Journal of Advanced Zoology

ISSN: 0253-7214
Volume 44 Issue S-5 Year 2023 Page 1571:1577

Advancements in Three-Phase Electric Motor Control: The Dual Voltag Motor Controller for Seamless Voltage Switching and Enhanced Efficiency

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Article History

Received: 06 June 2023
Revised: 05 Sept 2023
Accepted: 01 Nov 2023

Abstract

The primary objective of this research was to create, manufacture, and assess the operational efficiency of a Dual Voltage Motor Controller capable of automatically detecting the source voltage in a three-phase system and regulating the electric motor to function with either 220V or 440V AC. The resulting technology comprises a combination of magnetic contactors and a microcontroller, serving as a switching mechanism that streamlines the reconfiguration of the electric motor's twelve leads in a delta-delta configuration. This research was conducted at Guimaras State University, focusing on the development of a device aimed at eliminating the need for rewiring motor terminals when switching between 220V AC and 440V AC power sources, and vice versa. The device is designed exclusively for operation within a three-phase system and for electric motors utilizing a delta-delta configuration with twelve leads. Upon assessing the results of the technical evaluation, it was evident that the Dual Voltage Motor Controller effectively managed to switch the electric motor between 220V and 440V alternating current. Furthermore, the data revealed that the device allowed the electric motor to operate in both forward and reverse rotations, whether under low or high voltage conditions. By introducing this innovative technology, the research effectively resolved the limitations of existing motor controllers by introducing auto-detection of the source voltage and facilitating the seamless transfer of terminal connections via magnetic contactors. According to the feedback from technical experts, there is potential for expanding the device's applicability beyond delta-delta connected motors to also encompass wye-delta starting and running configurations for three-phase alternating current motors.

Keywords: *Dual Voltage Motor Controller, Automatic Voltage Detection, Three-Phase System, 220V AC, 440V AC, Magnetic Contactors, Microcontroller, Delta-Delta Configuration*

1. Introduction

Industrial plants have become highly dependent on alternating current electric motors, particularly three-phase electric motors that power large machinery and equipment (Pulicherla et al., 2022). Most of these motors are designed to operate at two different source voltages while maintaining their specified characteristics, often referred to as dual-voltage motors. For example, industrial plants in our country commonly use alternating current three-phase systems at 440 volts and 220 volts. The challenge arises when switching between these voltage configurations requires manual re-connection of motor terminals (Ni et al., 2019). Manual re-wiring of the twelve leads of electric motors from low to high voltage or vice versa is a complex task that demands expertise, safety considerations, and consumes valuable time. Steffen S. Brown's study introduced a solution to address these challenges. He developed a switch specifically designed for three-phase electric motors, which allows for easy and effective change in operating voltage (Mohanraj et al., 2022). This switch comprises both stationary terminal plates to which motor leads are connected and a movable part for interconnecting the motor's windings for high or low voltage operation.

In a different approach, Hubert Lee Keith and Mishawaka presented a dual voltage switching device that can be attached to standard two-voltage three-phase motors (Pulicherla et al., 2022). This device allows the selection of motor connections for operation at either of the two normal voltages using a conventional selector switch. Zhan Lengping introduced a control circuit for the forward and reverse rotation of general AC/DC motors (Mohanraj et al., 2022). This circuit employs a button switch and relays, with jumper wires to accommodate AC and DC environments. Despite these advancements, several drawbacks remain unaddressed. First, none of the devices mentioned are designed specifically for switching delta-connected motors between low and high voltage configurations. Second, the switching methods in the existing technology do not offer automatic detection of the input voltage for three-phase systems. Lastly, these devices do not have the capability to automatically connect the motor terminals for either low or high voltage sources while facilitating forward and reverse rotations.

Thus, this study centered on the design, fabrication, and evaluation of a Dual Voltage Motor Controller tailored to effortlessly switch three-phase, dual-voltage, and 12-leads out electric motors between low and high voltage sources. The prevalence of such motors in industrial plants and their dependence on manual re-wiring presented a compelling need for a more efficient and automated solution. The research and development of the Dual Voltage Motor Controller was executed with careful attention to detail, complying with industry standards. The critical technical evaluation involved experts from both academia and the industry, resulting in significant findings and conclusions. The study confirmed the Dual Voltage Motor Controller's exceptional performance in terms of automatic voltage switching, efficiency in forward and reverse rotations, and ability to adapt to low and high voltage inputs. The device proved to be a highly reliable and safe alternative to manual re-wiring, saving both time and ensuring operational safety.

While this technology demonstrates remarkable potential, it is important to note that future developments may further broaden its scope of application. It was suggested that the Dual Voltage Motor Controller could potentially extend its use beyond delta-connected motors and encompass wye-delta configurations, enhancing its versatility in various industrial settings. In essence, the Dual Voltage Motor Controller offers a substantial leap in the field of electrical motor control technology. Its innovative approach aligns with industry demands for enhanced efficiency, convenience, and safety, making it a promising solution for industrial plants relying on dual-voltage electric motors. As an exemplar of technological progress and excellence, it sets a high standard for future innovations in the industry.

Significance of Technology

The Dual Voltage Motor Controller has been engineered as an automated switching device, capable of seamlessly transitioning a three-phase electric motor between 220V and 440V alternating current sources within the three-phase system. This innovative technology is comprised of a combination of components, including a microcontroller, magnetic contactors, relays, and push button switches, all securely housed in a metal enclosure. Its multifunctional capabilities encompass automatic voltage detection, motor terminal reconfiguration for low or high voltage operations, and the facilitation of both forward and reverse motor rotations. The Dual Voltage Motor Controller boasts several noteworthy attributes that underscore its significance: Elimination of the need for motor terminal rewiring when transitioning between low and high voltage operations. Seamless initiation of the electric motor in forward rotation, regardless of the voltage source—be it low or high. Smooth commencement of the electric motor in reverse rotation, irrespective of the voltage source—whether low or high. Automatic detection of voltage supply changes within the three-phase system. Furthermore, the design of the Dual Voltage Motor Controller offers potential for further research and development, aimed at addressing any identified limitations and enhancing its technological capabilities.

2. Materials And Methods

Design Criteria

The device is designed to switch on the 12-leads out dual voltage alternating current electric motor connected in delta-delta configuration of two different voltages. Low-voltage switching configuration of 220VAC and high voltage switching configuration of 440VAC using a set of magnetic contactors. The device auto-detects the source voltage of either 220VAC or 440VAC and can also switch the motor in forward or reverse rotation of either low or high voltage connections. The device operates at three-phase, 60Hz frequency, and 220V or 440V alternating current with a rated maximum capacity of 15 horsepower, three-phase motor load. A set of magnetic contactors, overload relay, Arduino microcontroller and push button switches are wired and mounted in a metallic enclosure having a dimension of 16 centimeters in height, 30 centimeters wide and 40 centimeters long. The push button switches for forward and reverse rotation are positioned in the front cover of the enclosure.

Technically, the device operates in dry location of either wall mounted or positioned in such a way that the enclosure is in vertically-upright position.

Design Plan Preparation and Fabrication

The development of the device was anchored on the design criteria. The dual-voltage motor controller comprising of a set of magnetic contactors, an Arduino microcontroller, overload relay and push button switches enclosed in a metallic casing. The internal components is configured and wired using a no. 16 AWG auto-wire in such a way that the magnetic contactors main contacts are initially positioned in a normally open state. The Arduino microcontroller was programmed to automatically detect the source voltage at 220VAC or 440VAC and controls the switching of magnetic contactors configured in either low or high voltage connections. The internal components are mounted using screws and locknuts in an aluminum den rail of 12 centimeters long. The following illustration shows the dimensions and positioning of components of dual voltage motor controller: The dual voltage motor controller has the following features: Voltage Auto-detection. Using an Arduino microcontroller, the device automatically detects the source voltage in either low (220VAC) or high voltage (440VAC) in a three-phase system. Transfer of Motor Terminal Connections. The magnetic contactors are energized according to the source voltage detected by the controller and connects the motor terminals in low or high voltage configuration. Pilot Lamp Indicators. In the front cover of the device, three lamp indicators are positioned in such a way that one lamp is lighted and indicates the operation of motor. The lamp indicators are for standby, forward and reverse rotation of electrical motors. Push Button Switches. Three push button switches are placed in the front cover of the device that serves as switch for stop, forward and reverse rotation. Overload Protection. The dual voltage controller is equipped with overload relay connected at the load side terminals of magnetic contactor that protects the electric motor when the current flow exceeds the rated current.

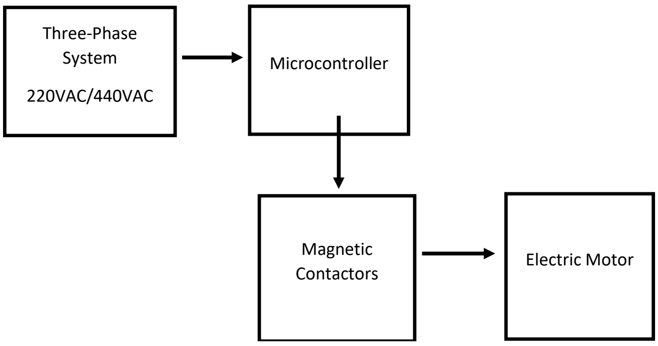

Figure 1: Block Diagram of Dual Voltage Motor Controller

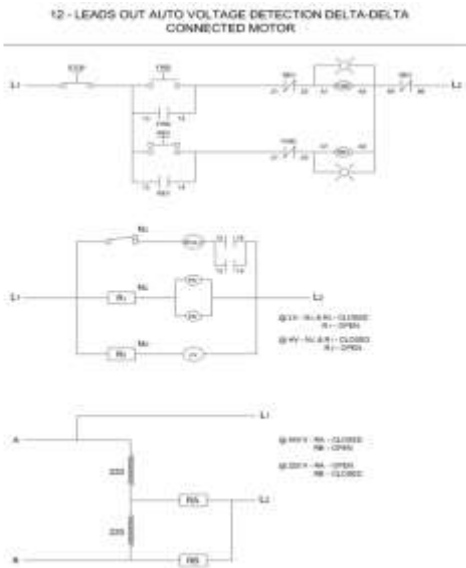

Figure 2: Schematic Diagram of Dual Voltage Motor Controller

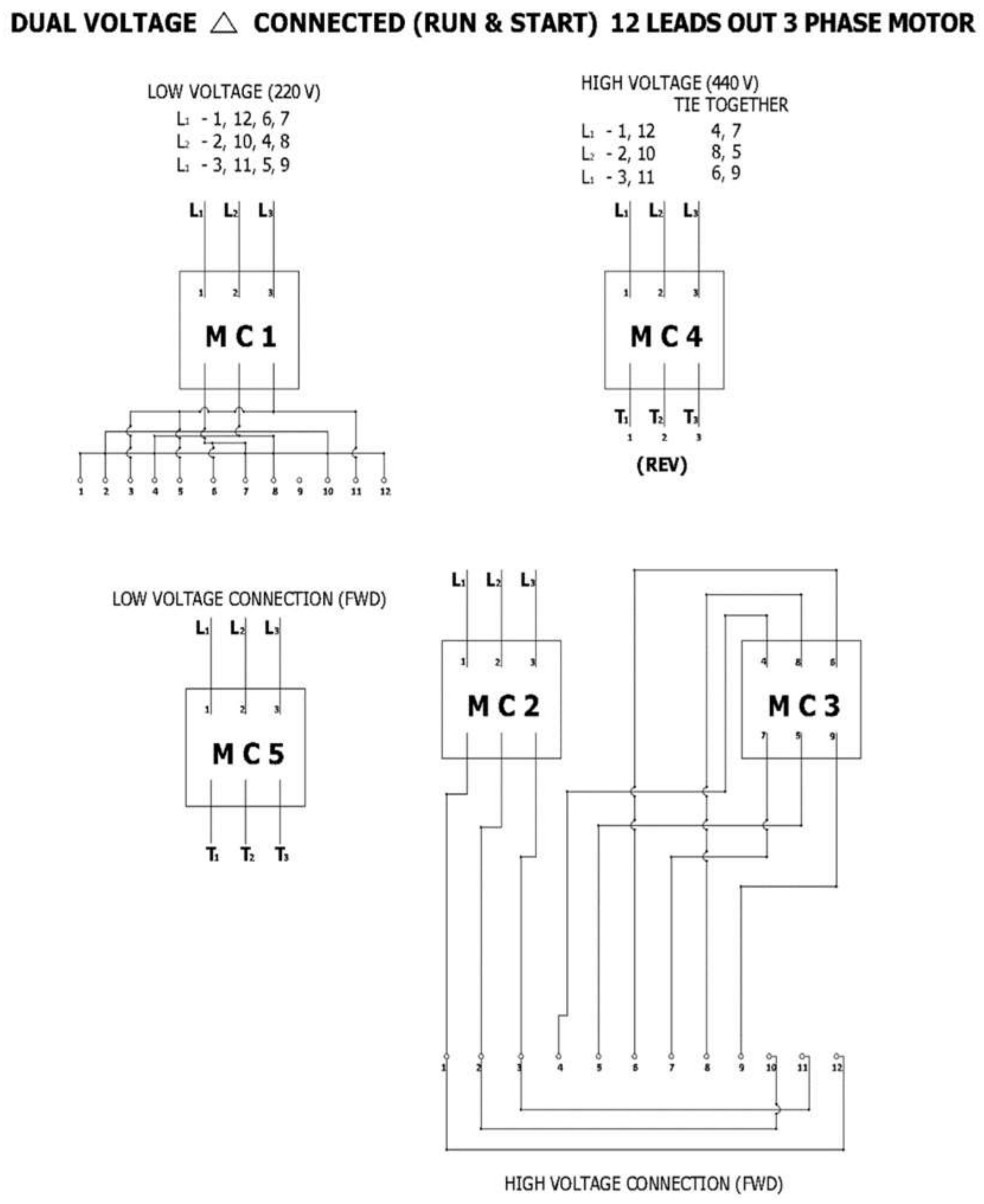

Figure 3: Wiring Diagram of Dual Voltage Motor Controller

Fabrication Procedure

Following a meticulous review of the design and drawings, the fabrication procedure was detailed, aligning with the design specifications and executed activities: Procurement of Materials: Initially, the researcher ensured the procurement of essential materials from local markets, encompassing magnetic contactors, overload relays, push button switches, Arduino controllers, lamp indicators, and automotive wires. Material Selection: Careful selection of materials was pivotal in the fabrication process. Durable and suitable materials capable of handling the requisite voltage and current loads were chosen. The functionality of each component was also considered, with all components subjected to thorough inspection and testing prior to purchase. Drilling and Component Mounting: Components were securely mounted using appropriate fastening materials. The weight and nature of materials used were considered to ensure stable component enclosure. Magnetic contactors, for instance, were affixed using denrails, facilitating ease of assembly and disassembly. Wiring and Soldering: Wiring and soldering of components were meticulously executed with the application of suitable wires, soldering irons, and soldering leads. Automotive-grade wires were employed to accommodate the current flow within the circuit. Careful soldering of components and terminals was undertaken to minimize power loss.

Testing and Performance Evaluation: Rigorous testing and performance evaluation were carried out to assess the Dual Voltage Motor Controller's functionality. Parameters assessed during the performance testing encompassed input and output voltages, response times during connection switching, and the electric motor's rotational direction. Troubleshooting and Revision: The troubleshooting and revision phase was instrumental in fine-tuning the device's operation. Minor operational issues were identified and promptly addressed during this stage. Final Packaging: Upon confirming the device's compliance with design criteria and specifications, the final packaging stage ensued. All components were meticulously arranged and securely mounted within the metal enclosure, ensuring a well-organized and functional assembly.

Technical Evaluation Procedure

The device was subjected to technical evaluation by the group of technical experts. The parameters measured were input voltage, switching time and direction of rotation of electric motor. Because of the pandemic, the technical evaluation was conducted through a recorded video and was viewed by technical experts. The technical experts were composed of electrical engineers and electrical professors with long experience in the actual field of specialization. The researcher conducted five trials to determine the performance on the device and was documented using video recording. The recorded video of the performance testing was then forwarded to the technical experts containing the instrumentation and testing of the above-mentioned parameters.

Instrumentation

The device was subjected to testing to determine the operating performance based on the established parameters. The researcher prepared the instruments and materials needed during the testing. Two source voltages (440VAC and 220VAC) of the three-phase system were prepared by the researcher. The input voltage was measured using Voltmeter; the switching time was measured using a digital timer while the direction of rotation was visually inspected. During the first five trials, the researcher checked the source voltage using a voltmeter, the initial result showed that the voltage on each phase of the three phase system ranges from 215 to 218 volts AC. In this case, the researcher performed the testing using low voltage source. The response time of switching the motor and direction of the rotation during the said trials was recorded. In the next five trials, the researcher checked the source voltage again, the result showed that the voltage on each phase of the three phase system ranges from 438 to 439 volts AC. In this case, the researcher performed the testing using high voltage source. The response time of switching the motor and direction of the rotation during the said trials was recorded. The testing and instrumentation was conducted to determine the performance of the dual voltage motor controller during operation based on the identified parameters being measured.

Parameters for Analysis

The following parameters were analyzed during the conduct of the study: Input Voltage. The input voltage was measured to determine the source voltage coming from a three-phase system. Two different voltages were set to test the device during low voltage and high voltage operations. A voltmeter was used to determine the amount of voltage coming from the three-phase source. The input voltage is very essential in the operation of dual voltage motor controller and was considered to be the determining factor in the automatic detection and switching of connections from low to high voltage operations and vice versa. Switching Time. Switching time refers to the amount of time needed to switch on the electric motor after the start button switch has been pressed. The switching time was measured in milliseconds using a digital stop watch. The switching time is one of the parameters evaluated to determine whether the device can switch on the dual voltage motor immediately. Rotating Direction of the Electric Motor. The rotating direction of electric motor was visually identified. This corresponds whether the forward or reverse rotation during operation was achieved. The rotating direction should conform to the desired direction of rotation regardless of either high or low voltage source.

3. Results and Discussion

The technical evaluation took place at the Guimaras State University in July 2023, with a panel of experts hailing from academic and industrial backgrounds, including engineers, instructors, and professors representing both city and provincial sectors. The device underwent rigorous testing based on input voltage scenarios encompassing both low and high voltage conditions. During the actual testing, the device was connected to an AC source, supplying both low and high voltage inputs. The primary focus of the evaluation was to assess the device's ability to automatically switch between low and high voltage inputs. This process also involved examining the device's output voltage under various input conditions. Additionally, the evaluators closely monitored and recorded the device's switching time during its connection to the main AC source. They also tested the forward and reverse functionality of the device by toggling the corresponding buttons. The unanimous consensus among evaluators was that the device performed flawlessly, demonstrating its safe operation under both low and high input and output voltage conditions.

Table 1: High and Low Voltage Motor Terminals Connection

Low Voltage Connection (22o Vac)	**High Voltage Connection** (440 Vac)	
Tie Together	Tie Together	
L1-T1-T12-T6-T7	L1-T1&T12	T4&T7
L2-T2-T10-T4-T8	L2-T2&T10	T5&T8
L3-T3-T11-T5-T9	L3-T3&T11	T6&T9

As shown in Table 2, the operating performance of dual voltage motor controller was tested using a low voltage source while the motor was energized in forward rotation. As reflected in the first column, there were five trials conducted. The next column indicates the measured voltage from the three phase source. The average input voltage supplied from the three phase source was 217.2 volts. It was also observed that the range of switching time varied from 265 milliseconds to 280 milliseconds at an average of 272.8 milliseconds. Based on the gathered data, the electric motor was able to energize at 215 volts to 218 volts which are tolerable voltages to operate a 220 volts electric motor. The data reflects that the dual voltage controller was able to switch the three-phase electric motor in low voltage, forward rotation accordingly.

Table 3: Testing Result of a Low Voltage Source Connected Motor in Reverse Rotation

Trials	**Input Voltage**	**Switching Time**	**Direction of Rotation**
1	216 Volts	282 ms	Reverse
2	218 Volts	273 ms	Reverse
3	218 Volts	274 ms	Reverse
4	218 Volts	267 ms	Reverse
5	218 Volts	280 ms	Reverse

The data in Table 4 shows the results of the performance testing of the device. High voltage source ranging from 438 volts to 439 volts was supplied to the input terminals of the device. Based on the results as reflected in the table, the average switching time of the device is at 242 milliseconds. The result revealed that the device was able to perform effectively in this set-up. The forward rotation in all five trials conducted was achieved.

Table 4: Testing Result of a High Voltage Source Connected Motor in Forward Rotation

Trials	**Input Voltage**	**Switching Time**	**Direction of Rotation**
1	438 Volts	250 ms	Forward
2	439 Volts	250 ms	Forward
3	438 Volts	240 ms	Forward
4	438 Volts	230 ms	Forward
5	438 Volts	240 ms	Forward

The table shows the results of testing conducted at high voltage source. The motor was energized in reverse rotation for the five trials. Based on the result presented in the table, it was observed that the switching time ranges from 240 milliseconds to 270 milliseconds. The direction of rotation in five trials was achieved.

Table 5: Testing Result of a High Voltage Source Connected Motor in Reverse Rotation

Trials	**Input Voltage**	**Switching Time**	**Direction of Rotation**
1	438 Volts	270 ms	Reverse
2	439 Volts	260 ms	Reverse
3	438 Volts	248 ms	Reverse
4	439 Volts	240 ms	Reverse
5	438 Volts	240 ms	Reverse

Claims

Claim 1. The dual voltage motor controller comprising: an enclosure, plurality of magnetic contactors, overload relay, microcontroller, transformers, electromechanical relay, push button switches, terminal logs and line terminals. The enclosure is a rectangular metal case that houses the internal components. The embodiment comprising the plurality of magnetic contactors that serve as switching contacts of the device. The said magnetic contactors is connected in such that the connection between the input and output terminals are interchanged whenever the input voltage is 220 volts or 440 volts alternating current. Claim 2. The dual voltage motor controller as claimed in claim 1, further comprising of an overload relay that is directly attached to the magnetic contactors that protects the motor from overloading. Claim 3. The dual voltage motor controller as claimed in claim 1 is composed of microcontroller that is programmed to automatically detect the input voltage of the three phase system. From the three phase source, the current flows through the step down transformers. The said transformers is connected in such that the output terminals of the transformers is attached to the microcontroller to determine the amount of the source voltage. The said microcontroller transmits the electrical signal to the coil terminals of magnetic contactors. Claim 4. The dual voltage motor controller as claimed in claim 1, that the said embodiment and the components are assembled and connected to automatically detect the source voltage of the three phase system. Claim 5. The dual voltage motor controller as claimed in claim 1, that the said embodiment automatically connect the dual voltage motor in low voltage terminals whenever the source voltage is at 220 volts alternating current. Claim 6. The dual voltage motor controller as claimed in claim 1, that the said embodiment automatically connect the dual voltage motor in high voltage terminals whenever the source voltage is at 440 volts alternating current.

4. Conclusion

Based on the findings, the following conclusions were drawn: The Dual Voltage Motor Controller is designed to activate three-phase electric motors with dual voltage compatibility and 12 leads, allowing operation with either low or high voltage sources. The Dual Voltage Motor Controller offers the capability to reconfigure motor terminals during switching processes. The Dual Voltage Motor Controller exhibits resilience to input voltage variations and can seamlessly transition the connection of three-phase electric motor terminals between low and high voltage modes and vice versa. The dual voltage motor controller effectively fulfilled its intended function.

Recommendations

Based on the findings of the study, the following recommendations were offered: For the electrical industries, it is recommended that the device color coding of switches shall be based on the industry's standard. It is recommended for the educators that this device will be used as an instructional device for students who are taking electrical technology courses. The design can be submitted for application of intellectual property.

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