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Electronic Controller for generating mode of Integrated Starter-Generator -Two Wheeler Application

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ABSTRACT--The aim of this paper is to design and develop an electronic controller (DC-DC Converter) for ISG which replaces the existing system in two wheelers. In the existing system, separate starter motor and magneto is used. The starter motor is used to self-start the vehicle and the magneto is to generate power from the running vehicle and provides supply to two wheeler accessories and charges the battery. In this system, a regulator rectifier is used as the voltage Regulator. The existing system faces a lot of issues: It does not allow Instant and Smooth engine start, and reliability is less. In the controller unit, the output ripple voltage and output ripple current is more, delivers average output current, power loss is more and less efficiency. To overcome these problems, we are going for ISG with DC-DC buck converter which solves all the above said problems. ISG also reduces the fuel consumption and eliminates the need for separate conventional starter motor and magneto. It combines the operation of the alternator, the starter motor and flywheel in a single unit. Electronic controller is used to step a voltage down from a higher voltage to a lower voltage, during the generator mode of ISG. Electronic controller used here produces a regulated voltage that is lower than its input voltage, delivering high current by minimizing power loss and providing high efficiency.

KEYWORDS: Electronic Controller, DC-DC Buck Converter, ISG-Integrated Starter-Generator, Starter-Motor, magneto, Regulator Rectifier, Voltage Regulator, ripple voltage, ripple current.

I. INTRODUCTION

1.1 integrated starter-generator (ISG)

ISG is a technology that eliminates the need for conventional starter-motor based engine start system. It results in instant and smooth engine start, improved reliability and also enables idling start feature. It combines the operation of alternator, starter motor and flywheel in a single unit. This Single machine performs both the function of starter-motor and alternator.

Advantages

- ISG can start the engine within 200 ms (comparing to 800 ms in DC starter-motor).
- It imparts an automotive STOP/START capability of engine.
- This allows the engine to shut down and avoid idle stop whenever the vehicle is stationary and restart quickly.
- Saving in the fuel consumption (typically 10%) and reduce the emission of CO₂.
- Energy recovery at braking by providing the ability to convert kinetic energy in to storable energy.
- Additional brake capability to automobile.

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Buck converter for Integrated Starter-Generator in two wheeler application is explained in detail in this document. Buck converters are, as explained above, converts a source of direct current from higher voltage magnitude level to a lower voltage magnitude level.

Linear regulators prove to be efficient over the switching regulators such as the above converters) only when the output is lightly loaded or when the output voltage desired is very close to the source voltage and also they are void of magnetic circuit involving transformers or inductors thus resulting in a relatively smaller circuit. Other than these conditions if a linear regulator is used, the BJT which is usually used for regulation, acts as a resistor, with the power loss across it numerically equal to the product of voltage drop across the transistor input and output terminals, and the current flowing through it. In order to make loss due to resistive drop almost negligible, we use switching regulators.

Buck converters are used only if the voltage levels to be reduced is less than the order of 10. If the scaling is more than 10, then we need to use an isolated type, flyback converters

1.3 overall project:

- Integrated Starter-Generator produces electric power from the running vehicle and supplies it to the electric devices and charges the battery, therefore reducing fuel consumption.
- The DC voltage produced by the ISG is varying between 16V-60V, but a fixed voltage should be given to charge the battery.
- To obtain a fixed DC voltage of 14V and a maximum current of 10A, an electronic controller is used.
- Electronic controller is used to step a voltage down from a higher voltage to a lower voltage, during the generator mode of ISG.
- Electronic controller used here produces a regulated voltage of 14V that is lower than its input voltage ranging between 16V-60V, delivering maximum current of 10A, minimizing power loss and providing high efficiency.

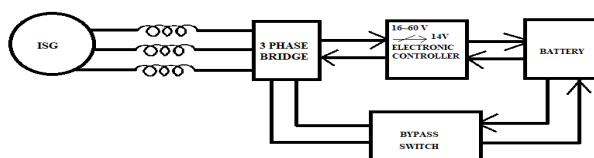


Fig.1

II. BUCK CONVERTER

Below figure shows the buck converter diagram. As shown, the converter consists of the following components.

1. Direct Voltage Source - V_g
2. Power Converter (represented as Switch) - SW
3. Filter Inductor - L_f
4. Filter Capacitor - C_f
5. Load Resistor - R_l
6. Freewheeling Diode - D_f

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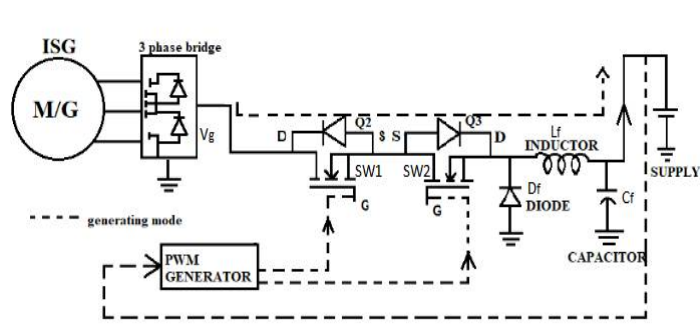


Fig.2

2.1 Analysis of Buck Converter

The Buck converter involves the conversion of a fixed direct voltage into a variable direct voltage source or variable direct voltage source to fixed direct voltage source without changing the power level (neglecting power losses in the switch). Hence, it is also called as a DC Transformer.

Assuming that the current flow in the inductor is continuous, we are now analyzing the buck converter in Continuous Conduction Mode. From the basic principles, we know that,

$$eL = Lf di/dt$$

Assuming that the inductor current raises linearly in the inductor. We can say that,

$$V_g - V_0 = Lf(I_2 - I_1)t_1$$

Where V_0 is the output voltage across the load resistor

$$t_1 = Lf \Delta I / V_g - V_0$$

Where $\Delta I = I_2 - I_1$

This the period for which the switch is ON. This time period t_1 is called the ON time period, and is denoted by $t_{ON} = k t_s$.

For time period, $(1-k)t_s = t_{off}$, that is the time period t_2

For which, the switch is OFF, the input is zero, so $V_g = 0$.

$$0 - V_g = Lf(I_2 - I_1)t_2$$

So,

$$V_0 = Lf \Delta I t_2$$

$$t_2 = Lf \Delta I / V_0$$

From the above equations, we get,

$$\Delta I = (V_g - V_0)t_1 / Lf = V_0 t_2 / Lf$$

Simplifying the above equation to get an expression for average voltage V_0 , we get,

$$V_0 = k V_g$$

Where $k = t_{ON} / T$, is the duty cycle of the switch.

Neglecting the losses in the switch, we can write that input power is equal to output power.

$$V_g I_g = V_0 I_0$$

Where,

I_g is the source current

I_0 is the average output current

From the above equation, we can write,

$$I_g = k I_0$$

To find the switching period,

$$T_s = 1/f_s = t_1 + t_2 = Lf \Delta I / V_g - V_0 = Lf \Delta I / V_0$$

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$$T_s = LfV_g \Delta I / V_0(V_g - V_0)$$

To find the peak to peak ripple current,

$$\Delta I = V_0(V_g - V_0) / f_s L f V_g$$

Or,

$$\Delta I = V_g k(1-k) / f_s L f$$

We assume that the load is free of ripple current and whatever ripple is present in the inductor current will be smoothened by the capacitor. Hence we can write,

$$i_L = i_C + i_0$$

$$\Delta i_L = \Delta i_C$$

So that $\Delta i_L = 0$

The waveform of inductor current i_L and i_C add up to make the steady state output current i_0 to be constant. For upper half to the current ripple triangle, we can write the equation of the area of the triangle as $\frac{1}{2}(t_{12} + t_{22})\Delta I$ which is nothing but equal to $\Delta I^2 / 4$ for a period of $t_{12} + t_{22} = T_s / 2$. Now for this period, the capacitor charges. So the charging current of the capacitor, i_C is given by

$$i_C = \Delta I / 4$$

Now, the capacitor ripple voltage is given by,

$$v_C = \frac{1}{C} \int i_C dt + v_C(0^-)$$

$$\Delta v_C = \frac{1}{C} \int_0^{T_s/2} i_C dt + v_C(0^-)$$

Or, we can write,

$$\Delta v_C = \frac{\Delta Q}{C} = \frac{1}{C} \int_0^{T_s/2} i_C dt = \frac{1}{C} \int_0^{T_s/2} \frac{\Delta I}{4} dt = \frac{\Delta I}{4} \frac{T_s}{2}$$

Where we have considered the charging cycle of the capacitor with ΔQ as the charge accumulated during period $t_{12} + t_{22} = T_s / 2$.

Now, putting the value of ΔI , correspondingly we get,

$$\Delta v_C = \frac{V_0(V_g - V_0) 8 L f C f_s^2}{k(1-k)^2}$$

$$\Delta v_C = \frac{V_g k(1-k) 8 L f C f_s^2}{k(1-k)^2}$$

To find the critical values of inductor and capacitor, the condition for continuous inductor current and capacitor voltage is,

$$I_L = \Delta I / 2$$

And,

$$V_0 = \Delta v_C / 2$$

Substituting the value of ΔI , we get

$$V_g k(1-k) / f_s L f = 2 I_L = 2 I_0 = 2 k V_g / R_L$$

$$L_c = L \geq (1-k) R_L / 2 f_s$$

Substituting the value of Δv_C , we get

$$V_g k(1-k) 8 L f C f_s^2 = 2 V_0 = 2 k V_g$$

$$C_c = C \geq \frac{1-k}{16 L f_s^2}$$

This completes the analysis part of power converter unit.

2.2 Design

Given specs of the buck converter

Input Voltage $V_g = 16V-60V$

Output Voltage $V_0 = 14V$

Output Current $I_0 = 10A$

Frequency of Switching $f_s = 10kHz$

Calculations of unknown parameters

To find the value of output resistor (R_L)

$$R_L = V_0 / I_0 = 14 / 10 = 1.4 \Omega$$

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To find the value of duty cycle (k)

$$k = V_0/V_g = 14/28 = 50\%$$

$$\therefore K_{\max} = 88.0\% \quad \& \quad K_{\min} = 23.0\%$$

To find the time period of switching (Ts)

$$1/f_s = 1/(10 \times 10^3) = 0.0001 = 0.1\text{ms}$$

To find the ON period of the switch (tON)

$$K T_s = 0.5 \times 0.0001 = 0.00005 = 0.05\text{ms}$$

To find the critical value the inductance to obtain a continuous mode of operation

$$L_C \geq (1-k) R L 2 f_s = (1-0.5) \times 1.42 \times 0.0001 = 0.35 \times 10^{-4} = 35\mu\text{H}$$

Let us choose the value of inductor to be 400μH

$$L_f = 400\mu\text{H}$$

To find the critical value of capacitance to obtain a continuous mode of operation

$$C_c \geq (1-k) 8 L C f_s^2 = 1 - 0.58 \times 35 \times 10^{-6} \times 102 \times 106$$

$$= 17.9 \times 10^{-6}$$

$$= 18\mu\text{F} \cong 20\mu\text{F}$$

Let us choose the value of capacitance as $C_f = 450\mu\text{F}$

$$C_f = 450\mu\text{F}$$

2.3 Selection of dc-dc buck components

Buck converter circuit:

- N-Channel Power MOSFET (STP100N8F6)
- Diode (RURP860)
- Capacitor (450μF, 63V)
- Bulk Capacitor (450μF, 100V)
- Inductor (400μH)
- Ground resistance (10 ohm)

III. CONTROL STAGE

3.1 Pulse width modulation circuit and MOSFET driver circuit

- 555 Timer
- Differential Amplifier (AD8207)
- Schmitt Trigger (LMV331)
- MOSFET Driver (L6491D)

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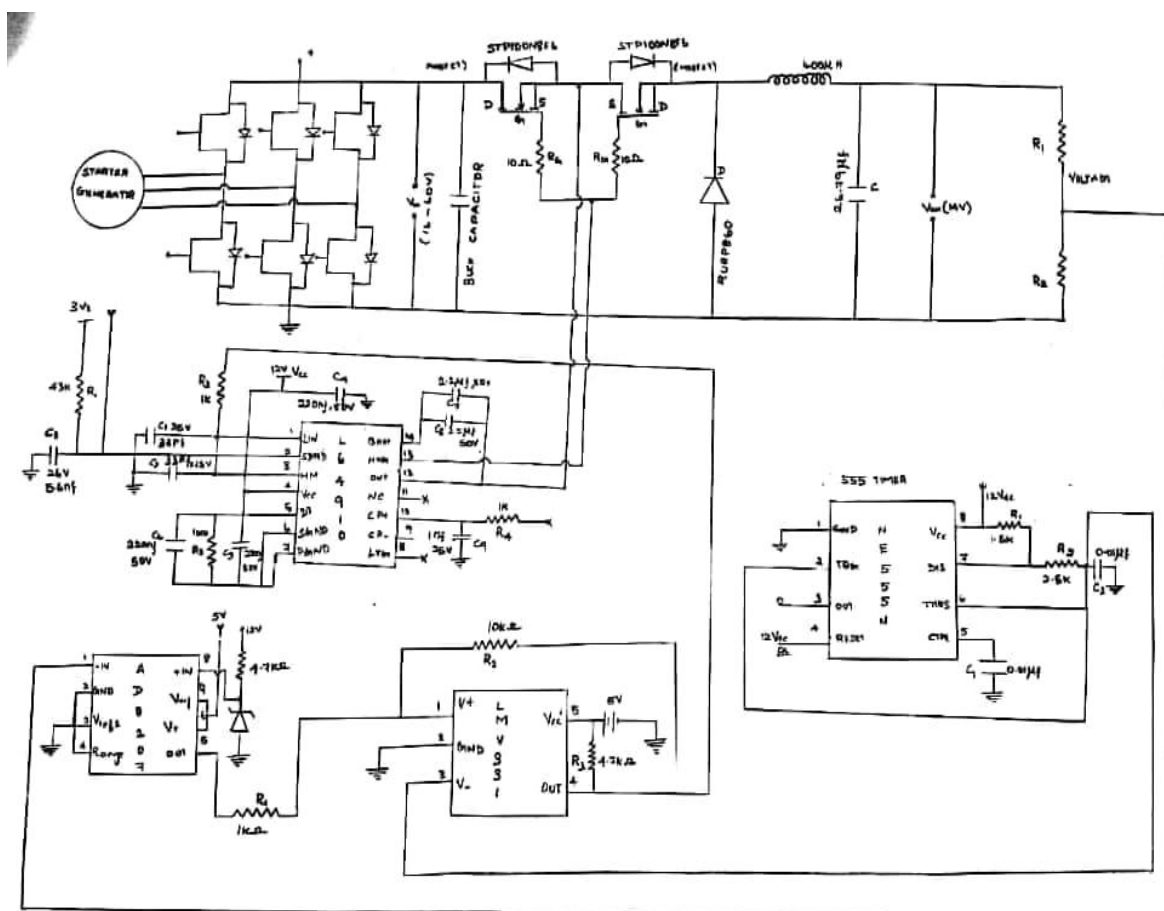


Fig.3

3.2 555 Timer

The 555 timer design:

Let us choose the value of capacitor and resistors:

$$R1=R2=4K\Omega$$

$$C=0.01\mu f$$

Duty cycle, $D=50\%$

$$t1=0.693 \cdot R1 \cdot C$$

$$t2=0.693 \cdot R2 \cdot C$$

$$t1=0.693 \cdot 4 \cdot 10^3 \cdot 0.01 \cdot 10^{-6}$$

$$t2=0.693 \cdot 4 \cdot 10^3 \cdot 0.01 \cdot 10^{-6}$$

$$\therefore t1 = t2 = 27.7ms$$

$$T= t1 + t2$$

$$T=27.7+27.7$$

$$T=55.4$$

$$\text{Now, } f=1/T=1/55.4$$

$$\therefore f=18.05KHz$$

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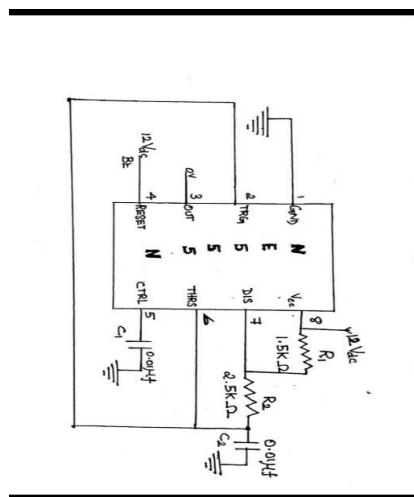


Fig.4

Working

For 50% duty cycle and 20kHz frequency, the saw tooth pulse is produced across the discharge capacitor of 555 timer (pin 6 discharge pin) hence the 555 timer produces the pulse we required and it is sent to the Schmitt trigger -ve terminal. At +ve terminal the output from the differential amplifier is given. The output of the differential amplifier is error voltage. The error voltage is obtained by comparing the reference voltage (V_{ref}) and feedback voltage (V_{fb}). The Schmitt trigger produces the square pulse, which is modulated, and that is given to the MOSFET driver. The output of the driver is used to drive the MOSFETs of the converter. The converter output is fixed DC voltage 14V with the maximum current 10A.

Output

The output taken between 2.5k Ω resistor and 0.01 μ f capacitor in pin7 is 8V. This is given to V- of Schmitt trigger

3.3 Differential Amplifier (AD8207)

The AD8207 is a single-supply difference amplifier ideal for amplifying small differential voltages in the presence of large common-mode voltage. It is ideal for bidirectional current sensing applications.

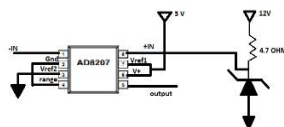


Fig.5

Output

The differential amplifier amplifies the voltage difference between the feedback of the voltage from the Buck converter and the reference voltage.

The output of the differential amplifier should ranges between 3.3 and 5V. This output is given to V+ of the Schmitt trigger.

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3.4 Schmitt Trigger (LMV331)

LMV331 is a Quad General-purpose Low-voltage Comparator. It is the most cost-effective solutions for applications where low-voltage operation, low power, and space saving are the primary specifications in circuit design for portable consumer products.

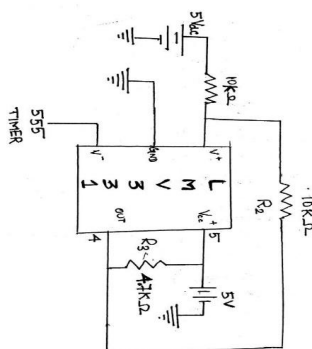


Fig.6

Output

The output of the Schmitt trigger is an PWM pulse (square pulse). Its voltage is 5V. This output is given to the 3rd pin of the MOSFET driver.

3.5 MOSFET Driver (L6491D)

High voltage high and low-side 4 A gate driver. The L6491 is a high voltage device manufactured with the BCD6 "OFF-LINE" technology. It is a single-chip half-bridge gate driver for N-channel power MOSFET or IGBT. The high-side (floating) section is designed to stand a voltage rail up to 600 V. The logic inputs are CMOS/TTL compatible down to 3.3 V for easy interfacing microcontroller/DSP.

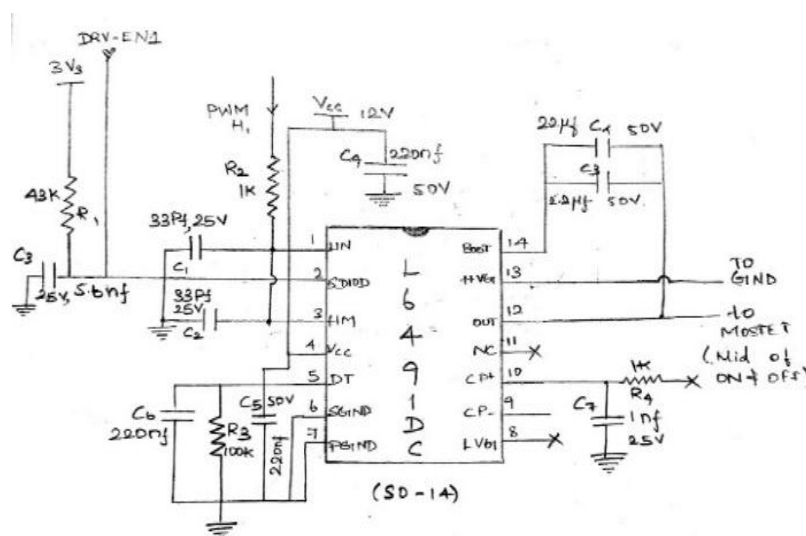


Fig.7

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The MOSFET driver drives the MOSFET on its high side according to the varying input voltage, 16V-60V, by changing duty cycle, keeping the frequency constant.

The High-side (floating) common voltage is given to the MOSFET source and the High-side driver output is given to the MOSFET gate. Thus the MOSFET is driven according to the requirement.

IV. CONCLUSION

Therefore it minimizes the output ripple voltage and output ripple current, delivers maximum output current of 10A, minimizes power loss and provides high efficiency

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