ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 5, May 2017

Comparative study of standalone PV systems for different DC/DC converter topologies of same specification

Mr. Aravinda M[1], Dr. Padmavathi K[2]

PG Student [Power Electronics], Dept. of EEE, B.M.S. College of Engineering, Bengaluru, Karnataka, India[1]

Associate professor, Dept. of EEE, B.M.S. College of Engineering, Bengaluru, Karnataka, India[2]

ABSTRACT: The main objective of PV standalone systems are to be either a main source or a backup source of electricity in an electricity distribution system. It mainly consists of PV arrays, MPPT controlled DC/DC converter, Battery bank and dump load and/or main loads. Since there are many DC/DC converter topologies are available and each has their own advantages. Here in this paper the results of performance analysis of PV standalone systems realized with different DC/DC topologies using MATLAB/SIMULINK has discussed. Also, the relationship between the terminal voltage of battery bank and maximum power point voltage of PV array, PV array configurations and their loading limitations has explained.

KEYWORDS: Standalone PV system, DC/DC converter, Maximum Power Point.

I.INTRODUCTION

Even though solar energy is not a base source for electricity generation. Nowadays, standalone PV systems are playing a major role to meet the condition uninterrupted power supply for many users like apartments, small scale industries, hospitals, shopping malls etc. The installation of depends on many factors like availability of space for PV panels, capacity of battery bank, amount of load to be served etc. Since, PV cells are constant current sources having limitation of current zero condition after specified terminal voltage i.e. load resistance. The load resistance can't be changed in real time but the effective resistance of the load seen by the PV cells can be adjusted by using DC/DC converters as interface such that the power extracted from the PV cells is always maximum. But, each DC/DC converter topologies maintains their own relationship between input and output voltages. Hence, it is necessary to analyze these topologies. So the results obtained from simulation study of standalone PV systems having different DC/DC converter topologies and the relationship between maximum power point voltage of PV array, terminal voltage of battery bank and maximum load that can be applied for the system has discussed in next sections

II. SPECIFICATIONS

A. PV MODULE

The PV module mentioned in this paper has 13 PV cells connected in series. The PV cells has the specifications as follows:

Sl.No.	**At, A.M=1.5, G_{ref} = 1000 W/m^2, T_{cell_ref} = 38.8 ^{0}C = 311.8 K.**	
1	V_{oc_ref}	0.574 V
2	V_{mpp}	0.46 V
3	I_{sc_ref}	6.24 A
4	I_{mpp}	5.748 A

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 5, May 2017

Sl.No.	At, A.M=1.5, G_{ref} = 1000 W/m^2, T_{cell_ref} = 38.8 ^{0}C = 311.8 K.	
5	P_{mpp}	2.644 W
6	R_{s_op}	0.005 Ω
7	R_{sh_op}	10 Ω
8	NOCT	43 ^{0}C = 316 K
9	A	1.2
10	k_v	-0.0018 V/K
11	k_i	0.065 % A/K

The equations of single diode model for PV module are as follows [1],

$$I_{output\_op} = (I_{ph\_op} - I_{d\_op})C_p - I_{sh\_op} \text{ ---Eq.1.}$$

$$I_{ph\_op} = \left(\frac{G_{op}}{G_{ref}}\right) I_{sc\_op} \text{ ---Eq.2.}$$

$$I_{sc\_op} = I_{sc\_ref} + k_i (T_{cell\_op} - T_{cell\_ref}) \text{ ---Eq.3.}$$

$$T_{cell\_ref} = T_{air\_ref} + \left(\frac{NOCT - 20}{800}\right) G_{ref} \text{ ---Eq.4.}$$

$$T_{cell\_op} = T_{air\_op} + \left(\frac{NOCT - 20}{800}\right) G_{op} \text{ ---Eq.5.}$$

$$I_{d\_op} = I_{rs\_ref}\left(e^{\frac{V_{output\_op} + I_{output\_op} R_{s\_op}}{V_{t\_op} C_s A}} - 1\right) \text{ ---Eq.6.}$$

$$I_{rs\_ref} = I_{rs\_op} \cdot \left(\frac{T_{cell\_op}}{T_{cell\_ref}}\right)^3 . \; e^{\left[\left(\frac{1}{T_{cell\_ref}} - \frac{1}{T_{cell\_op}}\right)\frac{q\,E_g}{A\,k}\right]} \text{ ---Eq.7.}$$

$$I_{rs\_op} = \frac{I_{sc\_op}}{\left(e^{\frac{V_{oc\_op}}{V_{t\_op} A C_s}} - 1\right)} \text{ ---Eq.8.}$$

$$V_{oc\_op} = V_{oc\_ref} + k_v (T_{cell\_op} - T_{cell\_ref}) \text{ ---Eq.9.}$$

$$V_{t\_op} = \frac{T_{cell\_op}\, k}{q} \text{ ---Eq.10.}$$

$$I_{sh\_op} = \frac{V_{output\_op} + I_{output\_op} R_{s\_op}}{R_{sh\_op}} \text{ ---Eq.11.}$$

$$P_{output\_op} = V_{output\_op} I_{output\_op} \text{ ---Eq.12.}$$

Where,

C_s : Number of cells connected in series in a PV module.
C_p : Number of PV modules connected in parellel.
I_{output_op} : Output current of PV module under operating conditions. (A)

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 5, May 2017

I_{ph_op} : Photo current generated in PV module under operating conditions. (A)
I_{d_op} : Current through internal diode of PV module under operating conditions. (A)
I_{rs_op} : Reverse saturation current of the internal diode in PV module under operating conditions. (A)
I_{rs_ref} : Reverse saturation current of the internal diode in PV module under reference conditions. (A)
I_{sh_op} : Current through the shunt resistance in PV model of module under operating conditions. (A)
I_{sc_op} : Short circuit current of PV module under operating conditions. (A)
I_{sc_ref} : Short circuit current of PV module under reference conditions. (A)
I_{MPP} : Output current of the PV module when it is delivering the maximum power. (A)
V_{output_op} : Output voltage of PV module under operating conditions. (V)
V_{oc_op} : Open circuit voltage of PV module under operating conditions. (V)
V_{oc_ref} : Open circuit voltage of PV module under reference conditions. (V)
V_{t_op} : Thermal voltage of the internal diode in PV module under operating conditions. (V)
V_{MPP} : Output voltage of the PV module when it is delivering the maximum power. (V)
P_{output_op} : Output power of PV module under operating conditions. (W)
P_{MPP} : Maximum possible power which can be extracted from PV module. (W)
G_{op} : Irradiation on PV module under operating conditions. (W/m^2)
G_{ref} : Irradiation on PV module under reference conditions. (W/m^2)
T_{cell_op} : Cell temperature under operating conditions. (K)
T_{cell_ref} : Cell temperature under reference conditions. (K)
T_{air_op} : Ambient air temperature under operating conditions. (K)
T_{air_ref} : Ambient air temperature under reference conditions. (K)
NOCT : Normal Operating Cell Temperature. (K)
Rs_op : Effective series resistance of PV module under operating conditions. (Ω)
Rsh_op : Effective shunt resistance of PV module under operating conditions. (Ω)
A : Ideality factor of the internal diode in PV module.
q : Charge of electron = 1.602×10^{-19}C
E_g : Band gap energy in PN junction of PV cell = 1.12eV
K : Boltzmann constant = $1.3806 \times 10^{-23} m^2 kg s^{-2} K^{-1}$
k_i : Temperature coefficient of output current of PV module. (A/K)
k_v : Temperature coefficient of output voltage of PV module. (V/K)
A.M : Air mass coefficient.

B. BATTERY

The battery mentioned in this paper has the specifications as follows:
Type: Li-ion
Rating: 3.3 Ah
Terminal voltage, V_{bat} = 16.8V (SOC = 100%)
V_{bat} = 14.8V (SOC = 60%)
Nominal operating voltage, V_{nom} = 14.8 V

C. DC/DC CONVERTER

Here, all the topologies are designed [2] for the following specifications and assuming converter is lossless. But during simulation on state resistance and voltage drops in power diodes and power mosfets are considered according to the MATLAB/SIMULINK standards.

Input power = P_{in} = 52*2.644 W = 137.488 W
Safety factor = 1.2632
Hence, P_{in} =173.68 W
Output voltage = V_{out} = V_{bat} = 14.8 V
Output current = $I_{out} = P_{out}/V_{out} = P_{in}/V_{out}$ = 11.73 A
Effective output resistance = $R_{out} = V_{out}/I_{out}$ = 1.26 Ω

Percentage voltage ripple in capacitor voltage = δV_C = 0.5% = 0.005
Percentage current ripple in the inductor current = δI_L = 5% = 0.05
Operating frequency = f = 30 KHz

The values of inductors and capacitors obtained after designing the different topologies for above mentioned rating are tabulated table.1.

TOPOLOGY	L_1 (μH)	L_2 (μH)	C_1 (μF)	C_2 (μF)
BUCK	420.57	-	33.02	-
BOOST	105.14	-	2640	-
BUCK-BOOST	210.28	-	2640	-
CUK	420.64	420.64	33.01	2640
SEPIC	420.64	420.64	2640	2640

TABLE I.

III. RELATIONSHIP BETWEEN MAXIMUM POWER POINT OF THE PV ARRAY AND BATTERY VOLTAGE

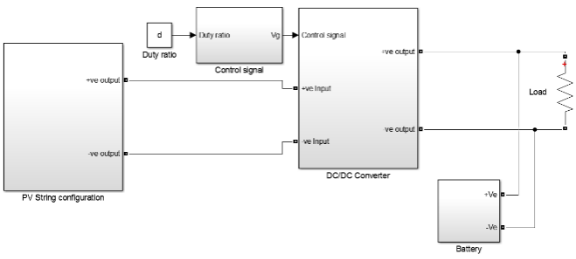

Fig.1 Block diagram of standalone PV system

Here,
Input voltage at converter = $V_{converter\_input}$ = V_{pv_output}= Output voltage of PV array
Output voltage at converter = $V_{converter\_output}$ = V_{bat}

Since the battery voltage will be maintained at the output of the converter, the input voltage can be varied by changing the duty ratio of the control signal. The input voltage has to be maintained at maximum power point voltage to extract maximum power from the PV panels.
i.e. V_{pv_output} = Voltage corresponds to MPP of PV array = $V_{pv\_output\_MPP}$

For buck operation, $V_{converter\_input} = \frac{V_{converter\_output}}{D}$

Therefore, $V_{pv\_output} = \frac{V_{bat}}{D}$ --Eq.13

For boost operation, $V_{converter\_input} = (1-D)V_{converter\_output}$
Therefore, $V_{pv\_output} = (1-D)V_{bat}$ ---Eq.14

For buck boost operation, $V_{converter\_input} = \left(\frac{1-D}{D}\right)V_{converter\_output}$

Therefore, $V_{pv\_output} = \left(\frac{1-D}{D}\right)V_{bat}$ ---Eq.15

To extract the maximum power at D=0.6, (Substituting D in equations.13, 14 and 15)

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 5, May 2017

- For buck operation , select PV array with $\mathbf{V_{pv\_output\_MPP}} = \mathbf{1.67}\ \boldsymbol{V_{bat}}$----------------Eq.16
- For boost operation , select PV array with $\mathbf{V_{pv\_output\_MPP}} = \mathbf{0.4}\ \boldsymbol{V_{bat}}$ ------------------Eq.17
- For buck boost operation , select PV array with $\mathbf{V_{pv\_output\_MPP}} = \mathbf{0.67}\ \boldsymbol{V_{bat}}$ ---------Eq.18

IV. DETERMINING MAXIMUM POWER POINT TRACKING CAPABILITY OF BUCK, BOOST AND BUCK-BOOST OPERATIONS.

FOR BUCK OPERATION,

We know that [3] ,

$$V_{output\_converter} = D.V_{converter\_input} = D.V_{pv\_output}$$

$$I_{output\_converter} = \frac{I_{converter\_input}}{D} = \frac{I_{pv\_output}}{D}$$

Therefore,

$$R_{out} = D^2.R_{in}$$

Where,

R_{out} = Effective output resistance seen at converter output, Ω

R_{in} = Effective input resistance seen by PV array, Ω

Hence,

$$R_{in} = \frac{R_{out}}{D^2} \text{-----------------------Eq.19}$$

But for buck operation in order to achieve the condition mentioned in eq.16 and each PV cell can provide 2.644W at 0.46V and 5.748A. This requires a string with 53.73 cells in series. Hence 4 modules are connected in series. (Each module has 13 cells in series)

Therefore,

$$R_{in\_MPP} = \frac{V_{pv\_output\_MPP}}{I_{pv\_output\_MPP}}$$

$$R_{in\_MPP} = \frac{(0.46 \times 13 \times 4)}{(5.748)}$$

$$R_{in\_MPP} = 4.1614\ \Omega$$

Where,

R_{in_MPP} = Effective input resistance seen by PV array at MPP , Ω

$V_{pv\_output\_MPP}$ = Output voltage at terminal of PV array at MPP , V

$I_{pv\_output\_MPP}$ = Output current delivered by PV array at MPP , A

Hence,

The maximum effective resistance that can be seen by converter at output beyond which it is not possible to track the maximum power from the source, R_{out_max} can also be calculated by,

$$R_{out\_max} = D_{max}{}^2.R_{in\_MPP}$$

$$R_{out\_max} = 0.9^2 \times 4.1614$$

$$R_{out\_max} = 3.37\ \Omega$$

Where,

R_{out_max} = Maximum effective output resistance seen by converter output beyond which tracking MPP is not possible, Ω

It can be seen that as R_{out} crosses 3Ω. The range of upper limit of the duty cycle crosses 0.9 and hence it is not possible to track the maximum power.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 5, May 2017

SIMILARLY FOR BOOST OPERATION,

$R_{in} = (1-D)^2 . R_{out}$ --------------------------------------Eq.20

And to achieve the condition mentioned in eq.17 requires a string with 12.86 cells in series. And total number of cells is 52 , we can have four modules in parallel.

Therefore,
$R_{in\_MPP} = 0.26\ \Omega$

And,
$R_{out\_max} = 29\ \Omega$

SIMILARLY FOR BUCK-BOOST OPERATION

$R_{in} = \left(\frac{1-D}{D}\right)^2 . R_{out}$ ---------------------------------------Eq.21

And to achieve condition mentioned in eq.18 requires a string with 21.55 cells in series. And total number of cells is 52 , we can have two modules in series and together parallel to two more modules connected in series.

Therefore,
$R_{in\_MPP} = 1.04\ \Omega$

And,
$R_{out\_max} = 84.24\ \Omega$

V. RESULT AND DISCUSSION

Few major factors to be considered while designing a standalone PV systems are compared by the help of simulations and using the relationship which are discussed in above sections. They are as follows,

	SERIES	**PARALLEL**	**SERIES-PARALLEL**
$V_{PV\_OUTPUT\_MPP}$	23.92 V	5.98 V	11.96 V
$I_{PV\_OUTPUT\_MPP}$	5.748 A	22.992 A	11.496 A
$P_{PV\_OUTPUT\_MPP}$	137.4921 W	137.4921 W	137.4921 W
R_{IN_MPP}	4.1614 Ω	0.26 Ω	1.04 Ω
R_{OUT_MAX}	3.37 Ω	29 Ω	84.24 Ω

TABLE II. COMPARISION OF PARAMETERS OF PV ARRAY

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 5, May 2017

D	Settling time, t_s (milli Seconds)				
	Load=1.26Ω , Filter capacitance=330µF				
	Buck	Boost	Buck-Boost	Cuk	SEPIC
0.1	29	2.06	2.9	52	93
0.3	4.4	3	3.7	27	116
0.5	3.34	4.9	5.65	90	75
0.6	2.92	-	10	70	89
0.65	7.86	-	9.3	45	48
0.7	6.4	10.8	25	60	70
0.75	-	9.4	35	53	70
0.8	2	10.2	33	56	67
0.85	25	-	35	61	75
0.9	34	29	32	58	52.8

TABLE III. COMPARISION OF PARAMETERS OF DC/DC CONVERTER

D	Ripple content, ΔP_{in} (Watts)				
	Load=1.26Ω , Filter capacitance=330µF				
	Buck	Boost	Buck-Boost	Cuk	SEPIC
0.1	0.04	0.48	0.15	0.16	0.15
0.3	0.21	2.05	0.93	0.53	0.53
0.5	0.39	2.9	1.85	0.85	0.8
0.6	0.52	-	14.81	0.31	0.43
0.65	3.37	-	0.61	0.01	0.01
0.7	2.17	1.08	4.21	0.06	0.05
0.75	-	0.25	3.78	0.05	0.05
0.8	0.22	0.14	3.01	0.04	0.04
0.85	0.39	-	2.31	0.03	0.03
0.9	0.32	0.11	1.53	0.03	0.01

TABLE IV. COMPARISION OF PARAMETERS OF DC/DC CONVERTER

D	Efficiency				
	Load=1.26Ω , Filter capacitance=330µF				
	Buck	Boost	Buck-Boost	Cuk	SEPIC
0.1	0.4524	0	0	0	0
0.3	0.2810	0	0.4077	0.0867	0.7898
0.5	0.2793	0.4169	0.4205	0.3373	0.7196
0.6	0.3427	-	0.8352	0.8068	0.8886
0.65	0.8786	-	0.7917	0.8102	0.8315
0.7	0.9015	0.7317	0.7594	0.7845	0.7876
0.75	-	0.5970	0.7189	0.7520	0.7471
0.8	0.9199	0.6044	0.6924	0.7174	0.7155
0.85	0.9264	-	0.5958	0.6575	0.6591
0.9	0.9406	0.3828	0.5046	0.5990	0.5965

TABLE V. COMPARISION OF PARAMETERS OF DC/DC CONVERTER

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 5, May 2017

Parameter	Topology				
	Load=1.26Ω , Filter capacitance=330μF				
	Buck	Boost	Buck-Boost	Cuk	SEPIC
D_{MPP}	0.8	0.75	0.65	0.65	0.65
$V_{pv\_output\_MPP}$	23.02	5.86	11.8	11.75	11.79
$I_{pv\_output\_MPP}$	5.96	21.74	11.99	11.56	11.6
$P_{pv\_output\_MPP}$	137.1	127.3	141.48	135.83	136.76
$V_{converter\_output}$	17.64	17.71	-17.78	-17.75	17.77
$I_{converter\_output}$	7.155	4.295	-6.3	-6.2	6.4
$P_{converter\_output}$	126.2	76.06	112.01	110.05	113.72
$V_{bat} = V_{load}$	17	16.88	-16.94	-16.95	16.92
I_{bat}	6.34	9.151	-7.758	-7.578	7.493
P_{bat}	107.7	154.4	131.42	128.44	126.78
I_{load}	13.49	13.44	-14.05	-13.77	13.893
P_{load}	229.4	226.9	238.14	233.53	235.06
t_s	2	9.4	9.3	45	48
ΔP_{in}	0.22	0.25	0.61	0.01	0.01
P_{in_peak}	136.4	136.4	136.4	136.4	136.4
Efficiency	0.919	0.597	0.7917	0.8102	0.8315
R_{in}	3.862	0.269	0.9841	1.0164	1.0163
R_{out}	2.465	4.123	2.8223	2.8629	2.7765

TABLE VI. COMPARISION OF PARAMETERS OF OVER ALL STANDALONE PV SYSTEM AT MPP

VI.CONCLUSION

From the above study it can be concluded that standalone systems with,

- Series-Parallel PV array has greater loading capability compare to parallel and series connected arrays. And parallel PV arrays has greater loading capability compare to series connected arrays.
- To use Buck converter the MPP voltage of PV array should be greater than terminal voltage of the battery.
- To use Boost converter the MPP voltage of PV array should be less than terminal voltage of the battery.
- To use Buck-Boost, Cuk, SEPIC converter the MPP voltage of PV array is independent of terminal voltage of the battery.
- If the user wants to expect the MPP at particular value of duty ratio. Then the PV array and the battery has to be selected properly depending on the selected DC/DC converter topology.
- At MPP, for a similar design specifications the output of buck converter has lesser settling time compare to other topologies. SEPIC has better efficiency and less power ripple.
- When the overall system is considered, Buck-Boost, Cuk and SEPIC has tracked the maximum power close to the duty cycle for which they have designed. The power tracked by Buck-Boost converter is highest.

REFERENCES

[1] Dominique Bonkoungou et.al. “Modelling and simulation of photovoltaic module considerung single-diode equivalent circuit model in MATLAB” IJETAE, volume 3, March 2013.

[2] Danial w. Hart “ Power Electronics “. Tata McGraw-Hill publications.

[3] Dhananjay Choudhary et.al. “ DC-DC Buck converter for MPPT of PV system” IJETAE, Volume 4, July 2014.