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Synchronous Buck Converter-Based Solar Power for Utility Purpose

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ABSTRACT

This project explores the potential of synchronous buck converters as a vital technology for integrating utility-scale solar power. We focus on the design, implementation, and performance evaluation of a high-efficiency synchronous buck converter tailored for grid-connected photovoltaic (PV) systems. Unlike traditional designs that use diodes, our approach leverages MOSFETs as switching elements, significantly reducing conduction losses and improving efficiency—key factors for maximizing solar energy harvest.

The primary objective is to optimize the converter for large-scale applications, emphasizing conversion efficiency, power density, and dynamic response. We develop a detailed mathematical model to analyse its steady-state and dynamic behaviour, forming the basis for an advanced control strategy. This strategy precisely regulates output voltage while incorporating Maximum Power Point Tracking (MPPT) to ensure optimal energy extraction despite variations in solar irradiance and temperature.

Beyond efficient power conversion, we explore the converter's role in grid stability. Our research investigates grid support functionalities, including reactive power injection and harmonic mitigation, which enhance voltage stability and power quality. Additionally, we assess the converter's performance under grid disturbances, evaluating its fault ride-through capability and contribution to overall grid resilience as renewable energy penetration grows.

I. INTRODUCTION

Solar energy is a highly promising renewable source due to its abundance and sustainability. As global energy demands continue to rise, integrating renewable energy into the grid becomes increasingly important. However, the intermittent nature of solar irradiation presents challenges in efficiently converting solar power into usable electricity. Utility grids require stable and regulated voltage levels, making advanced power conversion techniques essential for effective solar integration.

Power electronics play a vital role in the conversion and distribution of solar energy. Among the various converter topologies, the synchronous buck converter stands out as an efficient solution for solar power applications. It effectively regulates voltage levels while minimizing conduction losses, leading to improved system efficiency. Unlike conventional buck converters that rely on diodes, synchronous buck converters utilize MOSFETs as switching elements, reducing power dissipation and enhancing overall performance.

In addition to efficiency, synchronous buck converters offer faster dynamic response and better power density, making them ideal for grid-connected photovoltaic (PV) systems. They also facilitate stable power injection into the grid while supporting advanced functionalities such as Maximum Power Point Tracking (MPPT). By optimizing these converters, we can enhance solar energy utilization, improve grid stability, and contribute to a more sustainable energy future.

II. METHODOLOGY

The primary objective of this project is to transform variable DC voltage into a stable DC voltage. This initiative is entirely hardware-based and experimental in nature. The main energy source for our model is solar power, while alternative sources such as batteries, wind energy, and MSECB can also be utilized.

Key components of our project include a buck-boost converter equipped with a current and voltage setting module, an Arduino Nano, sensors, and a display. Unlike traditional buck converters that utilize diodes for switching, our project employs a synchronous buck converter, which uses MOSFETs for this purpose. The MOSFETs are controlled by the Arduino Nano through pulse width modulation techniques, allowing for waveform modification of the voltage. This approach enhances efficiency to 92% and employs a soft switching method, resulting in reduced switching losses. Additionally, our project incorporates sensors capable of measuring both current and voltage.

Calculations

Design of Buck Converter for PV system:

I. PV arrays specification (1000/m² & 25⁰C)

S = Standard testing conditions

$P_{mps} = 110W$

$V_{mps} = 12V$

$I_{mps} = 9.16A$

Worst Condition (50w/m² & 25⁰C)

W= Worst condition

50w/m² is 5% of (0.005) & 1000w/m²

$P_{mpw} = 0.005 \times P_{mps} = 0.005 \times 110 = 0.55W$

$V_{mpw} = 0.9 \times V_{mps} = 0.9 \times 12 = 10.8V$

$$I_{mpw} = \frac{P_{mpw}}{V_{mpw}} = \frac{0.5}{10.8} = 0.050A$$

II. Buck Converter Switching Frequency (Fs)

Fs= 25 Hz

Ripples in current and voltage signals i.e. ΔI and ΔV

$\Delta V_1 = 0.2\% \, V_1$ $\quad \Delta I_1 = 2\% \, of \, I_1$

$\Delta V_0 = 0.2\% \, V_0$ $\quad \Delta I_0 = 4\% \, of \, I_0$

III. PV arrays internal-resistance at mpp, $R_{MP} = \frac{V_{mp}}{I_{mp}}$

$$R_{mps} = \frac{V_{mps}}{I_{mps}} = \frac{12}{9.16} = 1.31\Omega$$

$$P_{mpw} = \frac{V_{mpw}}{I_{mpw}} = \frac{10.8}{0.050} = 216W$$

IV. Load-Resistance (R_0)

$$R_0 = \frac{R_{mps}}{2.5} = \frac{1.31}{2.5} = 0.524\Omega$$

5. Valw of duty ratio at Mpp, $D_{mp} = \sqrt{\frac{R_o}{R_{mp}}}$

$$D = \sqrt{\frac{R_o}{R_{mps}}} = \sqrt{\frac{0.524}{1.31}} = 0.6324$$

6. load voltage (V_0) & current (I_0): V_0= D_{mp} X V_{mp}, I_0: V_0/I_0

$$V_D = D_{mps} \times V_{mps} = 0.6324 \times 12 = 7.588\,V$$

$$I_{os} = \frac{V_{os}}{R_o} = \frac{7.588}{0.524} = 14.48\,A$$

$$V_{os} = D_{mps} \times V_{mpw} = 0.0492 \times 10.8 = 0.531\,V$$

$$I_{ow} = \frac{V_{ow}}{R_o} = \frac{0.531}{0.524} = 1.013\,A$$

7. Ripple Voltage (AV) & current (OP)

$\Delta V_{IS} = 0.002 \times V_{IS} = 0.002 \times 12 = 0.024\,V$

$\Delta V_{os} = 0.002 \times V_{OS} = 0.002 \times 7.588 = 0.015\,V$

$\Delta I_{IS} = 0.2 \times I_{IS} = 0.2 \times 9.16 = 1.832\,A$

$\Delta I_{OS} = 0.4 \times I_{OS} = 0.4 \times 14.480 = 5.792\,A$

$\Delta V_{IW} = 0.002 \times V_{IW} = 0.002 \times 10.8 = 0.0216\,V$

$\Delta V_{OW} = 0.002 \times V_{OW} = 0.002 \times 0.531 = 0.001\,V$

$\Delta I_{IW} = 0.2 \times I_{IW} = 0.2 \times 0.050 = 0.01\,A$

$\Delta I_{OW} = 0.4 \times I_{OW} = 0.4 \times 1.013 = 0.4052\,A$

8. Following Equation are Used to calculate values of L_1, C_I & C_0

$$L = \frac{2 \times V_{mps} \times D_{mps} \times (1 - D_{mpw})}{\Delta I_{OW} \times F_s} \; ; \; C_I = \frac{\Delta I_{IS}}{\Delta I_{SW} \times F_s}$$

$$C_o = \frac{\Delta I_{OS}}{32 \times \Delta V_{OW} \times F_s}$$

- $L = \frac{2 \times 12 \times 0.6324 \times (1-0.042)}{0.4052 \times 25000} = 1.3mH$
- $C_I = \frac{\Delta I_{Is}}{\Delta I_{iw} \times I_s} = \frac{1.832}{0.01 \times 25000} = 7328\,\mu F$
- $C_o = \frac{\Delta I_{os}}{32 \times \Delta V_{ow} \times I_s} = \frac{5.792}{32 \times 0.001 \times 25000} = 7240\,\mu F$

Final designed Parameters Value of Buck Converter

$L = 1.5\,mH$

$C_o = 7500\,\mu F$

$I_s = 25\,KHz$

$C_I = 7500\,\mu F$

$R_0 = 0.524\,\Omega$

DC-DC Buck Converter in PV system:

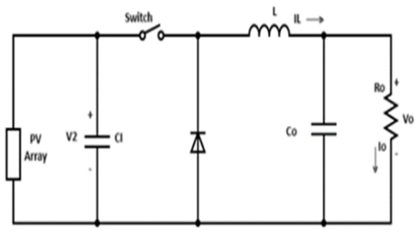
P_A : 0W – P_{max}

V_A : 0V – V_{OC}

V_Q is not fixed or constant

D Fluctuates

~P_A: R_0 & I_0 cannot be calculated



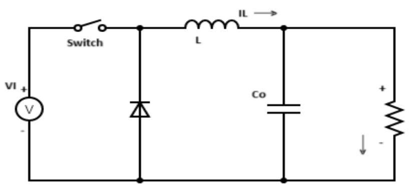
Conventional Equation cannot be utilized to design buck converter in PV system.

Conventional DC-DC Buck Converter:

$$D = \frac{v_0}{v_1}$$

$$L = \frac{(V_I - V_0) \times D}{I_s \times \Delta I_L} \; Where, (0.2 + 0.4) \times I_0$$

$$C_0 = \frac{\Delta I_L}{8 \times I_s \times \Delta V_0}$$



Constant

P_R & V_0 are usually know.

∴ I_0 can be easily found.

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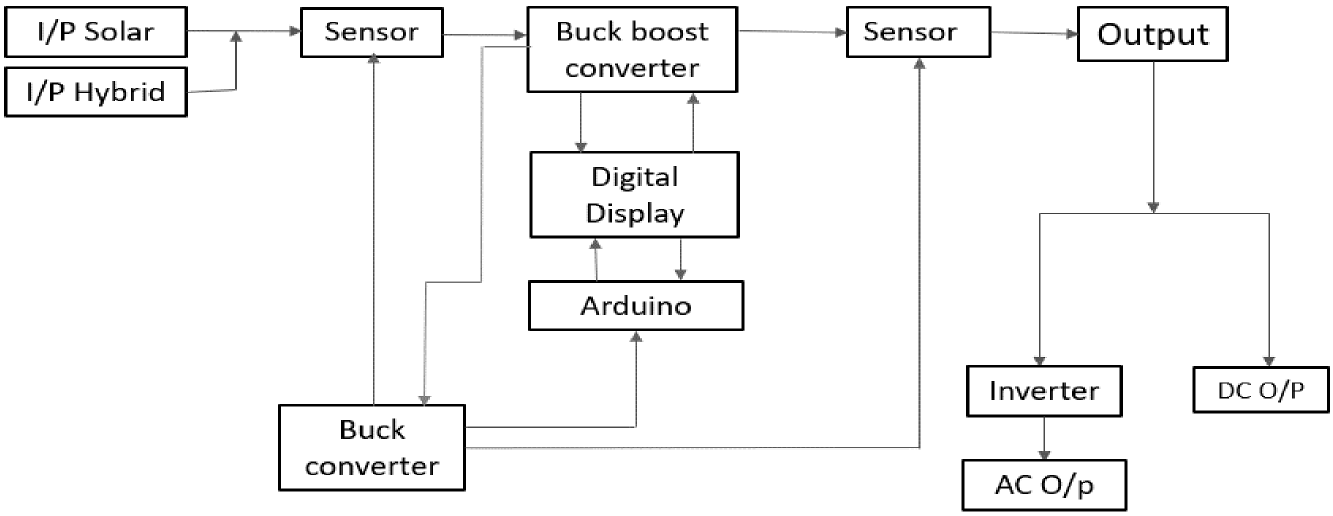
III. PROPOSE MODEL



❖ Working:

Initially, the title of our project, Synchronous Buck Converter, indicates that it also functions as a DC Stabilizer, capable of converting variable DC voltage into a constant output. In this project, we utilize two types of power sources. The primary source is solar energy, which is increasingly favored due to its renewable nature, as it is an inexhaustible resource. The secondary source is the Maharashtra State Electricity Distribution Company Limited (MSECB), which provides AC power that we convert to DC using a rectifier. In the event that solar power generation is compromised or falls below 12V, the system automatically switches to the secondary source via an automatic switching module.

We have implemented current sensors on both the input and output sides. The input sensor collects data on voltage and current, with a blue wire connecting the sensor to an Arduino Nano at pin A0 to measure current, while a green wire measures voltage at pin A3. The red and black wires serve as neutral and phase connections at pins 9 and 10, respectively. Pins A5 and A6 display the voltage readings on the screen through the Arduino.

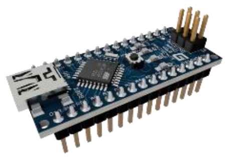
Additionally, we employ a 7-segment display to set the desired voltage and current, with these signals transmitted to the Arduino. The Arduino then generates PWM signals for the Buck-Boost converter, which determines whether to buck or boost the voltage based on the settings specified on the 7-segment display, ensuring the output voltage is appropriately adjusted.

On the output side, we also utilize a current sensor to verify that the correct voltage and current are being supplied, with the output voltage displayed via the Arduino. A 12V DC motor is connected at the output, and we also incorporate an inverter to produce AC current for a 220V LED bulb. Ultimately, our goal is to provide a stable DC output, enhancing the efficiency and reliability of our appliances.

IV. PROJECT COMPONENTS

Sr.no.	Components	Specification	Quantity
1	**Arduino**	**5V**	**1**
2	**Buck Boost Converter**	**0 – 38V**	**1**
3	**Buck Converter**	**3.5 – 35V**	**1**
4	**Current Sensor**	**Range: 2A – 20A**	**2**
5	**Automatic Switching Module**	**12V**	**1**
6	**Rectifier**	**230VAC – 12VDC**	**1**
7	**Solar Panel**	**20V, 1A DC**	**1**
8	**Motor**	**12V DC**	**1**
9	**Display**	**5V**	**1**

❖ Arduino



- Microcontroller: ATmega328P
- Architecture: 8-bit AVR
- Operating Voltage: 5V
- Input Voltage (VIN Pin): 6-12V
- DC Current per I/O Pin: 40mA max
- Clock Speed: 16 MHz
- Digital I/O Pins: 14 (6 of which provide PWM output)
- Analog Input Pins: 8 (A0 to A7, 10-bit resolution)
- PWM Output Pins: 6
- Flash Memory: 32 KB (2 KB used by the bootloader)
- SRAM: 2 KB
- EEPROM: 1 KB

❖ Buck Boost Converter

- Input Voltage Range: Typically, 3V – 36V
- Output Voltage: Adjustable or fixed (e.g., 3.3V, 5V, 12V)
- Input Current: Depends on load and efficiency
- Output Current: Typically, 0.5A – 10A
- Conversion Efficiency: Typically, 85% – 95%
- Switching Frequency: Usually between 100 kHz – 1 MHz

❖ Buck Converter

- Input Voltage Range: 4.5-40V
- Output Voltage Range: 3-35V
- Output rated Current: 2A
- Operating Temperature: -20 to +50 degrees
- Efficiency: 92%

❖ Current Sensor

Specifications:

- Current sensor chip ACS712ELC-20A.
- Pin SV power supply, on-board power status LED. The module can be measured plus or minus 20A current, corresponding analog output: 100 mV/A
- No test current through, the output voltage is VCC/2 PCB size: 31(mm) x 13(mm).

❖ Automatic Switching Module

- Input Voltage Range: 12V to 48V DC
- Maximum Load Current: 10A
- Module Dimensions: 61mm x 29mm
- Operating Temperature: -25°C to 85°C
- Working Humidity Range: 5% to 95% RH

❖ Rectifier

- Input Voltage Range: 230V AC
- Frequency: Typically, 50Hz
- Output Voltage: 12V
- Efficiency: Typically, 80% to 95%

❖ Solar Panel

- Monocrystalline
- Peak Power: 80W
- Maximum Power Voltage: Approximately 17.5V
- Maximum Power Current: Around 4.58A

❖ Motor

- Power Source: 12V DC
- Power Consumption: 60W
- Flow Rate: Approximately 30 L/min
- Motor Speed: 8,500 RPM

V. PROGRAMMING

```
#include <Wire.h>
#include <Adafruit_GFX.h>
#include <Adafruit_LEDBackpack.h> // Library for 7-segment display
// Pin Definitions
#define PWM_PIN 6 // PWM control pin for the buck converter
#define INPUT_CURRENT_PIN Al // Input current sensor (blue wire)
#define INPUT_VOLTAGE_PIN A3 // Input voltage sensor (green wire)
#define OUTPUT_CURRENT_PIN A@ // output current sensor (blue wire)
#define OUTPUT_VOLTAGE_PIN A2 // output voltage sensor (green wire)
// Display Pins (I2C-based 7-segment display)
#define SDA_PIN A4
#define SCL_PIN A5
// Constants
const float MAX_INPUT_VOLTAGE = 40.0; // Maximum input voltage (V)
const float MAX OUTPUT_VOLTAGE = 38.0; // Maximum output voltage (V)
const float CURRENT_SENSOR_SCALE = 30.0; // #30A current sensor scale
const int PWM_FREQUENCY = 31500; // PWM frequency (31.5kHz)
// Target values
float targetvoltage
float targetCurrent
12.0; // Desired output voltage (adjust as needed)
2.0; // Desired output current (adjust as needed)
// Display object
Adafruit_7segment display = Adafruit_7segment();
void setup() {
// Initialize Serial Monitor for debugging
Serial.begin(9600);
// Initialize the PWM pin
pinMode(PWM_PIN, OUTPUT);
TCCROB = TCCROB & B11111000 | BO@00V010; // Set PWM frequency to ~31.5kHz
// Initialize the display
display.begin(0x70); // Default I2C address for the display is ox7e
Serial.println("System Initialized");
void loop() {
// Read sensor values
float inputvoltage = readVoltage(INPUT_VOLTAGE_PIN, MAX_INPUT_VOLTAGE);
float inputCurrent = readCurrent(INPUT_CURRENT_PIN);
float outputvoltage = readvoltage(OUTPUT_VOLTAGE_PIN, MAX_OUTPUT_VOLTAGE);
float outputCurrent = readCurrent(OUTPUT_CURRENT_PIN);
// Print values to Serial Monitor for debugging
Serial.print("Input Voltage: ");
Serial.print(inputvoltage);
Serial.print(" v, Input Current: ");
Serial.print(inputCurrent);
Serial.println(" A");
Serial.print("output voltage: ");
Serial.print(outputvoltage);
Serial.print(" v, Output Current: ");
Serial.print(outputCurrent);
Serial.println(" A");
// Closed-loop control to adjust PwM signal based on output voltage
adjustPWM(outputvoltage, targetvoltage);
// Update the display with input/output values
updateDisplay(inputvoltage, inputCurrent, outputvoltage, outputCurrent);
delay(100); // Delay to stabilize readings and control Loop timing
// Function to read voltage from a specified analog pin
```

```
float readvoltage(int pin, float maxvoltage) {
int rawvalue = analogRead(pin); // Read raw analog value (6-1623)
return rawvalue * (maxvoltage / 1023.0); // Scale to actual voltage range
}
// Function to read current from a specified analog pin
float readCurrent(int pin) {
int rawvalue = analogRead(pin); // Read raw analog value (0-1023)
return (rawvalue - 512) * (CURRENT_SENSOR_SCALE / 512.0); // Scale to #36A range
}
// Function to adjust PWM signal based on actual and target voltages
void adjustPwWM(float actualvoltage, float target) {
static float integral = o;
const float Kp = 10.0; // Proportional gain (tune as necessary)
const float Ki = 0.1; // Integral gain (tune as necessary)
float error = target - actualvoltage; // Calculate error between target and
actual voltage
integral += error; // Accumulate integral term
int pwmvalue = constrain(kp * error + Ki * integral, e, 255); // Calculate PwM value and
constrain it
integral += error; // Accumulate integral term
int pwmvalue = constrain(kp * error + Ki * integral, e, 255); // Calculate PwM value and
constrain it
```

VI. RESULT

Our model provides a stable DC output voltage as specified. We have utilized a submersible motor rated at 12V on the output side, ensuring consistent DC output. Additionally, we incorporated an AC component, specifically a 220V LED bulb powered by an inverter. Our project effectively reduces fluctuations in the sinusoidal wave, delivering a constant output.

In this model, we employ two types of power sources: solar energy and the Maharashtra State Electricity Distribution Company Limited (MSEB). The primary source is solar; however, if it becomes compromised, the system automatically switches to the secondary source. Furthermore, if the output voltage from the primary source falls below 12V, the model will transition to the secondary source.

We have designed this model to adjust the voltage according to user requirements. The implementation of this system ensures reliable power delivery, enhanced efficiency, improved performance, and better battery charging for home appliances. An Arduino is utilized to manage voltage regulation, whether through buck or boost conversion, and a display indicates both input and output voltage and current, facilitated by input and output current sensors.

VII. CONCLUSION

The developed system presents an efficient and reliable solution for stabilizing variable DC voltage, ensuring a consistent and regulated output. By leveraging a closed-loop configuration with automatic power switching, sensors, and an Arduino Nano, the system maintains high precision and stability in voltage regulation. A dedicated buck converter powers the sensors and controller, optimizing energy efficiency and functionality.

Additionally, the integration of a 12V to 220V inverter expands its applicability to AC-powered devices, making it a versatile solution for various real-world applications. Through efficient voltage regulation, switching, and sensing, the system minimizes energy losses while maximizing performance, demonstrating a strategic approach to energy conversion and management.

This project exemplifies the seamless fusion of hardware and software in power electronics, showcasing advanced electrical engineering principles in voltage stabilization and power supply design. Its ability to provide both stable DC and AC outputs highlights its adaptability for diverse applications. Ultimately, this work contributes to advancements in energy management, reinforcing the importance of innovative solutions in modern electrical systems.

VIII. ACKNOWLEDGEMENT

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IX. REFERENCES

1) S. Rahman, M. A. Khallat, and B. H. Chowdhury, "A discussion on the diversity in the applications of photovoltaic systems."
2) N. Mohan, T. M. Undeland, and W. P. Robbins, Power Electronics: Converters, Applications, and Design, Wiley, 2003.
3) R. Erickson and D. Maksimovic, Fundamentals of Power Electronics, Springer, 2001.
4) L. Hassaine, E. Olias, J. Quintero, and A. Haddadi, "Digital control of grid-connected photovoltaic inverters."
5) M. G. Villalva, J. R. Gazoli, and E. Ruppert Filho, "Comprehensive approach to modeling and simulation of photovoltaic arrays."
6) H.-S. Kim and S.-Y. Jung, "Development of maximum power point tracking control algorithm for photovoltaic systems."
7) B.-K. Bose, Power Electronics and Motor Drives: Advances and Trends, Academic Press, 2006.
8) J.-H. Park et al., "A novel buck-boost converter with high efficiency for solar power applications."
9) T.-F Wu et al., "Design considerations of a high-efficiency DC-DC converter for photovoltaic systems."
10) Y.-S Chen et al., "Performance evaluation of synchronous buck converters in solar energy applications."
11) A.-N Al-Khayat et al., "Grid stability enhancements using advanced power electronics converters."
12) Z.-H Liu et al., "Reactive power injection for grid-connected solar power systems."
13) K.-T Chau et al., Electric Vehicle Machines and Drives: Design, Analysis and Application, Wiley-IEEE Press.
14) S.-J Lee et al., "Fault ride-through capability analysis for renewable energy systems."
15) P.-C Loh et al., "Harmonic mitigation in photovoltaic systems using advanced converters."
16) M.-C Wong et al., "Dynamic response optimization of power converters in solar applications."
17) A.-M El-Naggar et al., "Integration of MPPT algorithms in grid-connected solar systems."
18) X.-L Zhang et al., "Efficiency improvements in MOSFET-based synchronous buck converters."
19) J.-M Lee et al., "Design parameters optimization for DC-DC converters in renewable energy systems."
20) R.-C Wu et al., "Voltage regulation strategies for utility-scale PV systems."
21) T.-Y Yang et al., Advanced Control Strategies for Renewable Energy Systems, CRC Press.
22) C.-J Li et al., "Role of Arduino microcontrollers in modern power electronics applications."
23) K.-L Ho et al., "Automatic switching modules for hybrid energy systems."
24) D.-P Wang et al., "Performance analysis of current sensors in solar power converters."
25) Z.-W Qureshi et al., "Energy management strategies for grid-connected PV systems."