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Design And Development Of String Inverter To Integrate Microgrid To Grid

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Abstract :
With the rising adoption of renewable energy sources, particularly solar photovoltaic systems, the demand for efficient microgrid systems that can interface seamlessly with the main utility grid is increasing. The paper focuses on the design and development of an inverter system tailored for such integration. The methodology adopted combines both simulation and experimental validation. In the simulation phase, MATLAB/Simulink was used to model the entire system architecture. The simulation included components such as the solar PV source, boost converter to raise the DC bus voltage, a three-phase inverter for AC output generation, LCL filter and a dq-based Phase-Locked Loop (PLL) to ensure synchronization with the grid. In the hardware implementation, an Arduino Uno microcontroller was programmed to produce six-step commutation signals for driving a push-pull inverter configuration. These gate signals were amplified using a transistor driver stage to properly switch a pair of complementary MOSFETs. The low-voltage AC output from the inverter was then stepped up using a transformer. The hardware power supply setup included isolated supplies for the microcontroller and the gate driver circuitry to prevent noise interference and ensure stable operation. Though real-time synchronization with the grid was not implemented in hardware, the system was able to produce a consistent quasi-sinusoidal waveform suitable for off-grid or standalone applications.

Keywords: *Boost converter, 3-phase Inverter, Phase-Locked Loop, Arduino UNO, Sinusoidal pulse width modulation, Grid Synchronization*

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I. Introduction

The growing global energy demand and depletion of fossil fuels such as coal, oil, and natural gas have raised concerns over sustainability and environmental impact. These non-renewable energy sources are significant contributors to greenhouse gas emissions, which drive global warming and climate change. In response, the integration of renewable energy sources such as solar, wind, hydro, and biomass has gained prominence due to their abundance. Microgrids offer a decentralized solution by incorporating distributed energy resources like solar PV panels, wind turbines, and battery storage systems. These systems enhance energy security, provide operational flexibility, and improve resilience during grid disturbances. Microgrids can function in both grid-connected and islanded modes, making them essential in transitioning to a renewable-based energy future.

Among renewable technologies, solar systems are widely used for their ease of installation and flexibility. However, since solar panels produce DC output, inverters are required to convert this into synchronized three-phase AC suitable for grid integration. This involves voltage and frequency regulation and minimizing total harmonic distortion.

Modern power systems employ advanced inverter topologies—such as voltage source inverters and multilevel inverters—along with techniques like SPWM, Space Vector Modulation, and MPPT for stable energy conversion. In many cases, a two-stage design is adopted: a DC-DC boost converter elevates the voltage, followed by a DC-AC inverter to generate grid-compatible output .

For small-scale applications, Arduino-based inverter systems are gaining popularity due to their affordability and ease of programming. These systems generate PWM signals, control power switches (MOSFETs/BJTs), and manage phase synchronization to produce reliable three-phase AC output. Such systems are especially useful in microgrids, remote areas, and backup power setups, offering a compact and flexible solution to convert low-voltage DC from solar panels or batteries into usable AC power.

II. System Design And Specification

Figure 1 presents the simulation block diagram. The PV panel generates a variable DC voltage influenced by irradiance and temperature, which is stepped up by a boost converter. This converter is controlled using a Maximum Power Point Tracking (MPPT) algorithm to ensure optimal power extraction. The output is fed to a regulated DC bus, which supplies to the inverter. An inverter is used to convert DC into a three-phase AC waveform. Sinusoidal Pulse Width Modulation (SPWM) signals, generated using a dq-based Phase-Locked Loop, ensure grid synchronization. An LCL filter eliminates high-frequency harmonics, delivering clean sinusoidal output to the grid.

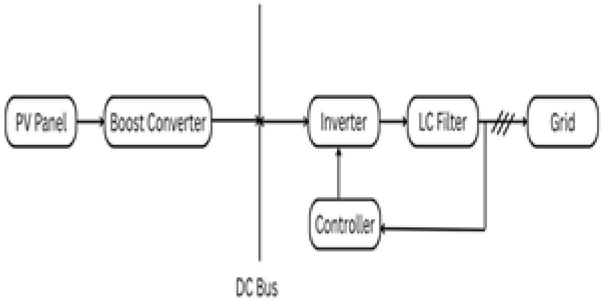

Fig 1 Block diagram of simulation

PV Panel

Table.1 Key Specifications of the Photovoltaic (PV) Module

Parameters	Values
Parallel strings	3
Series-connected modules per string	2
Maximum Power (Pmax)	250.2 W
Cells per module	60
Open Circuit Vol tage (Voc)	44.64 V
Short Circuit Current (Isc)	7.27 A
Voltage at Maximum Power Point (Vmp)	36 V
Current at Maximum Power Point (Imp)	6.95 A

Rated Ouput Calculation:
P = 250.2 X 3 X 2 = 1500 W
2.2 Boost Converter Design

L= $\frac{\text{Vin} * \text{D}}{\text{delI} * \text{fs}}$

Substituting, Vin=72V, D=0.89, fs= 10,000Hz in (1)
L=72*0.89/(2.083*10000)
L=3.07mH

C= $\frac{\text{D}}{\text{R}\left(\frac{\text{delVo}}{\text{Vo}}\right) * \text{f}}$

C=0.89/(327*0.1*10000)
C = 2.72 microF
R = V^2out/Pout
Vout= 700V, Pout=1500 W
R= $(700)^2$ / (1500) = 326.6 ohm
2.3 DC Link Capacitor

$$\text{C} = \frac{\text{P} * \text{D}}{2 * \text{Vdc} * \text{delV}}$$

Substituting, P=1500 W, Vdc=665 V , ΔV=5% of 665=33.25 V, D=0.05 in (4)

$$C = \frac{1500 * 0.05}{2 * 665 * 33.25} = \frac{75}{44161.25} = 1700\ microF$$

2.4 LCL Filter Design
Fsw=10khz
Fres = Fsw/10 = 1000Hz
Vph=

S = $\frac{100 * 10^3}{3} = 33.33kVA$

$C = \frac{0.05*S}{Vph^2*2*pi*f}$

$C = \frac{0.05*(100*10^3)/3)}{230^2*2*pi*50} = 100.28\, microF$

$I = \frac{S}{V} = \frac{33333}{230} = 144.92\ A$

$L = \frac{0.2*Vph}{2*pi*50*I}$

$L = \frac{0.2*230}{2*pi*50*144.92} = 1mH$

L1=L2= 1mH /2 = 500microH

III. Simulation Analysis And Hardware

Simulation analysis

The proposed system shown in Fig 2 integrates a PV array, boost converter, and three-phase inverter for grid-connected operation. The PV panel produces a variable DC voltage based on solar irradiance, which is regulated using a closed-loop boost converter controlled by a Perturb and Observe (P&O) MPPT algorithm. This algorithm, implemented in a MATLAB function block, samples PV voltage and current to compute the optimal duty cycle. A PI controller fine-tunes the duty ratio, and PWM pulses are generated to drive the boost converter, which steps up the voltage via energy transfer through an inductor and diode.

The regulated DC voltage feeds a three-phase inverter employing Sinusoidal Pulse Width Modulation (SPWM). Reference sine waves are compared with a triangular carrier to generate gate signals for six MOSFETs arranged in a three-leg topology. Dead-time is implemented between complementary switches to avoid shoot-through conditions. The inverter's output is filtered using an LCL filter to suppress high-frequency harmonics and ensure grid-compatible sinusoidal voltage.

Grid synchronization is achieved using a dq-based Phase-Locked Loop (PLL), which transforms grid voltages into the rotating dq frame and minimizes the q-axis component (Vq) using a PI controller. Current control is also performed in the dq frame by comparing reference and measured currents, with PI controllers regulating the errors. The inverse Park transformation converts the modulated voltages back to the abc frame for PWM generation. These signals are amplified and sent to the inverter driver stage, ensuring precise, synchronized switching for clean AC output compatible with the grid.

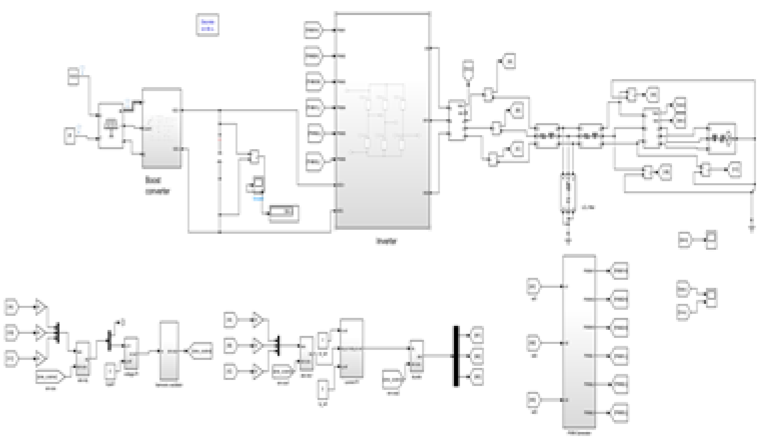

Fig 2 Simulation setup

Boost converter

Fig 3 shows the simulation of boost converter it includes a control loop where PV voltage and current are sampled and processed via a MATLAB function block implementing the P&O MPPT algorithm. The calculated duty cycle is fine-tuned using a PI controller, and PWM pulses are generated for switching. The power circuit steps up the input voltage by storing and releasing energy through an inductor and diode.

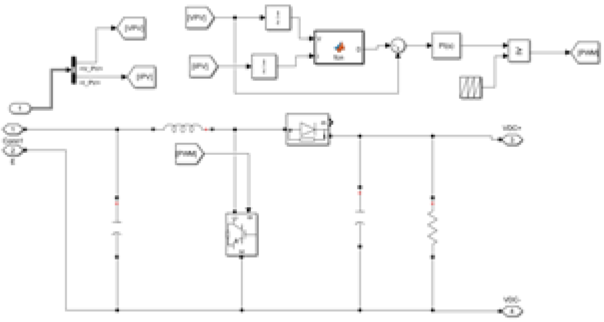

Fig 3 Boost converter simulation

Inverter

The three-phase inverter is modelled with complementary MOSFETs in each leg. PWM signals (PWM1–PWM3 for upper switches, PM4–PWM6 for lower switches) drive the legs to generate AC output. Fig 4 is the simulation of the inverter.

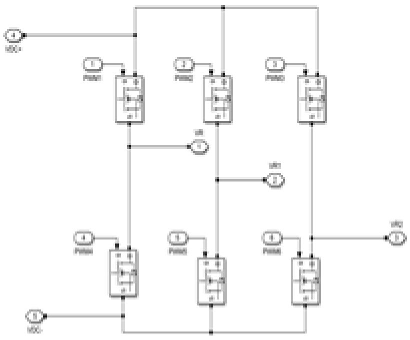

Fig 4 Inverter Simulation

Dq-PLL and Current control

Grid synchronization is achieved using a dq-based PLL. Three-phase voltages are transformed into the rotating dq frame, and the q-axis component (Vq) is minimized via a PI controller to maintain phase alignment. In parallel, the current control loop operates in the dq frame, comparing actual and reference currents. The resulting errors are regulated through PI controllers, and the inverse transformation yields modulated voltage references for each phase.

PWM Generation

PWM signals are produced by comparing the modulated reference signals (m1, m2, m3) with a triangular carrier wave. Each phase produces a high-side and low-side gate signal, which are amplified and sent to the inverter driver stage. This guarantees accurate and synchronized switching, resulting in a smooth AC output.

Hardware Approach

A prototype inverter system was developed for experimental validation, as shown in Fig. 6. The setup uses an Arduino UNO microcontroller to generate six-step commutation signals for a three-phase inverter. These signals are fed to gate driver circuits, which provide electrical isolation and voltage amplification for high-power MOSFET switching.

The inverter uses a three-leg H-bridge configuration with IRF640 (N-channel) and IRF9640 (P-channel) MOSFETs to synthesize a stepped AC waveform from a DC input. Gate driver stages are built using complementary BJTs (BC548 and BC558), with current-limiting resistors and protection diodes (1N4007) ensuring safe operation. The output is monitored via a digital oscilloscope to verify waveform integrity.

Power to the control unit is supplied through a two-stage system: a 230 V AC mains input is stepped down and rectified to 9 V DC, then regulated to 5 V for Arduino operation. A separate linear supply delivers 6.6 V DC to gate. drivers, ensuring isolation between logic and power sections

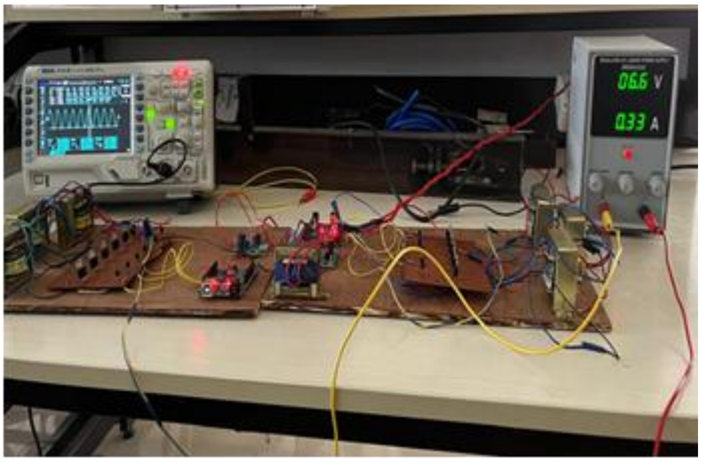

Fig 6 Hardware set

IV. Results And Discussions

Fig 7 illustrates the DC-link voltage response during the inverter startup phase. The voltage starts from 0 V and rises steadily to around 600 V, where it stabilizes. This ensures that the voltage across the DC bus reaches the desired level needed for effective DC-AC conversion.

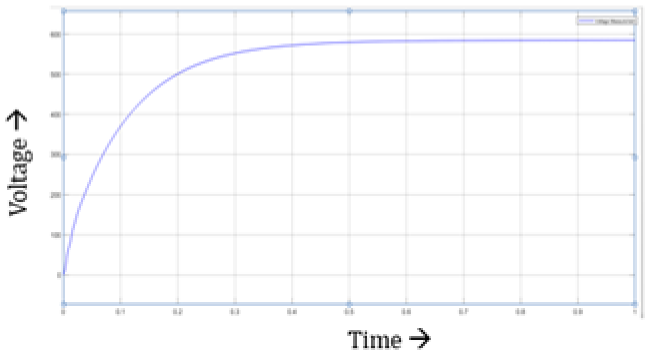

Fig 7 DC bus voltage

Fig. 8 shows the three-phase grid and inverter voltages. The upper subplot displays the grid voltages, while the lower subplot shows the corresponding inverter output voltages. Both waveforms are balanced, sinusoidal, and phase-aligned, confirming effective synchronization using SPWM and dq-PLL control.

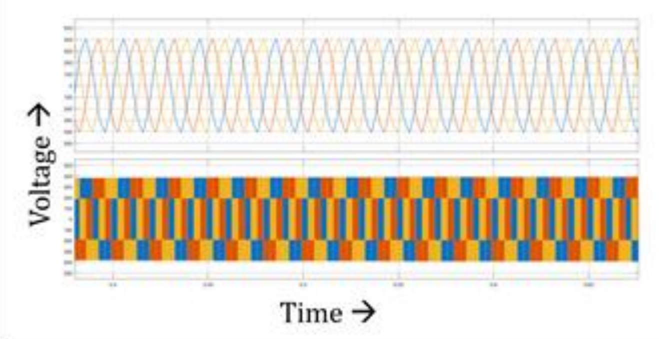

Fig 8 Three-phase grid voltage and inverter voltage

Fig 9 shows the filtered three-phase grid-injected currents are nearly sinusoidal, balanced, and phase-aligned, indicating successful synchronization via the dq-based Phase-Locked Loop (PLL).

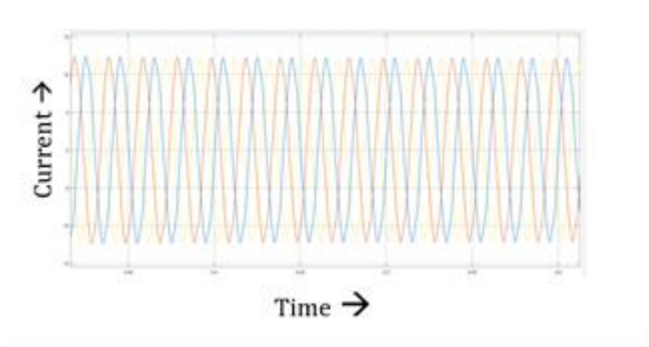

Fig 9 Three-phase grid current

Fig.10 presents the inverter output waveform captured on a digital oscilloscope, demonstrating six-step commutation control. The quasi-sinusoidal waveform displays a peak-to-peak voltage of approximately 212 V, an average voltage of 144 V, and an RMS value of 73.4 V, indicating efficient DC-AC conversion. These results validate the proper operation of the Arduino-based control, gate drivers, and inverter circuitry.

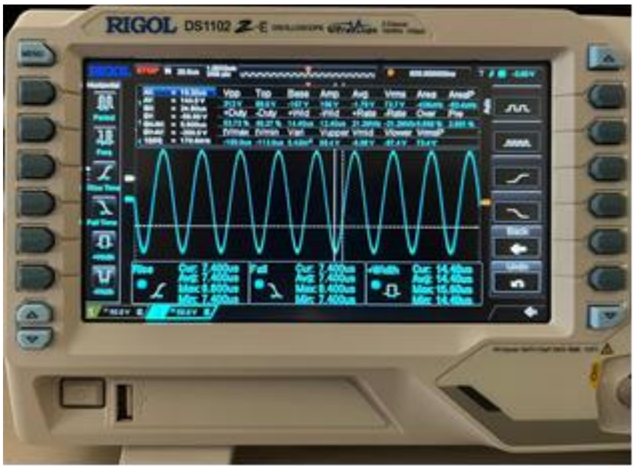

Fig 10 Oscilloscope output of the voltage waveform

V. Conclusion

The project showcases the hardware implementation of a compact Arduino-controlled inverter system tailored for microgrid applications. It utilizes a two-stage conversion process—DC-DC boosting followed by DC-AC inversion—to convert low-voltage solar DC into a stable, grid-synchronized three-phase AC output in simulation. PWM and six-step commutation enabled efficient switching, while the LCL filter and transformer ensured output quality.

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