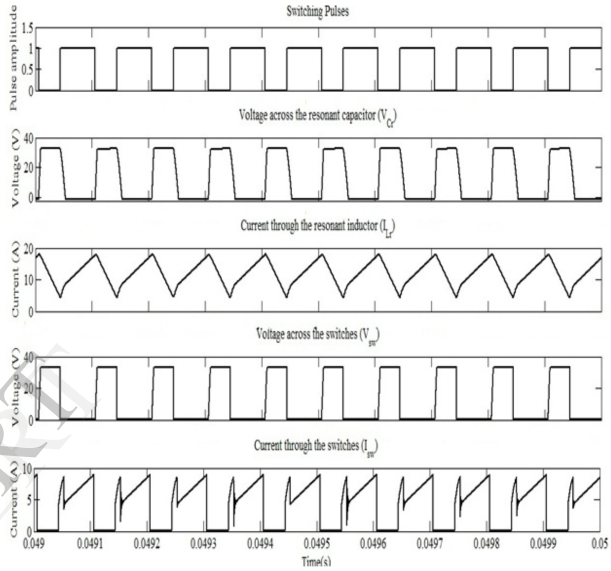

Figure 14. Simulation waveforms of buck boost converter in continuous conduction mode

is shown in figure 15. This indicates that at variable load conditions also, system can deliver a constant output voltage for which it is designed with the power converter being soft switched. The output voltage at half the load is shown in figure 16.

VIII. Conclusions

In this paper, standalone PV system with soft switching buck boost converter has been presented. Mathematical model of solar radiation, equivalent circuit of PV module and soft switched buck boost converter has been simulated in MATLAB/SIMULINK environment. Maximum power is tracked from the PV panel using P&O algorithm. Buck boost converter with partial resonant circuit conditions the output power of the PV panel to meet the load requirements.The simulated results show the operation of the system in continuous and discontinuous mode and also with half and full load.

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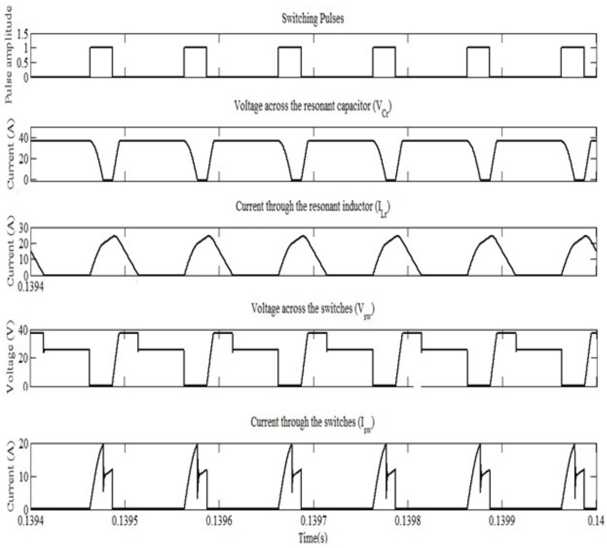

Figure 15. Simulation waveforms of buck boost converter at half load

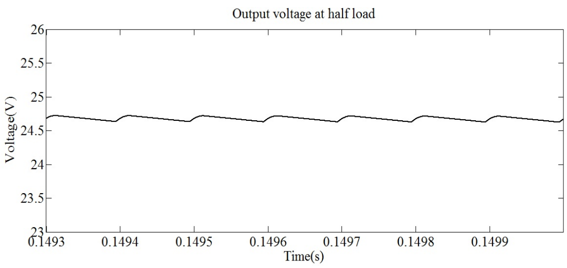

Figure 16. Output voltage of the system with half the load

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