Mathematical Modeling and Algorithm Application
ISSN: 3006-0842 | Vol. 10, No. 1, 2026

Design of Intelligent Allocation Model for Electric Vehicle Charging Station Oriented to Teaching Demonstration

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Abstract: Aiming at the problems of abstract theories and insufficient physical teaching aids in the teaching of intelligent micro-grid and V2G technology for new energy and transportation majors in universities, a visual physical demonstration model for intelligent allocation of electric vehicle charging stations is designed in this paper. Two STC8 series single-chip microcomputers are adopted in the model to undertake main control and independent safety protection functions respectively. It integrates simulated photovoltaic power generation, dual energy-storage units, V2G bidirectional charging piles, simulated power grid and offline voice interaction module. According to illumination conditions and load status of charging piles, the system switches energy paths in accordance with the preset scheduling strategy matrix to realize the power distribution demonstration of each link of source-grid-load-storage, and possesses millisecond-level hardware protection and voice broadcast capability. The test results show that the model can reproduce multiple operating conditions such as sunny days, weak light and night. The output voltage of charging piles remains stable and protection actions are reliable. It can serve as a practical training carrier with observability, operability and measurability for relevant courses.

Keywords: Vehicle-to-Grid (V2G); Intelligent scheduling; STC8 single-chip microcomputer; Photovoltaic-storage-charging micro-grid; Experimental teaching model

1. Introduction

Driven by the "dual-carbon" strategy, intelligent connected new-energy vehicle technology has become a critical direction for the transformation and upgrading of the transportation sector.[1] The Catalogue of Vocational Education Majors (2025) issued by the Ministry of Education has added new specialty directions including new-energy vehicle intelligent technology, smart energy system, energy-storage technology and charging pile operation & maintenance. It requires colleges and universities to build intelligent charging and scheduling practical training platforms integrating visual display, on-site practical operation and simulation.[2] Nevertheless, most universities and vocational colleges still adopt outdated fixed charging pile teaching aids. Such devices generally lack functions of visual scheduling, intelligent power distribution and load regulation, and are obviously disconnected from the practical competence requirements of enterprises for posts such as smart charging, V2G and peak-valley dispatching.

Meanwhile, existing researches in the field of active distribution networks have constructed evaluation systems from three dimensions of source, grid and load, and proposed multi-stage optimal scheduling methods to cope with fluctuations caused by the large-scale integration of renewable energy and electric vehicles.[3] These studies provide a theoretical framework for charging station scheduling, yet appropriate carriers are still lacking to convert such theories into physically observable processes in teaching scenarios. Targeting this gap, this paper designs a low-cost, modular and detachable miniature intelligent charging station model, which transforms abstract scheduling logic into observable phenomena such as relay on-off actions, energy flow and voice feedback.

2. Model Function Orientation and Overall Architecture

2.1. Functional Requirements

Targeted at experimental teaching and popular science demonstration for majors of new energy, electrical engineering and transportation, the core objective of the model is to convert the energy distribution logic of "source-grid-load-storage" in intelligent micro-grids into manually operable physical processes. Specific functional requirements are as follows:

2.1.1. Multi-source collaborative scheduling

The system is connected with simulated photovoltaic power generation, Energy Storage A, Energy Storage B, simulated power grid and V2G charging piles. It dynamically switches energy transmission paths according to illumination signals and vehicle power consumption demands. Illumination acquisition is completed by GL5516 photoresistors, which output three statuses of 00, 01 and 11 after threshold discrimination, corresponding to sunny days, weak illumination and cloudy/nighttime respectively. Vehicle demands are simulated via two groups of TC620 capacitive keys. The main controller reads the scheduling strategy matrix and drives relays to realize operating conditions including photovoltaic priority grid-connection, photovoltaic direct power supply for vehicles, energy-storage power compensation and independent power supply by energy storage.

2.1.2. Demonstration of V2G bidirectional charging and discharging

In discharging mode, power from photovoltaic panels, Energy Storage A or the simulated power grid is stepped down to 5 V via DC-DC converter to supply power for simulated vehicles. In reverse mode, 5 V electric energy from vehicles

is boosted to 14.8 V through DC-DC converter to charge Energy Storage B, simulating the scenario where electric vehicles act as mobile energy-storage units to participate in power grid regulation. This function is the key feature that distinguishes the model from ordinary photovoltaic experimental boxes.

2.1.3. Independent safety protection

The protection circuit is independently constructed by STC8G1K08A, which does not rely on the main-control single-chip microcomputer. Its inputs include flame/smoke sensors and manual emergency-stop button, and its output directly controls the main relay. It will cut off the main power supply immediately upon abnormality to form safety redundancy independent of main-control software.

2.1.4. Voice interaction and status broadcast

Equipped with the ASR Pro offline voice chip, the model can broadcast real-time information including current illumination environment, vehicle demand and energy flow path. It can also respond to voice commands such as "Electricity price is quite low now, energy storage can be performed" to trigger charging of Energy Storage B by the simulated power grid or charging piles.

2.1.5. Visualization and modularization

Each energy unit reserves external interfaces. Relay switching status, battery charging-discharging status and energy direction of charging piles can be measured on site. The overall modular structure facilitates group debugging and fault troubleshooting.

2.2. System Architecture

The system is organized into perception layer, control layer, execution layer and human-computer interaction layer. The perception layer includes two GL5516 photoresistors, two TC620 capacitive keys, MQ-2 flame/smoke detection channel and manual emergency-stop button. The control layer consists of STC8H1K08 main-control single-chip microcomputer and STC8G1K08A protection single-chip microcomputer with physical isolation and separated responsibilities. The execution layer comprises 7-channel SRD-05VDC-SL-C relays and controlled objects including simulated photovoltaic power generation, Energy Storage A, Energy Storage B, V2G charging piles and simulated power grid. The human-computer interaction layer is the ASR Pro voice module.

3. Hardware Circuit Design

3.1. Central Control Module

STC8H1K08 is selected as the main-control chip to build a control system of "multi-input — table-lookup decision-making — relay output". Four key input signals are collected in real time: combined status of two photoresistors and status of two capacitive keys. The main loop runs every 100 ms to complete key debouncing, illumination sampling and voice-command reading. A 6-bit input signal is assembled to obtain outputs for 7-channel relays via table lookup, and 500 ms status anti-chattering is configured to avoid frequent operating-condition switching.

3.2. Simulated Photovoltaic Module

A 14.8 V adjustable power supply is adopted to simulate output characteristics of photovoltaic arrays. Two groups of photoresistors are deployed on its surface to perceive ambient illumination. The system identifies combined status of two photoresistors: 00 for sunny days, 01 for insufficient illumination, and 11 for cloudy days or nighttime, so as to dynamically simulate output fluctuation of photovoltaic power generation and restore the correspondence between illumination intensity and generating power.

3.3. Energy-storage Module

Two groups of 12 V lithium-battery modules are configured to form a dual-energy-storage collaborative architecture. Energy Storage A mainly receives electric energy from photovoltaic power generation for local storage, and can supply power to the load terminal of V2G charging piles according to scheduling demands. Energy Storage B supports multi-channel bidirectional energy storage. It can be supplemented with energy via the simulated power grid or receive electric energy from vehicles through the V2G reverse discharge link, undertaking functions of backup power supply and peak-load shifting.

3.4. V2G Bidirectional Charging-pile Module

As the core innovation point, two links for charging and discharging are set. The discharge link integrates photovoltaic power generation, Energy Storage A and simulated power grid, and steps down voltage to 5 V via DC-DC converter to charge simulated vehicles. The charging link receives 5 V electric energy from vehicles and boosts it to 14.8 V through DC-DC converter to charge Energy Storage B, simulating the V2G bidirectional interaction process.

3.5. Simulated Power-grid Module

DC-DC boost and DC-AC-DC bidirectional conversion links are built to realize energy interaction between the simulated power grid and the internal DC bus of the system, reproducing access and output logic of real power grids.

3.6. Independent Safety-protection Module

Independent of the main controller, STC8G1K08A polls flame sensors and emergency-stop buttons at 200 μs, with external interrupt configured as redundancy. Once a fault is detected, the main power supply is cut off immediately and locked. The system is allowed to restore power supply only when three conditions are met simultaneously: fault elimination, emergency-stop button release and reset-button pressing.

4. Scheduling Strategy Design

4.1. Main-controller Program Flow

After power-on, the main-control chip completes initialization of GPIO, timer and ASR Pro voice module, and all relays are disconnected by default. The main loop is executed every 100 ms. It reads signals from two charging-pile keys, two illumination photoresistors and two voice commands to assemble a 6-bit input signal, and obtains outputs for 7-channel relays by table lookup. After operating-condition switching, codes are sent through serial port to trigger synchronous voice broadcast.

4.2. Scheduling Strategy Matrix

The scheduling table is stored in the Flash of the single-chip microcomputer, featuring fast table-lookup speed to satisfy real-time demonstration requirements. Table 1 presents typical operating conditions without voice

commands. Among input signals, K1 and K2 denote charging-pile keys, L1 and L2 denote illumination signals. The outputs control 7 relays corresponding to photovoltaic power generation, Energy Storage A, Energy Storage B, simulated power grid and V2G charging-discharging paths respectively.

Table 1 Typical operating-condition scheduling strategies (without voice commands)

No.	K1	K2	L1\L2	Operating Condition	Status of Path 1-7	Energy Flow Direction
1	0	0	00	Sunny day, no vehicle	1011000	Photovoltaic power charges Energy Storage A and B
2	1	1	00	Sunny day, one vehicle	1001010	Photovoltaic power supplies charging pile, residual power charges Energy Storage B
3	1	0	01	Sunny day, two vehicles	1100010	Photovoltaic power and Energy Storage A jointly supply charging pile
4	0	0	01	Cloudy day, no vehicle	0001100	Grid valley-period electricity charges Energy Storage B
5	1	0	01	Cloudy day, one vehicle	0100110	Power grid and Energy Storage A jointly supply charging pile
6	1	1	01	Cloudy day, two vehicles	0100110	Power grid as main source, Energy Storage A for peak compensation
7	0	0	10	Nighttime, no vehicle	0000100	System standby, power grid on standby
8	1	0	10	Nighttime, one vehicle	0100110	Power grid and Energy Storage A supply charging pile
9	1	1	10	Nighttime, two vehicles	0100110	Power grid as main source, Energy Storage A for peak compensation

Voice commands have high priority. Commands such as valley-period electricity energy storage, V2G reverse power supply and system standby will forcibly rewrite relay outputs and overwrite table-lookup results.

4.3. Protection-program Flow

Physically isolated from the main controller, the protection single-chip microcomputer polls flame sensors and emergency-stop buttons at 200 μs, with external interrupt as redundancy. Upon fault detection, it cuts off the main power supply and implements self-locking. Repowering is permitted only after fault elimination, emergency-stop button release and reset-button pressing.

5. System Test and Result Analysis

5.1. Test Environment and Methods

The prototype is tested in the embedded laboratory of Wanjiang University of Technology. Test instruments include oscilloscope, digital multimeter, DC electronic load and flame simulator. Table lamps and hoods are used to simulate different illumination conditions, keys simulate vehicle loads, and human voices send voice commands. Each operating condition is repeated 10 times to record voltage and relay actions. Each group of safety-protection tests is repeated 20 times.

5.2. Multi-operating-condition Functional Test

In order to test the actual operation effect of the model's multi-source collaborative scheduling, V2G two-way interaction, voice command response and other functions, the combination of lights and shades are used to simulate different lighting conditions, and the capacitor button simulates the electric vehicle's access to the load, and offline voice control instructions are issued at the same time. Repeatedly carry out 10 groups of experiments for each test condition, collect the output voltage of the charging pile and the voltage of the energy storage busbar, count the correctness of the execution of the working condition, and obtain the test results of multiple working conditions, as shown in Table 2.

Table 2 Multi-operating-condition test results

No.	Operating Condition	Charging-pile Voltage/V	Energy-storage Bus Voltage/V	Accuracy	Test Conclusion
1	Sunny day, no vehicle	—	14.8	10/10	Energy storage is charged under normal illumination
2	Sunny day, one vehicle	5.02	14.7	10/10	Photovoltaic power directly supplies charging pile
3	Sunny day, two vehicles	5.01	12.6	10/10	Photovoltaic power and energy storage jointly perform charging
4	Cloudy day, no vehicle	—	14.9	10/10	Power grid realizes valley-period electricity energy storage
5	Cloudy day, one vehicle	5.03	12.5	9/10	Joint power supply for charging pile, occasional misjudgment of illumination threshold
6	Cloudy day, two vehicles	5.02	12.4	9/10	Power grid as main source, energy storage supplements energy
7	Nighttime, no vehicle	—	—	10/10	System standby works normally
8	Nighttime, one vehicle	5.01	12.5	10/10	Power grid and energy storage jointly supply charging pile
9	Nighttime, two vehicles	5.02	12.4	9/10	Power grid as main source, energy storage performs peak compensation
10	Voice command for valley-period energy storage	—	14.8	9/10	Voice control works normally
11	Voice command for V2G reverse operation	5.00	14.7	8/10	Recognition accuracy drops slightly under noisy environment
12	Voice command for standby	—	—	10/10	All loops are disconnected

The output voltage of charging piles remains stable and the overall scheduling logic conforms to design requirements. Minor faulty actions occur at illumination critical points and under noisy conditions

5.3. Safety-protection Test

The system adopts a dual single-chip computer architecture, and the STC8G1K08A single-chip computer independently realizes the fault protection logic, which is not affected by the operation status of the main control program. In order to evaluate the safety protection performance, the functions of flame sensing fault triggering, manual emergency stop cut-off, and power-on recovery after failure were tested respectively. Each group of experiments was repeated 20 times, and the protection response time and execution success rate were counted. The test results are shown in Table 3.

Table 3 Safety-protection test results

Test Item	Average Response Time/ms	Maximum Response Time/ms	Success Rate
Flame-sensor triggering	18.6	24.3	20/20
Manual emergency-stop triggering	12,4	15,1	20/20
Fault recovery and reset	-	-	20/20

All protection actions are completed within 25 ms. Reliable self-locking is realized after faults, independent of main-control program failures.

5.4. Result Analysis and Deficiencies

The prototype operates stably for 72 consecutive hours. Charging-discharging chips maintain batteries within safe voltage range. Charging-pile voltage features high precision. Photoresistor thresholds are prone to chattering, and ambient noise reduces voice-recognition accuracy. Teaching-oriented visual demonstration can be completed by indicator lights and voice broadcast.

Deficiencies to be improved include: adding hysteresis filtering in software to mitigate photoresistor chattering; enabling bidirectional discharge function of Energy Storage B; adding Internet-of-Things module for data cloud uploading; introducing simple load-prediction algorithm to replace fixed table-lookup strategy. Subsequent upgrades will be completed via PCB revision and ESP8266 module deployment.

6. Conclusion

Aiming at the shortage of teaching carriers for intelligent micro-grid and V2G courses for transportation, new-energy and electrical majors under the "dual-carbon" strategy, this paper completes the design, construction and test of a visual physical demonstration model for intelligent allocation of electric vehicle charging stations. Taking STC8H1K08 as the main-control core and STC8G1K08A for independent protection channel, the system integrates simulated photovoltaic power generation, dual energy-storage units, V2G bidirectional charging piles, simulated power grid and ASR Pro voice interaction module. It converts energy flow of "source-grid-load-storage" into observable, operable and measurable physical processes.

Four major innovations are reflected in this design. First, the dual-single-chip-microcomputer structure with separated main control and protection realizes redundancy of "control for operation, independent safety guarantee" at low cost. Second, V2G bidirectional charging-discharging is transformed into observable physical process, making up for the deficiency of ordinary photovoltaic experimental boxes that only support unidirectional demonstration. Third, complex micro-grid scheduling is transformed into a modular, detachable and measurable teaching model, helping students understand energy flow and relay logic. Fourth, offline voice broadcast and command control are introduced to provide real-time feedback for abstract operating-condition changes.

It should be noted that the value of this model lies not in pursuing industrial-grade power, but in converting abstract scheduling theories into observable, measurable and controllable teaching processes. Restricted by time and physical device conditions, the current model still has room for improvement. Photoresistors are prone to chattering at illumination critical points, and ambient noise impairs voice-recognition accuracy. Energy Storage B has not fully supported bidirectional discharge yet. The scheduling strategy mainly relies on fixed table-lookup method, and the system lacks networking and data accumulation capabilities. Follow-up researches will focus on hysteresis filtering, bidirectional-discharge expansion, Internet-of-Things access and load-prediction algorithms.

Acknowledgements

This work is supported by College Students' Innovation and Entrepreneurship Training Program of Wanjiang University of Technology (Grant No. 202614203070).

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