

# Development of a Smart Distribution Panel for Improving the Safety of Multi-Distributed EV Chargers

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**Abstract:** The recent rapid adoption of electric vehicles (EVs) is creating new load characteristics in the distribution system, and in particular, the widespread use of single-phase charging methods is exacerbating phase load imbalances, leading to voltage unbalance issues. Such voltage imbalances can undermine the stability of the distribution system and may cause side effects such as reduced power quality and shortened equipment lifespan. This study proposes a smart distribution panel system that can detect voltage imbalance issues caused by uneven electric vehicle charging loads in real time and actively compensate for them. The proposed system aims to contribute to the stability and power quality improvement of the distribution network by integrating a load balancing algorithm with inter-phase voltage monitoring functionality.

**Keywords:** Electric vehicles, Charging, Voltage imbalance, Smart distribution board, Load balancing algorithm

The recent rapid spread of electric vehicles (EVs) is causing new load characteristics in the power distribution system, and in particular, the spread of single-phase charging is exacerbating inter-phase load imbalances, causing voltage imbalance problems. This voltage imbalance can undermine the stability of the distribution system and cause adverse effects such as reduced power quality and shortened equipment lifespan.

Park et al. [1] analyzed the voltage imbalance problem caused by electric vehicle charging and suggested the need for technical measures to compensate for it. Kim & Park [2] analyzed the structural causes of the spread of single-phase charging methods that exacerbated voltage imbalance in the distribution system and emphasized the importance of a strategic approach to respond to this. In addition, Lee et al. [3]

analyzed the current status of domestic EV charging infrastructure and suggested the need for technological improvement measures, including voltage imbalance problems [4].

In this study, we developed a smart distribution system that can detect and actively compensate for voltage imbalance problems caused by imbalances in electric vehicle charging loads in real time. The proposed system aims to contribute to the stability of the distribution system and improvement of power quality by integrating a load distribution algorithm and inter-phase voltage monitoring function.

The ultimate goal of the study was to develop a smart distribution panel capable of redistribution to resolve voltage imbalance and improve the stability of the system linked to electric vehicle chargers. Therefore, an integrated MCCB sensor module capable of responding to single-phase and three-phase power lines was designed as a priority.

The module integrates current sensing and communication

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functions to enhance installation convenience and reliability, and a monitoring program for real-time data collection was developed in parallel to enhance connectivity with sensors.

A smart distribution panel was implemented that predicts charging load based on data collected from sensor modules and applies a redistribution algorithm to improve current imbalance. The system automatically adjusts the load when the imbalance rate exceeds the threshold to maximize

equipment protection and energy efficiency.

To verify the reliability of the developed sensor module, voltage, current, and power measurements, as well as insulation resistance tests, were conducted. In addition to the power measurement and insulation resistance tests, voltage and current tests were also carried out to check the monitoring accuracy.

The PCB layout was designed to be directly connected to

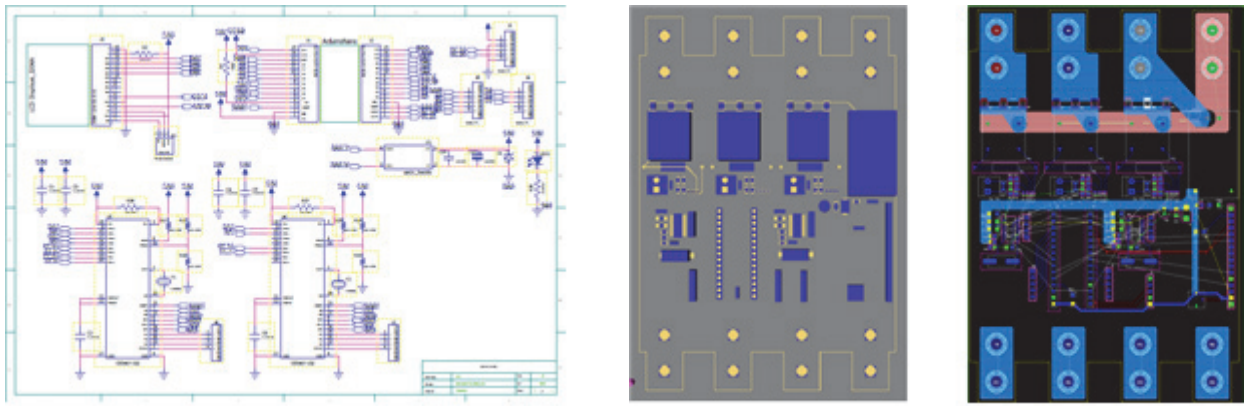


Fig. 1. Smart MCCB IoT sensor board.

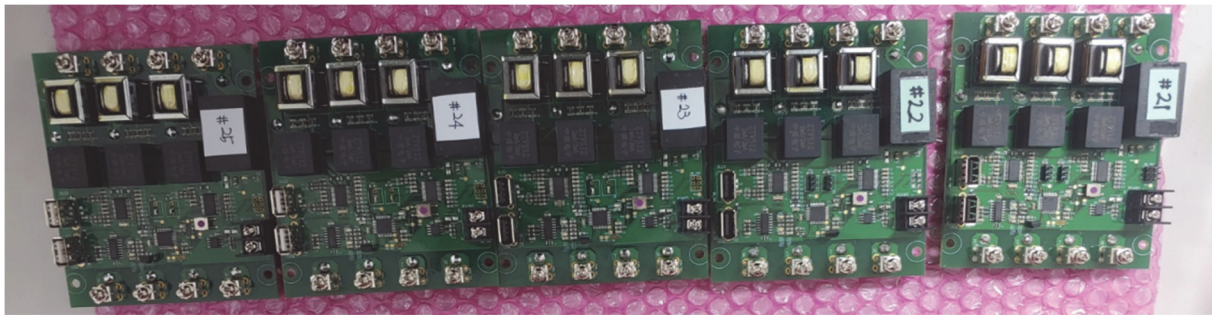


Fig. 2. Smart MCCB IoT sensor module.

Table 1. Sensor module specifications.

Sensor no.	Sensor voltage	Measuring Inst. (V)	Offset adjustment	Current	Measuring Inst. (A)	Offset adjustment	Power	Measuring Inst. (A)	Offset adjustment
21	219.4	220.3	G 1.0	1.4	1.5	0.46	322.9	330.9	3.5
				0.6	1				
				0.2	0.5				
22	219.4	220.4	G 1.0	0.5	1	0.4	224	221.2	1
23	219.4	220.4	G 1.0	0.6	1	0.4	214	221	3.1
24	219.4	220.4	G 1.0	0.6	1	0.4	217.1	220.1	1.5
25	219.2	220.1	G 1.0	0.6	1	0.4	215.8	220.1	2.5

the secondary side of the breaker in order to interface the development board with the three-phase breaker.

It was designed to operate either by receiving DC power through RS-485 or by receiving DC power externally, but a separate SMPS was configured to operate when 220 V or 380 V power was applied externally, and initial tests were carried out using an Arduino for each test.

In order to remotely meter digital electricity meters, communication between the electricity meter and the PLC

must be established. To ensure smooth and accurate communication between the digital electricity meter, the PLC, and the PC, a protocol is specified, and through various factors, the parameters of electricity consumption can be monitored in the GUI program.

The total number of pulses was counted to detect the amount of electricity, and the output frequency was used to detect the amount of electricity per specific time period.



Fig. 3. Monitoring accuracy analysis.

Table 2. Monitoring accuracy measurement results.

	Power measurement test results			Voltage measurement test results			Current measurement test results		
	Sample measurement value	Test Equipment Measurement Value	Error rate (%)	Sample measurement value	Test Equipment Measurement Value	Error rate (%)	Sample measurement value	Test Equipment Measurement Value	Error rate (%)
#1	221.1W	222.1W	0.5	220.3V	220.1V	0.1	1.0A	1.01A	1
#2	220.4W	220.1W	0.1	220.2V	220.1V	0	1.0A	1.01A	1
#3	220.9W	222.2W	0.6	220.1V	220.1V	0	1.0A	1.01A	1
#4	220.0W	222.2W	1	220.0V	220.1V	0	1.0A	1.01A	1
#5	220.6W	222.1W	0.7	220.2V	220.1V	0	1.0A	1.01A	1

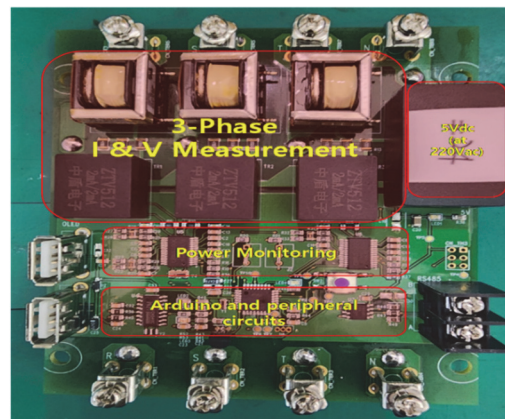
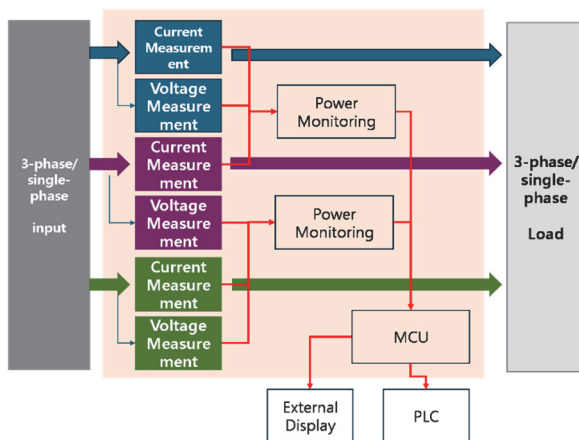


Fig. 4. Block diagram & prototype.

The detected power consumption is monitored every 15 minutes through the PLC, and the system is set up to store hourly, daily, and monthly data.

In order to integrate and downsize smart MCCBs and distribution panels, it is composed of a measurement unit capable of phase-by-phase measurement that measures voltage, current, and temperature and transmits and receives data, a communication conversion unit that transmits and

receives data collected from the measurement unit to the status display monitoring unit, and a monitoring unit that manages information such as the condition of the distribution panel and power usage in an integrated manner.

It was developed to allow on/off control in automatic/manual mode and to display power consumption data. It was developed to enable not only real-time monitoring but also remote control in manual/automatic mode.



Fig. 5. Power load monitoring system.

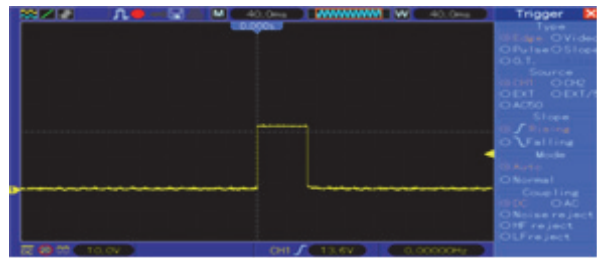
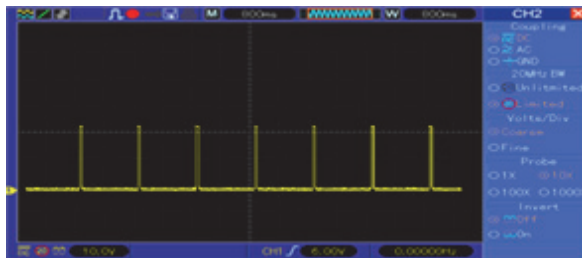


Fig. 6. Output characteristics.

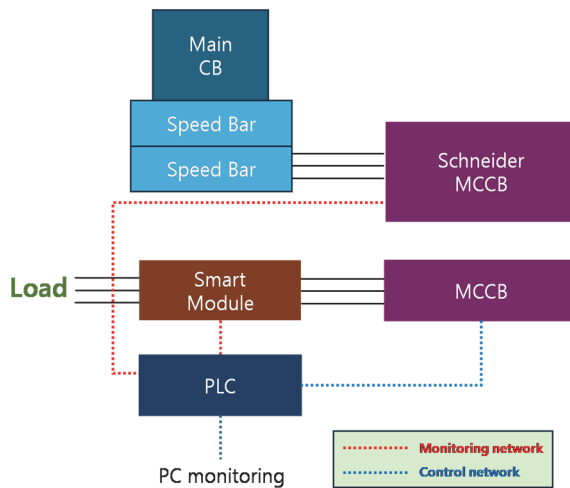


Fig. 7. Smart distribution panel block diagram and system product.

This development product is designed to be installed in front of the load-specific power circuit breaker of the distribution panel with a smart distribution panel and sensor module with improved stability, and to provide load-specific power measurement and automatic power cutoff functions.

This product is anticipated to be commercialized as it enables precise power usage measurement and artificial intelligence-based power cutoff control for each load within the industrial complex, and direct production, in line with the government's project to build microgrid infrastructure for smart green industrial complexes to increase energy self-sufficiency and implement low-carbon industrial complexes.

In this study, we conducted research on the technology that forms the basis of the product, and plan to further develop market-adaptive products with improved design and price competitiveness through a step-by-step plan.

Once final product development is complete, it will be possible to flexibly respond to the limitations of the electric vehicle charger's usable power capacity by utilizing spare power and adjusting the power of some chargers when electricity usage is high. In addition, by pre-installing smart distribution panels in charging facilities such as apartment complexes, space efficiency and power management stability will be improved, and it is anticipated that the cost burden on residents will be reduced when installing additional chargers)

As demand is anticipated to explode in the mid- to long-term due to increased power consumption and the expansion of new and renewable energy and electric vehicles, it is anticipated that the development of an artificial intelligence business model will contribute to the development of new markets and increase in corporate sales.

It is anticipated that various markets will be created in conjunction with artificial intelligence technology, and

various business types and business models, such as energy big data services, will emerge as new services as new industries expand and demand management resource markets are formed. It is anticipated that this field will be ranked as a new technology in the future electric vehicle infrastructure market.

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