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Maximum Power Point Tracking (Mppt) Solar Charger By Using Cuk Converter For Battery Energy Storage

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Abstract: ***The rapid increase in the demand for electricity and the recent change in the environmental conditions such as global warming led to a need for a new source of energy which is cheaper and sustainable with less carbon emissions. PV energy is free, clean, pollution free and inexhaustible. The efficiency of solar cells depends on many factors such as temperature, spectral characteristics of sunlight, dirt and shadow. In addressing the poor efficiency of PV systems, some methods are proposed. The Maximum Power Point Tracking (MPPT) is used in PV systems to maximize the PV array output power which is irrespective of the temperature and radiation conditions and of the load electrical characteristics. The MPPT technique is used for extracting the maximum power from the solar PV module and transferring that power to the battery (or load).The Incremental Conductance(IncCond) based MPPT method for PV system can track rapidly increasing and decreasing irradiance conditions with high accuracy.It tracks correct direction of operating point to reach Maximum Power Point(MPP).Among all the DC-DC converter topologies available, both Cuk and BuckBoost converters provide the opportunity to have either higher or lower output voltage compared with the input voltage. Also the current ripples of the system are lower in Cuk converter when compared to that of the boost converter. The Cuk converter can step up or step down the voltage according to application. Cuk converter is chosen because of the low switching losses, high efficiency, lowest ripple content in output. All stand alone PV systems require an energy buffer to bridge the mismatch between available and required energy. Battery technology like lead acid battery is the most popular form of energy storage utilized among other types of batteries. The lead acid batteries have low cost, high energy density, low power density and wide availability. It has a profound effect on the systems reliability and global performance.***

Keywords: ***Photovoltaic (PV), Maximum Power Point Tracking (MPPT), IncrementalConductance (IncCond) Method, Cuk DC-DC type of Converter, Lead acid Battery Energy Storage.***

I. PROBLEM DEFINITION

Due to the nonlinearity nature of PV and unpredictable environmental conditions,the Maximum Power Point Tracking (MPPT) system of standalone PV is a nonlinearcontrol problem. Actual gain can vary widely depending on weather, temperature,battery state of charge and other factors. MPPT methods vary in complexity, sensorsrequired, convergence speed, cost, range of effectiveness, implementation of hardware,popularity etc. All the common MPPT algorithms like Perturb and Observe, Incremental Conductance, Hill Climbing Methods and their advanced and adaptive variationswork with very high efficiencies during uniform insolation. The traditional MPPT algorithmsduring non-uniform insolation or partial shading do not work well. Incrementalconductance MPPT method is an advantageous method. Most of the DC-DC converter topologies have disadvantages such as poor tracking behaviour, discontinuous input current,high peak currents in power components, poor transient response, high switchinglosses, less efficiency, cost etc. Buck-Boost DC-DC converter has disadvantages such asdiscontinuous input current, high peak currents in power components and poor transientresponse. Cuk DC-DC converter is advantageous. Energy storage devices have problemsregarding the power density, energy density,availability, efficiency, cost, reliability, lifetimeetc. To overcome the identified problems related with MPPT methods and DC-DCconverters proposed by various researchers, Incremental conductance based MPPT SolarCharger by using Cuk Converter for battery energy storage is proposed.

II. Scope of Work

The Maximum Power Point (MPP) in PV system can be achieved by the MaximumPower Point Tracking (MPPT) method under rapidlychanging atmospheric conditions.Incremental conductance method (*IncCond*) is chosen as it overrides over many drawbacksof other MPPT methods. It has advantages such as good tracking efficiency, fastresponse and well precise control for the extracted power. Cuk converter is chosen becauseof the low switching losses, high efficiency, lowest ripple content in output. TheCuk type of DC-DC Converter ensures to achieve the (MPP) continuously from PV celloutput by using suitable Incremental Conductance method of MPPT. The MPPT solarcharger by using Cuk converter for battery energy storage for off-grid solutions is in thescope of work. The dissertation work is an integration of a PV system with its model,Incremental Conductance method of MPPT, Cuk DC-DC Converter, Battery systemwith its model for off-grid applications and with Battery charging algorithm.

III.System Selected and Methodology Followed

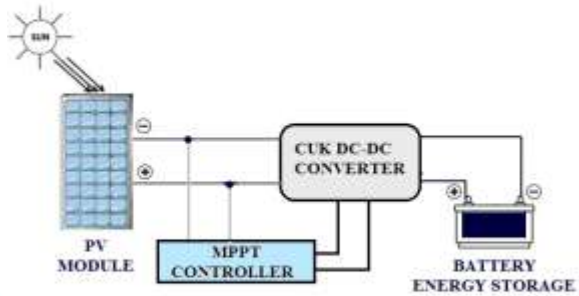

Figure 1:System block diagram

The main system block diagram consists of followingcomponents:Photovoltaic PV Module,Cuk DC-DC Converter,MPPT Controller,Battery Energy Storage.

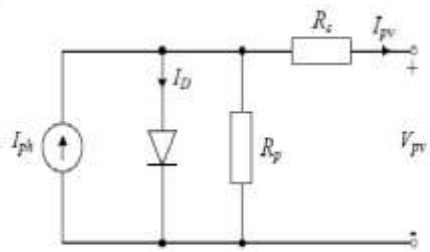

Figure 2: Electrical equivalent circuit of a PV cell

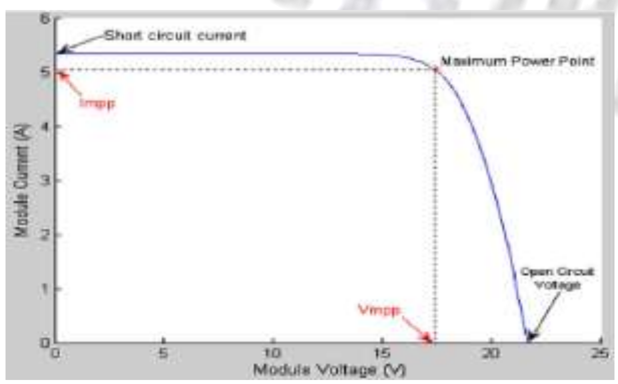

Figure 3: Current versus voltage curve of a PV cell

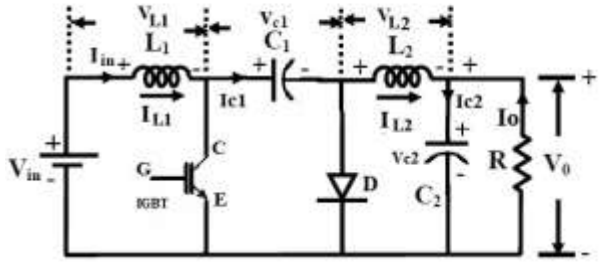

Figure 4: Electrical circuit of Cuk converter

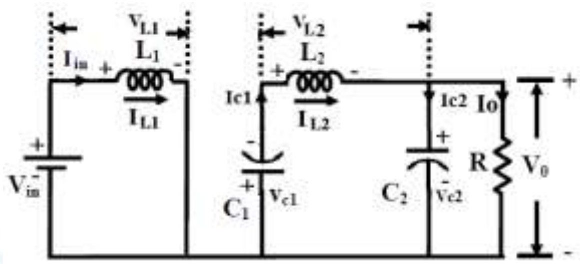

Figure 5:Cuk converter with switch is closed (ON)

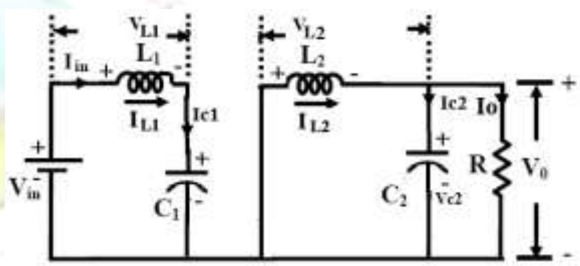

Figure 6:Cuk converter with switch is opened (OFF)

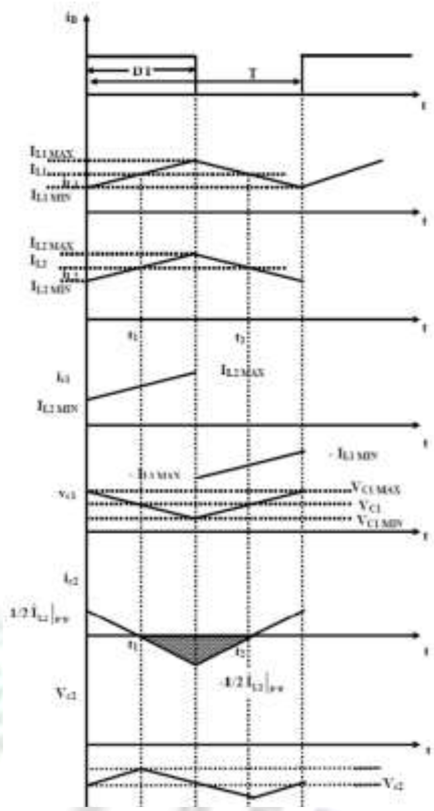

Figure 7: Waveforms of circuit variables in Cuk converter

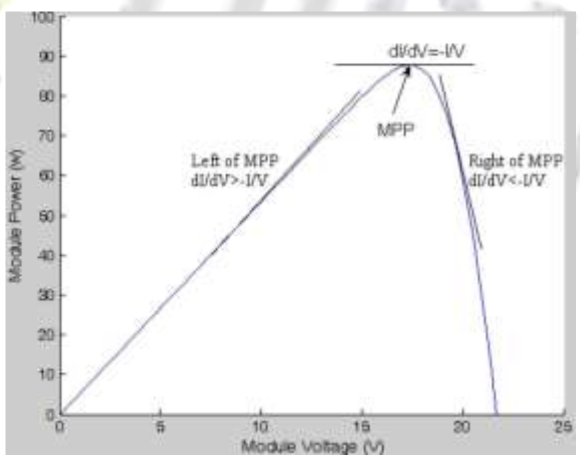

Figure 8: Incremental conductance MPPT method on a PV curve of a solar module

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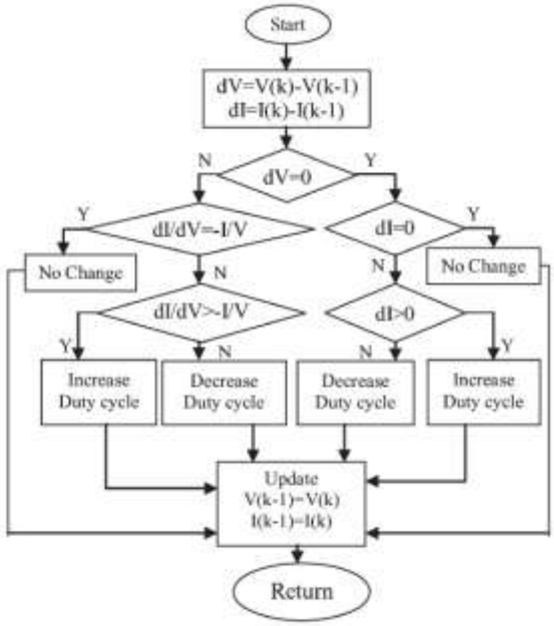

Figure 9: Flowchart of Incremental conductance MPPT method

IV. Load analysis and calculation for a residential load

With an example of average daily load schedule is considered and it is shown in the following Table 1.

Sr. No.	Typeof load	Qty. (No.)	Rating (W)	Consumption Time /day (Hrs)	Total Consumption/day (Wh)
1	Tube	2	48	4	384
2	CFL	2	23	4	184
3	Tube	3	10	4	120
4	Fan	3	70	5	1050
5	TV	1	70	6	420
6	Refrigerator	1	500	1	500
7	PC	1	80	2.5	200
8	Electric Iron	1	400	0.5	200

Table 1: Calculation of electricity consumption for a residential load

Different formulae resulted from the equations of Cuk Converter, PV module, IGBT switch, Diode, Battery are used directly instead of deriving in the paper here again. These formulae are taken from the research papers enlisted in the references.

A. Sizing of PV modules

Total daily energy consumption= 3 kWh

Here considering only 50% load of the total daily energy consumption is supplied by solar power system and rest is by some other system in a hybrid renewable system.

Power generation considered by Solar Power System=(3000)(0.5)=1500 Watts
Assumptions made:
Efficiency of the Batteries = 90%

Efficiency of Cuk DC-DC Converter = 90%
Efficiency of Inverter = 90%

Power generated from PV panel per day=1500/(0.9X0.9x0.9)Watts=2057.61 Watts=2058 Watts
Annual Average Solar Irradiation in India = 5.5 kWh/m^2/day
Annual Average Solar Irradiation in Nashik = 5.09 kWh/m^2/day

Power generated from PV panel per day= (2058)/(1.15x1.25x5.09)Wp =581.21 Wp= 581 Wp

Number of PV panels needed=581 Wp/300 Wp =1.94 modules=2modules

So this system should be powered by at least 2 modules of 300 Wp PV module.

B. Sizing of Solar charge controller

Case1:V_{PV}=21V,P_{PV}=600W

$$Solar\ charge\ controller\ rating = \frac{P_{PV}}{V_{PV}}$$

Solar charge controller rating= 28.57 A
Case2:V_{PV}=26V,P_{PV}=600W
Solar charge controller rating= 23.08 A
Case3:V_{PV}=30V,P_{PV}=600W
Solar charge controller rating= 20 A
Solar Charge Controller Output Rating Selected:
Current Rating=28.57 A and Voltage Rating=30 V

C. Designing the Cuk DC-DC Converter
i) Output voltage magnitude can be either larger or smaller than that of the input, and there is a polarity reversal on the output.
ii)The inductor on the input acts as a filter for the dc supply to prevent large harmonic content. Unlike the previous convertertopologies where energy transfer is associated with the inductor, energy transfer for the Cuk converter depends on the capacitor.
Assumptions:
i) Both inductors are very large and the currents in them are constant.
ii) Both capacitors are very large and the voltages across them are constant.
iii) The circuit is operating in steady state, meaning that voltage and current waveforms are periodic.
iv) For a duty ratio of d, the switch is closed for time dt_s and open for (1-d) t_s.
v) The switch and the diode are ideal.

Select:
i) The duty ratio.
ii) The switching frequency.
iii)The inductor sizes such that the change in inductor currents is no more than 20% of the average inductor current.
iv) The output ripple voltage is no more than 3%.
v) The ripple voltage across C_1 is no more than 5%.

Case 1:V_{in}=35 V, V_O=21 V, P_{in}=600 W

$$\frac{Vo}{Vin} = -\left(\frac{d}{1-d}\right)$$

d=0.375

$$I_{L2} = \frac{Po}{-Vo}$$

$$I_{L2} = 28.57A$$

$$P_{in} = P_o$$

$$I_{L1} = \frac{Pin}{Vin}$$

$$I_{L1} = 17.14A$$

Assumption: Ripple current of the inductor should be less than 20%.

$$\Delta i_{L2} = \left(\frac{20}{100}\right) I_{L2}$$

$$\Delta i_{L2} = 5.71A$$

$$\Delta i_{L1} = \left(\frac{20}{100}\right) I_{L1}$$

$$\Delta i_{L1} = 3.43A$$

$$L_2 = \left(\frac{V_{in} d}{f_{sw} \Delta i_{L2}}\right)$$

$$L_2 = 45.97 \mu H$$

$$L_1 = \left(\frac{V_{in} d}{f_{sw} \Delta i_{L1}}\right)$$

$$L_1 = 76.53 \mu H$$

Maximum inductor current for L_1 is I_{L1MAX}

Maximum inductor current for $L_1 = I_{L1} + \left(\frac{\Delta i_{L1}}{2}\right)$

Maximum inductor current for $L_1 = 18.86A$

Maximum inductor current for L_2 is L_{2MAX}

Maximum inductor current for $L_2 = I_{L2} + \left(\frac{\Delta i_{L2}}{2}\right)$

Maximum inductor current for $L_2 = 31.43A$

The output ripple voltage is no more than 3%

$$\frac{\Delta Vo}{Vo} = \frac{3}{100} = 0.03$$

$$C_2 = \frac{1-d}{\left(\frac{\Delta Vo}{Vo}\right) 8 L_2 f^2_{sw}}$$

$$C_2 = 22.66 \mu F$$

Average voltage across C_1 is

$V_{in} = V_o = 35 - (-21) = 56V$

The ripple voltage across C_1 is no more than 5%. So, the maximum change in V is calculated by following equation.

Maximum change in V across $C_1 = 56\left(\frac{5}{100}\right)$

Maximum change in V across $C_1 = 2.80V = \Delta v_{c1}$

The equivalent load resistance $R = \frac{V_o^{\ 2}}{P_o} = 0.74\Omega$

C_1 is computed from the ripple specification.

$$C_1 = \frac{V_o d}{R f_{sw} \Delta v_{C1}}$$

$$C_1 = 76.01\mu F$$

Maximum capacitor voltage for C_1 is V_{C1MAX}

Maximum voltage across capacitor C_1 = $\left(V_{in} + V_o\right) + \left(\frac{\Delta V_{C1}}{2}\right)$

$V_{in} = V_{OC}$ of PV Module = 43V.

V_O of PV Module=21V.

Maximum voltage across capacitor C_1 =65.40 V

Maximum capacitor voltage for C_2 is V_{C2MAX}

$$\Delta V_{C2} = \left(\frac{5}{100}\right)\left(V_O\right) = 1.05V$$

Maximum voltage across capacitor $C_2 = \left(V_O\right) + \left(\frac{\Delta V_{C2}}{2}\right)$ =21.75V

Case 2:V_{in}=35 V, V_O=26 V, P_{in}=600 W

$L_2 = 56.82\mu H$ $L_1 = 86.94\mu H$

$C_2 = 16.84\mu F$ $C_1 = 64.27\mu F$

Case 3:V_{in}=35 V, V_O=30 V, P_{in}=600 W

$L_2 = 80.76\mu H$ $L_1 = 94.18\mu H$

$C_2 = 11.11\mu F$ $C_1 = 56.80\mu F$

Inductor rating is shown in the following Table 2.

Inductor	Inductor Value (μH)	Current (A)
L_1	94.18	18.86
L_2	80.76	31.43

Capacitor rating is shown in the following Table 3.

Capacitor	Capacitor Value (μF)	Voltage (V)
C_1	76.01	74.63
C_2	22.66	30.75

D. Sizing of IGBT switch

IGBT Voltage Rating = $(V_{inMAX} + V_{OMAX})(Safetyfactor)$
= (43 V +30 V)(1.25)=91.25V

IGBT Current Rating = $(I_{L1MAX} + I_{L2MAX})(Safetyfactor)$ =(18.86A+31.43A)(1.25)=62.86A

IGBT should be rated at 91.25 V, 62.86 A.

E. Sizing of Diode

During IGBT switch ON condition, voltage across C_1
Comes across the diode.

Diode voltage rating V_{diode} = 91.25 V

Diode current rating = $(I_{L1MAX} + I_{L2MAX})(Safetyfactor)$
= (18.86 A + 31.43 A)(1.25) = 62.86 A

Diode should be rated at 91.25 V, 62.86 A or greater.

E. Sizing of Battery Energy Storage

Total number of units(kWh) required per day=3
Autonomy factor of a battery =2
Efficiency of Inverter =90%

Total energy required from a battery = $\frac{(3)(2)}{0.9}$
=6.7 kWh=6666.67 Wh
Battery voltage consideration =24 V
Voltage per battery = 12 V
Total batteries of 12 V to be connected in series to get 24 V = 2 Nos.

AH required for a battery = $\frac{6666.67}{24} = 277.78AH$

Assuming DOD of Battery = 0.8 pu
Design Margin for Battery = 1.15 pu

AH capacity for a battery = $\left(\frac{277.78}{0.8}\right)(1.15) \cong 400AH$

400 AH, 12 V, 2 number of batteries are required.

III. Conclusion

In this paper several research papers are reviewed. In this paper electrical consumption is calculated for some load. Sizing of PV module, Designing of Cuk converter, sizing of IGBT switch, sizing of diode, sizing of battery is done. So that the proposed system can be made as an efficient one.

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