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Solar Charging the Battery Using Different Choppers at Different Duty Cycles

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Abstract: This paper proposed to study about the solar charging with various choppers like Buck, Boost in continuous mode of operation and also study about the ratings of inductor, capacitor, diodes which were used in different choppers. The control circuit between the solar panel will used to Turnoff the charging of battery to avoid frequent charging and also isolates solar panel under maintenance of battery. This circuit increases the net charging voltage at battery input. The normal MOSFET without body diode is placed in circuit to reduce complexity which was suitable for moderate power application however we can also use the High Side (HS) FET Common Source Inductance (CSI) Technology for Synchronous buck converter to minimize the switching losses by limiting HS CSI values.

Key words: Choppers, Convertors, Sulfation, Periodic charging, MMPT.

Introduction: The Solar energy is main renewable energy resource in the world due to abundant availability, free of cost and cleanest. The Solar energy receives to the earth in the form of solar radiation. The amount of solar radiation that reaches any given location is dependent on various factors like location, scope, season, time of day, and local weather. Because the earth is round, the sun rays fall on the earth surface at an angles ranges from 0° to 90°. When sun rays are vertical with respective of earth, the earth's surface gets maximum possible radiation in w/m^2. in. India receives 4 to 7 kWh /m^2/day of solar radiation. India receives solar energy more than $5000*10^{12}$ kWh per year. A solar cell, or photovoltaic cell, is an electrical device that converts the light energy directly into electricity, Russian physicist Aleksandar Stoletov built the first cell, later cell based on the outer photoelectric effect discovered by Heinrich herz in 1887 It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Individual solar cell devices are the electrical building blocks of photovoltaic modules, in the language of ordinary known as solar panels, now a day's most of the solar cells made up of silicon crystalline with heavily doped N-type channel. The single junction silicon solar cell can contribute a maximum open-circuit voltage of approximately 0.5 to 0.6 volts. Solar cells also called as photovoltaic cells, due to its operation as photo energy converted in electrical energy. By this way of producing energy principle, they can be used as a photo detector to detecting light, electromagnetic radiation near the visible range, measuring light intensity. Solar panels can be connected in series or in parallel to increase voltage or current respectively. The rated terminal voltage of a solar panel is usually in range of 12.0 to17.0 Volt, but by using regularly, this voltage is reduced to around 10 to 15 Volts as required for battery charging [11].To maintain constant output voltage at input side of battery convertors (kind of chopper were output was depends on input voltage and duty cycle) are required. By this convertors we can also achieve periodic charging which is defined as applying a periodic equalizing charge brings all cells to similar levels by increasing the voltage to 2.50V/cell, or 10 percent higher than the recommended charge voltage by varying duty cycle. An equalizing charge is nothing more than a deliberate overcharge to remove sulfate crystals which was build up on the plates by over time charging [12], Sulfation can reduce the resultant output power for further usages Solar panel output is affected by the cell operating temperature. Panels are rated at a nominal temperature of 25 ^{0}C, the output of a solar panel can be expected 2.5% variation for every 5 degrees variation in temperature. As the temperature increases, the output decreases, this can be cooled when battery charging system is well managed which was done with proper controlling network.

Power flow from PV module to load :

As we discussed briefly above, that power flow from solar panel to load (Battery) with proper convertor is more reliable than without convertor. In fig-1 a converter is placed in between load and PV solar panel

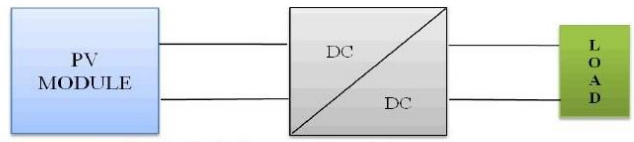


Fig-1 Power flow diagram without feedback

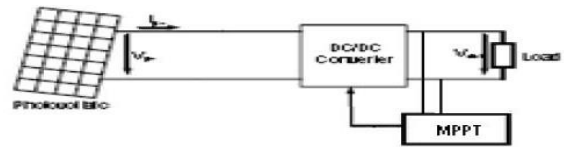
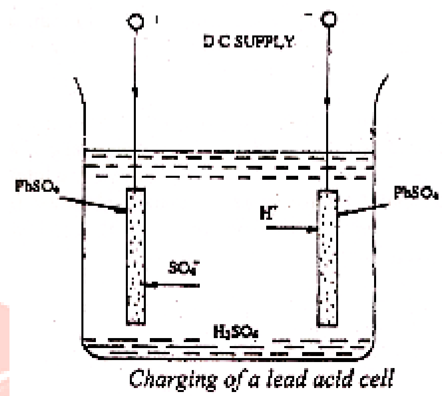


Fig-2 Power flow diagram with MPPT as a feedback [16]

Where as in Fig-2 the MPPT (Maximum Power Point Tracker).It is an algorithm which makes to charges the battery at maximum power (generally at constant) and as we know that the output of the solar panel is varies with respect to climate in order to maintain constant output the MPPT by acting as a feedback

Charging Process of Lead Acid Cell Battery :

In order to recharge the cell, direct current is passed through cell in the reverse direction to which the cell provided current, for this we make anode is connected to positive terminal of DC and cathode is to the negative terminal. H_2SO_4 is an electrolyte splits into hydrogen ions ($2H^+$) and sulphate ions (SO_4^{--}).



Charging of Lead acid cell Battery[15]

At anode:

$SO_4^{--} - 2e^- \rightarrow SO_4$ (radical)

$SO_4 + H_2O \rightarrow H_2SO_4 + O$

At cathode

$2H^+ + 2e^- \rightarrow 2H$

$PbSO_4 + 2H \rightarrow Pb + H_2SO_4$

Noted that SO_4 (Sulphate) is accumulated at cathode before recycling the electrolyte which is known as Sulfation (shows an yellow build-up on plates)

Causes of sulfation :

1. Takes more time for further charging. 2. Requires extra power to overcome the layer, then comes into charging mode. 3. By the reason of point 2 the temperature will raises inside the battery so efficiency will decreases gradually when compare to efficiency with ideally (zero sulfation)

Faraday's Laws of Electrolysis :

It states that Mass of substance liberated at an electrode is directly proportional to the quantity of electric charge is passed through the electrolyte

$m \,\alpha\, q$

$m = zq \quad \because q = it$

$m = zit$

here m = mass

z = electrochemical equivalent (ECE) in KgC^{-1}

i = Electric current

t = time

By the above equation we come to know that sulfation is depends on current flow through the electrodes. To minimize sulfation at plates power would be provided to battery at High Voltage and Less Current. As the battery is not a 100 % free from sulfation, this sulfation layer should be overcome with in less time to minimize heat ($i^2 rt$) which is also directly proportional to current (i), resistance(r) and time (t) .This problem is also minimized by providing the power at 10% of rated voltage called Periodic charging, but the output voltage of solar panel array is less. Increasing the voltage input of battery using boost convertor is more economical rather than the voltage achieved by increasing the number of solar panels, in the other hand we can also go through periodic charging at initially and isolation can also be done between solar panel and battery under the maintenance. The periodic charging can be achieved by the boost convertor at a suitable duty cycle

Fixed Duty Cycle algorithm	Variable Duty Cycle (Perturb & Observe) algorithm
Remarks : 1.Poor efficiency due to less output from solar panel during climate changes 2.It is open loop so, much stable but rarely used 3.No need of sensors	**Remarks :** 1.Good efficiency ,maintain maximum constant power at Sending side of battery 2.It is closed loop system so, not so stable as fixed duty cycle algorithm and it is in usage in now a days 3.voltage and current sensors required

Inductor Selection	Diode Selection	Input Capacitor	Output Capacitor
Inductor is selected on bases of load current (I_o), for high I_o large inductor is required. Note that the inductor must always have a higher current rating than the maximum current given in below equation, because the current increases with decreasing inductance. $L_{buck} = 125\% \{\frac{R(1-D)}{2f}\}$ L_{boost} =125%$\{\frac{RD(1-D)^2}{2f}\}$	Schottky diode is used generally by the reason that it have a high peak current rating than average rating in addition it has less power losses[3] $P_{dis} = I_{f\,or} \times V_{for}$ where P_{dis}= Power dissipation I_{for} = forward current $I_{for}=I_{out}$ V_{for} = forward voltage	The minimum value is necessary to stabilize the input voltage due to the peak current requirement of a switching power supply, it is better way to place a low equivalent series resistance (ESR) ceramic capacitors. The value can be increased if the input voltage is noisy.	It is better to use a low equivalent series resistance (ESR) ceramic capacitors[3]. to minimize the ripple on the output voltage $C_{out(buck)} = \frac{(1-D)}{8\,L_{crt} f^2}$ $C_{out(boost)} = \frac{D \times I_{out(min)}}{f_s \times \Delta V}$ Where ΔV = change in voltage f_s = supply frequency

Charging the battery with buck convertor :

This is a kind of convertor which gives less output voltage than input voltage and also known as step down chopper .A high speed on/off semi conductor switch (we used MOSFET over hear) is connected in series with source, by change the state of switch from OFF to ON the T_{ON} is considered up to next OFF on the other hand from state of ON to OFF is a T_{OFF} period up to next ON, generally $T_{ON} > T_{OFF}$ (for buck converter) so that we can keep the duty cycle (D) >0.5 , by this we will get voltage which is less than input, but not much less than input voltage. The diode in circuit will acts as freewheeling diode (FD), it makes closed path for load during T_{OFF} period. The current stored in inductor during T_{ON} period will be discharged through load since FD (for ideal) is short circuited and inductor is also short circuited (pure inductor) so the voltage across load is zero (only for ideal case but, in practical some resistance will existed) for this case, by this reason we get out voltage across load during T_{ON} period .

Calculations for devices used in convertor and maximum operating Duty cycle:

Maximum duty cycle is essential for operate an convertor (Particularly in boost & buck boost) to minimize ripples at output and switching rms and average currents which causes to raise switching losses.

$\Delta V_c = \frac{VD(1-D)}{8LCf^2}$; here I_o = output current

$I_{(sw)rms} = I_{L(avg)} * \sqrt{D}$; f = frequency of operation in hertz

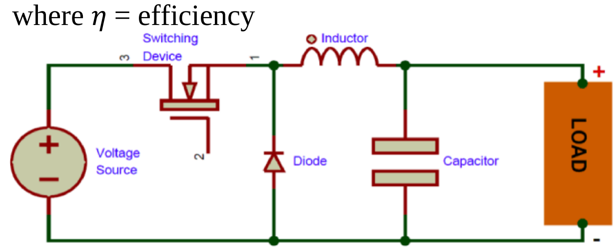
$I_{(sw)avg} = I_{L(avg)} * D$ c = capacitance in faraday

By the above parameters which are proportional to duty cycle and switching losses are depends on duty cycle i.e. switching increases by increasing duty cycle

So maximum operation duty cycle $D_{max} = 1 - \frac{V_{in\,(min)}}{V_{out}} \eta$ [3] where η = efficiency

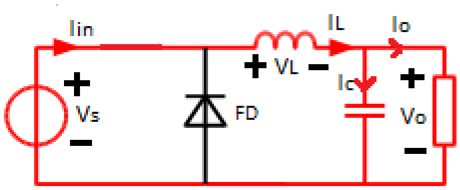
$V_{out} = \frac{T_{ON}}{T_{ON}+T_{OFF}} * V_{in} = D * V_{in}$ where $D = \frac{T_{ON}}{T_{ON}+T_{OFF}}$

$D = \frac{Vout}{Vin}$ gives relation between V_{in} and V_o



Buck converter [13]

During T_{on} :



In this mode inductor is charges fully and acts as short circuit at the final state. The FD is reverse bias so it inactivate as shown in black colour. The capacitor connected across load will makes output voltage stable(but not fully)

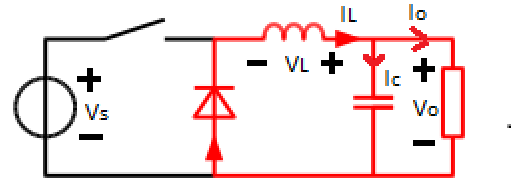
$i(t) = \frac{V}{R}(1 - e^{-\frac{t}{\tau}})$ here $\tau = \frac{L}{R}$ sec

$i(\infty) = \frac{V}{R}$ steady state current

$V_{L(on)} = V_S - V_o$ where V_S , V_o are source output voltages respectively

$I_{c(on)} = I_L - I_o$ Where I_l ,I_o are inductor, output voltages respectively

During T_{off} :



In this mode the stored energy will be dissipated at load, the FD will be forward bias and inductor will be replaced with current source. The voltage drop across FD and inductor (but not for practical case)

Apply KCL at capacitor node

$I_L = I_c + I_o$

$I_{c(off)} = I_L - I_o$ same as the current in ON mode

By KVL of path FD, inductor, load

$V_{L(off)} + V_{FD} + V_o = 0$ $\because$ $V_{FD} = 0$

$V_{L(off)} = - V_o$

Assuming I_o is continuous

In OFF mode $V_{L(off)} = -$ V_o, it does not mean that the voltage is switched to – ve plane, it mean that voltage across load is negative for OFF mode the net voltage is resultant of both ON & OFF modes. Voltage – Sec balance method which gives relation between source voltage (V_S), load voltage or output voltage (V_o) and Duty cycle

$V_{l(on)} * T_{ON} + V_{L(off)} * T_{OFF} = 0$

$(V_S - V_o) * T_{ON} + (- V_o) * T_{OFF} = 0$ ——— (A)

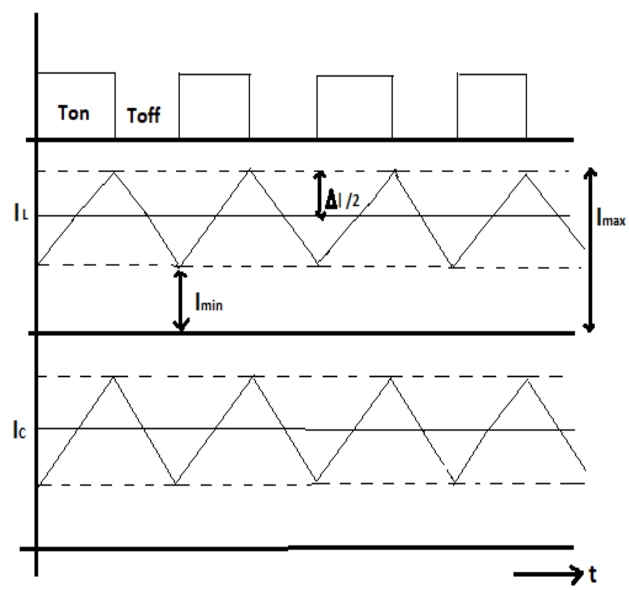
$T = T_{ON} + T_{OFF}$; $\because D = \frac{T_{ON}}{T_{ON}+T_{OFF}} = \frac{T_{ON}}{T}$

$T = D*T + T_{OFF}$

$T_{OFF} = T(1-D)$ ——— place in (A)

$(V_S - V_o) * D*T + (- V_o) * (1-D)T = 0$

$\boxed{V_o = DV_S}$ $0 \le D \le 1$



V_o is always less than V_S except at D = 1 (at this $V_o = V_S$), so buck Converter is also called as Step down chopper due to above reason

Similarly load current (I_o) can be determined by using Current – Sec balance

$I_{c(on)} * T_{ON} + I_{c(off)} * T_{OFF} = 0$

$(I_L - I_o) * T_{ON} + (I_L - I_o) * T_{OFF} = 0$

$(I_L - I_o) * D * T + (I_L - I_o) * (1-D)T = 0$

$\boxed{I_o = I_L}$

<u>Ripple in inductor current(ΔI)</u> :

continuous conduction mode (CCM) is obtained by high value of inductor, the output wave form is ramped saw tooth as shown in figure, gives DC if we take average for it. The sudden increase in load will decreases load current will increases ΔI

so, inductor value will decreases (L α $\frac{d\emptyset}{dI}$)

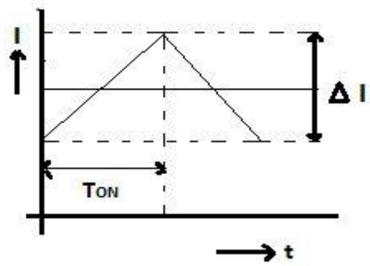
$V_{L(on)} = V_S - V_o$

$L\frac{di_{on}}{dT_{on}} = V_S - V_o$

$L\frac{dI}{D*dT} = V_S - D\,V_S$

$\Delta I = \frac{V_S D(1-D)T}{L}$

$\boxed{\Delta I = \frac{V_S D(1-D)}{Lf}}$



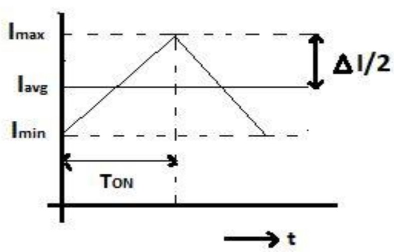
<u>I_{max} & I_{min}</u> :

$I_{Lmax} = I_L + \frac{\Delta I}{2}$ $\quad\because I_L = I_o$

$\boxed{I_{Lmax} = I_o + \frac{\Delta I}{2}}$

$I_{Lmin} = I_L - \frac{\Delta I}{2}$

$\boxed{I_{Lmin} = I_o - \frac{\Delta I}{2}}$



<u>Source current</u> :

When we neglect the power loss at FD, Inductor (ie resistance free) and capacitor then

$P_{out} = P_{in}$

$V_S I_S = V_o I_o$

$\boxed{I_S = \frac{Vo*Io}{VS}}$

<u>Ripple in capacitor voltage (ΔV)</u> :

The sudden change in voltage across capacitor will also affect on load voltage variation, if it is high then the output will not be a stable which makes to place costly filter circuit for proper DC output, practically ΔV is less compare to ΔI, however ΔV will depends on type of capacitor were used, for low equivalent series resistance (ESR) ceramic capacitors for ΔV is low as I was mentioned above also (capacitor selection). The ΔV will be depends on below

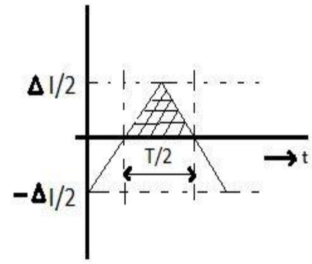
$I_c = I_L - I_o \qquad \because Q = CV; \Delta Q = C*\Delta V$

ΔQ = Area of shaded in figure

$= \frac{1}{2} * \frac{T}{2} * \frac{\Delta I}{2} \Rightarrow \frac{\Delta I}{8f}$

$\frac{\Delta Q}{C} = \Delta V = \frac{\Delta I}{8fc} \quad \because \Delta I = \frac{VSD(1-D)}{Lf}$

$\boxed{\Delta V = \frac{V_S D(1-D)}{8LCf^2}}$



For what value of D we get max ΔV can be obtained by making $\frac{d\Delta V}{dD} = 0$

$\frac{d}{dD}\frac{VSD(1-D)}{8LCf^2} = 0$; by solving it we get D = 0.5

it means that at D = 0.5 the voltage ripple is high which was not preferable

<u>Critical Inductance</u> :

It is the minimum value of inductor for which inductor current or load current is just hold on Continuous conduction mode or $I_{L(min)}$ = o

At worst case $I_{L(min)}$ = o

$I_L - \frac{\Delta I_L}{2} = 0 \qquad \because$ Taken from previous result

$I_o - \frac{V_S D(1-D)}{2L_{crt}f} = 0 \quad \because I_o = \frac{V_o}{R} = \frac{D*V_S}{R}$

$\frac{D*V_S}{R} = \frac{V_S D(1-D)}{2L_{crt}f}$ by solving

$\boxed{L_{crt} = \frac{R(1-D)}{2f}}$

Noted that L_{crt} will increases by increasing R which is not a favorable for continuous conduction

<u>Critical Capacitance</u> :

The minimum value of capacitance for which output voltage is just continuous or ΔV = 0

Under worst case $V_{c(min)} = 0$

$V_o - \frac{\Delta V_C}{2} = 0 \qquad \because V_o = D*V_S$

$D*V_S - \frac{\Delta V_C}{2} = 0 \qquad \because \Delta V_C = \frac{V_S D(1-D)}{8LCf^2}$

$D*V_S = \frac{V_S D(1-D)}{16LC_{crt}f^2}$ by solving it

$\boxed{C_{crt} = \frac{(1-D)}{16\,L_{crt}f^2} = \frac{1}{8fR}}$ $\qquad$ Where $L_{crt} = \frac{R(1-D)}{2f}$

Noted that C_{crt} will decreases by increasing R which is not a favorable for continuous conduction

Charging the battery with boost convertor :

This is a kind of convertor which gives high output voltage than input voltage and also known as step up chopper .A high speed on/off semi conductor switch, MOSFET was connected across source, the rating of MOSFET is high compared to buck converter as inductor is connected in series with source, the sudden change in current will be opposed by inductor, under steady state inductor is short circuited ,under this condition if turnoff MOSFET thus we need highly rated MOSFET in order to neglect spark . In this converter the source is connected to load in both OFF & ON modes, apart from this the charged energy of inductor during ON mode will also contribute voltage to load during OFF, by this reason we will get voltage which is higher than input

Calculations for devices used in convertor and maximum operating Duty cycle:

Maximum duty cycle is essential for operate an convertor(Particularly in boost & buck boost) to minimize ripples at output and switching rms and average currents which causes to raise switching losses.

$\Delta V_c = \frac{I_o D}{fC}$; here I_o = output current

$I_{(sw)rms} = \frac{I_o}{1-D}\sqrt{D}$; f = frequency of operation in herz

$I_{(sw)avg} = \frac{I_o}{1-D} D$ c = capacitance in faraday

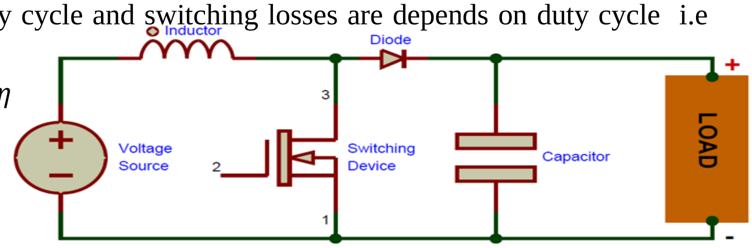
By the above parameters which are proportional to duty cycle and switching losses are depends on duty cycle i.e switching increases by increasing duty cycle

So maximum operation duty cycle $D_{max} = 1 - \frac{V_{in\,(min)}}{V_{out}}\eta$

The output voltage for boost converter = $V_o = \frac{V_{in}}{(1-D)}$

$D = \frac{T_{ON}}{T_{ON}+T_{OFF}}$ place it in above equation

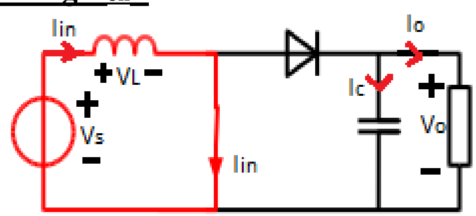
$V_o = \frac{V_{in}}{1-\frac{T_{ON}}{T_{ON}+T_{OFF}}}$ by solving it



Boost converter [14]

$V_o = \frac{V_{in} * T}{T_{OFF}}$ shows that $V_o \propto \frac{1}{T_{OFF}}$ i.e, output voltage is increase while decrease in T_{OFF} and at constant T , if $T_{ON} >> T_{OFF}$ in other words with less T_{OFF} we can achieve more voltage at output

During T_{on} :



After reaching steady state inductor will short circuited and it is the moment that can store maximum energy by inductor ,although diode is forward bias the current produced by source (if load act as source diode will be in reverse bias)will choose low resistance path (through MOSFET), thus Load current(I_o) equal to zero (for resistive load) so $I_{in} > I_o$, this is the another advantage that I_o is low if T_{OFF}

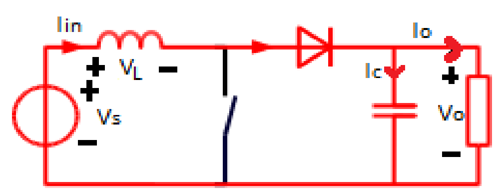
$i(t) = \frac{V}{R}(1 - e^{-\frac{t}{\tau}})$ here $\tau = \frac{L}{R}$ sec

$i(\infty) = \frac{V}{R}$ steady state current

$V_S - V_{L(on)} = 0$; $V_{L(on)} = V_S$

$I_{c(on)} = - I_o$ (initially we assumed that I_o as positive but Load is contributing current so polarity is –ve)

During T_{off} :



The un activated MOSFET is shown in black colour, in this mode both source and inductor will contribute voltage to load so, net output voltage is higher than input as well output of buck converter. The capacitor connected across load will gives stable output, but current is less compare to input current and output current incase of buck converter, this is main reason of using it for battery charging which achieves periodic charging

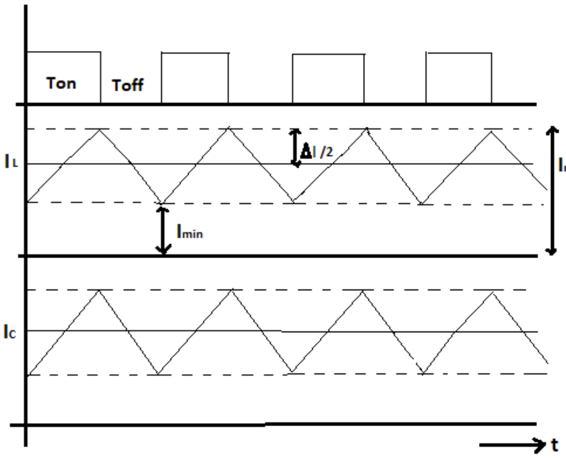
Apply KVL in path source, inductor and load

$V_S - V_L - V_O = 0$

$V_L = V_S - V_o$

Apply KCL at capacitor node

$I_{c(off)} = I_L - I_o$



Voltage – Sec balance method which gives relation between source voltage (V_S), load voltage or output voltage (V_o) and Duty cycle

$V_{l(on)}*T_{ON} + V_{L(off)}*T_{OFF} = 0$

$V_S * T_{ON} + (V_S - V_o)* T_{OFF} = 0$ ——— (A)

$T = T_{ON} + T_{OFF}$; $\because D = \frac{T_{ON}}{T_{ON}+T_{OFF}} = \frac{T_{ON}}{T}$

$T = D*T + T_{OFF}$

$T_{OFF} = T(1-D)$ ——— place in (A)

$V_S * D*T + (V_S - V_o)* (1-D)T = 0$

$\boxed{V_o = \frac{V_S}{(1-D)}}$ $0 \le D \le 1$

We can also derive above relation using V_o is always greater than V_S except at D = 1 (at this $V_o = V_S$), so boost converter is also called as Step Up chopper due to above reason. Similarly load current (I_o) can be determined by using Current – Sec balance

$I_{c(on)} *T_{ON} + I_{c(off)} * T_{OFF} = 0$

$I_o *T_{ON} + (I_L - I_o)* T_{OFF} = 0$

$I_o *D*T + (I_L - I_o)* (1-D)T = 0$ by solving this

$\boxed{I_L = \frac{I_o}{(1-D)}}$

Note:

(a) In boost converter $I_o \neq I_L$ where as in buck converter $I_o = I_L$

(b)I have already mentioned different parameters at buck portion, over here I am just derive

Ripple in inductor current(ΔI) :

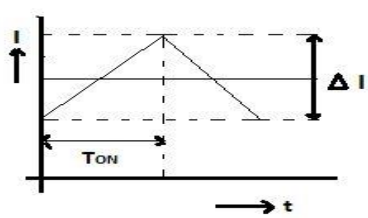
Since inductor charges for both modes in this converter ΔI is lesser than the ΔI of buck converter. During T_{ON} I_L will raises linearly, then decreases linearly T_{OFF} , due reason of adding the load impedance as well, results saw tooth waveform as in figure

$V_{L(on)} = V_S$

$L\frac{di_{on}}{dT_{on}} = V_S$

$L\frac{dI}{D*dT} = V_S$

$\boxed{\Delta I = \frac{V_S D}{Lf}}$



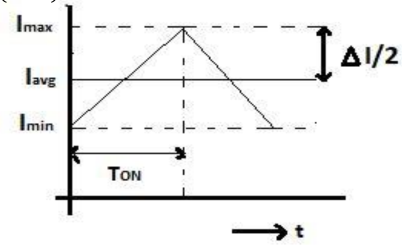
Imax & Imin :

$I_{Lmax} = I_L + \frac{\Delta I}{2}$ $\because I_L = \frac{I_o}{(1-D)}$

$\boxed{I_{Lmax} = I_o + \frac{\Delta I}{2}}$

$I_{Lmin} = I_L - \frac{\Delta I}{2}$

$\boxed{I_{Lmin} = I_o - \frac{\Delta I}{2}}$



Source current :

When we neglect the power loss at FD, Inductor (i.e. resistance free) and capacitor then

$P_{out} = P_{in}$

$V_S I_S = V_o I_o$

$\boxed{I_S = \frac{Vo*Io}{VS}}$

Ripple in capacitor voltage (ΔV) :

During ON condition either capacitor feed energy to load

or load (Battery) supply energy to capacitor, assume that capacitor is feeding

$I_c = - I_o$

$C*\frac{dV}{dt} = - I_o$ => $dV = \frac{Io}{C}dt$

Apply integration on both sides

$\int_{V_{max}}^{V_{min}} dV_c = \int_0^{DT} \frac{Ic}{C} dt$

Here we have applied V_{max} as lower limit and V_{min} as upper limit, due to capacitor is discharging as capacitor is acting as source

$V_{min} - V_{max} = - \frac{Io}{C}*DT$ by taking - common

$\boxed{\Delta V = \frac{Io}{fC}*D}$

Here ΔV is depends on Io where as in buck converter it depends on V_s .Here ripple is proportional to duty cycle (D), so D at max ripple occurs will not exist.

Critical Inductance:

As I mentioned Critical inductance already

$I_L - \frac{\Delta I_L}{2} = 0$ $\because$ Taken from previous result

$\frac{I_o}{(1-D)} = \frac{DV_S}{2*L_{crt}f}$ $\because$ $I_o = \frac{V_o}{R} = \frac{V_S}{R(1-D)}$

$\frac{V_S}{R(1-D)^2} = \frac{D\,V_S}{2L_{crt}f}$ by solving

$\boxed{L_{crt} = \frac{RD(1-D)^2}{2f}}$ I_{crt} of boost < L_{crt} of buck,

Critical Capacitance :

Under worst case $V_{c(min)} = 0$

$V_o - \frac{\Delta V_C}{2} = 0 \qquad \because V_o = V_c$

$V_o = \frac{\Delta V_C}{2} \qquad \because \Delta V_C = \frac{Io}{fC} * D$

$V_o = \frac{Io * D}{2 f c_{crt}} \qquad \because Io = \frac{Vo}{R}$

$$\boxed{C_{crt} = \frac{D}{2Rf}}$$

Noted that C_{crt} will decreases by increasing R which is not a favorable for continuous conduction and stability

Parameters calculations for Buck converters :

Let's take V_S = 12v; D = 0.45; ΔV = 0.5%; f = 40000 Hz

Load = R =10 ohm, Solar radiations = 1000 w/m^2

Parameter	Formula	Value
Inductance	$125\% \{\frac{R(1-D)}{2f}\}$	86*10^{-6} H
Capacitance	$\frac{(1-D)}{8 L_{crt} f^2}$	100*10^{-6} F
Output Voltage	$D*V_S$	5.4V

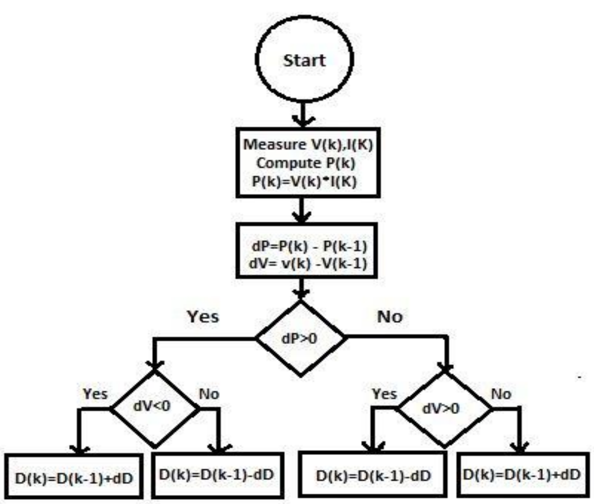
Parameters calculations for Boost converters :

Let's take V_S = 12v; D = 0.45; ΔV = 0.5%; f = 40000 Hz

Load = R =10 ohm, Solar radiations = 1000 w/m^2

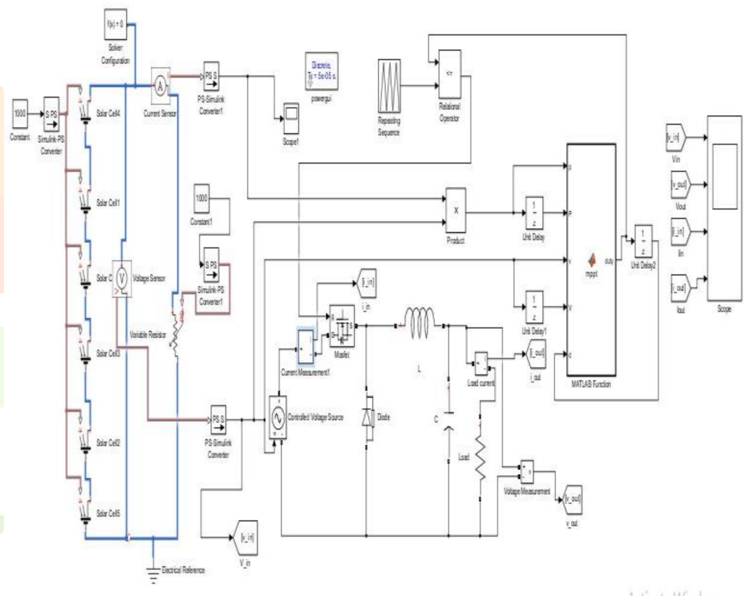
Parameter	Formula	Value
Inductance	$125\%\{\frac{RD(1-D)^2}{2f}\}$	21.269*10^{-6} H
Capacitance	$\frac{D \times I_{out(min)}}{f_S \times \Delta V}$	225*10^{-6} F
Output Voltage	$\frac{V_S}{(1-D)}$	21.818 V

Algorithm for MPPT

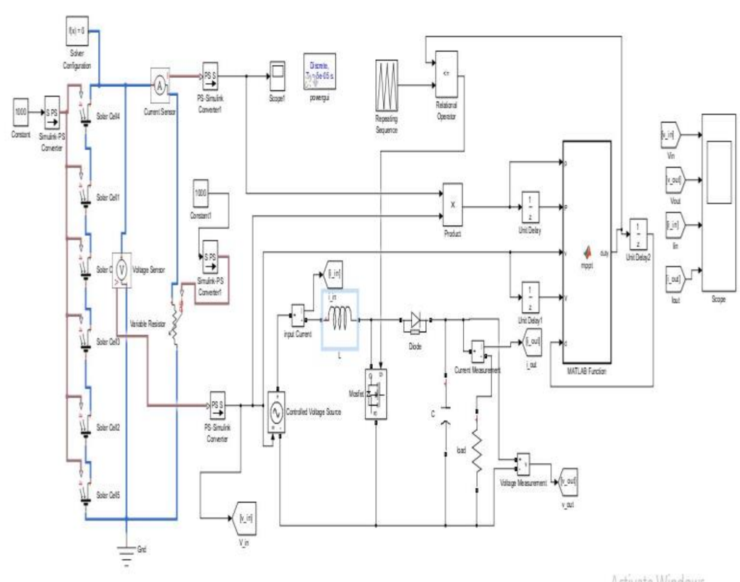


you see the duty cycle in both cases in calculations part, it was same ,we have to observe the output voltage in both converters at same duty cycle, another question raises that converters at different duty cycles as mentioned in title, as we know that solar panel can't provide continuous voltage due to temperature variations ,moisture conditions, mist etc .In order to achieve maximum power we used an electronic device called Maximum Power Point Tracker (MPPT) which was operated on algorithm shown in figure. This module will tends to check the condition of $\frac{dP}{dV} = 0$, the point at which maximum power flow, to satisfy this condition the variations will takes place in duty cycle(we had taken dD=0.05),thus the converter is operating in different duty cycles in order to flow maximum power from source to load. We did MATLAB simlink based on the algorithm called Perturb and Observe algorithm as shown in below figure.

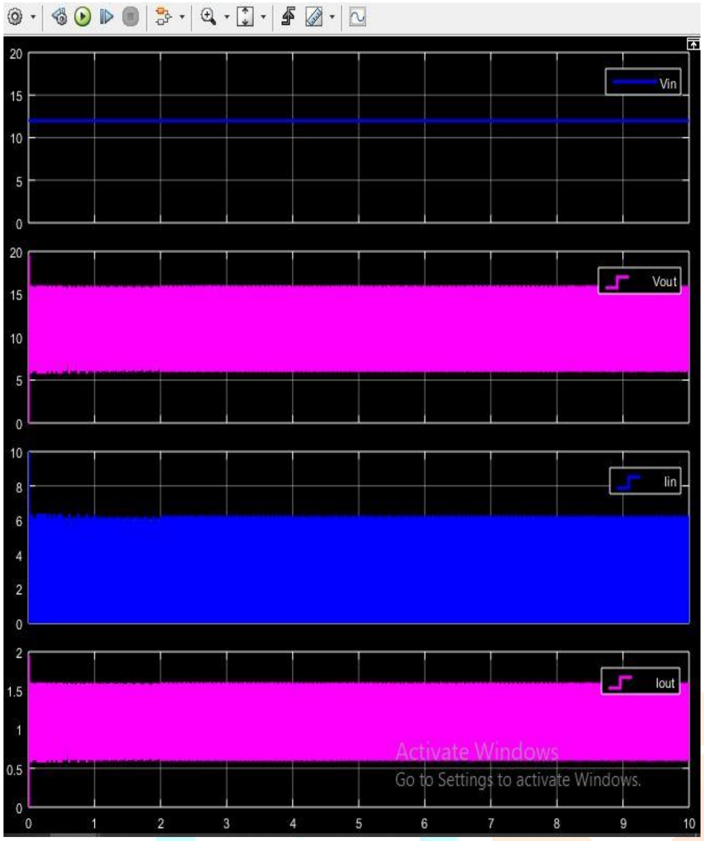
Buck converter :



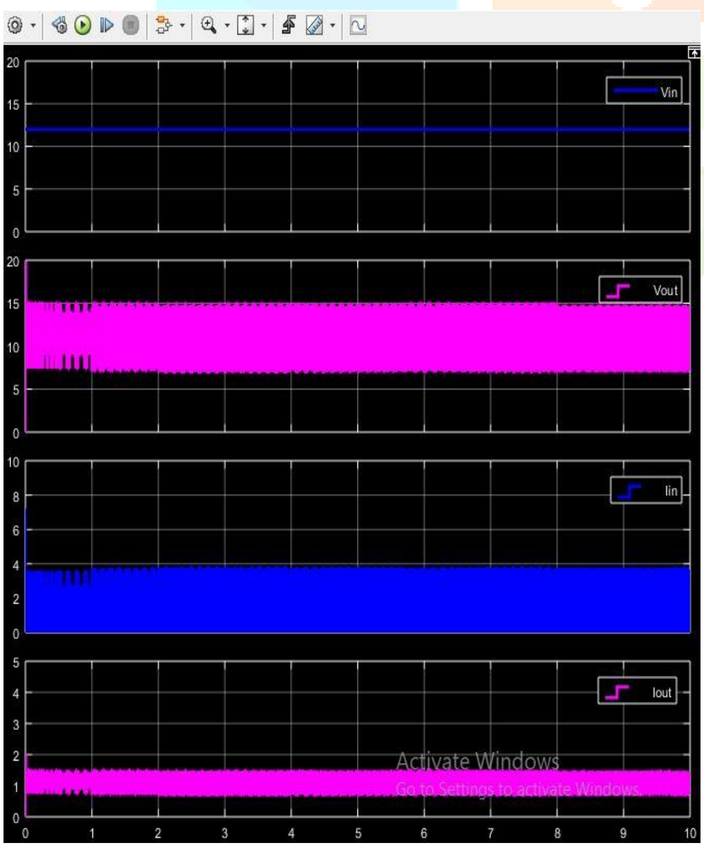
Boost converter :



Output of Buck converter at Critical Inductance(1):

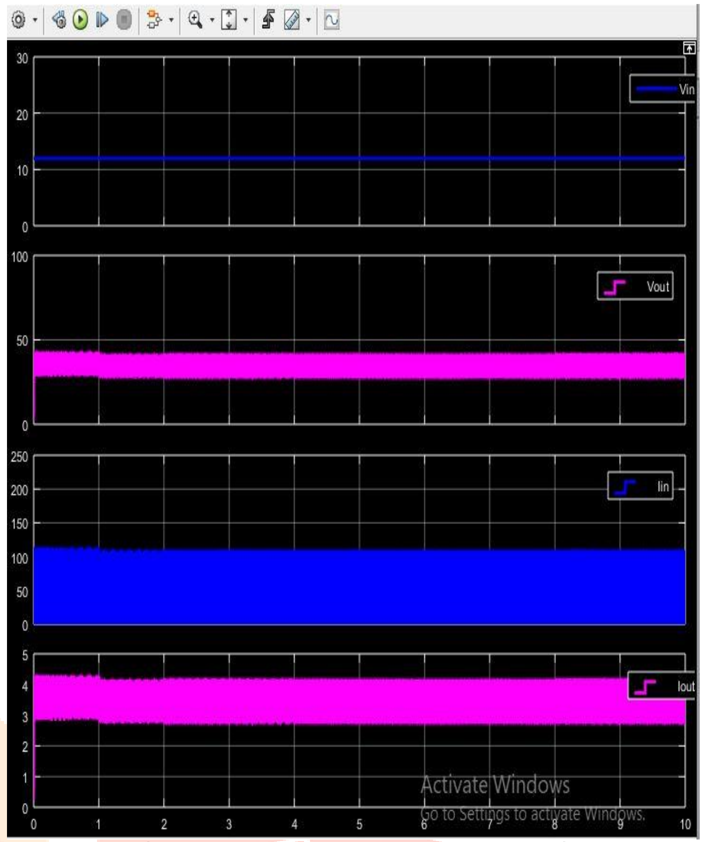


Output of Buck converter at Inductance of 200 µH (2):

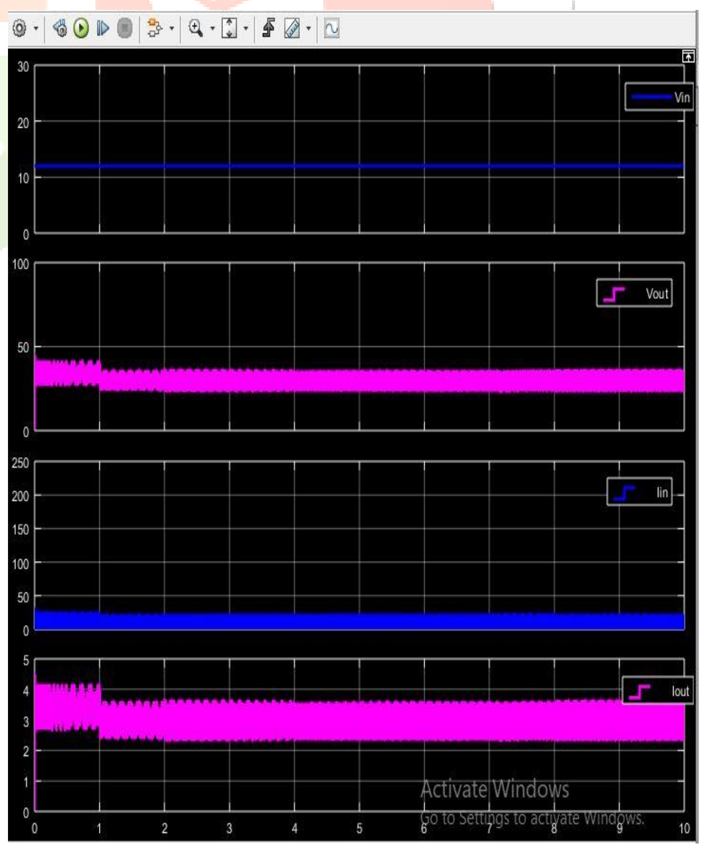


By observing above, placing high inductance had made the I_o continuous with less ripple and by gradually increasing the inductance (up to certain value) the $I_o > I_{in}$ and $V_o < V_S$

Output of Boost converter at Critical Inductance(3):



Output of Boost converter at Inductance of 200 µH (4) :



By the above waveforms, the $V_o < V_S$, $I_{in} >> I_o$,due to large current flow through inductor under short circuit T_{ON} mode. If we increase inductance the I_{in} decreases, due to adding some impedance.

Conclusion:

By this paper authors analyzed various parameters of converters before going to design them , the results were tested using MATLAB-Simlink software at different values of parameters. This paper compared between charging with buck and boost converters, it explained removal of sulfation at electrodes by supplying power in such a way at high voltage low current by using boost converters. The periodic charging was achieved using boost converter, so With help of this charge controller authors utilized the solar in efficient way and extend the lifetime of battery as well. Placing high value inductor will in increases continuity with less ripples, another advantage of using high inductor rather than critical inductance is decrease the short circuit current in case of boost converter during T_{ON} mode, it is similar as minimize the abnormal current flow in alternator during fault condition. In this paper the MATLAB-Simlink done using algorithm called P&O algorithm for MPPT, which contributes constant maximum power to load by satisfying $\frac{dP}{dV} = 0$ and operated at load line $\frac{1}{R} = \frac{\Delta i}{\Delta v}$ in i-v characteristics. We can isolate between load and PV module by converter is acting as isolator (only in buck converter)

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