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A Study on Quality Education in Vocational Education—A Case Analysis of Teaching the PFC Circuit Principle in Vehicle Onboard Chargers

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Abstract: *In the implementation of quality education in vocational education, we have chosen the PFC circuit principle of an onboard charger as a teaching case for analysis. During the teaching process, we encountered the following three issues: First, students tend to have inappropriate ways of understanding knowledge; second, they struggle to concretize abstract knowledge; third, they face difficulties in flexibly applying their knowledge. To address these problems, we adopt the strategies of simplifying complex issues, refining simple problems, and visualizing abstract concepts. By doing so, we aim to enhance students' corresponding vocational skills and contribute to the development of quality education.*

Keywords: *Quality education, Vocational abilities, PFC circuit, Teaching case analysis*

1. Introduction

The Central Committee of the Communist Party of China and the State Council proposed in the "Decision on Deepening Education Reform and Promoting Quality Education" that the implementation of quality education should be integrated into all levels and types of education, including preschool education, primary and secondary education, vocational education, adult education, and higher education. In its view, teaching tasks are restructured, and course content is enriched [1]. Emphasis is placed on strengthening practical teaching and promoting the integration of teaching content with professional skills. The breadth and depth of the curriculum are expanded, and information technology platforms are utilized to enhance students' vocational abilities as the ultimate goal [2].

2. Case Analysis

Using the PFC circuit principle in vehicle onboard chargers as a case study, we have provided corresponding adjustments and solutions to address the issues that emerged during the teaching process.

2.1. Overview of Vehicle Onboard Charger

In electric vehicles, the vehicle onboard charger serves as a dedicated charging device that converts grid AC electricity into DC power to charge the vehicle's battery. It mainly consists of input/output ports, a power unit, a control unit, and a low-voltage auxiliary unit [3]. The input and output ports are connected to the grid's high voltage and the electric vehicle's power battery, respectively. The electric vehicle is connected to the charging station, and the energy is transported and converted within the vehicle onboard charger, providing AC slow charging or DC fast charging to charge the battery.

The working principle of the vehicle onboard charger is shown in the Figure 1. The main AC input of the charger first goes through an EMI (Electromagnetic Interference) filter circuit to remove electromagnetic and noise interference from the input AC power. After filtering, the AC power is rectified by the rectifier bridge to obtain DC power [4]. Then, the power factor correction (PFC) circuit is used to boost the voltage, and the voltage amplitude is changed through inversion, converting it back to pulsating AC input [5]. The AC current passes through the isolation transformer primary coil and is transformed. The output from the secondary coil of the transformer is again rectified by a full bridge rectifier, converting it back to pulsating DC power [6]. After passing through a filter circuit composed of

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capacitors and inductors, the DC power is output as the input for the power battery.

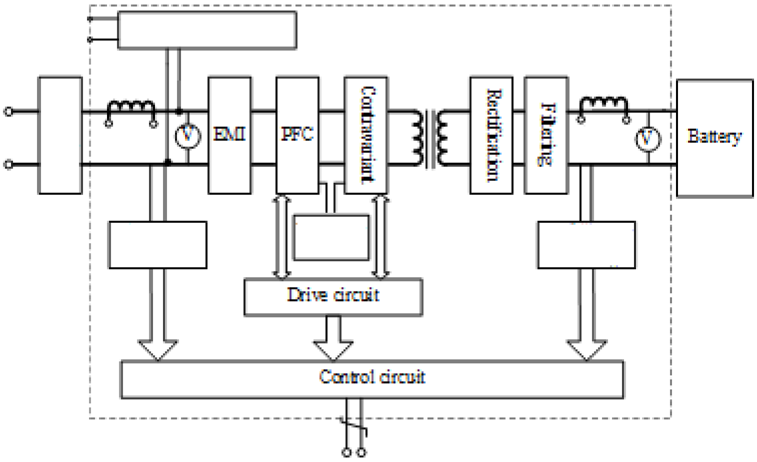

Figure 1: Vehicle Onboard Charger Schematic Diagram.

2.2. First Section

The PFC circuit is composed of a single-phase bridge rectifier and a Boost converter (consisting of inductor L, switch Q, diode D5, and capacitor C). The bridge rectifier converts the input AC power into DC power, while the Boost converter, under the control of a specific duty cycle, controls the switching on and off of the switch Q. Through inductor L and capacitor C, the power factor is corrected, ensuring that the voltage and current are in phase and increasing the active power, as shown in Figure 2.

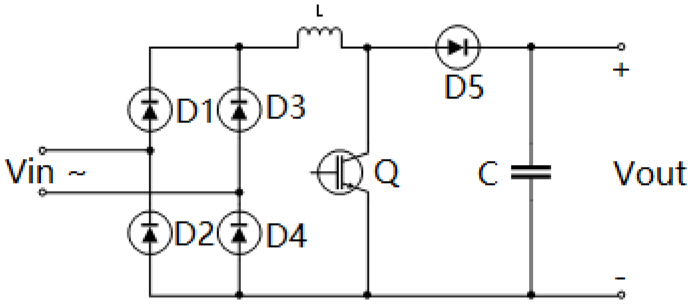

Figure 2: Depicts the traditional PFC Boost topology.

When the IGBT switch Q is turned on, it acts like a short circuit, and no conduction voltage drop reaches the diode D5. A portion of the current flows back to the input through the inductor and switch Q.

When the IGBT switch Q is turned off, it acts like an open circuit. The inductor converts the magnetic energy stored in the previous state into electrical energy, and the current charges the capacitor C through diode D5. At the same time, the DC power supply provides power to the subsequent load.

2.3. Issues Identified During the Teaching Process

While explaining the PFC circuit in the vehicle onboard charger and engaging in discussions with students, we identified the following issues.

2.3.1. Students have difficulty understanding or grasping the knowledge, and their approach to dealing with the knowledge is mostly rote memorization

Students often face a phenomenon where they lack in-depth understanding or mastery of knowledge and tend to resort to simple rote memorization. For instance, when studying the rectifier bridge in circuits, students may recognize its form but merely treat it as additional extracurricular knowledge. Furthermore, teachers may not provide sufficient explanations about the working principles of the rectifier bridge current during the teaching process. As a result, students' understanding of the current direction and function of the rectifier bridge remains superficial. Similarly, when it comes to capacitors and inductors as energy storage components, students know that capacitors allow AC but block DC, and inductors allow DC but block AC. However, they often lack a genuine understanding of the underlying reasons.

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They may simply memorize the mnemonics taught by the teacher and then apply them to circuit problems. Consequently, students do not deeply comprehend why capacitors have corresponding characteristics in voltage and why the voltage across capacitors cannot change abruptly, or why the current in inductors cannot change abruptly.

Furthermore, students lack knowledge about semiconductor power devices such as switch tubes; they are unfamiliar with their circuit symbols and operating principles. Similarly, they only learn the calculation formulas for power but do not understand the principle that the expression is the product of current and voltage multiplied by the cosine of the angle between them. Additionally, they fail to grasp the reasons for power factor correction and why circuits need voltage boosting.

2.3.2. Students can "understand" the knowledge but struggle to concretize abstract concepts

For instance, when learning about the unidirectional conductivity of diodes, students may know that "current can only flow from the anode to the cathode." However, without observing the phenomenon of light emission in light-emitting diodes, they find it difficult to truly grasp this concept. Similarly, regarding the energy storage characteristics of inductors and capacitors, students may not understand their practical applications. For instance, they might struggle to comprehend the phenomenon of discharging capacitors into loads after being charged without the real-time numerical display from a digital voltmeter.

Moreover, students might find it challenging to understand the concept of energy conversion in inductors, where energy is stored as magnetic energy and then converted back to electrical energy, resulting in the generation of an induced electromotive force with an opposite direction. Without tangible representations, students might struggle to comprehend the concept of "delayed response" in energy storage devices.

2.3.3. Students struggle to apply the knowledge they have learned to understand real circuits effectively

Even though they have studied topics related to diodes, inductors, and other relevant concepts, they find it challenging to apply this knowledge to real circuits and gain a deep understanding. For instance, although they understand that diodes have unidirectional conductivity, allowing current flow from the anode to the cathode, they cannot comprehend how a diode bridge achieves the conversion of AC electricity into DC electricity. Similarly, while they have learned about inductors, including concepts such as self-inductance, induced electromotive force, and Lenz's law, they do not grasp the reasons behind the induction of different directions of electromotive force in inductors under switch tube states. Moreover, they struggle to understand the current flow and capacitor discharge in boost circuit modules. As a result, students face difficulties in gaining a profound understanding of the application of energy storage devices in AC circuits.

3. Solution

To improve this situation, educators should encourage students to go beyond rote memorization when learning knowledge. Instead, they should delve into understanding the principles and reasons behind the concepts. Providing more detailed explanations and practical application examples can help students better comprehend and apply the knowledge they acquire. Additionally, guiding students towards self-directed learning and research can foster their spirit of exploration and problem-solving abilities.

3.1. Simplifying Complex Problems

Simplifying complex problems helps us grasp the main contradictions and understand the essence of the issues by focusing on the key aspects of the main contradictions. When simplifying complex problems, it is important to maintain their reasonableness and scientific nature, ensuring that the simplified results align as closely as possible with real-world situations without compromising the core essence of the problem.

The diagram below represents the main circuitry of an electric vehicle on-board charger fault diagnosis experimental platform developed by Tianjin Jinghong Intelligent Technology Co., Ltd. This platform addresses the diagnosis of faults in electric vehicle AC charging systems, employing a combination of software and hardware to design basic detection circuits, simulate fault circuits, collect data, monitor operations, and establish an in-vehicle communication system. It offers guidance and practical experience to students in vocational and technical colleges for understanding and practicing electric vehicle AC charging systems, as shown in the Figure 3.

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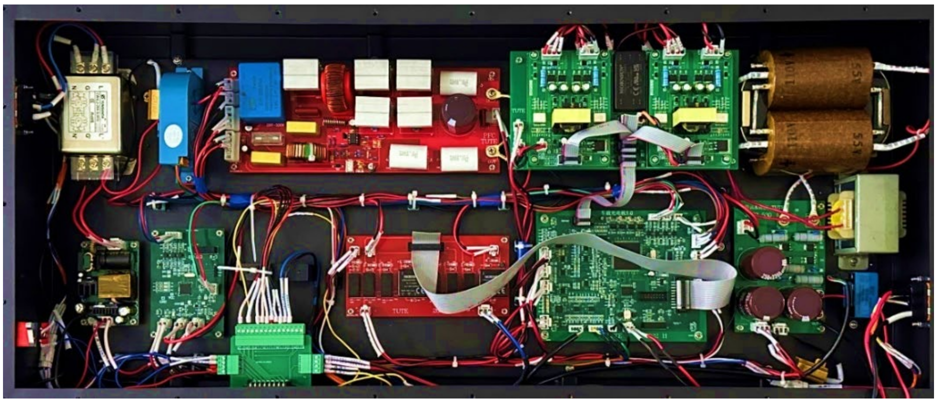

Figure 3: Main Circuit Part of Electric Vehicle On-Board Charger Fault Diagnosis Experimental Platform.

We can see that the actual wiring of the training platform is relatively complex, which can be challenging for middle and high vocational school students who are just starting to work with on-board chargers. By simplifying the main circuit diagram and highlighting the main components and power devices, we can guide students in analyzing the circuit, helping them grasp the most important and core knowledge for learning. The following diagram shows the simplified main circuit diagram of the training platform, which can be divided into six parts: EMI filtering circuit, bridge PFC circuit, inverter circuit, isolation transformer, full-bridge rectifier, and LC filtering circuit, as shown in the Figure 4.

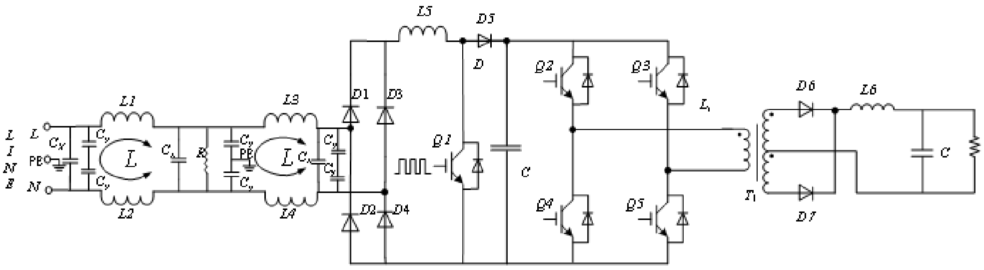

Figure 4: Simplified Main Circuit Diagram of On-Board Charger.

The design of the PFC circuit on the training platform is relatively complex. By focusing on the core components of the PFC circuit, we can compare and study the physical diagram and the simplified main circuit diagram together. The following diagram shows the PFC circuit board on the training platform and its corresponding circuit figure, as shown in the Figure 5.

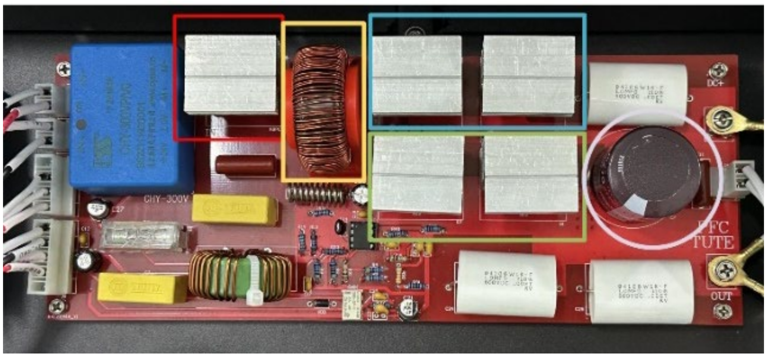

Figure 5: PFC Circuit Board and Corresponding Circuit Diagram on the Training Platform.

The PFC circuit is divided into two parts: the rectifier bridge and the Boost circuit. The following figures show the principle diagrams of the two circuit parts, as shown in the Figure 6.

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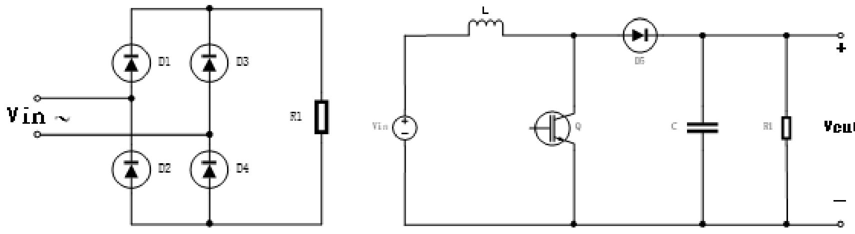

Figure 6: Rectifier Bridge (left) & Boost circuit(right).

3.2. Issues Identified During the Teaching Process

Most vocational and technical college students choose to pursue vocational education mainly due to difficulties in pursuing traditional higher education or personal reasons. Compared to students in traditional higher education, these students may have weaker learning and knowledge comprehension abilities, and lack the ability to connect knowledge from different subjects and think critically. They might not fully understand the knowledge they are learning and struggle to apply it to real-life scenarios for analysis.

To address these issues, knowledge can be refined and presented in a more detailed manner based on the simplified PFC circuit diagram. The circuit can be divided into two parts, and each part can be explained in-depth to help students gain a profound understanding of the entire circuit. By refining the teaching process, students can gradually grasp the operational principles of complex circuits, thereby enhancing their learning and comprehension abilities. Moreover, by integrating learned knowledge with practical applications, students will become more actively engaged in their learning and experience the true value of knowledge. This practical teaching approach not only contributes to students' academic development but also cultivates their problem-solving skills, preparing them for their future careers.

3.2.1. Rectifier Bridge

We name the connection point between diodes D1 and D2 in the bridge rectifier as point A and the connection point between diodes D3 and D4 as point B. Taking one cycle as an example, during the first half-cycle, the upper half of the sine wave corresponds to a higher potential at point A than at point B. For a closed circuit to allow current flow, there must be a potential difference. As a result of the diodes' one-way conduction, the current in the circuit flows from the higher potential to the lower potential. Therefore, the current direction in the bridge rectifier during the first half-cycle is as shown in the following figure. During the second half-cycle, the lower half of the sine wave corresponds to a higher potential at point B than at point A, as shown in the Figure 7.

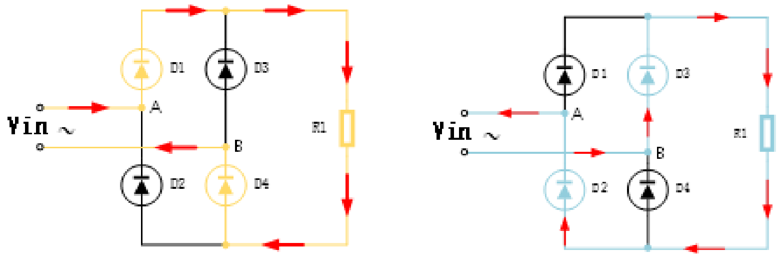

Figure 7: The current direction in the bridge rectifier during the first (L) & second(R) half-cycle.

The resulting waveform after passing through the bridge rectifier is shown in the following Figure 8.

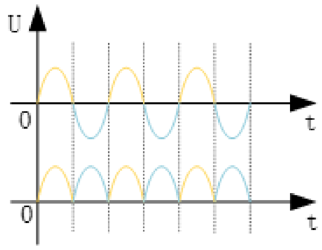

Figure 8: Comparison of Rectified Waveforms before and after Rectification.

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3.2.2. Simplifying complex problems by refining them into simpler components

When the PWM wave is in the high state, the switch is turned on, creating a short circuit. According to Faraday's law of electromagnetic induction, the inductor generates an induced electromotive force (EMF) in the opposite direction of the current to impede the increase in circuit current. At this time, the potential at both ends of the inductor L is positive on the left and negative on the right.

Assuming the charging time is dt_{ON}, we know that the charging time is the product of the duty cycle and the switching period, that is:

$$dt_{on} = DT \tag{1}$$

We can express the voltage across the inductor in this state as follows:

$$V_{in} = V_L = L\frac{di_{on}}{dt_{on}} = L\frac{di_{on}}{DT} \tag{2}$$

Upon simplification, we get:

$$di_{on} = \frac{V_{in}DT}{L} \tag{3}$$

After the switch is turned off, the stored magnetic energy in the inductor is converted back to electrical energy, forming a current. At this moment, the forward voltage drop of the diode is reached, and the capacitor discharges to the load. According to Faraday's law of electromagnetic induction, the inductor will produce an induced electromotive force in the same direction as the current to resist its decrease.

Similarly, we can express the relationship between input and output voltage as follows:

$$V_{out} = V_{in} + V_L \tag{4}$$

Assuming the discharge time is dt_{off}, the discharge time is the product of (1-duty cycle) and the switching period, which can be obtained as follows:

$$dt_{off} = (1 - D)T \tag{5}$$

$$V_L = V_{out} - V_{in} = L\frac{di_{off}}{dt_{off}} = L\frac{di_{off}}{(1-D)T} \tag{6}$$

Upon simplification, we get:

$$di_{off} = \frac{(V_{out}-V_{in})(1-D)T}{L} \tag{7}$$

During both the ON and OFF times of the switch, the charging and discharging of the inductor are the same, which is referred to as the inductor's volt-second characteristic:

$$di_{on} = di_{off} \tag{8}$$

By rearranging the equations, we can derive the relationship between the input and output voltages:

$$V_{in} = V_{out}(1 - D) \tag{9}$$

3.3. Visualization of abstract problems

Students are unable to effectively apply the knowledge they have learned to real-world problems. To help them understand and internalize abstract concepts, creating validation models can be beneficial. By concretizing abstract knowledge, students can gain a better grasp of the subject matter. Considering the composition of the PFC circuit and the difficulties students face in understanding the concepts, we have designed the following models:

3.3.1. Connecting a diode and a small light bulb in series: verifying unidirectional conductivity

Due to the diode's one-way conductivity, we can connect the diode and a small light bulb in series, or directly use an LED (Light Emitting Diode), add a voltage-dividing resistor, and include a circuit switch. Then, connect it to the battery with both correct and reverse polarity to observe the light bulb or LED's on and off states.

Through the NOBOOK virtual experiment website (www.nobook.com), we can build circuits to compensate for the lack of physical demonstrations during teaching by school teachers. Students can also enhance their practical skills through hands-on operation. The circuit we built is shown in the Figure 9 below. The entire circuit includes 2 battery packs (6V) E1, E2, a single-pole double-throw switch S1, a

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sliding variable resistor R1, two ammeters to measure the current in two branches, and a voltmeter to measure the voltage across the LED.

By switching the S1 to the left or right, we respectively connect circuits 1 and 2. From the images, we can observe the current direction in the circuit corresponding to two battery packs with opposite output currents, the on/off state of the LED, and the change in the voltmeter reading. This allows us to visually verify the diode's one-way conductivity. At the same time, we can observe that the variation of the sliding variable resistor in the circuit affects the brightness of the LED. When connecting the ammeter to the circuit, careful attention should be paid to selecting the appropriate range and the direction of the wiring.

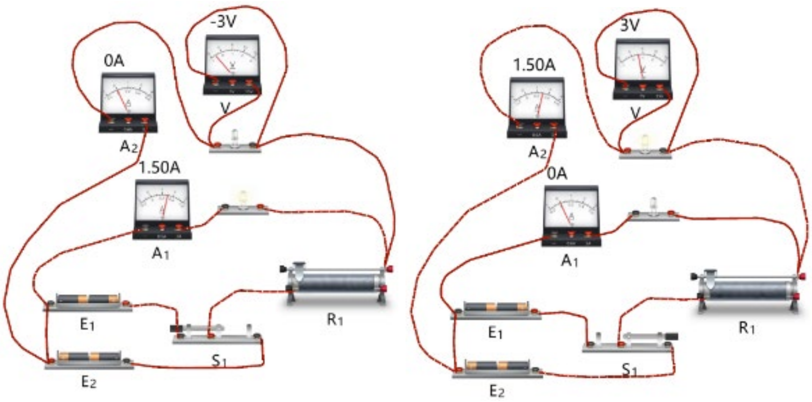

Figure 9: Virtual Experiment Circuit Diagram (Switch Left and Right).

3.3.2. Verify the abrupt change in the direction of the induced electromotive force due to Faraday's law of electromagnetic induction

The ammeter and resistor are connected in series to create a voltmeter. We can utilize the sensitivity of the ammeter to clearly observe changes in current and its characteristic of the pointer being in the middle of the instrument panel. The left or right deflection of the pointer can be used to determine the change in direction of the induced electromotive force in the inductor.

As the control circuit generated by the PWM wave to control the switch state is relatively complex, we simplified it to a single switch in the circuit diagram as shown in Figure 10 below:

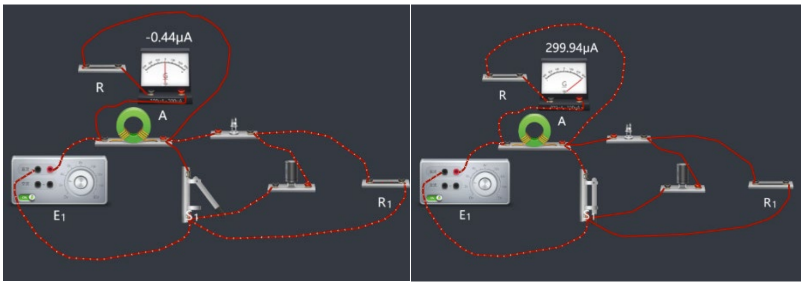

Figure 10: Switch On & Off

4. Conclusion

In the process of vocational education development, integrating quality education is crucial. It is essential to cultivate students' comprehensive abilities and thoroughly analyse whether the integration of quality education and the cultivation of students' vocational abilities are in place. Adjustments should be made based on the issues that arise. After implementing these adjustments, students' feedback improved, and their vocational abilities were enhanced:

1) Students' quality abilities were enhanced. Their learning, communication, and information extraction skills were exercised through course optimization. Students became more proactive in questioning and critical thinking, transforming from passive recipients to active learners, and enhancing their ability to express doubts clearly.

2) Students' professional abilities were improved. Through the simplified explanation of the rectifier

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bridge circuit, students gained a deeper understanding of the application of diode unidirectionality, enhancing their knowledge processing and transformation skills. Teachers' use of virtual experiments not only provided students with more vivid representations of theoretical analysis but also improved their hands-on operational skills.

3) Students' thinking abilities were also enhanced. As students struggled to concretize abstract concepts, the construction of virtual experimental circuits helped to visualize these abstract ideas, fostering their thinking abilities.

4) Throughout the teaching process, Marxist ideology was incorporated by analyzing the main contradictions and the principal aspects of these contradictions. This approach allowed students to grasp the essence of problems and continually think critically, integrating ideological education into the curriculum.

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References

[1] Pan X. Exploring the Reform of "Career Planning and Quality Education" Curriculum in Higher Vocational Education from the Perspective of Integrating Five Developments[J]. Road to Success, 2023, No. 746(10), 5-8.
[2] Duan Xiuzhen. Research on Fault Diagnosis of Onboard Chargers[J]. Tianjin Vocational Technical Normal University, 2023. DOI: 10.27711/d.cnki.gtjgc.2023.000042.
[3] https://blog.csdn.net/helaisun/article/details/126808979?utm_medium=distribute.pc_relevant.none -task-blog-2~default~baidujs_utm_term~default-2-126808979-blog-127374202. 235%5ev38% 5epc_ relevant _sort_base2&spm=1001.2101.3001.4242.2&utm_relevant_index=5
[4] Wang Jianshe. The Deviation Problem and Integration Strategy of Vocational Education in Quality Education[J]. Journal of Yellow River Conservancy Vocational and Technical College, 2011, 23(01): 73-75. DOI: 10.13681/j.cnki.cn41-1282/tv.2011.01.031.
[5] Zhang Huimin, Shi Jing. Issues and Solutions in the Development Process of New Forms of Teaching Materials in Higher Vocational Colleges[J]. Journal of Jiangsu College of Economic and Trade Vocational and Technical Institute, 2023, No.167(03): 86-88. DOI: 10.16335/j.cnki.issn1672-2604. 2023. 03. 024.
[6] Tang Linwei. Three Perspectives on Knowledge Transformation in Vocational Education in the Era of Artificial Intelligence[J]. Journal of Hebei Normal University (Educational Science Edition), 2023, 25(04): 105-111. DOI: 10.13763/j.cnki.jhebnu.ese. 2023.04.014.