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Design And Implementation of Power Quality Management in Ev Chargers Using Power Charge Pro Converter

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Abstract: One of the significant elements of the implementation and utilization of electric vehicles (EVs) is the establishment of charging stations. In this research, the researchers present an advanced power converter meant for on board EV battery chargers that is capable of taking a universal. The proposed converter is to be implemented to reduce the total harmonic distortion of the supplied current, correct the power factor, and maintain accurate regulation of the output voltage. This study is to suggest and construct a converter for power that will effectively minimize the THD in the supply current since power quality is a critical component in the effectiveness of on-board EV battery chargers. The aim of this work is to improve power quality by eliminating the three-level Direct current (DC)-DC single-ended primary-inductor converter (SEPIC) converter in the EV chargers and replacing with the Power Charge Pro converter. First, the charger model for the Two-Wheeler EV Simulink was created to begin with and it is incorporated on-board. Next, it should involve creating a prototype of the "Power Charge Pro converter" based on the simulated design. Subsequently, an assessment of power quality factors comprising total harmonic distortion and power factor is performed. Subsequently, tuning the control converter and its parameters continues in an attempt to enhance the efficiency of the entire converter. Here, we employ MATLAB/Simulink simulation models to develop models for the proposed converter design and its simulation. The performance should therefore be measured using parameters like; Total Harmonic Distortion Percentage (THD) (2.78 %), efficiency (97.75 %), Switching Losses (1.32 W), and Voltage Stress (225 volts). The conceived power converter seems to provide a solution superior to those currently employed in electric vehicle on board battery chargers because it boasts of having solutions for some main issues affecting the systems, hence creating a platform for higher efficiency in on board chargers and other improvements in EV charging stations.

Keywords: *Charging infrastructure, electric vehicles (EVs), power converter, on-board charger, total harmonic distortion (THD), power factor correction, output voltage regulation, Power Charge Pro converter*

INTRODUCTION

The market for electric vehicles (EVs) is quickly expanding globally, and integral charging networks are required to enable its expansion. The charging stations for EVs are crucial components to bring about a change and help in avoiding range anxiety amongst other things. Some of the findings include that charging has been highlighted as the most critical issue that continues to affect the usage of electric vehicles through constraints placed on charging networks by policymakers [1]. These can be divided into many kinds of chargers based on the usage, such as the AC Level 1 and 2 chargers for residential and commercial use and the DC fast chargers for the fast-charging demands [2]. Nevertheless, some barriers include; Grid constraints in terms of their capacity and availability of charging stations which is a limiting factor [3]. Challenges such as limited EV range and charging infrastructure density require the use of ground-breaking innovations like advanced power converters and smart grid solutions.

Electricity quality affects the effectiveness and availability of EV charging systems. A high-power quality also avoids wasting energy, ensures that there is no harm to the equipment, and increases energy transfer efficiency [4]. The major parameters like, total harmonic distortion and power factor directly affect the charger and its performance. High THD levels in supply currents cause more heating, less efficiency, and equipment damage [5]. Further, low power factor is a potential threat to electric power systems because it puts pressure on electrical systems and causes higher costs of operation. Solving these problems with high-level power quality management systems, such as Antigen presenting cells (APC) and THD is necessary [6]. Improving power quality does not only address the issue with chargers but also helps to maintain the stability of the grid as well as increase the capabilities for accommodating more

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renewable energy resources [7]. It is important that power quality management in EV charging infrastructure is well managed to enhance sustainable and reliable transportation.

The integration of these technologies promises to enhance the efficiency and reliability of EV charging but also supports the broader goals of reducing greenhouse gas emissions and achieving energy sustainability. By improving the infrastructure that supports EV adoption, we might accelerate the shift of the world's transportation system to one that is more sustainable and cleaner. The objective of our paper is to develop and evaluate the Power Charge Pro converter for on board EV battery chargers, aiming to enhance power quality by reducing THD and improving efficiency.

RELATED WORK

Vehicle-to-grid (V2G) mode was the main topic of discussion in the article [8] on utilized EVs in DC charging stations. To regulate grid power, maintain battery safety, and combine EV batteries with additional energy storage devices, a board with a state-of-charge (SOC) balanced method was suggested. The controller design underwent testing in several scenarios, demonstrating its effectiveness in offline simulation and controllers-hardware-in-loop implementation.

To examine the fact that the charging and discharge control over the aggregated EV groups helps in the V2G system of frequency regulation, the study [9] created a power grid model that involved a lot of Photo voltaic (PV) power and conducted numerical tests using the time series data. According to the findings, there were clear suggestions for designing stations for charging and strategies for charging and discharging of EVs between transport and power sectors, and these problem areas have led to better communication and integration.

As for the one-stage on board charger, the article [10] offered greater voltage charging and reversible operation; they also recommended running the motor and traction inverter. Tests that were carried out on the prototype proved that it was capable of functioning at 19. 2 kW when supplied by a 110 kW EV motor and two inverters, with peak efficiency greater than 97% in a real-world scenario, proving the viability of integrated charging in functioning conditions.

A new concept of a V2V charging system was proposed in the paper [11]. It involved joining two EV batteries together using type-2 AC charger input ports and switches. The reduced duplication of power conversion and the associated losses led to an overall enhancement of V2V efficiency. An efficient energy-sharing study amongst EVs was demonstrated by the validation of the suggested technique using a scaled experimental prototype. In comparison to the off-board power-sharing interfaces now in use, the suggested solution proved more effective.

Robust controllers were necessary for load frequency management in complicated, unpredictable power systems, according to the research [12]. For thermal and hydrothermal systems, a brand-new, ideal cascade fuzzy-fractional order integral derivative with filter (CF-FOIDF) controller was employed. To reduce system frequency fluctuations, EVs were employed as energy storage systems. To test the control approach, simulations were run after a composite model of EV fleets was incorporated into control zones.

For fuel cell/battery-based hybrid EVs, the research [13] suggested a real-time energy management system (EMS) aimed at minimizing costs. A multi-objective cost function was used in the approach to account for both hydrogen consumption and energy source degradation. Power-splitting decisions were optimized by the application of dynamic programming. By comparing the technique to a rule-based benchmark, a comparative analysis showed that it was beneficial for lowering operating expenses. Also confirmed the online calculation time of the method.

An effective Energy Management System (EMS) for a four-wire, 1000 kW micro grid system that combines solar and wind farms was given in the paper [14]. The power of PV arrays was, tracked using a hybrid optimization method to determine their highest power under different weather conditions. Validated by Hardware-in-Loop (HIL) for the system’s genuineness and backed up by a TS-Fuzzy-based controller to ensure power quality. The efficient usage and reliable client support of renewable energy resources were assured with that technique.

Regarding fuel cell EVs, a novel EMS based on predictive control was introduced in the study [15]. Among them, it incorporated an adaptive battery

SOC reference generator as well as a cooperative speed forecasting method. In urban-based postal delivery missions, the method might save over 3.79% on hydrogen usage and decrease fuel cell power dynamics by 40.04%. It was suited for practical use since the predictive energy management was resistant to inaccuracies in trip time prediction.

METHODOLOGY

The methodology section consists of three steps, designing the charger, creating a prototype, and adjusting control circuits and conditions. The first phase involves Designing on-board charger for two-wheeler vehicles. The second phase focuses on creating a specific prototype, like the "Power Charge Pro converter", to maximize converter performance. In the third phase, fine-tune control parameters. The overall flow is depicted in Figure 1.

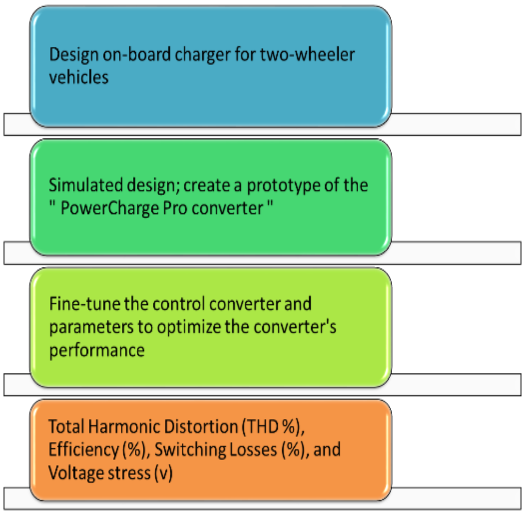

Figure 1: Overall process

On-Board Charger for a Two-Wheeler EV Simulink Model

This is a comprehensive simulation model created to optimize the charging process for EVs. It combines components including alternative current (AC)-DC converters, Battery Management System (BMS), and power electronics to provide effective energy transmission and management. This model provides a virtual platform for creating and testing charging plans for two-wheeler EVs. Figure 2 demonstrates the block diagram of the on-board charger for a two-wheeler EV model.

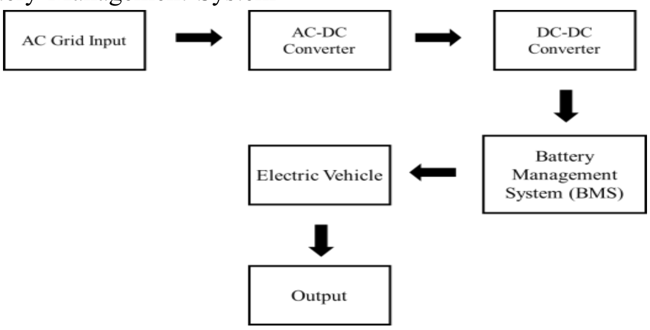

Figure 2: Block Diagram of On-board Charger

AC Grid Input: The on-board EV chargers' major power source is the AC Grid output that comes from an external battery charging station or normal power outlet. It is mathematically expressed as follows,

$$V_{grid}\,(t) = V_{rms}.\sqrt{2}.\sin\,(\omega t + \phi) \qquad (1)$$

In this equation, V_{rms}represents the root-mean-square voltage, ω is the angular frequency, t represents time, and ϕ is the phase angle. This input passes through the conversion phase to enable DC charging suited for the EV battery system, delivering efficient control and energy transmission.

Power Conversion Stage: The stage contains essential elements that convert AC-DC sufficient for charging EV batteries. The DC-DC converter is critical for optional regulation or alignment with EV battery's particular demands.AC-DC Converter, rectification techniques are used to convert the sinusoidal AC voltage grid $V_{grid}(t)$ to a stable DC voltage V_{DC}, which is crucial in this procedure.

$$V_{DC}(s) = V_{peak}.\sqrt{2} \quad (2)$$

The peak AC voltage is denoted as V_{peak}. The converter step enables effective energy transfer while keeping voltage levels in acceptable limits for EV battery, allowing for dependable and quick charging operations. DC-DC Converter, this component makes it easier to match the nominal voltage required for charging the EV battery with the DC voltage V_{DC} acquired through the AC-DC conversion stage, ensuring optimal lifetime and performance

$$V_{battery} = V_{DC} (3)$$

The required battery voltage is depicted by $V_{battery}$. The DC-DC Converter optimizes the entire charging process and extends battery life by dynamically adjusting voltage levels.

Battery Management System (BMS): The BMS is a vital component of on-board EV chargers, monitoring and developing battery pack performance and durability. It has 2 main modules. The BMS's battery model faithfully captures significant factors including the temperature, condition, and SoC. These are essential for figuring out the battery's efficiency and operating limits throughout the cycles of charging and discharging. The battery's SoC is shown as equation (4).

$$SoC = \frac{Q_{actual}}{Q_{rated}} \times 100\% \quad (4)$$

The battery's current charge and associated capacity are denoted by the terms "Q_{actual}" and "Q_{rated}", respectively. For the battery to continue functioning and lasting a long time, temperature monitoring guarantees that stays in acceptable thermal bounds. The overall status is assessed by the health assessment component, which looks for problems like cell imbalance or capacity decline. The charge control algorithm aims to control the charging voltage (V_{charge}) and current (I_{charge}) using real-time data pulled from the battery model. By making sure that the charging settings match the operational needs and specifications of the battery, its highest safety and efficiency throughout the charging process. To prolong battery life and enhance dependability, the algorithm continually alters the charging setting to avoid undercharging, overcharging, or excessive heating.

$$I_{charge}(t) = f(SoC, temperature, health) \ (5)$$

$$V_{charge}(t) = g(SoC, temperature, health) \ (6)$$

This determines the functions f and g for optimal charging circumstances. The BMS's combination battery model and charge control algorithm guarantee the safe and effective functioning of the EV battery, improving the EVs lifetime and performance.

Electric Vehicle (EV): EVs include all the important parts needed to make the car function well and integrate with the on-board charging system. There are 2 important components. The energy storage component of an EV is the battery, which stores and provides the electrical energy needed to run the vehicle's electric propulsion system. To reach the necessary voltage and capacity, it is made up of lithium-ion cells that are connected in series and parallel. The energy storage capacity of the battery, or $E_{battery}$ is essential for deciding the driving range and general performance of the EV.

$$E_{battery} = V_{battery} \times Q_{rated} \quad (7)$$

In this equation (7), $V_{battery}$ represents the nominal voltage of the battery, and Q_{rated} is the rated capacity. Energy conversion and distribution are ensured by an EV's power electronics, which control the energy flow in both directions among the battery and the EV components. This contains inverters, controllers, and converters that manage voltage, current, and frequency to fulfill the vehicle's dynamic power requirements. Regenerative brakes and energy recovery during electric motor running require the power electronics system to convert the battery's DC power to AC power,

$$P_{inverter} = V_{DC} \times I_{motor} \quad (8)$$

The inverter's power output is represented by $the\ P_{inverter}$, the DC voltage by V_{DC}, and the electric motor's current by $the\ I_{motor}$. The Power Electronics system improves EV performance, energy economy, and battery life by effectively managing the energy flow.

Power Charge Pro Converter

To enhance energy management and the charging process, a complex and coordinated simulation system, the Power Charge Pro Converter model for the two-wheelers has been constructed. For safe and reliable operations this model requires some key components and technologies. Here, the major aspects in which they operate are explained. Table 1 gives the Power Charge Pro converter parameters and the characteristic values that belong to them.

Table 1: Power Charge Pro Converter's Parameters

Category	Parameter	Value	Description
1-MVA 3-Level Active Rectifier (main DC supply)	Pnom_dc_3L	1e6 VA	Nominal DC link Power
	Vnom_dc_3L	1000 V	Nominal DC link voltage
	H_3L	2 cycles	DC link stored energy constant
	Clink_3L	4 F	PM DC link capacitor
	Vc_Initial_3L	500 V	PM capacitor initial voltage
Transformer (Tr1)	Lxfo_3L	0.10 pu	Total Leakage inductance
	Rm_3L	200 pu	Magnetization resistance
	Pnom_3L	1e6 VA	Transformer nominal power
	Lm_3L	200 pu	Magnetization inductance
	Vnom_sec_3L	272.166 V	Nominal secondary voltage
	m_nom_3L	0.8	Nominal modulation index for 3-Level rectifier
	Vnom_prim_3L	25e3 V	Nominal primary voltage
	Rxfo_3L	0.0033 pu	Total winding resistance
Filter 1	Qnom_Filter1	0.15e6 VA	Nominal reactive power
	Fn_Filter1	1980 Hz	Tuning frequency
	Q_Filter1	5	Quality factor
Control Parameters	Fc_3L	1980 Hz	PWM carrier frequency
	Freq_Filter	1500 Hz	Measurement filters natural frequency
VDC Regulator (VDCreg)	Kp_VDCreg_3L	2.5	Proportional gain
	LimitU_VDCreg_3L	1.5 pu	Output (Idref) Upper limit
	Ki_VDCreg_3L	275	Integral gain
	LimitL_VDCreg_3L	-1.5 pu	Output (Idref) Lower limit
Current Regulator (Ireg)	Ki_Ireg_3L	8	Integral gain
	Lff_3L	0.10	Feedforward L
	LimitU_Ireg_3L	1.5 pu	Output (Vdq_conv) Upper limit
	Rff_3L	0.0033	Feedforward R
	Kp_Ireg_3L	0.1	Proportional gain
	LimitL_Ireg_3L	-1.5 pu	Output (Vdq_conv) Lower limit
2-MVA Twin 2-Level Statcom	Pnom_stat	2e6 VA	Nominal power
	Vnom_prim_stat	25e3 V	Primary nominal voltage (LLrms)
	Vnom_sec_stat	2250 V	Secondary nominal voltage (LLrms)
	Lxfo_Tr_stat	0.06 pu	Total Leakage inductance
	Rxfo_Tr_stat	0.002 pu	Total winding resistance
	Rm_Tr_stat	200 pu	Magnetization resistance
	Lm_Tr_stat	200 pu	Magnetization inductance
	Lbase_sec	0.00156 H	Secondary base inductance
	Lstat	0.000156 H	Phase reactor inductance
	Rstat	0.0059 Ohms	Phase reactor resistance
DC Link	Vnom_dc_stat	2400 V	Nominal DC link voltage
	H_stat	1 cycle	DC link stored energy constant

	Clink_stat	0.2778 F	DC link capacitor
	Vc_Initial_stat	2400 V	Initial DC link capacitor voltage
Filter	Cfilter	200e-6 F	Capacitor
	Rfilter	0.0265 Ohms	Resistor
Control Parameters	Fc_stat	1620 Hz	PWM Carrier Frequency
	Freq_Filter_stat	1500 Hz	Measurement filter natural frequency
VDC Regulator (VDCreg)	Kp_VDCreg_stat	10	Proportional gain
	LimitU_VDCreg_stat	1.5 pu	Output (Idref) Upper limit
	Ki_VDCreg_stat	800	Integral gain
	LimitL_VDCreg_stat	-1.5 pu	Output (Idref) Lower limit
Current Regulator (Ireg)	Rff_stat	0.004 pu	Feedforward R
	LimitU_Ireg_stat	1.5 pu	Output (Vdq_conv) Upper limit
	Ki_Ireg_stat	80	Integral gain
	LimitL_Ireg_stat	-1.5 pu	Output (Vdq_conv) Lower limit
	Kp_Ireg_stat	0.35	Proportional gain
	Lff_stat	0.12 pu	Feedforward L
DC Motor Drive	Ra_La	[0.0597, 0.0009]	Armature resistance and inductance
	Rf_Lf	[200, 160]	Field resistance and inductance
	Laf	2.621 H	Field armature mutual inductance
	J	10 kg.m^2	Total inertia
	Bm	0.272 N.m.s	Viscous friction coefficient
	w_Initial	1200*pi/30 rad/s	Initial speed
	If_Initial	2.5 A	Initial field current
	wref_Initial	1200 rpm	Initial motor speed
	Tload	1000 N.m	Load torque
	Fc_motor	2000 Hz	PWM carrier frequency
	RateLimit_wref_motor	2000 rpm/s	Limit rising/falling rate speed setpoint
	RateLimit_Iref_motor	20000 A/s	Limit rising/falling rate current reference
Speed Regulator (wreg)	Kp_wreg_motor	15	Proportional gain
	Ki_wreg_motor	50	Integral gain
	Limit_wreg_motor	[1000, -1000]	Output limit [Upper Lower] (Iref)
Current Regulator (Ireg_motor)	Kp_Ireg_motor	0.0015	Proportional gain
	Ki_Ireg_motor	0.25	Integral gain
	Limit_Ireg_motor	[1, 0]	Output limit [Upper Lower] (D)
60-Hz Load	Lchoke_HB	500e-6 H	Choke inductance
	Rchoke_HB	5e-3 Ohms	Choke resistance
	Vnom_Load_HB	340 Vrms	Nominal load voltage
	P_Load_HB	400e3 W	Active power
	Q_Load_HB	50e3 var	Capacitive reactive power
	Fc_HB	1980 Hz	PWM carrier frequency
	m_HB	1	Modulation index
Variable DC Load	Lchoke_Buck	5e-3 H	Choke inductance

	Rchoke_Buck	10e-3 Ohms	Choke resistance
	Rload_Buck	0.1 Ohms	Load resistance
	Vload_Buck	500 V	DC source voltage
	AmplitudeVar_Buck	50 V	Vload variation amplitude
	FrequencyVar_Buck	5 Hz	Vload variation frequency
	Fc_Buck	2000 Hz	PWM carrier frequency
	D_Buck	0.55	Duty cycle
DC Supply	Lchoke_Boost	1e-3 H	Choke inductance
	Rchoke_Boost	50e-3 Ohms	Choke resistance
	V_DCsrc	500 V	DC source voltage
	R_DCsrc	0.5 Ohms	DC resistance
	Fc_Boost	2000 Hz	PWM carrier frequency
	D_Boost	0.8	Duty cycle
50-Hz Load	Lchoke_FB	1e-3 H	Choke inductance
	Rchoke_FB	50e-3 Ohms	Choke resistance
	Fsys_FB	50 Hz	Nominal frequency
	Vnom_Load_FB	600 Vrms	Nominal load voltage
	P_Load_FB	200e3 W	Active power
	Q_Load_FB	50e3 var	Capacitive reactive power
	Fc_FB	1650 Hz	PWM carrier frequency
	m_FB	0.9	Modulation index

Power Converter: Power converters are at the core of the model because they transform the input power into a power level acceptable by an EV battery. For the effective transmission and control of energy, this process has the following stages.

1-MVA Active Rectifier: This part changes grid AC electricity to DC electricity that may be used to charge an electric car battery. It also increases the power factor, reduces harmonic distortions, and also enhances the power quality.

2-MVA STATCOM (Static Synchronous Compensator): Without going much into detail, it means that voltage control and reactive power correction are performed by the STATCOM. In this way, it guarantees that the charging procedure is not influenced by the variation of voltage of the charging point by stabilizing the electrical grid.

60Hz and 50Hz Loads: This means the model has provisions for operation emulation concerning different situations due to the presence of both 50Hz and 60Hz loads. These loads are acceptable for exercising the converter, as they mimic several types of electrical equipment and systems that may be connected and contribute to the grid across a range of frequencies.

Variable Load: This component makes it possible to simulate diverse load circumstances that may change with time. Testing should be carried out to measure the performance and future capacity of the converter to sustain high performance with changes in demand and or any other condition.

DC Supply: Thus, the DC supply is an approximation of the AC-DC converting stage output, which is a constant DC voltage. Ensuring there is a supply for charging the EV battery requires the supply to be fed to the converter in its later stages.

DC Motor Drive: The entire motion of a two-wheeled EV is simulated by the DC motor drive, which is used to represent the motor. It defines the actual load that the battery is going to support while it is in operation. Through varying the motor speed, the actual driving circumstances can be replicated and thus the converter's performance under dynamic load conditions can be tested.

The power charge pro converter is a complex of components and parameters responsible for managing the process of charging EVs. It begins with AC-DC conversion that involves the use of a 1-MVA 3-Level Active Rectifier that gives the most appropriate AC voltage obtained from the grid to generate DC power that is suitable for charging the batteries of EVs. In this phase, cyclic resonant effects are kept to the lowest levels, and maximum power factor is achieved through the control of various parameters using adjustment mechanisms like PWM carrier frequency and DC link capacitor settings. In addition, a Twin 2- 2level

STATCOM with a rating of 2-MVA with Compensation of reactive power and voltage control improves the stability and quality of the power supply even further. This component stabilizes the voltage and sustains the power supply during such conditions necessary for safe operation in changing load conditions and grid instabilities.

The control system smoothly organizes the interplay of these components, which is regulated by exact sample periods and control settings. It protects the integrity of the EV battery and electrical grid infrastructure while improving energy transfer efficiency. The Power Charge Pro Converter, when combined with sophisticated filtering techniques and DC motor drive control, provides efficient energy transmission but also increases the overall dependability and endurance of EV charging systems. Through incorporating modern power control and electronics technology, the entire strategy highlights its crucial role in providing sustainable transportation solutions.

Fine-tune the control converter and parameters.

The $fmincon$ method is used to fine-tune the PID controller parameters(Kp, Ki, Kd)using to obtain the greatest possible performance of the PowerCharge Pro converter in EV chargers. This iterative optimization method is to minimize the error between the actual output (V_{out}) and the target output voltage (V_{ref}), ensuring reliable oversight and effective functioning.

The objective function J is defined to minimize the error among the V_{out} and V_{ref}

$$J(Kp, Ki, Kd) = \frac{1}{T_{sim}} \int_0^{T_{sim}} \left(V_{ref} - V_{out}\right)^2 dt \quad (9)$$

Kp comparative gain of the PID controller, Ki Essential gain of the PID controller, Kd Derivative gain of the PID controller, and T_{sim} Simulation time. Constraints and bounds are applied to Kp, Ki, and Kd to maximize the stability and practical feasibility,

$$Ib \leq |Kp, Ki, Kd| \leq ub \quad (10)$$

To minimize$J$, the $fmincon$ method iteratively alters PID conditions based on simulation observations, using gradient-based optimization.

$$J(Kp, Ki, Kd) \quad (11)$$

Subject to $Ib \leq |Kp, Ki, Kd| \leq ub$ (12)

Simulation and performance evaluation, the Simulink model simulates the closed-loop action of the PowerCharge Pro converter by using optimized PID parameters $Kp^*, Ki^*, and\ Kd^*$. Settling time, overshoot, and voltage stability are measured to confirm the fine-tuned PID controller's capacity to achieve exact voltage management while improving overall system effectiveness. This optimization process improves the operational performance of the PowerCharge Pro converter but also provides to advancing the efficiency and reliability of EV charging infrastructure, supporting sustainable transportation solutions.

Result

On a Windows 11 operating system, we used MATLAB/Simulink to develop our converter. The system is powered by an Intel Core i7 CPU and has a high-performance IRIS GPU. The effectiveness of the suggested converter (PowerCharge Pro) was analyzed by applying a set of parameters including THD (%), Efficiency (%), Switching Losses (W), and Voltage Stress (V) are compared with the existing converter in Three-level DC-DC SEPIC converter[16]. Figure 3 demonstrates the on-board charger for Two-Wheeler EVs. Table 2 demonstrates the general and grid parameters. Table 3 provides a comparison of the existing and proposed converter.

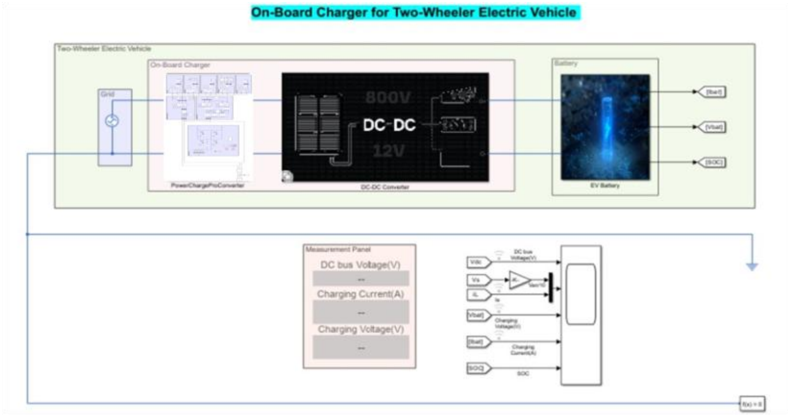

Figure 3: On-board charger for Two-Wheeler EVs

Table 2: General and Grid parameters

Category	Parameter	Value	Description
General Parameters	Ts_PWM	2.5e-6 s	PWM generator's sample time
	Ts_Control	50e-6 s	Control systems sample time
	Ts_Power	2.5e-6 s	Simscape Electrical Power Systems sample time
Grid Parameters	Fnom	60 Hz	Nominal system frequency
	Vnom_grid	25e3 V	Utility nominal voltage (L-L rms)
	Psc_grid	100e6 VA	Short-circuit level
	P_Ld1	1e6 W	Ld1

THD (%)

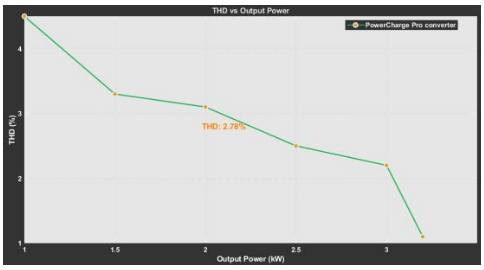

Figure 4:THD (%) vs. Output Power (kW)

The relationship between THD and Output Power (OP) for the PowerCharge Pro converter. OP range (1 kW to 3 kW).At the first OP of 1kW, the THD is 4.3%, indicating a relatively high level of THD. As the OP 1.5kW, 2kW, 2.5kW, and 3kW the THD reduces significantly to around 3.3%, 3.1%, 2.5% and 2.2%. Finally, the THD is its lowest approximately 1.1%. We obtain the ultimate average result of THD 2.78%. Figure 4 demonstrates that the OP of the PowerCharge Pro converter increases, the THD decreases, indicating an improvement in power quality at maximum output levels. This indicates that the converter is better at generating higher output, resulting in more efficient and consistent performance with harmonic distortion.

Efficiency (%)

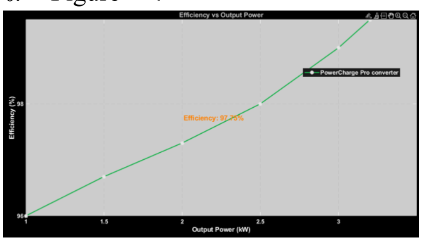

Figure 5:Efficiency (%) vs. Output Power (kW)

The connection within Efficiency and OP for the PowerCharge Pro converter. OP range (1 kW to 3 kW).At the first output power of 1kW, the efficiency is 96%. As the OP 1.5kW, 2kW, 2.5kW, and 3kW the THD reduces significantly to around 96.8%, 97.3%, 98% and 99.2%. Finally, the THD is at its highest approximately 99.7%. Inefficiency 97.75%, we get the final average outcome. Figure 5 demonstrates that as the OP of the PowerCharge Pro converter increases, the efficiency improves, indicating enhanced performance in power quality at higher output levels. This indicates that the converter operates more efficiently as it controls larger power outputs, which leads to enhanced effectiveness and constant performance at better efficiency.

Switching Losses (w)

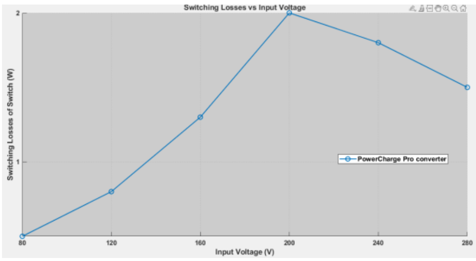

Figure 6:Switching Losses (w) vs. Input Voltage (V)

The connection within switching losses and input voltage for the powercharge pro converter. Input voltage range (80 V to 280 V). At the first input voltage of 80V, the switching losses is 0V. As the input voltage 120V, 160V, 200V, 240V and 280V the switching losses reduces significantly to around 0.65W, 1.17W, 2W, 1.82W and 1.61W. We determine the ultimate average result in switching losses of 1.32W. Figure 6 demonstrates that the switching losses of the PowerCharge Pro converter represent a non-linear pattern. This action illustrates the importance of carefully managing the input voltage to maximize converter efficiency and performance and ensure there is as little power loss as possible while switching between tasks.

Voltage Stress (V)

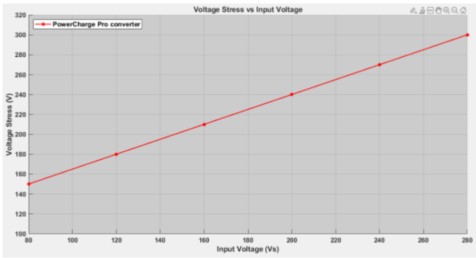

Figure 7:Voltage Stress (V) vs. Input Voltage (Vs)

The correlation among voltage stress and input voltage for the powercharge pro converter. Input voltage range (80 V to 280 V). At the first input voltage of 80V, the switching loss is 150V. This upward trend continues consistently, with the voltage stress increasing to approximately 120V, 160V, 200V, 240V, and 280V the switching losses increase significantly to around 180V, 210V, 240V, 270V, and 300V. The final average result in voltage stress was 225V ascertained. Figure 7 demonstrates a linear relationship between the input voltage and voltage stress of the powercharge pro converter. Recognizing this linear response is critical for enhancing converter performance and assuring consistent operation since it exposes the direct influence of input voltage on voltage stress levels.

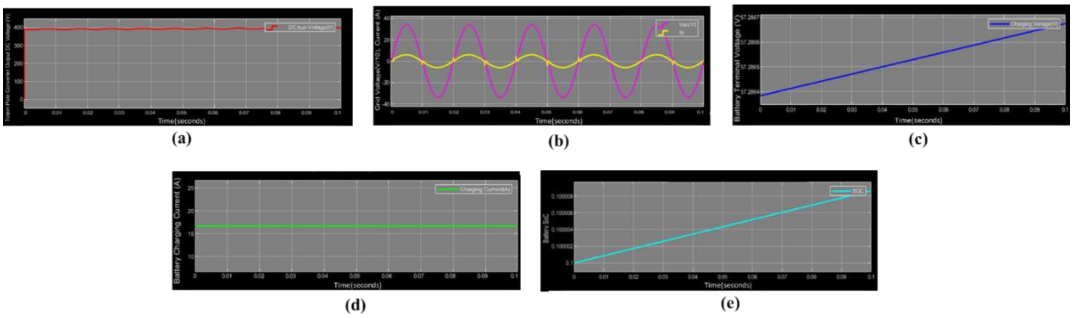

Figure 8: EV Charging Systems.

Figure 8 (a) is the regulated DC voltage obtained after converting the AC grid input, offering an efficient and stable power supply to the EV battery. Figure 8 (b) shows crucial parameters for managing power flow from the AC grid to the converter, resulting in optimal energy transfer to the EV battery. Figure 8 (c) indicates the voltage level at the battery's terminals, which is essential to proper charging, optimal efficiency, and the lifetime of the EV's battery system. Figure 8 (d) reflects the flow of electric charge into the battery during charging, and it is critical for assessing the pace at which the battery accumulates energy and the total effectiveness of charging. Figure 8 (e) represents the battery's current energy level as a percentage of full capacity, which is critical for charge sessions and battery health.

Table 3 compares two DC-DC converters, the three-level SEPIC [16] and the powercharge pro [proposed]. The power charge pro has lower THD, higher efficiency, lower switching losses, and reduced voltage stress.

Table 3: Comparison between Existing and Proposed Converters.

Converter	THD (%)	Efficiency (%)	Switching Losses (W)	Voltage Stress (V)
Three-level DC-DC SEPIC converter [16]	5 %	96.4 %	2W	400 Volts
PowerCharge Pro converter [Proposed]	2.78 %	97.75 %	1.32 W	225 Volts

CONCLUSION

The power charge pro converter and the process of developing as well as assessing it can be regarded as a great step forward in improving the charging system for EVs. By analyzing efficiency improvements and the overall better quality of power available from these efficient chargers, this work illustrates the desired level of efficiency and quality through THD reduction, PFC, and precise voltage regulation. Charger reliability and efficiency have significantly improved by applying power quality management techniques. Therefore, unlike the conventional three-level DC-DC SEPIC converter, the proposed powercharge pro converter fulfils and goes beyond the expectations as demonstrated by the simulated and experimental results. Consequently, the research contributions pinpoint the significance of power converters in managing resonant issues in EV charging structures today, such as challenges in the grid integration system and actual efficiency. By applying MATLAB/Simulink simulations for the converter, we were able to fine-tune the control strategies and parameters to the greatest possible efficiency, even resulting in lower THD (2.78 %), improved efficiency (97.75 %), fewer switches in the converter, lower switching losses (1.32 W) and considerable control over voltage stress (225 V). These outcomes reveal further opportunities for the converter referring to more effective, reliable, and eco-friendly solutions for EV charging. Nonetheless, given these highly encouraging findings, it will be crucial to conduct additional real-world tests and include the developed approaches in other large-scale EV charging networks in the future. Finally, the powercharge pro converter is a multifunctional and highly efficient device that has the potential to facilitate the development of the charging system for electric vehicles and prevent further deterioration of the environment.

LIMITATION & FUTURE SCOPE

One limitation of this study is the reliance on simulation-based evaluations rather than extensive real-world testing, which may limit the direct applicability and validation of the PowerCharge Pro converter's performance in diverse operational conditions and environments. Future research could focus on integrating the PowerCharge Pro converter into large-scale EV charging networks to validate its performance in real-world conditions. Exploration of additional advanced control strategies and integration with smart grid technologies could further enhance efficiency and reliability.

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