SEPIC FOR MAXIMUM POWER EXTRACTION FROM SOLAR PANEL

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***Abstract*—The impedance matching circuit is used in between load and PV module to ensure that we are operating at MPP. Impedance matching circuits are nothing but DC-DC converters. With the change in climatic conditions, the duty cycle of converter to operate at MPP changes. Thus the converter must be designed to be able to match MPP under fluctuating atmospheric conditions and load.This paper presents the design of a SEPIC (Single Ended Primary Inductor Converter) for maximum power extraction from Solar panels. The design of SEPIC converter for PV applications is explained in detail. The calculations of ratings and values of components are made considering maximum duty cycle equal to one and the minimum duty cycle equal to zero. The designed SEPIC is simulated on MATLAB/Simulink to evaluate the performance under varying irradiance and for different values of load resistance. The experimental results show the suitability of SEPIC for maximum power extraction as it can sweep the entire I-V curve of a solar panel.**

Keywords—DC-DC converters, photovoltaic systems, SEPIC (Single Ended Primary Inductor Converter),Load matching

I. INTRODUCTION

As environmental problems are due to the conventional energy resources, people become more concern about the use of renewable energy sources. Among the alternative sources, solar energy is one of the most used and readily available renewable energy sources.. Solar energy is used for many applications like supply power to the agricultural motor, home power supply, satellite power etc. Although their installation cost is high they have an advantage that they require less maintenance and they are pollution free.

Although the sun is available throughout the day energy from the sun varies due to the sun intensity and unpredictable shadows cast by trees and cloud etc. This drawback of the photovoltaic system makes this system unreliable. This drawback can be eliminated by using Maximum Power Point Tracking.The voltage at which PV panel can produce maximum power is called as Maximum Power Point (MPP).The DC-DC converter plays a very important role in Maximum Power Point Tracking .For higher conversion efficiency and reduction in losses, DC-DC converter needs to be carefully designed.

SEPIC converters are capable of achieving optimum resistance regardless of the load and operate with the best efficiency[1]The SEPIC (Single-Ended Primary Inductance Converter) is one of the most suitable converter for maximum power extraction from solar panels due to the following features[2]:

- It can sweep the entire I-V curve of a solar panel**.**
- Low input ripple and noise due to the input inductor.
- Inductors can be coupled on the same core.
- Non-inverted output.
- Simple gate driver circuitry.

This paper presents the design and implementation of SEPIC for MPPT.

The organization of the paper is as follows. Section II describes how SEPIC converter used as an impedance matching circuit. In section III, the detail design of SEPIC is explained. Section IV shows the simulation and experimental results. Finally, the main conclusions of the work are presented.

II. SEPIC AS A IMPEDANCE MATCHING CIRCUIT

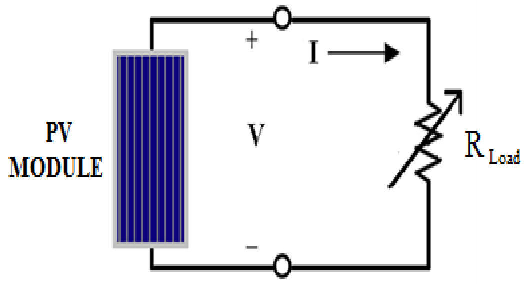


Fig. 1. PV module directly connected to the variable resistor

Above figure shows PV module directly connected to the variable resistor. The PV module will not always produce maximum power because the operating point is not always at the PV module's MPP. The operating point is at the PV module's MPP when R is equal to $R_{optimum}$. The $R_{optimum}$can be calculated as: $R_{optimum} = V_{mpp}/I_{mpp}$. If we consider above circuit we can operate at MPP when the value of R_{Load} matches with that of $R_{optimum}$ .In practical applications, it is impossible to change the load to match $R_{optimum}$ whenever irradiance changes. So, an impedance matching circuits are used in between load and PV module to ensure that we are operating at MPP. Impedance matching circuits are nothing but DC-DC converters. Below figure shows SEPIC converter connected in between PV module and load. Here the SEPIC is used as an impedance matching circuit.

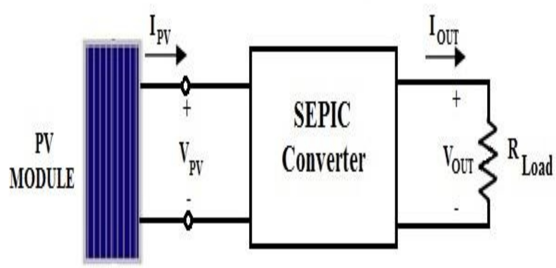


Fig. 2. SEPIC converter as an impedance matching circuit.

Fig. 2 can be converted in Fig. 3, which help's in understanding how SEPIC acts as an impedance matching circuit. As shown in the figure, the resistance seen by PV module is R_{equ}.

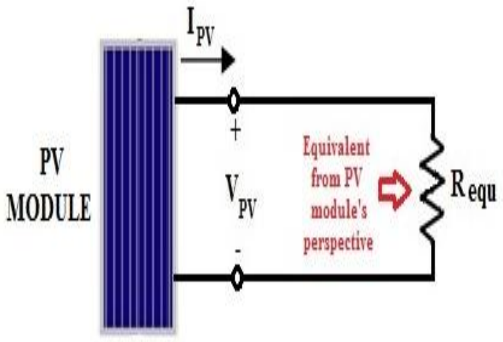


Fig. 3. Equivalent resistance from PV module's perspective

The R_{equ} is given by equation 2,

$$R_{equ}=(1\text{-}D/D)^2 R_{Load} \quad (1)$$

R_{equ}=Equivalent resistance seen by PV module

R_{Load} =Load resistance

D=Duty cycle of the PWM signal applied to a switch of the SEPIC .

III.SEPIC DESIGN

Below table shows the characteristics of solar panel considered for designing SEPIC converter. Two such solar panels are connected in parallel.

TABLE I CHARACTERISTICS OF SOLAR PANEL

Maximum Power(Pm)	10 W
Open Circuit Voltage(Voc)	21 V
Short Circuit Current(Isc)	0.61A
Voltage at Maximum Power(Vmp)	17 V
Current at Maximum Power(Imp)	0.59 A

The current gets doubled while voltage remains constant when two PV modules are connected in parallel. The current vs voltage and power vs voltage curves are shown in below Fig. 4.

The Single-ended primary-inductor converter is a type of dc-dc converter that allows voltage at its output to be less than, greater than, or equal to its input voltage; the output of the SEPIC is controlled by the duty cycle of the control transistor. The schematic diagram for a SEPIC is shown in Fig. 5, the SEPIC exchanges energy between the inductors and capacitors in order to convert from one voltage to another. The exchange of energy is controlled by switch S1.Typically the switch is a transistor such as a MOSFET. For MPPT we need to sweep along the entire V-I curve of solar panels and it is possible only when we are able to operate at any duty cycle from 0 to 1.The calculations of ratings and values of components are made considering maximum duty cycle equal to one and minimum duty cycle equal to zero. The switching frequency is 100 kHz.

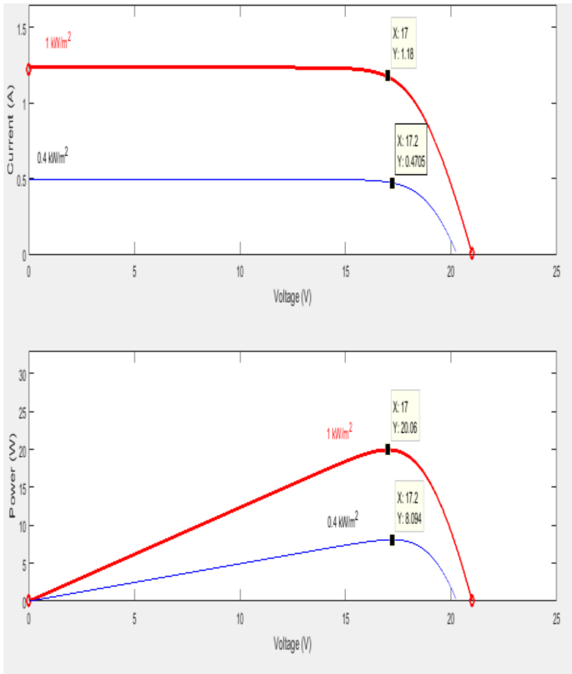


Fig. 4. Voltage vs current and voltage vs power curves when 2 modules connected in parallel

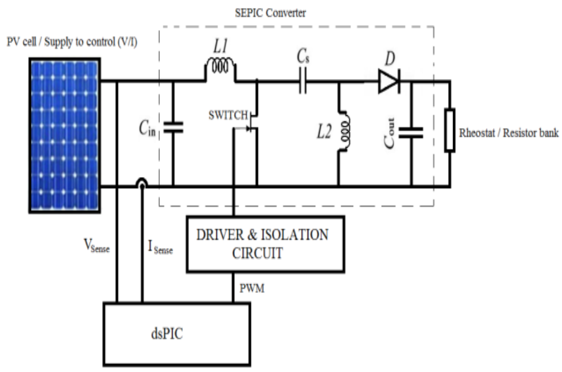


Fig. 5. Schematic of SEPIC converter.

A. MOSFET Rating Calculations

TABLE II CALCULATIONS OF MOSFET RATINGS

MOSFET	Drain to Source Voltage: $V_{DS} > 2 \times (Vout_{max} + Vin_{max})$ $V_{DS} > 2\times(21+21)$ $V_{DS} > 84$
	RMS Current: $I_{rms} = I_{L1_{rms}} + I_{L2_{rms}}$ $=1.385+1.385$ $= 2.77\ A$
	Peak Current : $I_{peak} = I_{L1_{peak}} + I_{L2_{peak}}$ $=1.461+1.461$ $=2.992\ A$

B. Inductor Calculations

TABLE III

CALCULATIONS OF INDUCTOR

Inductor L_1, L_2 **(L=L_1, L_2)**	Value: $L=\frac{Vin_{max}}{2\times Iin_{min}\times f_{sw(min)}}$ $L=\frac{21}{2\times 0.2\times 100k}$ $L_1 > 525\ \mu H$
	Ripple Current: $\Delta I_L=\frac{Vin_{min}}{L_{min}\times fsw_{(min)}}$ $\Delta I_L=\frac{8}{525\mu\times 100k}$ $\Delta I_L=0.152\ A$
	RMS and Peak Current : $I_{L_{rms}}=\frac{2}{\sqrt{3}}\times Iin_{max}$ $=\frac{2}{\sqrt{3}}\times 1.2=1.385$ $I_{L_{peak}}=1.385+\left(\frac{0.152}{2}\right)$ $I_{L_{peak}}=1.461$

C. Diode Rating Calculations

TABLE IV

CALCULATIONS OF DIODE RATING

Diode	Voltage Rating: $V_D > 2\times(Vout_{max}+Vin_{max})$ $V_D > 2\times(21+21)$ $V_D > 84\ V$
	Current Rating: $I_{rms}=I_{L1_{rms}}+I_{L2_{rms}}$ $=1.385+1.385$ $=2.77\ A$

Schottky diode is used as it has a low forward voltage drop.

D. Capacitor Calculations

TABLE V

CALCULATIONS OF CAPACITOR

Coupling Capacitor	$C_{S(min)}=\frac{Iout_{max}}{\Delta Vc_s\times f_{sw(min)}}$ $C_{S(min)}=\frac{1.2}{0.4\times 100k}$ $=30\mu F$	$\Delta Vc_s=Vin_{min}\times 5\%$ $\Delta Vc_s=8\times 0.05$ $\Delta Vc_s=0.4$
		Voltage Rating: $1.5\times Vin_{max}=1.5\times 21$ $=31.5V$
		Current Rating : $Ic_{rms}=\frac{2}{\sqrt{3}}\times Iout_{max}$ $Ic_{rms}=\frac{2}{\sqrt{3}}\times 1.2=1.38A$
Output Capacitor	$C_{out(min)}=\frac{Iout_{max}}{\Delta Vc_{out}\times f_{sw(min)}}$ $C_{out(min)}=\frac{1.2}{0.42\times 100k}$ $C_{out(min)}=28.57\mu F$	$\Delta Vc_{out}=Vout_{max}\times 2\%$ $\Delta Vc_{out}=21\times 0.02$ $\Delta Vc_{out}=0.42$
		Voltage Rating: $1.5\times Vout_{max}=1.5\times 21$ $=31.5V$
		Current Rating : $Ic_{out(rms)}=Iout_{max}$ $Ic_{out(rms)}=1.2A$
Input Capacitor	$C_{in}>\frac{28.57\mu F}{10}$ $C_{in}>\frac{C_{out}}{10}$ $C_{in}>2.85\mu F$	$1.5\times Vout_{max}=1.5\times 21$ $=31.5V$
		$Ic_{in(rms)}=\frac{\Delta I_L}{\sqrt{12}}$ $Ic_{in(rms)}=\frac{0.152}{\sqrt{12}}$ $Ic_{in(rms)}=0.0438$

IV. ANALYSIS AND RESULTS

A. Simulation Results

Schematic of SEPIC in Simulink is shown in Fig. 6.The solar irradiance and temperature signals generated by using signal builder blocks are applied as inputs to solar module (PV array block in Simulink).The characteristic values of PV module shown in Table I are used as parameter values for PV array block. The graph of voltage vs current and voltage vs power curves when 2 such modules are connected in parallel are shown in Fig. 4.The values of $R_{equ(min)}$(obtained at 1000W/m^2)and $R_{equ(max)}$ (obtained at 400W/m^2) calculated from voltage vs current curve are 14.4 and 36.55 respectively.

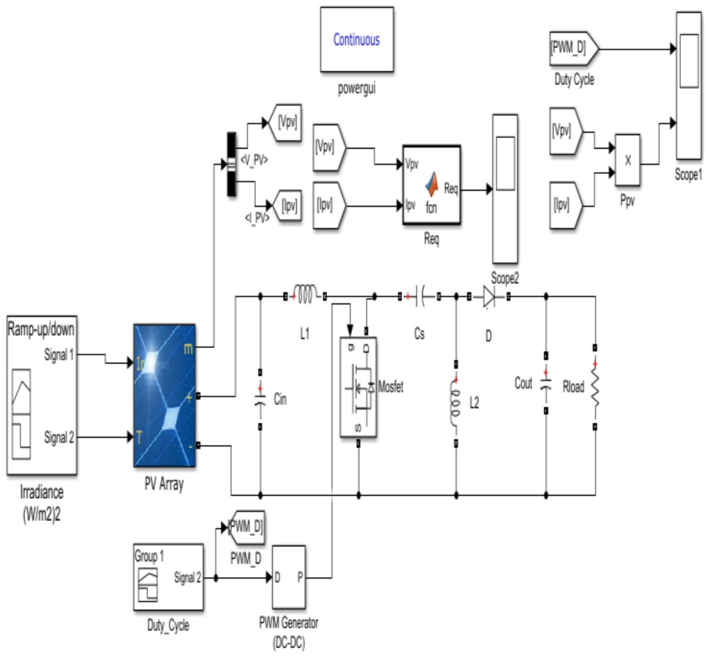


Fig. 6. Schematic of SEPIC in Simulink

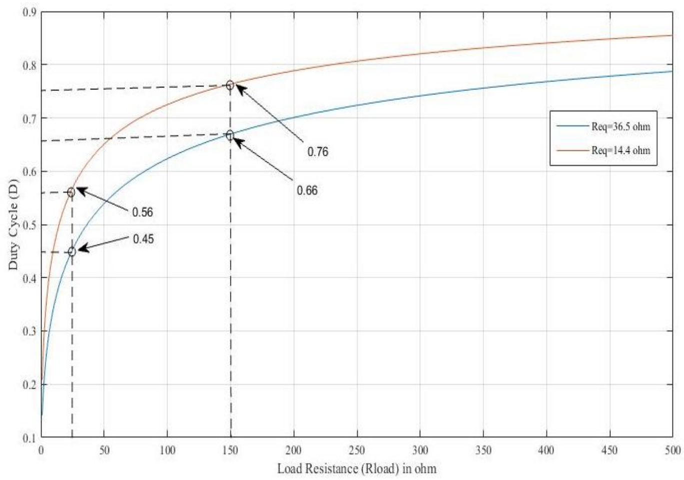
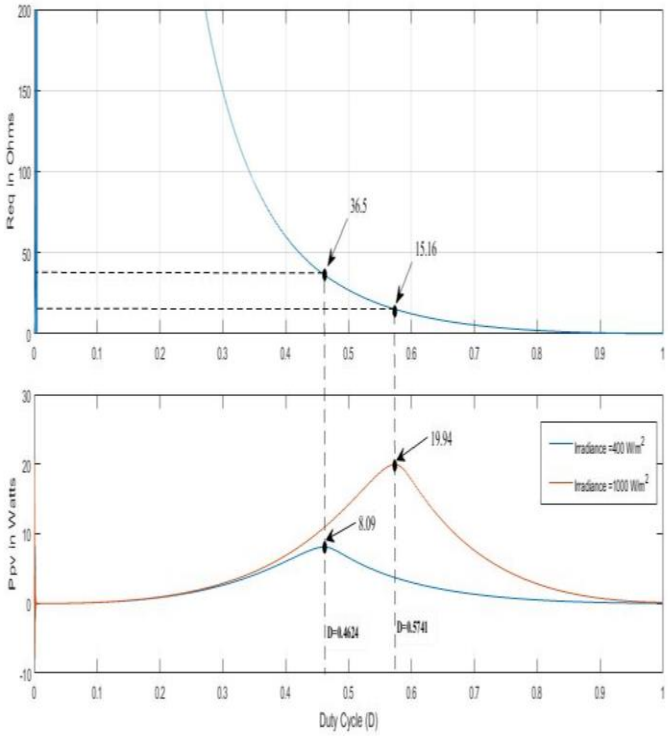


Fig. 7. The range of duty cycles for different values of R_{Load}

The curves shown in Fig. 7 are obtained using equation (1).

Whenever load changes, the range of duty cycle to operate at MPP that is to make R_{equ} equal to $R_{optimum}$ changes as shown in above Fig. 7.For $R_{Load} = 25\ \Omega$ range of the duty cycle is 0.45 to 0.56 and for $R_{Load} = 150\Omega$ the range is 0.66 to 0.76. The equation (1) is valid only when we operate in CCM (Continuous Conduction Mode).So, to operate in CCM at any value of R_{Load} we need to consider range of duty cycle from 0 to 1 and this is the reason we considered maximum duty cycle equal to one and minimum duty cycle equal to zero for calculating component values and ratings of SEPIC.

Fig. 8 and 9 show power from PV module at $400W/m^2$ and $1000W/\ m^2$ and corresponding values of R_{equ} with respect to duty cycle when $R_{Load} = 25\ \Omega$ and $R_{Load} = 150\Omega$.For $R_{Load} = 25\ \Omega$ the maximum power we get when the irradiance level is at lowest (at $400W/m^2$) is 8.09 W for which we need to set duty cycle to 0.46 and when the irradiance level is at highest (at $1000W/m^2$) is 19.94 W for which we need to set duty cycle to 0.57.Values of the duty cycle to operate at MPP for lowest and highest irradiance levels in Fig. 8 and 9 are approximately same as values in Fig. 7



. Fig 8. Minimum and maximum values of duty cycle and R_{equ} for $R_{Load} = 25\ \Omega$

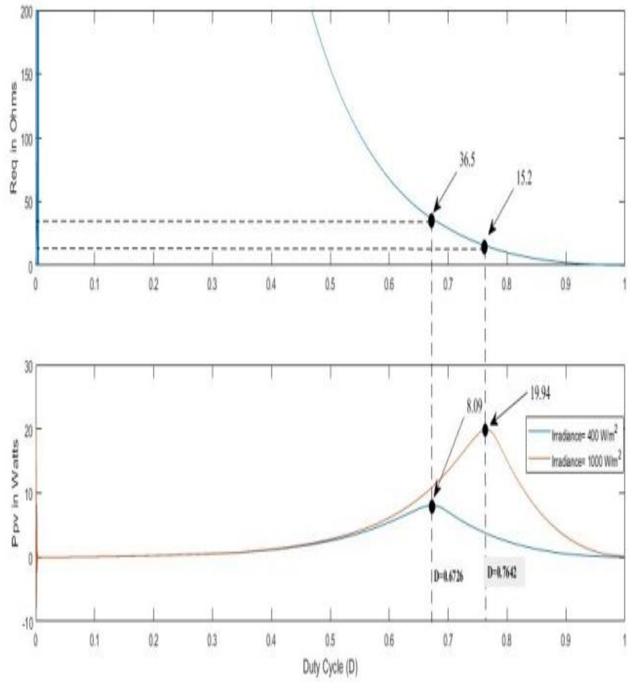


Fig. 9. Minimum and maximum values of duty cycle and R_{equ} for $R_{Load} = 150\ \Omega$

B. Experimental Results

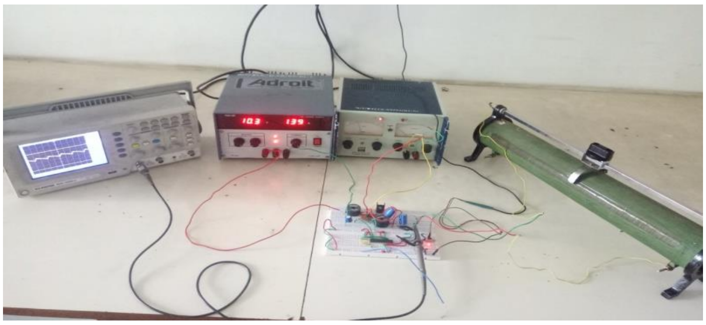


Fig. 10. Experimental setup

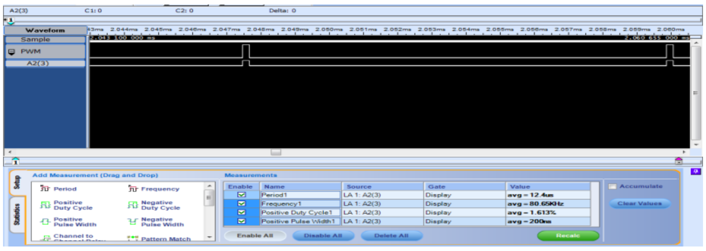


Fig. 11. dsPIC PWM output when D=1.613%

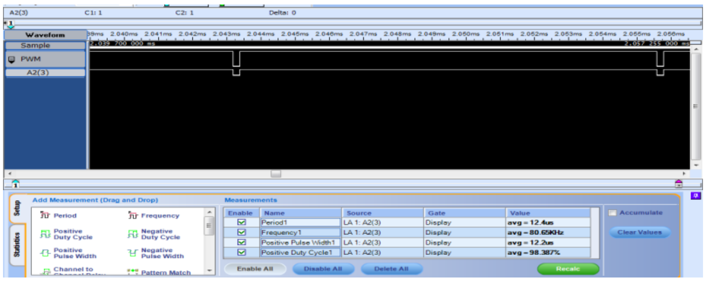


Fig. 12. dsPIC PWM output when D=98.387%

TABLE VI

DUTY CYCLE AND R_{equ}

Duty Cycle	Theorotical Value of R_{equ}		Practical Value of R_{equ}	
	$R_{Load}=70\Omega$	$R_{Load}=100\Omega$	$R_{Load}=70\Omega$	$R_{Load}=100\Omega$
0.362	310	310.6	415	496
0.403	219.5	219.5	277	373
0.443	158	158.1	166	213
0.483	115	114.6	110	166
0.524	82.5	83.3	83	115
0.564	59	59.8	69	78
0.604	42	42.7	47	57
0.645	30.3	30.2	35	44
0.685	21	21	26.5	33
0.725	14.5	14.4	20	25
0.766	9.3	9.23	15	18
0.806	5.8	5.8	11.5	14
0.846	3.3	3.3	8	10
0.887	1.5	1.6	6	8

The experimental setup is shown in Fig. 10.The Fig. 11 and 12 shows PWM output from dsPIC when duty cycle is 1.613% and 98.387% respectively. The duty cycle is varied from 0.362 to 0.887 in steps of 0.04 and values of $R_{equ}$are measured. The values of R_{equ} are measured for $R_{Load}=70\Omega$ and $R_{Load}=100\Omega$ .The duty cycle and corresponding theoretical (calculated using equation (1)) and measured values of R_{equ} are shown in Table VI.

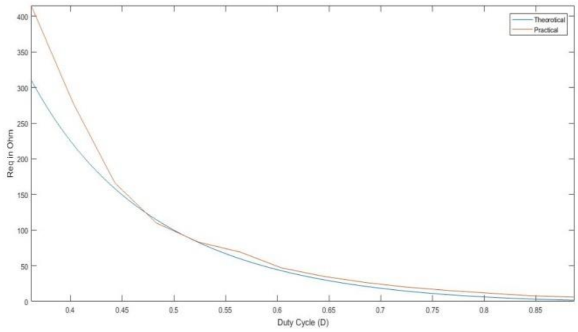


Fig. 13. Theoretical and practical curves of R_{equ} for $R_{Load}=70\Omega$

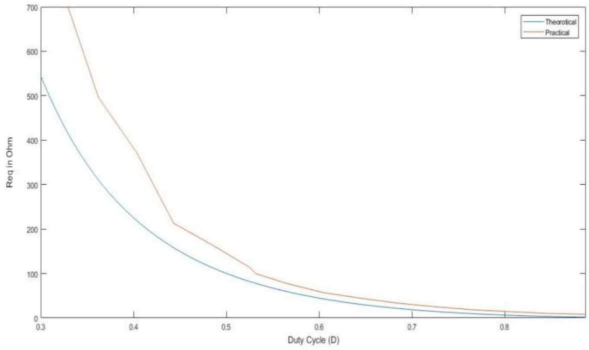


Fig. 14. Theoretical and practical curves of R_{equ} for $R_{Load}=100\Omega$

Fig. 11 and Fig. 12 are graphs of R_{equ} obtained from values in Table VI.The shape of both theoretical and experimental curves of R_{equ} are approximately same.

V.CONCLUSION

Whenever the load or atmospheric conditions such as irradiance changes, the duty cycle to operate at MPP changes. Depending on environmental and load conditions we may need to operate at very low or very high duty cycle to reach MPP.

It is observed that while designing SEPIC converter for extracting maximum available power from PV module regardless of value of R_{Load} ,we need to consider duty cycle range from 0 to 1.The equations for calculating component values and ratings are modified considering these duty cycle range. The experimental results shows that designed SEPIC is well suited for operating at MPP regardless of R_{Load} and atmospheric conditions.

REFERENCES

[1] M.H. Taghvaee, M.A.M.Radzi,et al., "A current and future study on non-isolated DC–DC converters for photovoltaic applications", Renewable and Sustainable Energy Reviews 17 (2013) 216–227
[2] Jose J. Chacon, et al., "Prototype for the Characterization of Photovoltaic Panels based on a SEPIC Converter", Power Electronics and Power Quality Applications (PEPQA)
[3]M.A. Farahat, H.M.B. Metwally,et al., "Optimal choice and design of different topologies of DC-DC converter used in PV systems, at different climatic conditions in Egypt", Renewable Energy 43 (2012) 393-402
[4]S.Kolsi,H.Samet,M.Ben Amar, "Design Analysis of DC-DC Converters Connected to a Photovoltaic Generator and Controlled by MPPT for Optimal Energy Transfer throughout a Clear Day", Journal of Power and Energy Engineering, 2014, 2, 27-34