Design and Simulation of Improved Fast Charging Technique for Modern Electric Vehicle

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Abstract: The design and development of the electric vehicle charging station presented in this study offer a universal solution compatible with a broad spectrum of modern EVs, emphasizing that successful real-time integration depends heavily on the strategic availability and seamless accessibility of the infrastructure within urban environments. By navigating the complexities of diverse charging standards, multi-level power delivery, and advanced control strategies, the research introduces a sophisticated "e-storage" paradigm where the grid doesn't just deliver power but actively manages and optimizes battery health through intelligent oversight. The transition from a passive power outlet to an active, rule-based modeling system demonstrates how charging behavior can be synchronized with grid demands to reduce charging times and prevent system strain. Ultimately, the findings validate the technical viability and immense potential of this suggested framework, proving that an integrated, high-efficiency charging ecosystem is not only a theoretical model but a practical necessity for the sustainable evolution of global transportation.

Keywords— Charger, Charging Station, Charging systems

1. INTRODUCTION

1.1 GENERAL

The primary technological bottleneck hindering the widespread adoption of electric vehicles lies in the challenge of facilitating safe and efficient rapid charging for lithium-ion batteries. As battery capacities grow larger to meet consumer demand for longer range, standard DC charging technologies face new hurdles in balancing speed with battery longevity; however, modern advancements are successfully shortening these traditional charging windows. Guided by the SAE J1772 standard, which categorizes three distinct levels of DC fast-charging for off-board equipment, the industry is shifting toward a more holistic infrastructure. This evolution necessitates the integration of renewable energy sources and advanced energy storage systems to manage the intense power loads required during the charging and discharging cycles. At its core, the charging mechanism functions by precisely regulating voltage and current through sophisticated controllers to deliver optimal power tailored to the battery's specific chemistry. By establishing universal charging stations capable of supporting a diverse array of manufacturers and battery capacities, the industry can guarantee the dependability and accessibility needed to significantly boost global EV demand.

Electric vehicles are increasingly becoming vital. As the number of electric vehicles rises, charging electric vehicles is becoming increasingly significant. Constructing an electric vehicle charger and starting a design without prior knowledge of charging technologies is difficult. We are consistently lagging in our efforts to develop innovative charging technologies or technical knowledge as technologyprogresses. To facilitate its implementation and encourage further research on the topic, this paper proposes and develops a design model with simulation of an electric vehicle charging station for charging systems. When developing charging stations, charging systems consider power source interfaces, communication protocols, and certification of the charging facility that meets regulatory and regional compatibility criteria.Quick charging solutions for electric vehicles are rapidly evolving in reaction to the growing demands of the industry. This approach thoroughly examines various fast charging techniques, innovative infrastructure, management systems, specific challenges, and potential future developments in fast charging for electric vehicles (EVs).

1.2 ELECTRIC VEHICLES

Transmissions are used to transfer electricity from a battery pack to an electric motor in most EVs, which then provides the vehicle's traction power [8]. A battery charger, which gets its juice from somewhere else like the electrical grid, is largely responsible for recharging the batteries. When the vehicle's speed is reduced by using regenerative braking, the motor doubles as a generator, feeding energy back into the batteries [9-12]. A major benefit of EVs is their simple, low-parts-count architecture. The biggest drawback is that the driving range is limited by the size of the battery, and recharging the battery may take anywhere from 15 minutes to 8 hours, depending on the previous drive's distance, the kind of battery used, and other factors. and battery charging method [13].

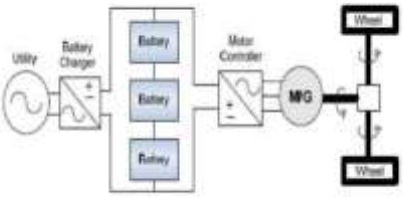

Figure 1: Typical EV configuration

1.3 PLUG-IN VEHICLES:

Over 40% of U.S. producing capacity works at decreased load overnight, and most PHEVs may be recharged during these off-peak hours, as reported by the Electric Power Research Institute (EPRI) [14]. Recent research shows that replacing half of the cars on the road with PHEVs by 2050 will only need an 8% increase in electricity output (a 4% increase in capacity) [15]. Many modern plug-in electric cars include their own on-board battery chargers that may be used to recharge the vehicle's batteries from a standard wall outlet. Plug-in electric vehicles (PEVs) are seen in their most basic form in Fig. 1. Power is supplied from the battery pack through the motor controller to the motor, which in turn drives the wheels. Many modern electric vehicles have a permanent magnet electric motor that doubles as a generator to keep the batteries charged. In regenerative braking, the motor is reversed so that it generates electricity to charge the vehicle's batteries as it slows down. When stopping the car rapidly is necessary or the batteries are fully charged, friction brakes are deployed. Electric batteries, a motor controller, a motor/generator, an internal combustion engine, a transmission, and a driveline are the main parts of a typical HEV.

The permanent magnet motor receives threephase power from the main power electronics, which consist of a DC-AC motor controller. In Fig. 2, we see the Toyota Prius in its HEV version. Two permanent magnet motor/generators, one 10kW and one 50kW, are used in the Prius's architecture. In order to power the motors and generators, the battery is hooked up to a booster and an inverter. The power electronics may both charge the battery and provide power to the motors. A planetary gear system receives power from the gasoline engine and motor/generators. Transmission ratio is dynamically set by power flow between the battery, motor/generators, and gasoline engine in a continuously variable transmission (CVT) mode [16]. Battery power may be replenished by regenerative braking of the massive motor/generators. The battery packs cannot be charged via an external source. In order to keep the batteries of a plug-in hybrid EV charged, the vehicle must sit idly for long periods of time. Typically, this is accomplished by utilising a utility-connected AC-DC converter to draw DC power from the grid. A DC-DC converter can be used to charge the batteries directly from a solar resource, and an AC-DC converter can be used to charge the batteries from a wind resource. As power is drawn from the grid in order to replenish the batteries, there is no two-way exchange of energy.

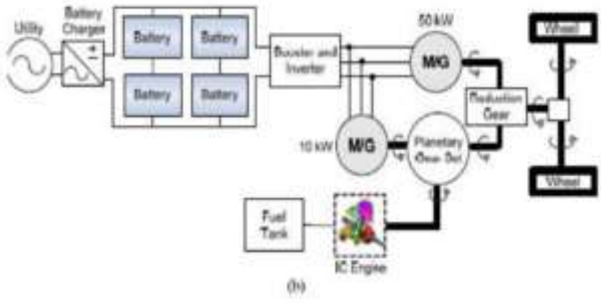

Figure 1.2: Configurations converted PHEV

2. Converters

2.1 Ac- Dc Converter (Rectifier)

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which is in only one direction, a process known as rectification. Rectifiers have many uses including as components of power supplies and as detectors of radio signals. Rectifiers may be made of solid state diodes, vacuum tube diodes, mercury arc valves, and other components.

When only one diode is used to rectify AC (by blocking the negative or positive portion of the waveform), the difference between the term diode and the term rectifier is merely one of usage, i.e., the term rectifier describes a diode that is being used to convert AC to DC. Almost all rectifiers comprise a number of diodes in a specific arrangement for more efficiently converting AC to DC than is possible with only one diode. Before the development of silicon semiconductor rectifiers, vacuum tube diodes and copper (I) oxide or selenium rectifier stacks were used.Early radio receivers, called crystal radios, used a “cat’s whisker” of fine wire pressing on a crystal of galena (lead sulfide) to serve as a point-contact rectifier or “crystal detector”. Rectification may occasionally serve in roles other than to generate direct current per se. For example, in gas heating systems flame rectification is used to detect presence of flame. Two metal electrodes in the outer layer of the flame provide a current path, and rectification of an applied alternating voltage will happen in the plasma, but only while the flame is present to generate it.

2.1.1 HALF-WAVE RECTIFICATION

In half wave rectification, either the positive or negative half of the AC wave is passed, while the other half is blocked. Because only one half of the input waveform reaches the output, it is very inefficient if used for power transfer. Half-wave rectification can be achieved with a single diode in a one-phase supply, or with three diodes in a three-phase supply.

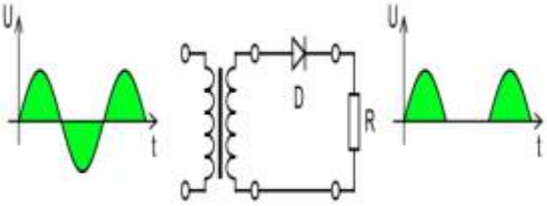

Fig.2 Half wave rectification

The output DC voltage of a half wave rectifier can be calculated with the following two ideal equations:

$$V_{rms} = \frac{V_{peak}}{2}$$

$$V_{dc} = \frac{V_{peak}}{\pi}$$

2.1.2 FULL-WAVE RECTIFICATION

A full-wave rectifier converts the whole of the input waveform to one of constant polarity (positive or negative) at its output. Full-wave rectification converts both polarities of the input waveform to DC (direct current), and is more efficient. However, in a circuit with a non-center tapped transformer, four diodes are required instead of the one needed for half-wave rectification. (See semiconductors, diode). Four diodes arranged this way are called a diode bridge or bridge rectifier.

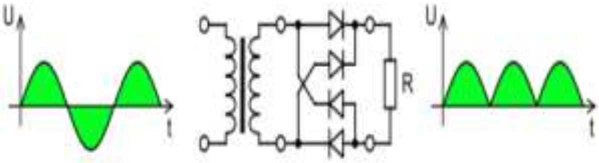

Fig.2.1 Full-wave rectifier using 4 diodes.

For single-phase AC, if the transformer is center-tapped, then two diodes back-to-back (i.e. anodes-to-anode or cathode-to-cathode) can form a full-wave rectifier. Twice as many windings are required on the transformer secondary to obtain the same output voltage compared to the bridge rectifier above.

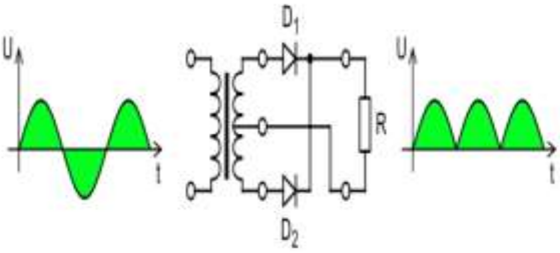

Fig.2.2 Full-wave rectifier using a center tap transformer.

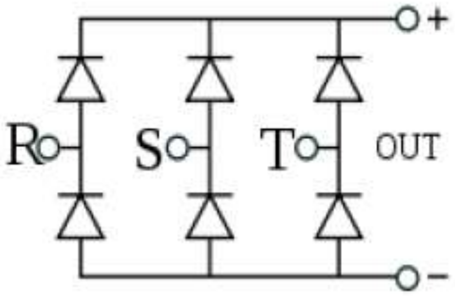

Fig.2.3 A three-phase bridge rectifier.

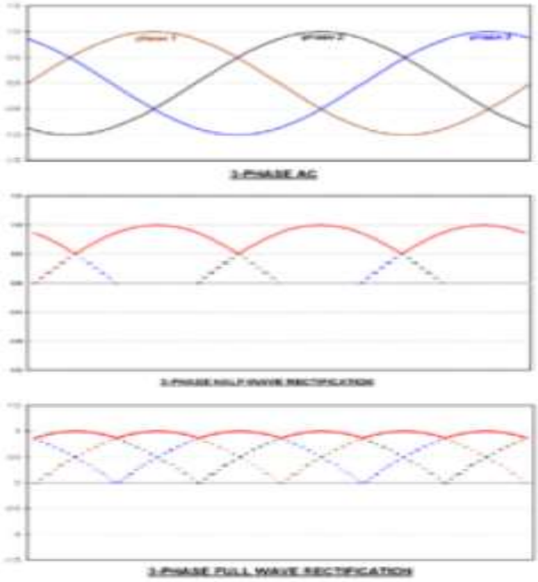

Fig.2.4-phase AC input, half & full wave rectified DC output waveforms

For three-phase AC, six diodes are used. Typically there are three pairs of diodes, each pair, though, is not the same kind of double diode that would be used for a full wave single-phase rectifier. Instead the pairs are in series (anode to cathode). Typically, commercially available double diodes have four terminals so the user can configure them as single-phase split supply use, for half a bridge, or for three-phase use.Most devices that generate alternating current (such devices are called alternators) generate three-phase AC. For example, an automobile alternator has six diodes inside it to function as a full-wave rectifier for battery charging applications.

The average and root-mean-square output voltages of an ideal single phase full wave rectifier can be calculated as:

$$V_{dc} = V_{av} = \frac{2V_p}{\pi}$$

$$V_{rms} = \frac{V_p}{\sqrt{2}}$$

Where

V_{dc}&V_{av} –the average and DC output voltage.
V_p - the peak value of half wave.
V_{rms} - the root-mean-square value of output voltage.

2.2 DC- AC CONVERTER (INVERTER)

An inverter is an electrical device that converts direct current (DC) to alternating current (AC); the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits.Solid-state inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries.There are two main types of inverter. The output of a modified sine wave inverter is similar to a square wave output except that the output goes to zero volts for a time before switching positive or negative. It is simple and low cost (~$0.10USD/Watt) and is compatible with most electronic devices, except for sensitive or specialized equipment, for example certain laser printers. A pure sine wave inverter produces a nearly perfect sine wave output (<3% total harmonic distortion) that is essentially the same as utility-supplied grid power. Thus it is compatible with all AC electronic devices. This is the type used in grid-tie inverters. Its design is more complex, and costs 5 or 10 times more per unit power (~$0.50 to $1.00USD/Watt). The electrical inverter is a high-power electronic oscillator. It is so named because early mechanical AC to DC converters was made to work in reverse, and thus were“inverted”, to convert DC to AC.The inverter performs the opposite function of a rectifier.

3. MATLAB & SIMULATION RESULTS

3.1 SIMULATION CIRCUITS

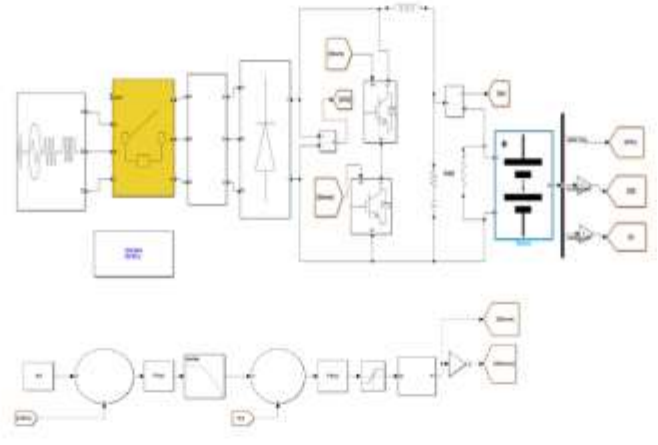

Fig.3.1 simulatioin circuit

1. AC Power Source & Input Stage: The process begins on the far left with a Three-Phase AC Source representing the utility grid. This flows through a Three-Phase Breaker/Switch and an

2. LCL filter or transformer block (the white rectangular blocks) to stabilize the signal and mitigate harmonics before rectification.

3. Rectification: The Three-Phase Diode Bridge Rectifier (the triangle symbol in the center) converts the AC input into a raw DC voltage (V_{DC}).

4. Bidirectional DC-DC Converter: This is the core of the system, utilizing two IGBT/Diode switches configured for Buck and Boost operations.

5. Buck Mode (Charging): The top switch (S_{buck}) steps down the rectified DC voltage to the specific level required by the battery.

6. Boost Mode (Discharging/V2G): While primarily used for charging here, this topology allows the battery to push power back if configured for Vehicle-to-Grid (V2G) applications.

7. Filter & Load: An Inductor (L) and RL Load filter the high-frequency switching noise to provide a smooth current (i_{dc}) to the energy storage element.

8. Battery Storage & Monitoring: The system terminates at the Battery Block. The output bus on the right monitors three critical parameters:

9. SOC: State of Charge (percentage of energy remaining).

10. VB: Battery Voltage.

11. Current/Voltage(b): Real-time power flow measurements.

3.2 CONTROL ALGORITHM

The control algorithm for the charging station is a Cascaded Dual-Loop Control System. This architecture is specifically designed to manage the DC-DC converter by regulating both voltage (outer loop) and current (inner loop).

1. Outer Voltage Control Loop:The process starts on the left with the Voltage Reference (VDC_Ref}) set to a constant value (e.g., 50V).

- Error Detection: The actual measured voltage (Vdc) is subtracted from the reference.
- PI Controller: The resulting error is processed by a Proportional-Integral (PI) controller, which generates a current reference signal (I_ref}).
- Filter: This signal passes through a low-pass filter to smooth out high-frequency noise before becoming the target current for the battery (Ib_ref).

2. Inner Current Control Loop This loop is responsible for the "real-time" dynamics of the charging process.

- Error Detection: The target battery current (Ib_ref) is compared against the actual measured battery current (Ib).
- PI Controller: A second PI controller processes this current error to determine the necessary control action.
- Saturation Block: The output passes through a saturation block to ensure the control signal stays within safe physical limits (preventing over-modulation).

3. PWM Signal Generation

- PWM Generator: The finalized control signal enters a Pulse Width Modulation (PWM) block (the D to P block), which converts the analog control value into a high-frequency digital switching signal.
- Complementary Switching: To prevent a short circuit (shoot-through) in the Buck-Boost converter:
    - One signal goes directly to Switch_2 (Boost).
    - An inverted signal (via the NOT gate) goes to Switch_1 (Buck).

3.3 RESULTS AND DISCUSSION

The simulation outcomes detailed here focus on the implementation of pulse-width modulation techniques to manage both current and voltage within a Level 2 charging environment. This approach allows for a granular level of control over how energy is transferred from the infrastructure to the electric vehicle's battery system.By utilizing a 22 kW power capacity, the study effectively evaluates how a high-output Level 2 station performs under real-world conditions. The assessment specifically looks at two critical factors: how the station governs the draw from the electrical grid and the resulting physical state of the battery during the charging cycle.

The data gathered from the simulation shows a consistent and healthy upward trend in the battery's charge status. Starting from an initial State of Charge (SOC) of 50 percent, the system was monitored continuously to ensure a stable progression as it moved toward a full charge.

Throughout the test, the percentage of the vehicle's battery was carefully tracked as it climbed from the 50 percent mark to 100 percent. This observation confirms that the control logic remains stable across the entire upper half of the battery's capacity, which is often where thermal management becomes most critical.

By employing this specific pulse-width modulation strategy, the research has successfully modeled what can be considered an "ideal" charger. The system ensures that the input port provides a steady flow of electricity, adhering strictly to the Constant Charging Current parameters defined in the setup.

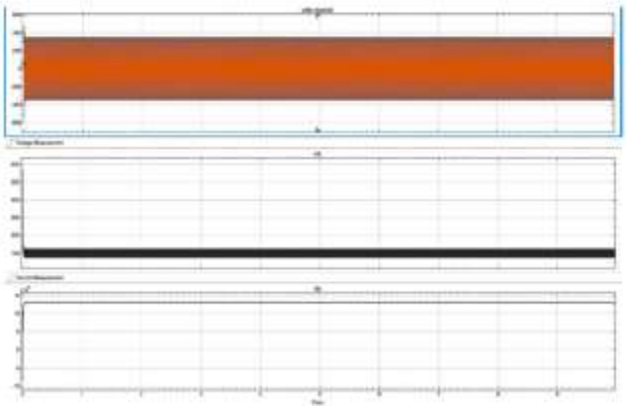

Fig 3.2: Simulation Results -Grid Scope

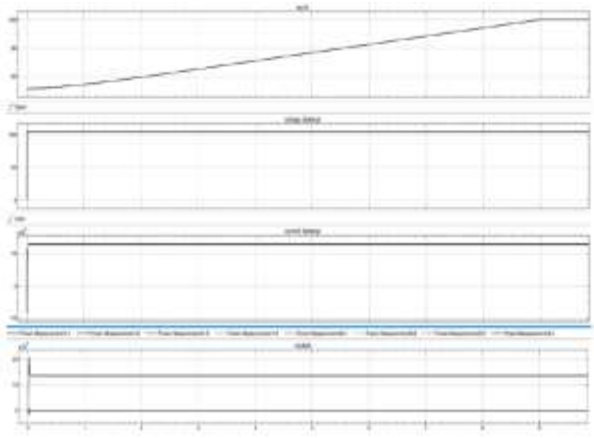

Figure 3.3: Simulation Results -Battery Scope

This steady flow continues until the system detects a "rising edge," indicating that the voltage has reached or exceeded the designated Voltage Threshold. Once this limit is sensed, the controller intelligently adjusts to maintain the constant charging level, ensuring the battery reaches its maximum capacity without overstressing the internal cells.

4. CONCLUSION

This research work presents a comprehensive model of a modern charging station, detailing each individual component alongside its specific operational parameters. To provide a complete picture of the hardware's performance, a sophisticated control system has also been integrated into the design. To facilitate further academic or practical investigation into this field, the modeling process is explained in an instructive, step-by-step manner.

The actual implementation of the model was conducted using MATLAB/Simulink and Sim Power Systems. This technical breakdown includes an explanation of the core simulation elements, such as the specific time steps used and the pulse width modulation (PWM) technique employed. Features like reactive power adjustment and Grid-to-Vehicle (G2V) compatibility were core priorities built directly into the charging station concept.

To test the design in a high-demand scenario, a realistic simulation of a 22-kilowatt charging station capable of supporting three electric vehicles simultaneously was created. The experiment confirmed that the station could effectively charge multiple vehicles at once without compromising performance. Based on these simulation results, the station demonstrates appropriate dynamic behavior, proving its stability under changing loads. Ultimately, this study serves as an introduction to the emerging trends in fast-charging station design specifically tailored for the infrastructure of future smart cities.

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