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Energy Storage System (ESS) To Integrate Intermittent Renewable Energy Sources

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ABSTRACT

Renewable energy sources generate power in a variable manner, and there may be unacceptably large fluctuations. Therefore, renewable energy is currently stored in batteries or super capacitors for later use, but this requires expensive maintenance. Therefore, the primary goal of the proposed system is to control renewable energy during fluctuations to provide a continuous power supply. To achieve this, we continuously monitor the solar panel's power generation and load usage, and we send these data to a machine learning model to categorize the switching status of the regulator circuit. All of these artificial intelligence processes are carried out on the Python platform.

Keywords--Renewable Energy Solar Power Generation Power Regulation Fluctuation Control Uninterrupted Power Supply,AI in Power Systems Switching Regulator Circuit Python for Energy Management Power Generation Forecasting Smart Grid Energy

Introduction

Community microgrids are reshaping energy markets, but their large-scale deployment faces challenges: grid synchronization, slip management, and inverter distortions. The Phasor Measurement Unit (PMU) Assisted Inverter (PAI) addresses these by continuously receiving real-time PMU data to generate a reference signal for the inverter. A novel DC microgrid architecture integrates PAI with AI-driven cloud systems to optimize shared energy resources like batteries and rooftop solar panels.Microgrids enhance grid reliability by integrating Distributed Energy Resources (DERs), small-scale energy sources that improve resilience during outages and disasters EMSs, typically operated from a centralized control room, employ high-performance computing for managing Distributed Energy Resources (DERs).

These systems solve complex optimization problems using computationally intensive algorithms, such as mixed-integer non-linear programming, evolutionary algorithms, and linear programming methods like Lagrangian relaxation and gradient descent. Distributed EMSs leverage multi-agent systems, where intelligent units collaborate to achieve both local and global objectives through robust peer-to-peer (P2P) connections. Advanced control techniques, including Distributed Cooperative Control (DCC) and leaderless consensus models, further enhance synchronization and coordination.

LITERATURE SURVEY

A. Voltage Regulation of Synchronous Condensers and Switching Capacitors

This study suggests regulating the voltage of switching capacitors and synchronous condensers in power grids that use ultra-high voltage (UHV) DC/AC systems.

The control can improve the dynamic voltage stability of the system, decrease the time it takes for capacitors to switch, and regulate the system voltages within the allowed range. First, the effects of synchronous condensers, switching capacitors, and the UHV DC/AC system on the dynamic voltage stability of the system are estimated. The switching capacitors are then chosen based on the sensitivity of reactive power and bus voltages. Synchronous condensers and switching capacitors are used in a voltage control model. Lastly, the voltage control model is solved using an enhanced interior point method. Validation is done using a real power grid with a UHV DC/AC system.

B. Composite DC-DC Converter with Bipolar/bidirectional Current-Fed Push-pull Voltage Regulator

This paper introduces a power converter to interface a low voltage bus (LV) (380 V) and an extra low voltage bus (ELV) in a 1.2 kW sruesgigdeesntteidal dc-dc nanogrid. The converter uses a composite structure in which the majority of the processed power between the DC buses is handled by a DC transformer (DCX converter). In order to minimize conduction losses, DCX is designed to run at a fixed duty cycle with an optimized transformer turns-ratio. A parallel voltage regulator (DCR) is used to regulate the voltage of the ELV bus. The input voltage across the capacitor determines how much power the DCR can handle.

C. Voltage Regulation Strategies for Multi-Terminal DC Networks

Traditional AC power grids are experiencing more stability problems as distributed energy becomes more widely used. Research on DC power grids has steadily increased because of their straightforward design and superior absorption capabilities for the production of new energy. A layered voltage adjustment method is presented in the paper along with an analysis of voltage stability. There are multiple components to the voltage adjustment. To regulate voltage, the DC grid's six ports are coordinated and managed. Lastly, a simulation model is built to confirm the effectiveness of the suggested approach.

D. DC-Series PV Collection Converter with Wide Voltage Regulation

Numerous benefits come with DC-series photovoltaic (PV) plants. Compared to other applications, the DC/DC converter, the most crucial component in the system, has certain unique technical requirements, particularly in the area of the DC-series converter's output voltage's wider regulation range. Based on the Boost Full Bridge Isolated DC/DC Converter (BFBIC), the paper suggests an IPOS cascaded converter. To increase power capacity and output voltage, a basic module is cascaded using the input parallel output series (IPOS) technique. In addition to a few standard operating modules, the converter has multiple backup modules installed to enhance the output voltage adjustment range and satisfy the demands of the DC-series PV generating units. MATLAB is used to create a 60kV/1.5MW system model and a 20kV/500kW DC/DC converter model.

PROPOSED METHODOLOGY

1. System Design

An experimental setup for closed-loop control of the converter's hardware prototype has been created in the current system. In order to regulate both the DC-link and the power supplied to the utility system, the project proposes a closed-loop control architecture of a grid- tied single-source multilevel inverter (MLI) with reduced switching loss. The main limitation of MLIs having multiple distinct dc sources is addressed by the converter topology, which makes use of a diode-capacitor ladder network to enable a variety of intrinsically balanced voltages. Additionally, the single high-frequency switch achieves zero-voltage-switching (ZVS), which reduces switching losses. The switch's high frequency operation makes it possible for the components to be smaller, which lowers the converter's weight and cost. The grid- connected MLI's performance is assessed under a range of real-time circumstances.

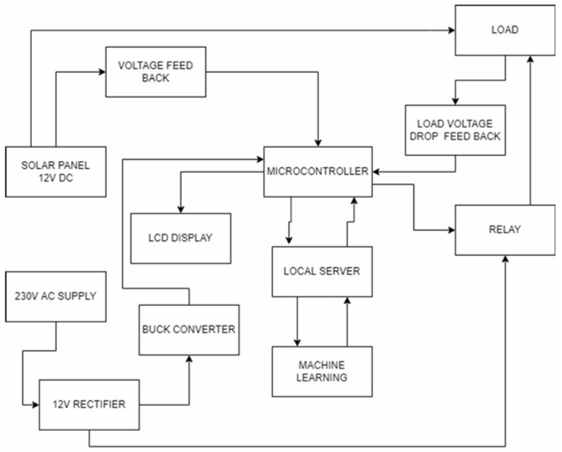

Figure 1: Block Diagram

NODEMCU (ESP8266): The Fig ure 2 The Atmel AVR® core has 32 general-purpose working registers and a comprehensive instruction set. The Arithmetic Logic Unit (ALU) is directly connected to all 32 registers, enabling the access of two separate registers in a single instruction that is completed in a single clock cycle. In comparison to traditional CISC microcontrollers, the resulting architecture achieves throughputs up to ten times faster while using less code. The following characteristics are offered by the read-and-write- capable in-system programmable flash Real Time ATmega328/P: 32Kbytes of Counter (RTC), 32 general-purpose working registers, 23 general-purpose I/O lines, 1Kbyte EEPROM, 2Kbyte SRAM, three flexible timer/counters with compare modes and PWM, One byte-oriented 2-wire Serial Interface (I2C), one serial programmable USART, a 6-channel 10- bit ADC a programmable Watchdog Timer with internal Oscillator, an SPI serial port, and six software selectable power saving modes.

Figure 2 : NODEMCU (ESP8266)

2. Working Of System

Modeling a DC-DC converter with a constant output voltage to the load is difficult because the output voltage of solar PV always fluctuates based on temperature and solar irradiation. Circuits for switching and drivers as well as an LC filter are used in the design to produce a steady voltage output to the load. A machine learning-based feedback switching controller based on voltage control mode is included in the design to guarantee a steady output voltage.

A. Hardware Implementation

The NodeMCU (ESP32) is the central component of the system's hardware, handling power regulation and data collection. With the help of a voltage regulator, it can be powered via a USB port or an external

5V/3.3V source. A rectifier circuit converts 220V AC to DC after it has been stepped down to 12V or 24V AC by a center-tapped transformer. Because of the ripples in the rectified output, a series inductor filter reduces fluctuations by preventing abrupt changes in current, and a shunt capacitor filter further smoothes the voltage by storing and releasing energy as needed.

Power levels are continuously monitored by a voltage detection sensor, guaranteeing steady operation. Relay modules manage high-power switching, allowing linked devices to operate safely and effectively. A 16x2 LCD screen that runs on 5V and has a contrast adjustment pin on the VEE provides real-time monitoring information.

In order to ensure smooth command execution and display updates, the LCD communicates with the microcontroller via specific control pins (RS, R/W, and Enable).

This integrated hardware configuration is appropriate for applications needing precise energy regulation because it guarantees effective power management, voltage stability, and real- time monitoring.

B. Software Development

The system incorporates a feedback control mechanism based on machine learning to regulate a DC-DC converter's duty cycle. A dataset (dataset.csv) with different duty cycle values (10, 50, 75, 100, 150, and 250) corresponding to various panel input conditions is used to train a K-Nearest Neighbors (KNN) model.

The knn.py script is first used to train the dataset, producing a trained model (model.sav) with a 91% accuracy rate. The final.py script then integrates this trained model with the hardware, guaranteeing real-time adjustments based on variations in the voltage of the solar panel. After retrieving input voltage values, the microcontroller calculates the ideal duty cycle for power transfer based on the prediction of the trained model. Stability and efficiency are ensured by the system's dynamic duty cycle adjustment based on available power. As a switching element, the Darlington transistor regulates power flow by turning on in accordance with the anticipated duty cycle. In order to ensure effective energy use from solar panels while maintaining a steady output, the software continuously monitors and controls voltage fluctuations.

RESULTS AND DISCUSSION

The suggested system uses a DC-DC converter and a machine learning-based feedback switching controller to efficiently stabilize the output voltage of a solar photovoltaic energy storage system. In reaction to changes in temperature and solar radiation, adaptive duty cycle control is ensured by the application of the K-Nearest Neighbors (KNN) algorithm. According to experimental results, the trained model optimizes the duty cycle based on real-time conditions and achieves an accuracy of 91%. Using a switching mechanism based on Darlington transistors, the system dynamically modifies power distribution to ensure effective energy use.

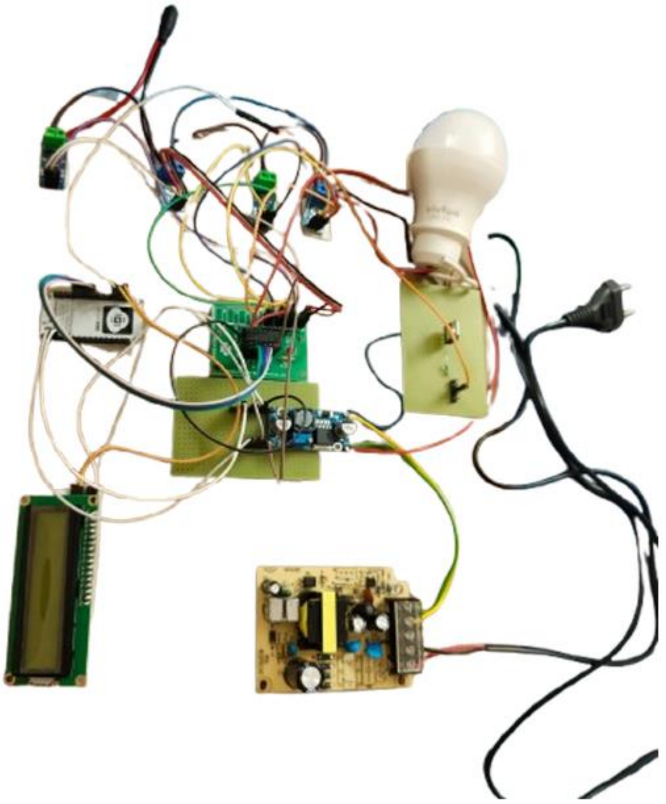

Figure 3 : Hardware

The duty cycle is lowered to minimize energy loss when there is enough solar power available, and it rises in proportion to lower irradiation levels. The stability and effectiveness of solar power generation and storage systems are improved by the machine learning model's ability to predict and control power distribution.

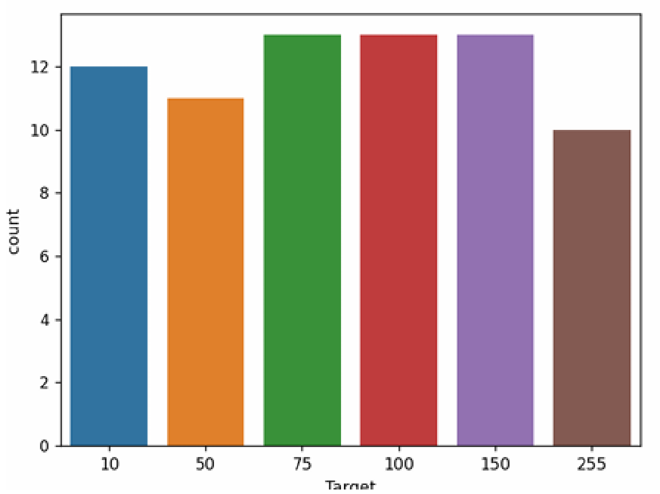

Figure 4 : Panel Input Stages

Depending on the amount of irradiation and power required, the solar panel runs in several stages. The panel first produces a baseline voltage that is continuously observed. The KNN algorithm is used to dynamically adjust the duty cycle of the DC-DC converter based on the amount of solar energy available. The panel provides enough voltage under high irradiation conditions, negating the need for further power adjustments. To compensate for the voltage drop and maintain a steady output under low irradiation conditions, the system raises the duty cycle. System efficiency is increased and energy distribution is optimized by this adaptive control mechanism.

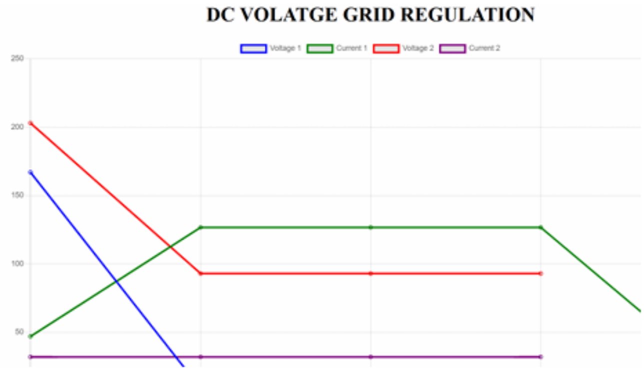

Figure 5 : Voltage Grid Regulation

Figure 6 : LCD Output

Real-time voltage readings are dynamically displayed on the LCD voltage output according to the load requirements and power generation of the solar panel. The LCD is initially blank when the system is turned on until a connection is made to the hardware. Once connected, it uses the duty cycle adjustments that the KNN algorithm determines to continuously update the voltage values (V1, V2). The output voltage is stable and requires little duty cycle adjustment when there is enough solar power available. To ensure accurate energy distribution monitoring, the system raises the duty cycle during low power conditions, and the LCD shows the corresponding voltage variations.

CONCLUSION AND FUTURE WORK

By using a machine learning-based feedback switching controller for a DC-DC converter, the suggested system efficiently controls variations in renewable energy. The system dynamically modifies the duty cycle using the K- Nearest Neighbors (KNN) algorithm to sustain a steady output voltage in spite of temperature and solar irradiation variations. Effective power distribution and optimal energy use are ensured by real-time monitoring via the LCD display.

Incorporating an adaptive control mechanism improves solar energy systems' performance and dependability, increasing their efficiency for real-world uses. This strategy shows how AI-driven solutions can stabilize renewable energy sources for environmentally friendly noawbelres management.ESP32 microcontroller seamless data acquisition and processing, ensuring quick response times to changes in solar input. Furthermore, the proposed system reduces dependency on external power sources, contributing to a more sustainable and self-sufficient energy infrastructure.

Future work on this project will concentrate on improving the system's efficiency and adaptability by incorporating cutting-edge machine learning models, like deep learning techniques, to increase the accuracy of voltage regulation. Real-time tracking and control of solar energy generation and consumption will be possible through the use of IoT-based remote monitoring. Energy distribution and storage can also be optimized by utilizing hybrid energy storage technologies like supercapacitors and lithium-ion batteries. Bidirectional energy flow will be made possible by connecting the system to a smart grid, which will enable the effective sharing of excess solar energy with the main power grid. Better energy management and stability for large-scale applications will also be ensured by employing predictive analytics to forecast variations in solar energy generation using historical weather and load data.

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