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An Overview on Electric Motors: Classification, Control and Applications

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ABSTRACT

This paper presents an overview on electric motors, including classification, control methods and applications. It will be made clear about components, operating principle and control methods for brushed motors, brushless motors, stepper motors, servo motors and AC motors. Structure of control circuits for above motor types will be represented and analyzed to describe the ability to regulate their rotating speed and change their rotating direction. This paper also introduce an application of electric motors in automatic proof doors and focuses on designing solution and control system. Control problems for the proof door will be proposed to enhance the ability to meet requirements of smart homes and automation of control system. An experimental model using a two-phase three-terminal electric motor will be designed to prove the ability to control a horizontal proof door. Due to using processing contacts, a rain sensor, a light sensor, a remote controller, and an Arduino board, the experimental results will show the capability to operate the proof door automatically in cases of having rain, night time, emergency stop, and stopping at fixed locations. They also showed the ability to apply electric motors in many fields and good adaptability for smart requirements if using control circuits and suitable controllers.

Index Terms— AC motor, Arduino controller, Control of proof door, DC motor, Electric motor, Light sensor, Rain sensor.

INTRODUCTION

Nowadays, electric motors play important roles to create movements and enhance the automatic capability for technical processes. Electric motors convert electric power to mechanical power. They have been manufactured with many product types, wide rated voltage and power ranges and different control methods to change their speed and direction. So, it must be make clear about components, operating principle and control method for each type of electric motor [1-3].

Electric motors can be classified by some ways, where rated power classification for both DC and AC motors is considered as the most suitable approach for studies in control methods and applications. They are used very widely in applications of industries, civil, building construction, vehicles, etc [1-5]. For DC motors, their magnetic field is created by the direct current. They are brushed motors, brushless motors (BLDC), stepper motors and servo motors. For AC motors, their magnetic field is created by the alternative current.

In general principles, the higher rated values for power or voltage are, the higher price is. It is the same as for motors that must be used advanced control methods. In real operating works, electric motors must be regulated both their rotating speed and direction (forward or reverse). To execute these tasks, all drives with the participation of power converters will be used. MOSFETs or IGBTs will be implemented in these drives to regulate power converters to expected destinations. Pulse width modulation (PWM) generators and pulse generating methods will be used to combine conducting modes of MOSFETs or IGBTs in a drive that create current mode or voltage mode for motors [1-11].

Electric motors and controllers must be installed at detailed locations to establish various applications. One of them is automatic proof door. Mechanical structures of various proof doors have been designed by many manufacturers, such as piston mechanism, lead screw mechanism, gear mechanism, etc. Depending on types of

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electric motors for proof doors, control structure must be had some individual requirements about motor characteristics, comfortable and safe factors. Nowadays, control technologies using microprocessors such as Arduino boards, PLC (Programmable Logic Controller), Embedded computer, and Internet of Things (IoT) are applied in many various fields of industry and civil [12-18]. They will solve problems based on requirements of customers, characteristic of devices and cost for investment. One of important technical issue in the proof door is safe factor for people who are living in buildings. The proof door must be opened automatically very fast to release fume from fire in the building or in night time; closed automatically in cases of having rain, etc. So, control of proof door is one of problems can be applied control techniques to enhance home comforts and safety which contributes well for smart home applications.

From above analysis, this paper will present some overviews on electrical motors used widely in industry and civil fields that focuses on components, operating principle, control methods and applications. The next section will show the classification, components and control methods for some main electric motors. The third section will present an application of electric motors in proof door field, some requirements for this object to improve comfortable and safe factors for people. This section will also show an experimental model and results to prove theory and the capability to regulate rotating speed and direction in proof door field. The last section will represent some conclusions and contributions of this paper.

CLASSIFICATION AND CONTROL OF ELECTRIC MOTORS

A. Brushed DC motors

Main components of brushed DC motors are a stator (provide rotating magnetic field to drive rotor), a rotor (rotating component), a shaft axis, a permanent magnet (to create rotating field), a collector and a carbon brush system. The carbon brushes are made by Carbon material and used to provide power for motors as depicted in Fig.1 [1-2]. Brushes are easy to abrade in working process, so they must be maintained and replaced regularly. The speed of brushed DC motors can be regulated by the change of voltage supply or magnitude of magnetic field. The rotating direction can be adjusted by alternating poles of power supply as represented H-bridge circuits in Fig.2 [1-2], [10], [14].

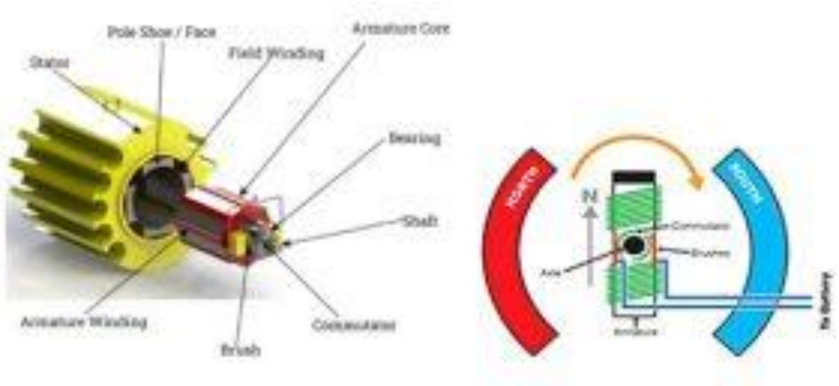
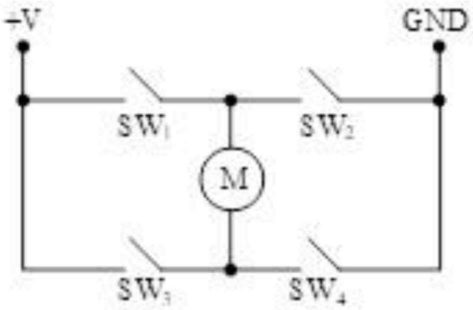


Fig.1 Brushed DC motor



a. H-bridge circuit

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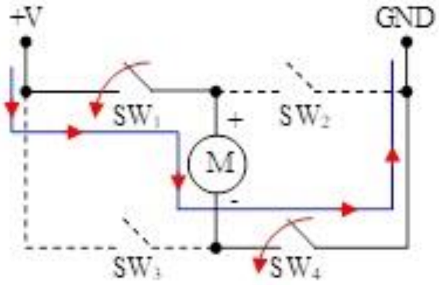
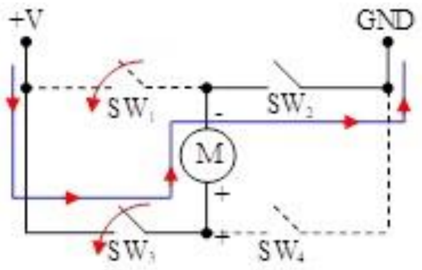


b. Forward direction



c. Reserve direction

Fig.2 H-bridge circuit and method to change rotating direction of brushed DC motors

The H-bride circuit uses 4 controlled switches such as transistors, MOSFETs or IGBTs. They are connected into a H-structure and controlled individually to establish two operating modes (forward and reserve directions) by changing voltage poles placed on the motor [2], [14].

To adjust the rotating speed of the motor, it must be used PWM generators as depicted in Fig.3 by changing the pulse width at a fixed frequency. It means that the on-time period in each cycle will conduct the current going from power source to the motor and the off-time period in each cycle will not conduct. Due to very small time for each cycle, energy supplied to the motor is regulated, the motor maintains the rotating state and the rotating speed can be changed as expected requirements.

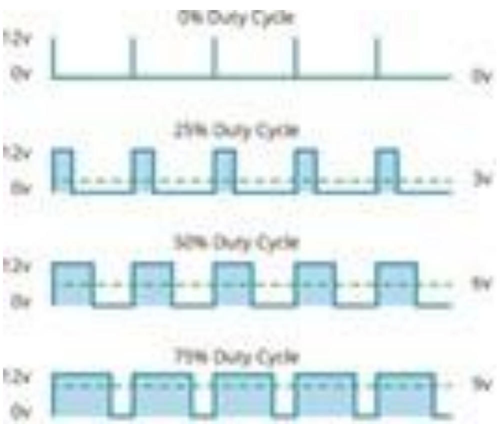


Fig.3 An example to adjust pulse width by PWM generator to change rotating speed of brushed DC motors

B. Brushless DC motors

BLDC is a type of synchronous motor where rotor speed is as equal as magnetic field speed. BLDCs use magnetic field to operate and sensors to determine locations. Due to without Carbon brush, friction is annulled completely and BLDCs have higher working time than brushed motors. Components in this motor type is depicted in Fig.4 [1], [4], [8-9], [16].

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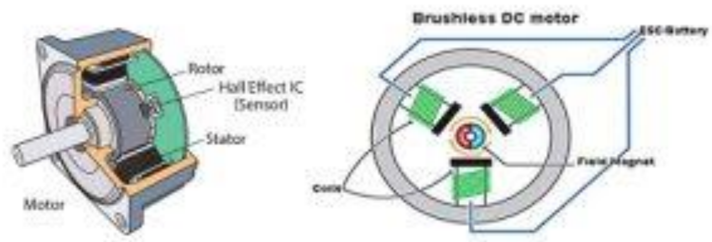

Fig.4 Brushless DC motors

Switching transistors, MOSFETs or IGBTs is traditional control method to regulate BLDCs by changing current in stator winding that is measured by Hall sensors. Diagrams of control drive for BLDCs and switching method are shown in Fig.5 và Fig.6 [1], [4], [8-9], [16].

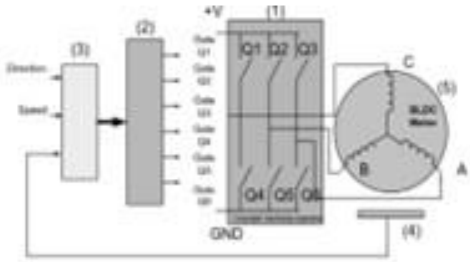

Fig.5 BLDC drive system

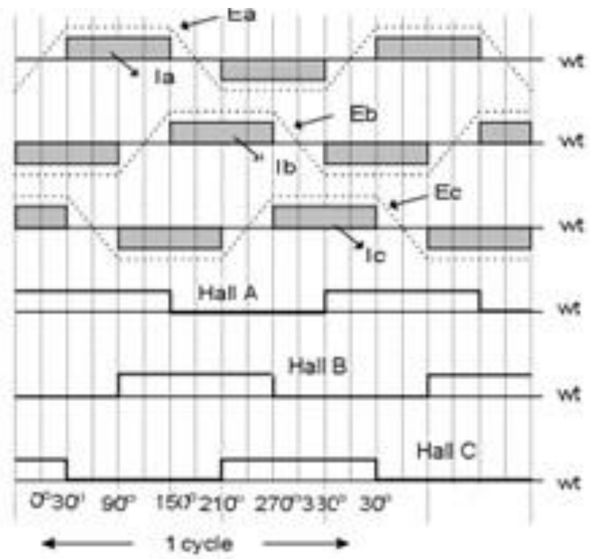

Fig.6 Back-EMFs, current and Hall position sensors waveform of BLDC motor

BLDC drive produce six different pattern in one cycle. Because there are six pattern of commutation, so it called six step commutations. The signal pattern shown in Fig. 4. This figure show the waveforms of Back-EMFs (Ea, Eb, Ec), current (Ia, Ib, Ic) and Hall position sensors (Hall A, Hall B and Hall C). Back-EMFs in this figure is the trapezoidal type, other type of Back-EMFs is sinusoidal. In this figure, the first commutation occurs in 30° until 90°, the 2th in 90° until 150°, the 3th in 150° until 210°, the 4th in 210° until 270°, the 5th in 270° until 330° and the 6th in 330° until 30°.

C. Stepper motors

Stepper motors have many pernament magnets in rotor, magnetic iron and windings in stator. They are considered as synchronous brushless motors so they also have long working time higher than brushed motors. Control pulse will be used to change both rotating angle location and rotating direction (reserve or forward) [1], [11], [15]. If classified into the number of phases, stepper motors can be included two-phase motor type (1,8°

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angle step), three-phase motor type (1,2° angle step), five-phase motor type (0,72° angle step). The structure of two-phase motor type (1,8° angle step) is shown in Fig.7.

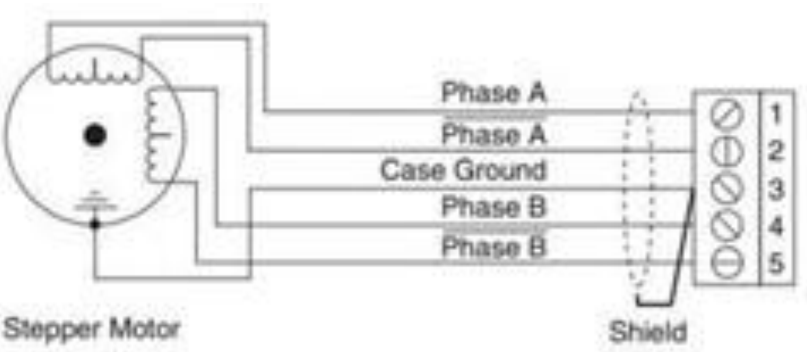
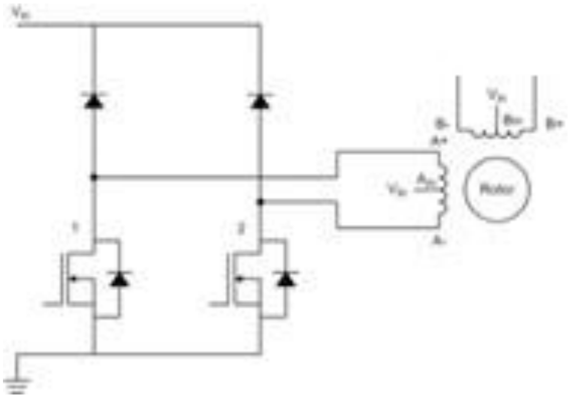
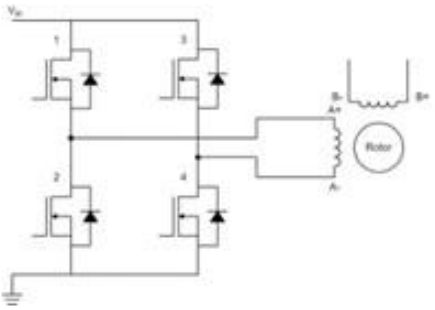


Fig.7 Structure of two-phase motor type

Stepper motors can be regulated by using power converters and switching frequency. Corresponding to the order and frequency of control signal, the rotating speed and direction will be changed by drives as depicted in Fig.8 [1], [11], [15].



a. Unipolar stepper motor



b. Bipolar stepper motor

Fig.8 Drive for two-phase stepper motors

For Unipolar stepper motors, if the first MOSFET is activated, the current will go from Am to A+ and if the second MOSFET is activated, the current will go from Am to A-. This control method is very simple but a winding is only used at any time, so magnetic field is only created a half.

For unipolar stepper motors, drivers use H-bridge converters. If the first and the fourth MOSFETs are activated, the current will go from A+ to A-. If the second and the the third MOSFET are activated, the current will go from A- to A+. This control method is more complex than above control method but it can help to provide maximum twisted moment. This control method can be made clear in Fig.9, Fig.10, Fig.11, and Fig.12 [1], [11], [15].

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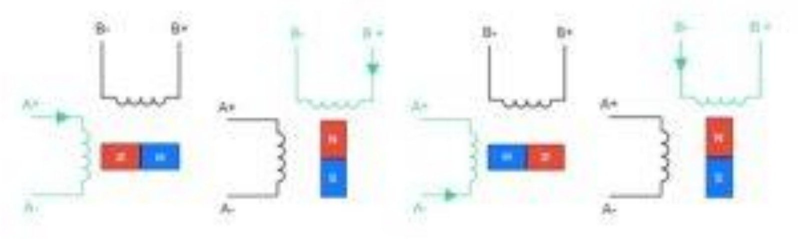

Fig.9 Control method using control pulse wave

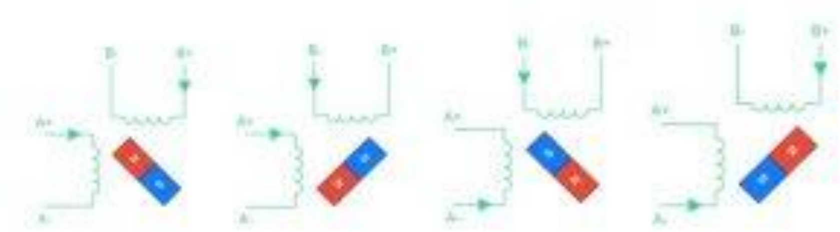

Fig.10 Control method using full step

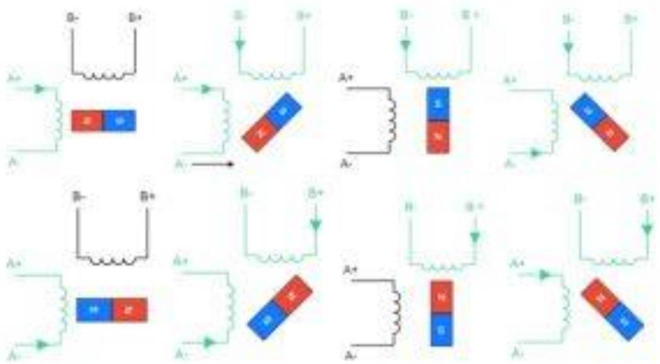

Fig.11 Control method using half step

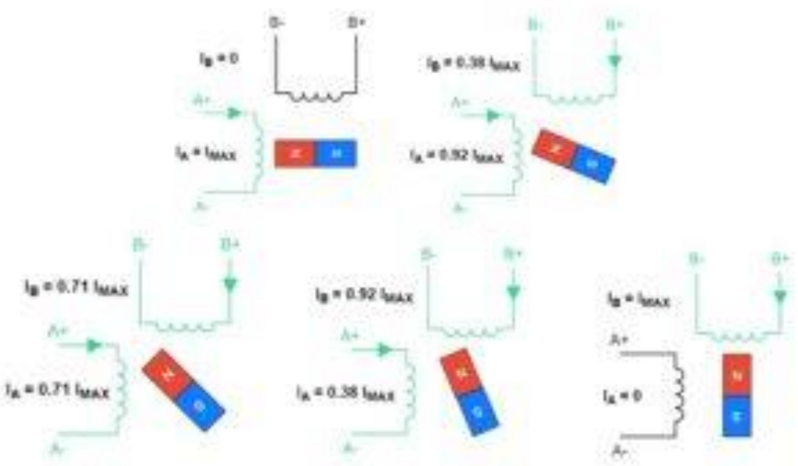

Fig.12 Control method using micro stepping

D. Servo motors

Servo motors have a stator and rotor using permanent magnets and windings. So, they are also synchronous motors with DC and AC types. They are often used in applications that require high moment and high accuracy. An encoder is installed in these motors with high resolution to provide feedback information about rotating direction and speed.

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For AC servo motors, drives can used close-loop principle and encoder feedback information as depicted in Fig.13.

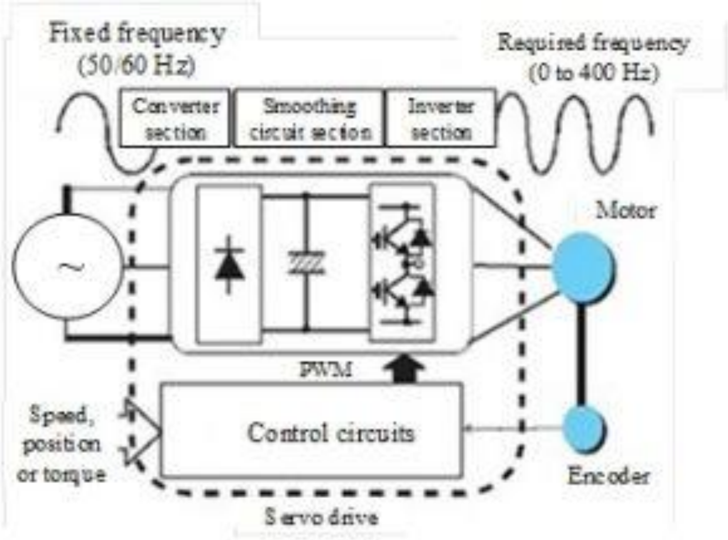

Fig.13 Power circuit and control of servo motors.

Control circuit will receive two input signals, including reference signal (expected location, speed and torque) and feedback signal from sensors. It will calculate instantaneous error value to adjust control signal that is amplified by an amplifier to create high value for voltage or control signal. Control process will stop if control signal is smaller than expected value.

E. Single-phase AC motor

Single-phase AC motors has only one phase in the stator. They have main components, such as motor case, stator, rotor, ball bearing, flange bracket, and shaft, two input terminals to provide power source, called phase line and neutral line, as depicted in Fig.14. [1].

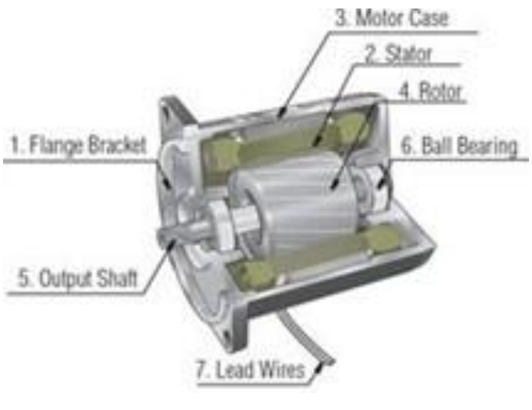

Fig.14 Main components of single-phase motors

AC power source is supplied to the stator. The current goes through stator winding and creates a rotating magnetic field corresponding to 60f/p, where f is grid frequency, p is the number couple of poles in stator winding. In rotating process, magnetic field will continuously scan conductor bars and create an electromotive force in rotor winding. When the motor works, rotor speed is smaller than the speed of magnetic field [1].

Some methods can be used to regulate the speed of single-phase motors, such as dimmers (regulating voltage or current), inverters (regulating frequency and voltage), thyristor regulator, PWM regulator, vector regulator, etc. Inverters can be considered as the best devices to control these motors in applications with high accuracy and efficiency.

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F. Single-phase induction motors

Single-phase induction motors can be changed the rotating direction by using a capacitor and power source supplied to white and red lines as depicted in Fig.15 [17]. An inverter also can be used to control both rotating speed and direction as depicted in Fig.16.

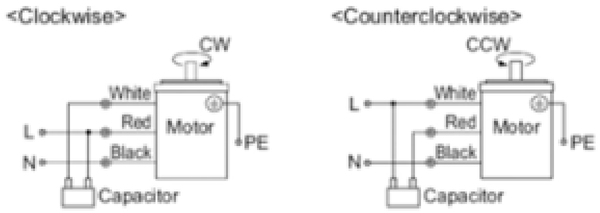

Fig.15 Clock wise and counter clock wise of single-phase induction motors

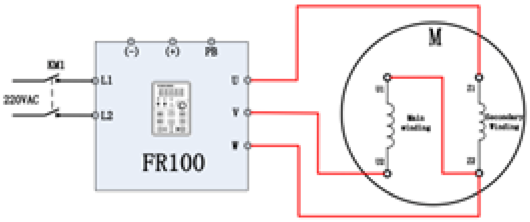

Fig.16 Control of rotating speed and direction for a single-phase induction motor using an inverter

E. Three-phase AC motors

Three-phase AC motors create rotating field to make the rotation of rotor and maintain mechanical power on their shaft. Current going from power source to stator winding, create a rotating field at n1 speed, where n1=60f/n (f is frequency of current, p is the number of pole couple). Rotating field will go across conductor bars of the rotor and create a current as depicted in Fig.17.

Method to change the rotating direction is represented in Fig.18. Assuming that the motor is rotating in forward direction, the states of contacts are: KH1(11-13) and KH2 (5-7) closed, KH1 (3-5) và KH2 (3-11) opened. At the end of forward operating process, KH2 button is pressed. Due to the activation of KH2 button, contact KH2 (3-11) closes, KH2 (5-7) opens and cause KH2 (5-7) open. Because KH2(5-7) was opened, power for KT coil is off and KT (13-15) is closed. It means that power for KN coil is on and the rotating direction is changed. At the end of reserve operating process, KH1 is pressed. Due to the activation of KH1 button, KH1 (3-5) contact is closed and KH1 (11-13) is opened. It means that power for KN coil is off and the rotating direction is changed [18].

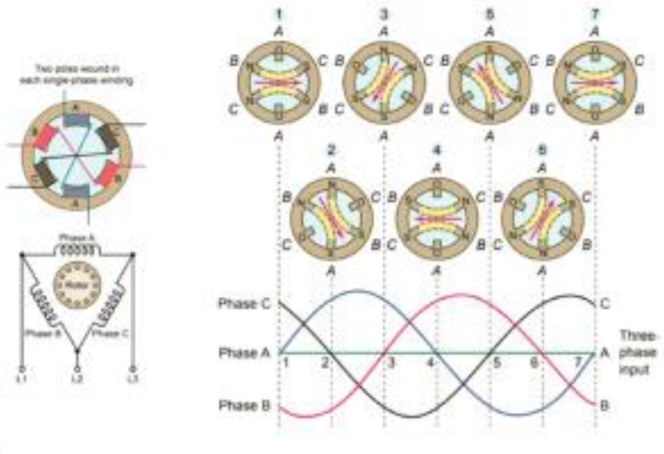

Fig.17 Operation of three-phase AC motor

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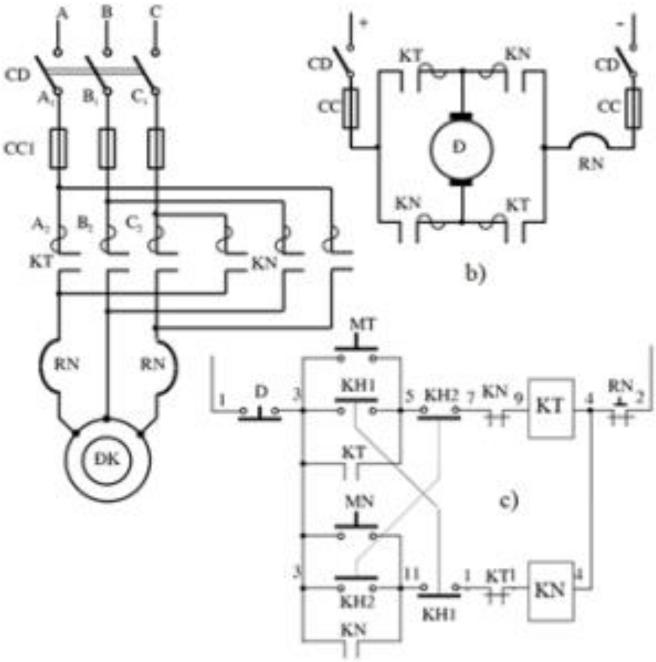

Fig.18 Control and power circuits to regulate the rotating direction for three-phase motors

AUTOMATIC PROOF DOORS AND CONTROL SOLUTIONS USING ELECTRICAL MOTOR

A. Automatic proof doors

Automatic proof doors are designed to harness natural lighting and considered as a safe solution in cases of having fire in domestic houses. Some type of proof doors are represented in Fig.19.

To operate proof doors automatically, it must be designed a suitable driven system using electrical motors. These driven systems can be classified into sliding type that help to move doors in horizontal axis or piston type that help to move doors in flap axis.

a. Industrial doors

b. Two sliding doors

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c. Single sliding doors

d. Piston doors

Fig.19 Some types of proof doors

Proof doors can be designed to open or close automatically as the followings:

The first, press hardware buttons to open/close: Fixed buttons located on the wall or on the remote controller are used to control proof doors. For buttons on the wall, some control signal transmission lines must be used from buttons to controller and motor location. For buttons on remote controller, a received controller must be designed in available radio range that can help to transmit signal information from the remote controller to the main controller.

The second, press software button to open/close: a software can be designed on mobile phones or computers to control proof doors. In this case, IoT technology can be used to combine advanced techniques to regulate speed, direction or current operating states flexibly.

The third, proof doors can be regulated in automatic modes with a fixed time. They can be opened in the morning or closed in the evening with expected time that was previous installed in controllers. To complete automatic control for proof doors that adapt to real operating conditions, it must be combined some sensors such as rain sensors, light sensors, smoke sensors, breeze sensors, proximity sensors, temperature sensors, wind sensors, etc. In case of having rain information, the door will be closed automatically to avoid falling water into the house. In case of having light information, the controller can distinguish night time or day time to close the door in night time or open the door in day time automatically. In case of having smoke information, it means that it has fire in the house and the door will be controlled to open automatically and release smoke. In case of having breeze information, the door will be controlled to close automatically to avoid dispensing breeze from the sky to the house. In case of having person information, the door will be controlled to close and generate warning signal automatically to warn own house about thieves. In case of having high temperature information, the door will be controlled to open automatically to make house cooler. In case of having high wind speed information, the door will be controlled to close automatically to protect itself. Moreover, the controller will stop sending signal information in cases of having error operating process such as barriers or other faults on driven system.

B. Experimental model

Control and power circuits of experimental model are presented in Fig.20.

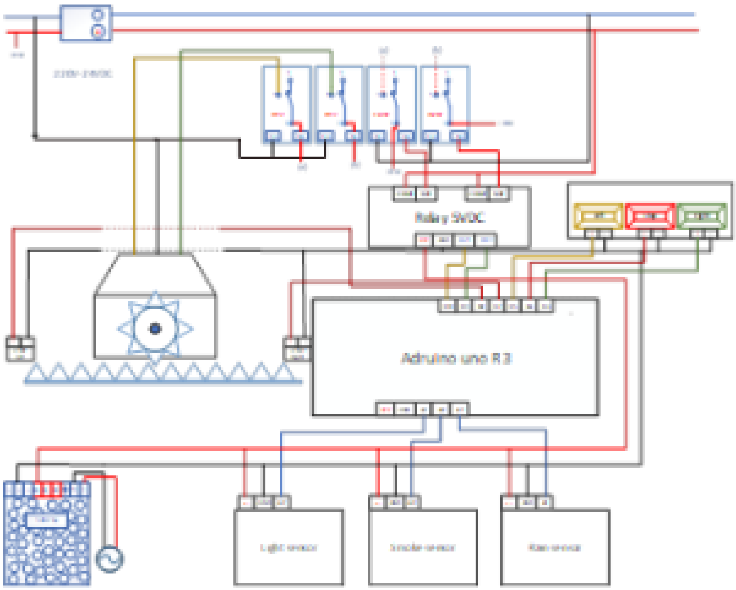
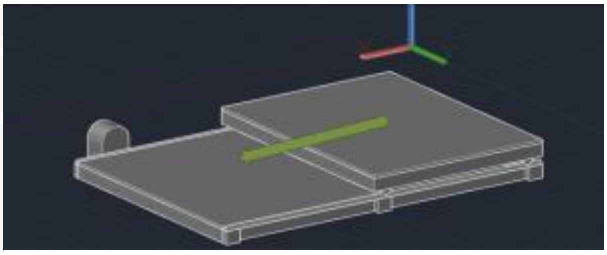


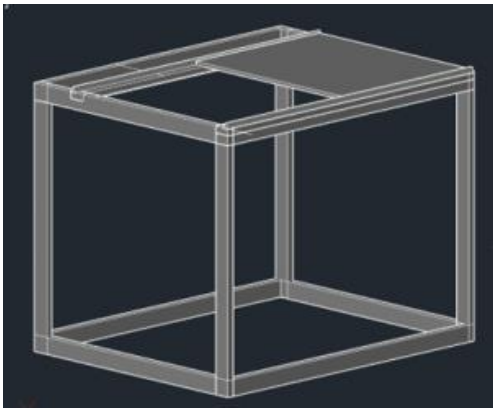
Fig.20 Control and power circuits of experimental model

Main devices in this experimental model: an Arduino Mega 2560 board; LDR light sensor; MQ8 gas sensor; YL-83 rain sensor; single-phase induction sensor; relays; 5 VDC power source; process contacts; buttons.

3D structure of the model is shown in Fig.21.



a. 3D description for the moving of proof door



b. 3D description for cage of proof door

Fig.21 Experimental structure for proof door

Arduino Mega 2560 board collects information from sensors and buttons to create control signal that change the operating states of relay to control motors. If light intensity is enough high, the light sensor works will close its circuit and the controller determines that working time is day time. In this case study, the controller will send a signal to open the door. If light intensity is not enough high, the light sensor works will open its circuit and the controller determines that working time is night time. In this case study, the controller will send a signal to close the door.

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Arduino Mega 2560 board also collects information from rain sensor. If it rain and water is falling into the surface of the sensor, the rain sensor works will close its circuit and the controller determines that it is raining. In this case study, the controller will send a signal to close the door. If it doesn't rain and water is not falling into the surface of the sensor, the rain sensor works will open its circuit and the controller determines that it is raining. In this case study, the controller will send a signal to open the door.

The experimental result for the moving of the motor in case of day and night time is shown in Fig.22 and Fig.23.

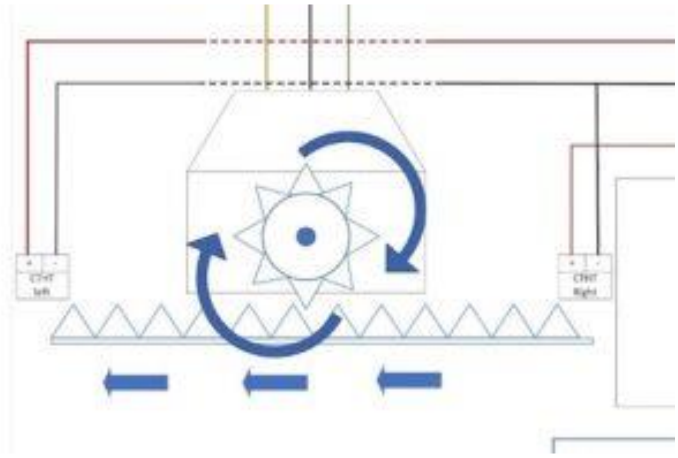

Fig.22 Moving of the motor in case of day time

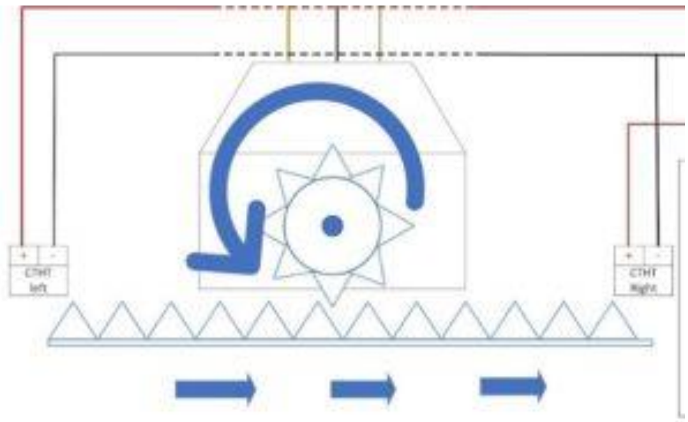

Fig.23 Moving of the motor in case of night time

In cases of both having day-time and rain information, the controller will send control signal to close the door as depicted in Fig.24.

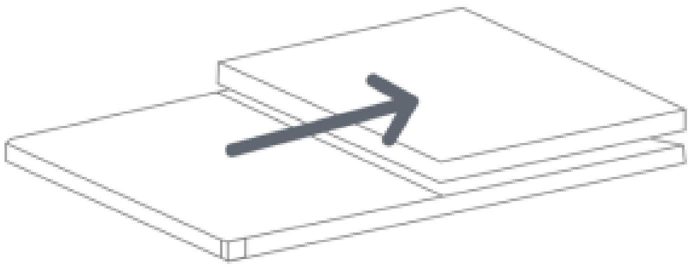

Fig.24 Moving door in case of having rain

Assuming that it is night time and the door is closing. In cases of having smoke or gas, the controller will understand that it has a fire or a fault in gas cooker. The controller will send a control signal to open the door immediately. It will help to reduce accidents in the house. The experimental model is represented in Fig.25.

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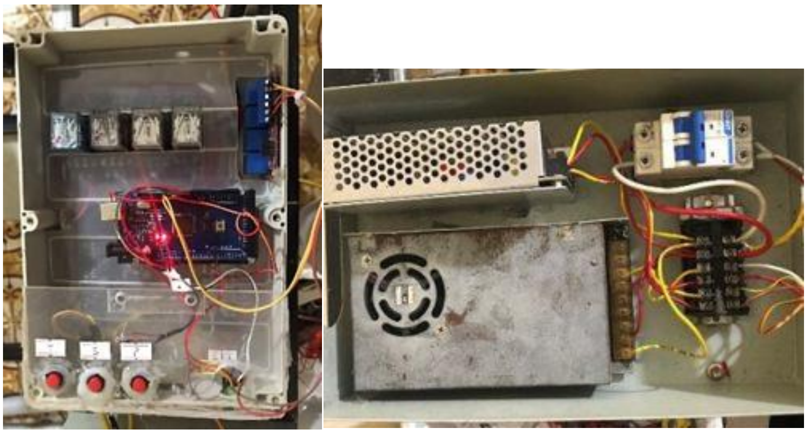
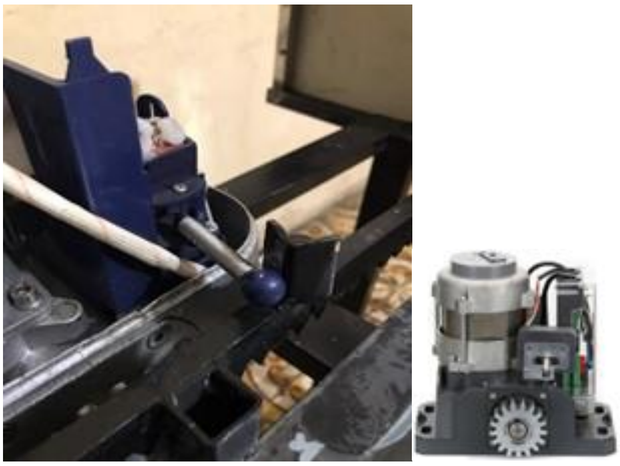


a. Controller



b. Motor and process contacts

c. Capacitor at output terminals of the motor

Fig.25 Experimental model

Day time is assumed by light from LED indicator. Experimental result in day time is depicted in Fig.26 (the door is opened automatically).

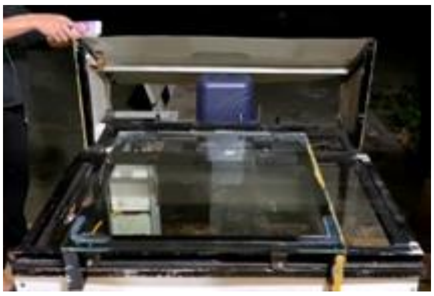


Fig.26 Experimental result in day time

Day time is assumed by shading light. Experimental result in night time is depicted in Fig.27 (the door is closed automatically).

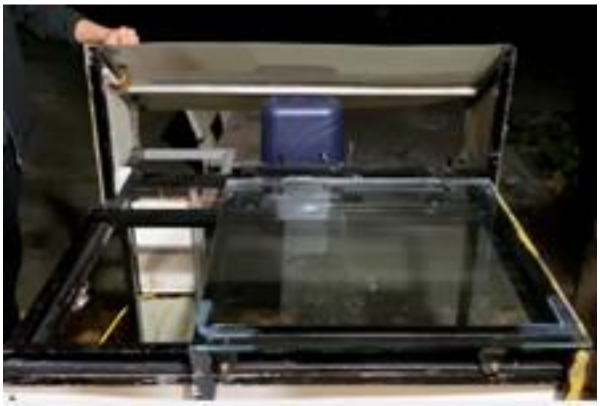


Fig.27 Experimental result in night time

Day time is assumed by watering into rain sensor. Experimental result is depicted in Fig.28 (the door is closed automatically).

Fig.28 Experimental result in case of having rain

Experimental results showed the motor is controlled to meet all operating requirements for automatic proof doors. Operating states of this system is created by the controller and proved completely about the meaning of this research. The motor and driven system can be regulated to always have moving state, pausing state, fixed stopping state and weather constrains.

CONCLUSION

Main contribution of this paper is to study an overview about components, control method and applications of electric motors in industry and civil. These motors were classified into brushed DC motors, brushless DC motors (BLDC), stepper motors, servo motors, single-phase and three-phase AC motors. Control solutions for each type of motors were made clear, including power circuit, control circuit, operating principle of control system to change the rotating speed and direction. An application of electric motor in proof doors was introduced, including designing structure and proposed automation control. Some experimental results were also introduced to prove the meaning of this study.

Experimental results showed that the single-phase induction motor can be controlled to meet the different operating requirements of proof door. These requirement are controlling at remote mote by using remote control, automatically open the door in day time or automatically close in night time without having special weather conditions. In cases of having rain in day time, the door will be closed automatically. In cases of having smoke or gas in the house at night time, the door will be opened automatically. Stopping locations of the motor in the model are created by process contacts. Due to using Arduino Mega 2560 board, the control schedule and scenarios are programmed to ensure that high accuracy for work.

Research results showed that electric motors can be established control solutions by designing power circuit, control circuit and suitable controllers such as Arduino boards, PLC, etc. In real application, motors can be regulated to change rotating speed corresponding to various time ranges to meet many operating requirements. These issues can be developed more deeply in the future using modern control techniques and new controllers to adapt to new problems or new requirements in real systems.

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