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The Speed Control of Four-Quadrant DC Motor with a PI Control Topology

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Abstract: This research article presents the speed control concept of the four-quadrant DC Motor with a proportional and integrated (PI) Control Topology. The novel method for this research is bootstrap half-bridge control techniques to control the device switch and reduce the circuit's complexity by creating a virtual ground and using the TMS320F28379 microcontroller for controlling the PI tuning with a quick response and less wrong. This research creates a prototype mechanism to test the performance and found that the speed control of the four-quadrant DC Motor with a PI Control Topology can control speed command not less than 95%. However, when tested by connecting to the motor using the electromagnetic brake is found to be able to control the speed command for not less than 90%. Consequently, it can be concluded that the method and concept of reducing the complexity of the device switch control circuit in the mechanism created can confirm the speed control of the four-quadrant DC Motor with a PI control topology is better than other types of control circuits.

Keywords: four quadrants, PI control, microcontroller, electromagnetic braking, DC motor.

具有PI控制拓扑的四象限直流电动机的速度控制

摘要：本文介绍了具有比例和积分（PI）控制拓扑的四象限直流电动机的速度控制概念。这项研究的新颖方法是引导半桥控制技术，该技术通过创建虚拟地并使用TMS320F28379微控制器以快速响应和更少错误来控制PI调谐，从而控制设备开关并降低电路的复杂性。这项研究创建了一个用于测试性能的原型机制，发现具有PI控制拓扑的四象限直流电动机的速度控制可以控制不少于95%的速度命令。但是，通过使用电磁制动器连接到电动机进行测试时，发现能够将速度指令控制在90%以上。因此，可以得出结论，在所建立的机制中降低设备开关控制电路复杂性的方法和概念可以确认具有PI控制拓扑的四象限直流电动机的速度控制优于其他类型的控制电路。

关键词：四个象限，PI控制，微控制器，电磁制动，直流电动机。

1. Introduction

In driving DC and AC motors, various driving styles have been developed, such as single-quadrant, two-quadrant with four-quadrant. These circuits can also be divided into several types depending on their use. However, when only DC motors are considered, the most popular driving control principle is a four-quadrant drive, which is best suited to the characteristics of a DC motor. The basic circuitry used to drive DC motors is arranged in a high- and low- side configuration. These introductory circuits often encounter gate driving problems for many all-power electronic switching devices. Typically, the solution is to use a high-frequency transformer for gate or oppo-IC driving. Either way, the problem remains with the high-frequency transformers due to the noise or the problem of the oppo-IC power supply that requires a common ground. Consequently, for this reason, researchers focus on solving these problems by offering the speed

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control concept of the four-quadrants DC Motor with a PI Control Topology. The novel method used for this research is to use control techniques bootstrap half-bridge to control the device switch and simplify the circuit by creating a virtual ground and use the TMS320F28379 microcontroller to control the PI tuning that has a quick response and less and high performance. The researcher has researched and reviewed relevant literature, which will be discussed in detail as follows.

High-power step-up DC-DC converter design using analog control circuit and DC motor speed regulation using TMS320F240DSP. The principle used is to convert the low voltage input source to high voltage. The conversion has two steps: use of a full bridge to increase the DC voltage. The output of the step-up converter uses a capacitor to hold the charge. This capacitor is used to compensate for the maximum power demand of the load during a sudden change in time to store energy under the braking condition of a DC motor. Principle adjusting the PID control for closed-loop control of the DC chopper motor four quadrants fed DC. Tracking the speed of the DC motor in front-powered mode uses the controller. The efficiency of the PID tuning using a linear quadratic regulator will find that the controller parameters will receive a time-domain analysis that includes the specifications of performance in the form of digging, finding, and the time to seduce the desired precipitation [1].

The speed control design for the DC motor of industrial machines was developed with a four-segment speed control system using a microcontroller [21]. The four functions of a DC motor are rotated clockwise. Anti-clockwise and instantaneous braking in both directions Systems designed to be used for brakes. Forward and reverse brakes are key features. Sudden braking in both directions occurs as a result of applying a reverse voltage on the motor that is run for a short period. And motor speed control is achieved with PWM pulses generated by the 8051 microcontrollers. The control output can be achieved according to the conditions and objectives [2]-[4]. The closed-loop speed control of the DC controller (DC) motor with separate excitement is carried out by the four-quadrant DC motor drive circuit operator. Nevertheless, MATLAB/Simulink control software is designed using the first PI controller, the bipolar switching cycle, and the second one is unipolar. The control signal received from these circuits is applied to four DC hack lights. The Single-phase quadrant is driven by the exciting DC motor that is separate at the reference speed. Comparing how to switch both simulation results of the output voltage and the frequency response is better than the two-terminal switching methods due to the frequency switching of the output voltage to double the unipolar switching method [5].

The shortcomings of low precision and latency in various methods of speed regulation are numerous. Proportional Integral Differential (PID) controller design and selection of Proportional, Integral, and Differential control parameters according to different system responses using MATLAB / Simulink program. There are many algorithms. Controlling the speed of a DC motor with Pulse Width Modulation (PWM) is another technique that involves the use of the same simulation software. Hardware control test results using infrared (IR) sensors and an Arduino to measure the rotation per minute of a DC motor and the motor speed can be in accordance with the established principles [6]-[12]. The modular brushless DC motor design and operation in four parts. The four applications of this design will cause the motor to rotate clockwise and counterclockwise in motion mode and regenerative brake mode. This is important to save energy, and at the same time, operation in regenerative braking mode is fed back to the power supply [13]-[15]. The torque fluctuation problem arising in the low-speed operation of intermittent motors, current and frequency control strategies can be applied to achieve constant motor speed regulation. According to the electromagnetic relationship, the slope of positive current, negative voltage, and zero voltage is estimated in the current control circuit so that the winding current can be precisely controlled. The simulations and validation results show that the presented method has a fast dynamic response and can track the reference current very well at low speeds, suppressing torque ripple [16]-[19]. DC Motors are used extensively for speed control and directional control using a four-quadrant. The speed below the base speed can be controlled using a switching device voltage regulator (IGBT). This pulse-width modulation is generated by setting the Digital Signal Processor program using Code Composer software, the above model simulated in MATLAB [20].

2. Concept and Principles Background

Notwithstanding, the design principles of a half-bridge bootstrap switch device used to control the speed of a four-quadrant DC motor for driving power electronic switching devices are shown in Fig. 1. In this paper, the researcher will create a mechanism to analyze the analysis. The power electronic switchgear driver works by using a virtual earthing topology to drive the switch on the H-bridge bootstrap circuit in the high-side driver. Moreover, Fig. 1 shows a functional diagram of a mechanism consisting of two parts. The first part is a power mechanism consisting of a one-phase full-wave rectifier, filter, H-bridge drive. The second part is a control system consisting of the PI control mechanism that produces a PWM signal, a dead time/isolate control, and a bootstrap power electronic switch mechanism. The next section shows the theories and principles involved in this research.

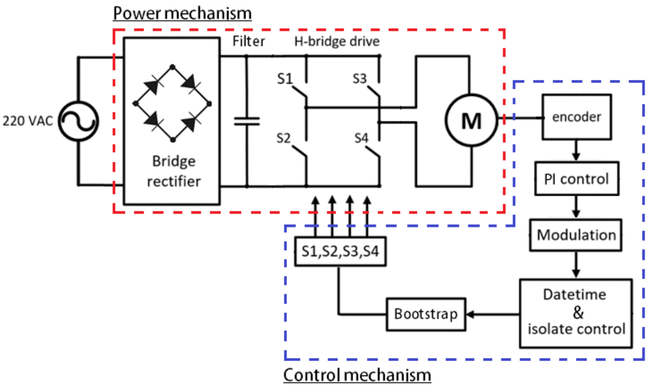
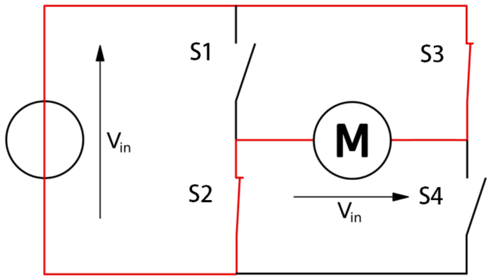


Fig. 1 Mechanism diagram of the H-bridge bootstrap topology



(b)

Fig. 3 Switching device status of H-bridge drive mechanism

2.1. The Basic Principle of the H-Bridge Drive Mechanism

As mentioned above, the basic structure of the H-bridge drive and the Full-Bridge inverter has the same characteristics as four power electronic switching devices. The H-bridge drive mechanism can select transistors, MOSFETs, and IGBT depending on their application to drive motors. However, for a full-bridge inverter mechanism, the switching device works as a switching inverter, so most of them use MOSFETs or IGBT devices. These two mechanisms are developed from half-bridge inverters, classified as the high side of the upper switch and the low side of the lower switch. Therefore, in the H-bridge Drive circuit, S1 and S3 are classified as High-Side, and S2 and S4 are classified as low-side.

Fig. 2 is the structure of the H-bridge drive mechanism. It can be seen that the switching devices in the same branch will not work simultaneously with their operation in two states.

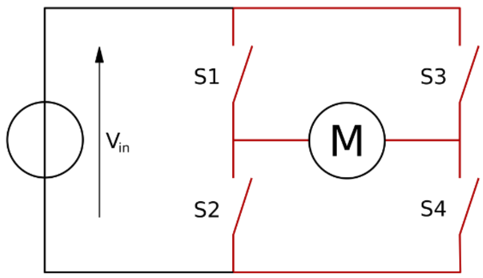
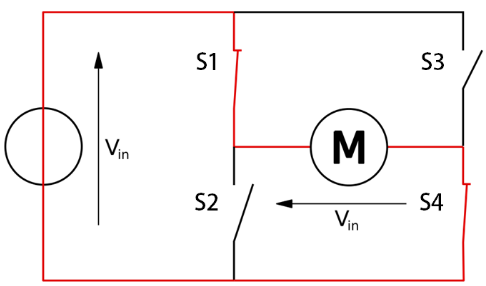


Fig. 2 The structure of the H-bridge drive mechanism with the motor as a load



(a)

Considering Fig. 3(a), the S1 and S3 states will turn on simultaneously, the S2 and S4 will be turned off at the same time. Meanwhile, S2 and S4 have a turn-on state.

Typically, the H-bridge arrangement is used to reverse the polarity/direction of the motor. But it can also be used to brake a motor where the motor stops suddenly. Table 1 describes the S1-S4 operations of Fig. 3(a) and (b).

Table 1 The working state of the switch device

S1	S2	S3	S4	State
1	0	0	1	Moves to the right
0	1	1	0	Moves to the left
0	0	0	0	Stops working
1	0	0	0	
0	1	0	0	
0	0	1	0	
0	0	0	1	
0	1	0	1	Brake
1	0	1	0	
x	x	1	1	Short circuit
1	1	x	x	

2.2. Principles of Switching Devices with Bootstrap Topology

Due to both of the above gate driving problems and limitations, there is a need for a separate source for the gate drive between the High-Side and the Low-Side. The H-bridge drive circuit has developed an IC High-Side driver using Bootstrap topology to drive the High-Side switch with the basic circuit, as shown in Fig. 4.

Fig. 4 consists of three parts: control unit, drive Hi (high-side), and drive Lo (low-side). There are also sub-sections Hi (High in) and Lo (Low in) pins. This is a PWM command to move the drive Hi or Lo controls to the high-side or low-side switching devices. This control supply is the source for the logic circuit, which is configured according to the logic voltage of the PWM coming to the Pin of Hi and Lo for reference to pin Vss.

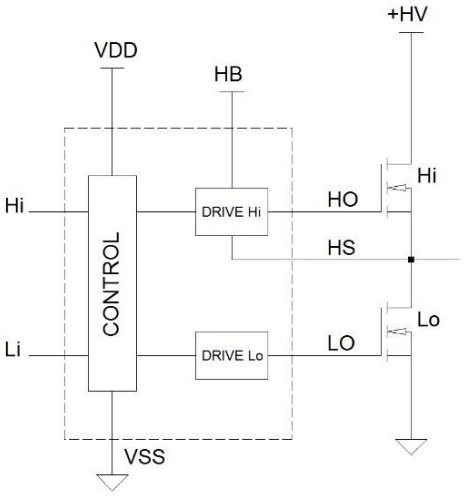


Fig. 4 Basic IC High-Side Driver circuit using Bootstrap technique

This is a common reference point used in conjunction with the drive Lo control unit and the Low-Side switch. Consequently, it is the same as the general switch drive circuit. The separate part is the HB, HO, and HS part of the drive Hi unit that drives the switch device on the High-Side, separated by a floating set. The HB pin is the pressure connection. That expelled on the HO side to drive the gate of the side switch device high-side, the voltage at this point HB with HO is the voltage used in reference to pin HS.

2.3. Four Quadrant Control Principles

The theory and principles of operation of the four quadrants for DC motor drive are forward braking, forward motoring, reverse motoring and reverse braking (Fig. 5). Generally, the motor will operate in two modes, forward and brake. The motor drive operates in both directions of rotation, which is known as a quad variable speed drive. For the multi-quadrant operation of the drive, the torque and speed signal specifications are used. When the motor rotates in the forward direction, the motor speed will be positive. The drive will operate in one direction only. The forwarding speed will be normal.

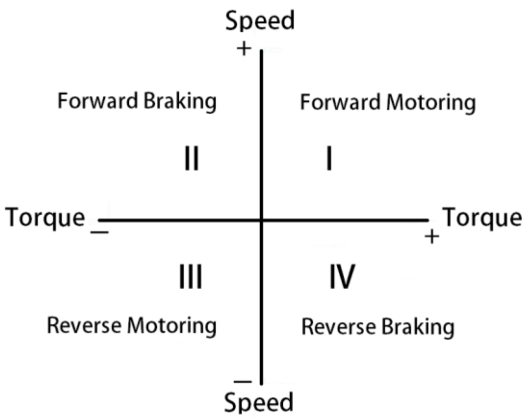


Fig. 5 The four-quadrant operation of drives

3. Result and Discussion

This topic is an experiment with the four-quadrant DC motor control mechanism using the bootstrap technique to drive the device. The electronic switch is using the proportional controller and the implementation that has been created.

Consequently, this research will experiment with the mechanisms created in various topics, consisting of experiments, the response of the prototype for the DC motor control when connected to the electromagnetic brake.

The experiment of the mechanism is produced in Fig. 6. It is found that the mechanism can respond to commands and control conditions according to the objectives. For this research method, the researcher uses the MATLAB/Simulink processor through the Microcontroller TMS320F28379D. However, when experimenting with the DC motor together with an electromagnetic brake, it is found to control the speed and torque and displayed by the torque-speed meter to compare with the speed detection device (Encoder), which results satisfactorily.

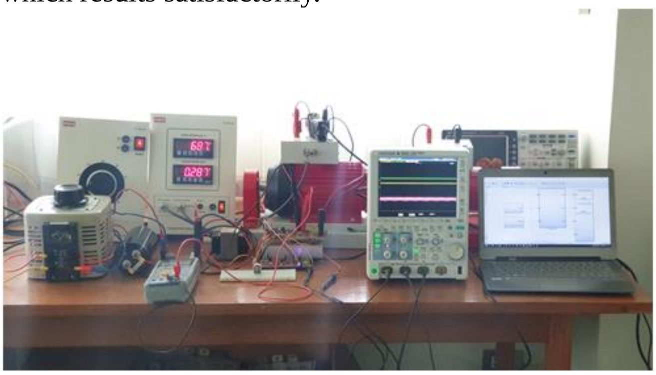


Fig. 6 The response of the prototype for the DC motor control

For proportion and integration, increasing torque for DC motor with electromagnetic brake found that the speed of the DC motor is reduced. Therefore, it is the cause of the closed-loop control called the proportion and integration so that the DC motor can control the speed. Proportional and intricate controls are used because the proportion and integration can respond to changes quickly. The derivative control is suitable for the type that is sensitive to slow change [22].

The mechanism experiment is carried out to compare speed command with speed encoder detection device (Fig. 7). Step speed command changes make the speed encoder detection device change according to the speed command signal. Therefore, it can be concluded that the proportion and integrated control applied for this research, responding to the speed control of the DC motor, can result satisfactorily.

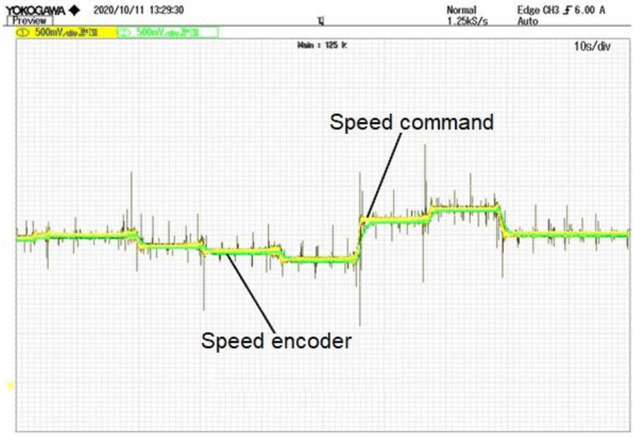


Fig. 7 Step speed command signal comparison with the speed encoder

The following topics are the speed control of the current DC motor in the case of no proportions and integration. The experiment of this prototype mechanism consists of no load, and the conditions are electromagnetic brakes. For this research, the quadrant four-quadrant control presented in various quadrant experiments that consist of one-quadrant, two-quadrant, three-quadrant, and four-quadrant by experimenting with the speed of 3000 rpm as follows.

Fig. 8 shows the speed control of the DC motor of one quadrant that does not contain proportion and integrated control and has a proportion and integrated control to compare the response of the device control towards the mechanism produced. However, in the experiment, the researcher tested the speed from 1000 rpm - 3000 rpm, respectively, but in this article, the researcher will present only the control equal to 3000 rpm. Considering Fig. 8(a), the speed of the DC motor cannot be controlled. It is equal to 3000 rpm according to the needs of the speed command. However, when using the proportion and integrated control (Fig. 8(b)), it can control the speed of the motor according to the needs of the speed command. Similarly, considering Fig. 8(c), when the DC motor is connected to the electromagnetic brake, there is no proportion and integrated control. It is found that the speed of the DC motor will be significantly reduced. Considering Fig. 8(d), the proportion and integration can control the speed according to the needs of speed commands.

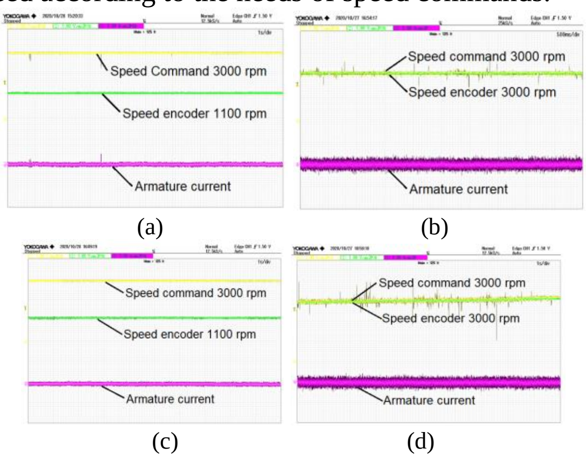


Fig. 8 Speed control of DC motor in one-quadrant

Fig. 9(a) shows experimenting with the mechanism in the two-quadrant, which is a working forward braking.

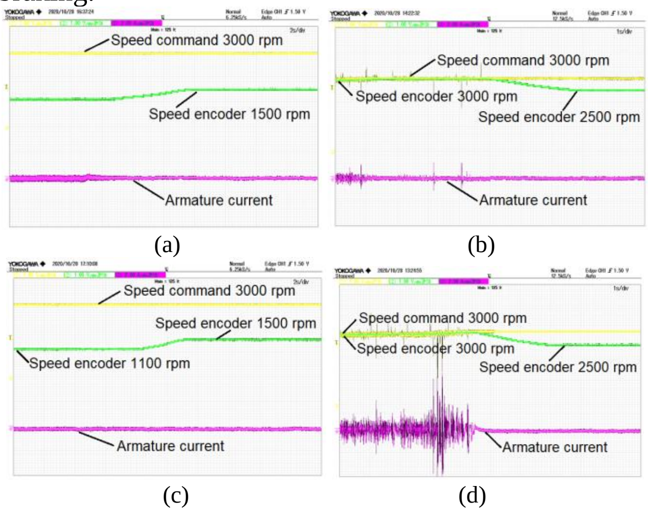


Fig. 9 Speed control of DC motor in two-quadrant

In this two-quadrant, the motor works in the forward direction and does not contain proportion and integrated control. Electromotive force induction that occurs in the DC motor is still positive. Nevertheless, the current voltage will be reduced, which is less than the back EMF. Consequently, the current that causes the torque to reverse the direction of this negative torque is reversing the direction of the energy flow.

Fig. 9(b) will find that when there is a control with the proportion and integrated, can control the speed according to speed command and when the experimental releases such control, it can be seen that it cannot be controlled. Fig. 9(c) will be consistent with Fig. 9(a), when there is no control with the proportion and integrated, even though it is connected electromagnetic brake. However, in Fig. 9(d), when the DC motor is connected to the electromagnetic brake and the torque increase by adjusting the current electromagnetic brake, the current of the current DC motor is as follows:

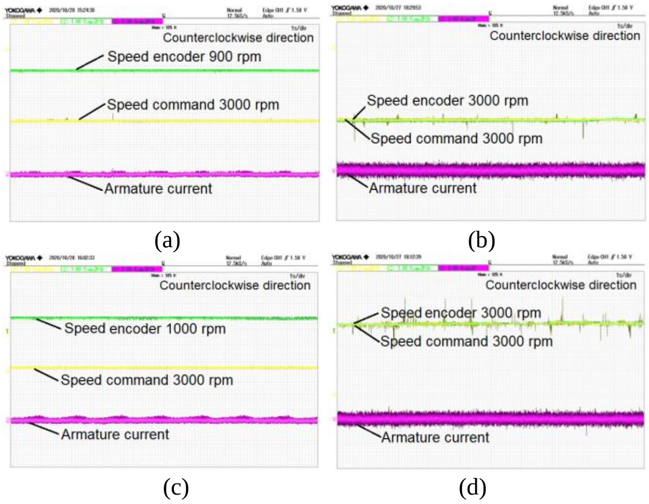


Fig. 10 Speed control of DC motor in three-quadrant

Fig. 10(a) shows the three-quadrant operation of the DC motor. The case is not controlled by proportion and integration. It is found that the voltage and the current of the motor will have a negative direction, thus causing positive power. The power from the source will go to the load due to the reverse current. The motor rotates in the counterclockwise direction. The speed can be controlled according to the needs of the speed command (Fig. 10(b)) if there is a control with proportion and integration. Nevertheless, Fig. 10(c) and 10(d) will be consistent with the explanation. However, the amplitude of current has also been found in connecting with electromagnetic brake with DC Motor. This three-quadrant is similar to one-quadrant, but there is a difference in the direction of the motor rotation only. The voltage to the motor is to control the desired speed in the opposite direction.

Fig. 11(a) shows the operation of a four-quadrant that is not controlled by proportion and integration. The DC motor voltage still has a negative direction, and the current of the armature will have a positive direction. This operation is similar to the operation of two-quadrant, so it can be explained from Fig. 11(a) that whenever electromagnetic force (Back EMF), more than negative supply, the torque voltage will be positive, which is against the torque of the load, so the speed of the motor will decrease during the back resistance of the motor.

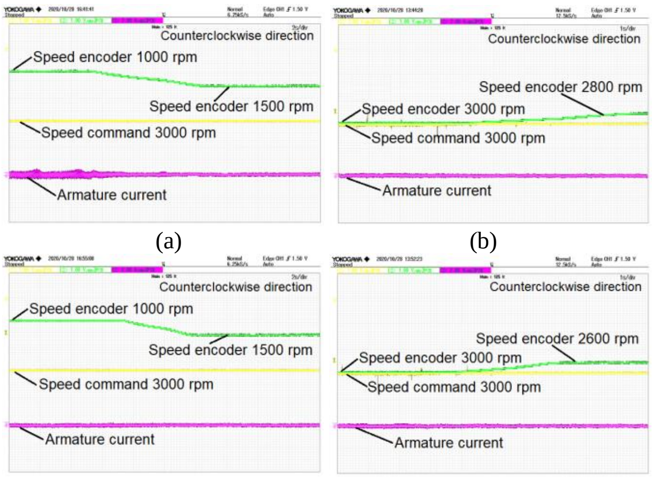


Fig. 11 Speed control of DC motor in four-quadrant

In the case controlled by the proportion and integration (Fig. 11(b)), the speed control will be in accordance with the speed command. The mechanism can work as needed. Moreover, in Fig. 11(c) and 11(d), the DC speed control experiment with the DC motor in the two mentioned conditions can operate according to the specified objectives.

Nevertheless, the operation for the speed control of the DC with a proportional and integrated control topology operated with the TMS320F28379D microcontroller has experimented with the mechanism created. The researcher found that if he wanted to control the speed of constant status, it could be controlled using the appropriate voltage amplitude. The motor torque section will be directly proportional to the armature current, which will depend on the voltage used with the electromotive force (Back EMF) with the DC motor. For microcontrollers, TMS320F28379D can respond to the control of the mechanism according to the objectives is satisfactory.

4. Conclusion

The DC motor's experimental research, speed control mechanism, four quadrants with proportional and integrated control topology were performed with the Microcontroller TMS320F28379D. The research focuses only on the control of the bootstrap half-bridge switch used for the DC motor's speed control for four quadrants. The use of half-bridge bootstrap topology can confirm the accuracy that can reduce equipment and circuits used for controlling the device for the speed of the DC motor according to the objectives. Moreover, it is also found that the speed control of the DC motor when connected to the electromagnetic brake can also control the speed of the DC motor. The result is satisfactory. However, the application should consider the limitations related to the PI tuning, especially the Kp and Ki adjustment, if it is inappropriate or stable, if it makes the speed control of the DC motor difficult.

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