Engineering and Technology Journal e-ISSN: 2456-3358

Volume 09 Issue 05 May-2024, Page No.- 3881-3886

DOI: 10.47191/etj/v9i05.02, I.F. – 8.227

© 2024, ETJ

Control the Speed of Separately Excited Dc Motor Using Sliding Mode Controller

Chinedu James Ujam[1], Adebayo Adeniyi D.[2]

[1]Department of Mechatronics Engineering, Federal University Otuoke, Bayelsa State, Nigeria.

[2]Department of Electrical and Electronic Engineering, Federal University, Otuoke, Bayelsa State, Nigeria.

ABSTRACT: This study looks into how a Sliding Mode Controller (SMC) can be used to control a Separately Excited DC Motor's (SEDCM) speed. The SMC is utilized to improve the system's resilience to unknowns and disruptions, guaranteeing accurate control under changing operational circumstances. Extensive simulations and experimental settings confirm the suggested control technique, which shows improved performance in terms of stability, disturbance rejection, and speed tracking. The results further the development of DC motor control techniques, especially in situations where robustness and precision are crucial.

KEYWORDS: Sliding Mode Controller (SMC), Separately Excited DC Motor (SEDCM), Speed Control, Resilient Control, Robustness, Precision

INTRODUCTION

Industries are driven by electrical drives that use different kinds of DC motors. In wealthy countries, motor drives utilize over 50% of the generated electrical energy. In a wide range of industrial applications, including electrical machinery, computer peripherals, robotic manipulators, actuators, steel rolling mills, electrical vehicles, and more, DC motors are utilized extensively. Because of its broad power, torque, and speed ranges, high efficiency, quick reaction, and straightforward and continuous control features, its applications range from low horsepower to multi-megawatt (Ambesange, et al., 2013). In the early 1950s, variable structure control, or VSC, initially appeared. Control actions in variable structure systems (VSS) are discontinuous functions of system states, disturbances, and reference inputs since the VSS is made up of a collection of continuous subsystems with appropriate switching logic. Sliding modes play a crucial part in VSS theory, and the basic idea behind creating VSS control algorithms is to enforce this kind of motion in certain system state space manifolds. A suitable control should be created when there are uncertainties and disturbances in the system to ensure that the intended responses and system stability are realized. When outside disturbances and uncertainties are present, sliding mode control (SMC) is insensitive. Due to SMC's resilience qualities, a wide range of linear and nonlinear systems can be effectively controlled using this intensive, well-liked, and appropriate technology. Particularly when the bound of uncertainty is big or the nonlinearity is very high, PI controllers are not always able to properly stabilize the system. Almost flawless disturbance rejection or control performance is needed in many real-world scenarios. Applying sliding mode control (SMC) to the system can achieve these kinds of performances From groundbreaking research conducted in the former Soviet Union in the 1960s, sliding mode control was developed. A decision rule and certain feedback control rules define this specific kind of variable structure system (VSS) (Dursun & Durdu, 2016).

2.0 DC MOTOR

Any rotating electrical motor that transforms electrical energy from direct current (DC) into mechanical energy is known as a DC motor. The most prevalent kinds depend on the forces that magnetic fields generate (Huan, 2008). Almost all varieties of DC motors contain an internal mechanism—electromechanical or electronic—that allows the motor's portion of the current to be periodically reversed. Since DC motors could be fueled by the direct-current lighting power distribution networks already in place, they were the first type of motor to be utilized extensively. The speed of a DC motor can be adjusted across a large range by adjusting the field windings' current strength or the variable supply voltage. Appliances, toys, and tools all employ small DC motors. Although it is a lightweight brushed motor used for portable power tools and appliances, the universal motor may run on direct current. Currently, drives for steel rolling mills, elevators, hoists, and electric car propulsion all employ larger DC motors. In many applications, AC motors can now replace DC motors thanks to the development of power electronics. When current flows through a coil of wire, an electromagnetic field is created that is oriented toward the coil's center.

The coil's magnetic field can be manipulated in terms of direction and magnitude by varying the current passing through it. A basic DC motor consists of an armature with one or more windings of insulated wire wound around a soft iron core to concentrate the magnetic field and a stationary set of magnets in the stator. Large motors may have numerous parallel current channels, and the windings typically have multiple rounds around the core. The wire winding's ends are attached to a commutator. Through brushes, the commutator connects the revolving coils to the external power source and permits each armature coil to be powered in turn. (Brushless DC motors do not have brushes; instead, their electronics turn on and off the DC current to each coil.) The strength of the electromagnetic field generated depends on the total current flowing through the coil, its size, and the object it is wrapped around. The order in which a specific coil is turned on and off determines the direction in which the electromagnetic fields are effective. A revolving magnetic field can be produced by sequentially turning on and off coils (Ananthababu and Reddy, 2009). The armature of the motor (stator) rotates due to a torque created by the interaction between these revolving magnetic fields and the magnetic fields of the permanent or electromagnet magnets in the stationary portion of the motor. More control over the motor is possible in certain DC motor designs where the stator fields generate their magnetic fields using electromagnets. DC motors are nearly always cooled by forced air at high power levels. Different intrinsic features of speed and torque management are provided by varying numbers of stator and armature fields and the ways in which they are coupled. A DC motor's speed can be adjusted by varying the voltage supplied to the armature. Controlling the armature or field circuit's variable resistance enables speed control.

Power electronics systems, which regulate voltage by "chopping" DC current into on and off cycles with a correspondingly lower voltage, are frequently used to operate modern DC motors. Series-wound DC motors are frequently employed in traction applications, such as electric locomotives and trams, because they produce their maximum torque at low speeds. For many years, the DC motor served as the cornerstone of electric traction drives on diesel and electric locomotives, streetcars, and trams, as well as diesel electric drilling rigs. A fresh second Industrial Revolution was sparked by the development of DC motors and an electrical grid system to power machinery beginning in the 1870s. Rechargeable batteries can be used directly to power DC motors. supplying the driving force behind the earliest electric cars, current hybrid and electric cars, and a variety of cordless tools. Even in modern times, DC motors can still be found in large-scale applications like paper machines and steel rolling mills, or in smaller ones like toys and disk drives. For mine hoists, winder drives and large DC motors with independently excited fields were typically utilized to provide great torque and smooth speed control via thyristor drives. These have been replaced with huge variable frequency drives-equipped AC motors. When a DC motor receives mechanical power from an external source, it functions as a DC generator, or dynamo. When a hybrid or electric automobile slows down, this capability is utilized to recharge its batteries or to feed electricity back into the electric grid for a street car or electric train line (Alfano et al, 2019). In electric and hybrid vehicles, this mechanism is known as regenerative braking. Diesel electric locomotives lose energy in resistor stacks while slowing down by using their DC motors as generators. Larger battery packs are being added to newer designs in order to recover part of this energy. In both industrial and residential equipment, DC motors are commonly utilized. A motor's position needs to be controlled with extreme precision. Figure 2.1 displays the rotor's free body diagram and the armature's electric circuit.

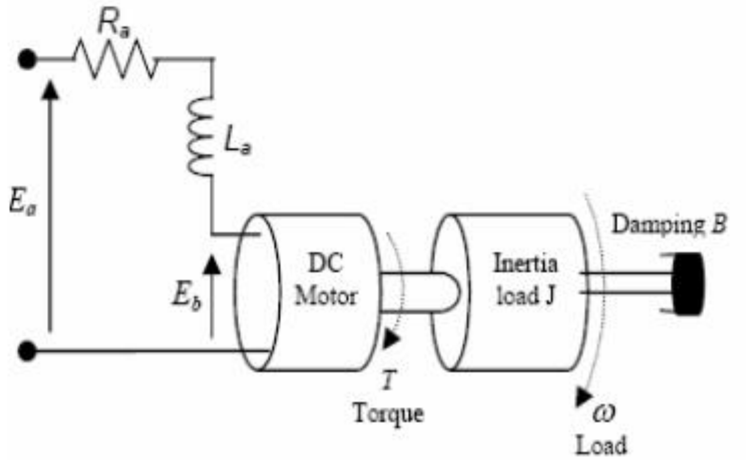

Fig. 2.1: The structure of a DC motor

When a desired shaft position is also needed, a desired speed can be tracked. Indeed, it might be necessary to use a single controller to regulate both the position and the speed. The intended position and/or speed are determined by the reference signal (Ghalimath and Sankeswari, 2015). The controller is chosen in such a way that the discrepancy between the reference signal and system output gradually trends toward zero, the minimal value. Different types of DC motors exist. A DC motor can be controlled by altering the input voltage or current, depending on its kind. Another motor can only be controlled by changing the input voltage.

For regulating a DC motor with current, the control architecture and theory are almost the same. To keep things simple, the system is given a reference signal in the form of a constant value to help it reach the required position. But any reference signal can be used with effectiveness using this strategy, especially any stepwise time-continuous function. This signal could be any signal to obtain a desired shaft position, such as a desired angle from a virtual horizontal line between 0 and 360 degrees. It could also be a periodic signal. One way to express a DC motor's dynamics is as follows:

$$V_t = R_a I_a + L_a \frac{dI_a}{dt} + E_a$$

(2.1)

$$T = J\frac{d\omega}{dt} + B\omega - T_l$$

(2.2)

$$T = K_T I_a$$

(2.3)

$$E_a = K_a \omega$$

(2.4)

$$\frac{d\omega}{dt} = \phi$$

(2.5)

With the following physical parameters:

Ea: The input terminal voltage (source), (v);

Eb: The back emf, (v);

Ra: The armature resistance, (ohm);

Ia: The armature current (Amp);

La: The armature inductance, (H);

J: The moment inertial of the motor rotor and load, (Kg.m2/s2);

T: The motor torque, (Nm)

ω : The speed of the shaft and the load (angular velocity), (rad/s);

φ : The shaft position, (rad);

B: The damping ratio of the mechanical system, (Nms);

Tk: The torque factor constant, (Nm/Amp);

Bk : The motor constant (v-s/rad).

2.1 Sliding Mode Control

Early in the 1950s, Emelyanov and a number of associate researchers in the Soviet Union suggested and developed variable structure control. The plant was seen as a linear second-order system that was modeled in phase variable form in their pioneering works. Since then, VSC has grown into a universal design approach that is being researched for a variety of system types, such as discrete-time models, large-scale and infinite-dimensional systems, nonlinear systems, and multi-input/multi-output systems (Fitzgerald et al., 2012).The most notable aspect of VSC is its capacity to produce extremely reliable control systems that are "invariant," or totally immune to external disturbances and parametric uncertainty. In variable structure systems, the primary mode of operation is the sliding mode (SMC). When described by differential equations, the majority of real-world processes in mechanical, electrical, aeronautical, and other engineering fields involve discontinuity. Some abnormalities in the behavior of the system are the cause of the discontinuity. The simplest example is the undefinable Coulomb friction in mechanical systems at zero velocity locations.

The system may experience motions in the form of a sliding mode if such discontinuities are purposefully induced on specific surfaces in the state space of the system. A new kind of system motion known as sliding mode emerges in a manifold as a result of the discontinuous control action in the feedback channels moving between two distinctly different system topologies (or components). As a result, the system performs very well, rejecting all disturbances and remaining insensitive to changes in parameters. A major issue with automatic control is the fluctuating dynamic properties of the control plant.

Hence, discontinuous control systems offer a useful tool for resolving control issues in intricately dynamic plants. That is to say, discontinuous systems need to utilize limited control gains, in contrast to continuous systems with nonmeasurable disturbances, where the criterion of invariance demands using infinitely large gains. Discontinuous control algorithms are naturally preferred over continuous control algorithms, which shape control as a high frequency discontinuous signal whose mean value equals the desired continuous control, from a technological perspective as well. This is because more and more electric inertia-less actuators are constructed around power electronics that operate in a switching mode.

Emelyanov and associates employed variable structure control (VSC) for the first time in Russia towards the end of the 1800s. Despite being unknown until 1977, when Utkin conducted a study, SMC, which is based on the VSC, has since been used for both linear and nonlinear applications in international communities (Kanojiya and Meshram, 2012). One of the primary focuses of contemporary control theory is control in the face of uncertainty. There is invariably a difference in the real plant dynamics and the controller design's mathematical model when a control problem is formulated. These differences (or mismatches) are mostly caused by parasite dynamics, unidentified plant factors, and outside disruptions. For a control engineer, designing control laws that yield the desired closed-loop system performance in the face of these disturbances/uncertainties is an extremely difficult assignment. The development of so-called robust control systems, which are meant to address this issue, has drawn a lot of attention as a result. Although robust adaptive control, H1 control, and backstepping approaches have been developed extensively and successfully, sliding mode control (SMC) is still arguably the most effective method for managing bounded uncertainties/disturbances and parasitic dynamics. In the past, sliding modes in variable structure systems (VSS) were identified as a unique mode. Instead of employing a single fixed structure, which could be unstable, these systems use a range of structures with rules for switching between them in real time to ensure suitable system performance. As a result, VSS is produced, which can be thought of as a collection of subsystems, each of which is valid for predetermined domains of system behavior and has a fixed control structure. It seemed that the closed-loop system might be built with unique characteristics not seen in any one of the individual substructures. Moreover, these characteristics include resistance to parasitic dynamics and insensitivity to specific (so-called matched) external shocks and model uncertainties in a unique mode known as a sliding mode. Another highly valuable characteristic of sliding modes is the ability to achieve reduced-order dynamics of the compensated system in a sliding mode (known as partial dynamical collapse).

The sliding variable, a "custom-designed" function, is the foundation of the SMC concept. The sliding manifold (also known as the sliding surface) is defined by the appropriately configured sliding variable when it approaches zero. While the system trajectories belong to the sliding manifold, an appropriate closed-loop system performance can be achieved by properly designing the sliding variable (Kumar and Mija, 2014). By guiding the system's trajectory to the appropriately selected sliding manifold and then using control to maintain motion there, SMC takes advantage of the primary characteristics of the sliding mode. its controllability, ultimate accuracy, and finite-time convergence of the sliding variables to zero, all of which are matched by its insensitivity to internal and external disturbances. The primary contributions to SMC theory were finished by 1980 and published in Utkin's 1981 monograph (first published in Russian) and its English translation. DeCarlo et al. performed a thorough study in 2013. These papers made apparent the two-step process for SMC design.

In order for the system motion on the sliding manifold—also referred to as the sliding motion—to meet the design requirements, the first stage entails designing a switching function. The choice of a control law that will render the sliding manifold appealing to the system state in the face of both internal and external disturbances/uncertainties is the focus of the second stage. Keep in mind that this control law isn't always discontinuous.

SMC, which is resistant to both disruptive impacts and system parametric changes, is a useful technique for managing dynamic, complicated systems. Furthermore, it can function in unpredictable environments, which are typical of contemporary technology. SMC comprises two components, referred to as the sliding mode and reaching mode, and its phase portrait is depicted in Figure 2.1(a). Initially, a surface is made to be controlled by a system. The sliding surface is the result of the control signal switching the system's high frequency slide state trajectories to this surface, as seen in Fig. 2.1(b). The system's output action is represented by the movement along this surface. The SMC approach seeks to move system states from the sliding surface back to the origin. The term "reaching mode" refers to the stage from the beginning point to the sliding mode that is indicated by movement in a sliding surface. System states are impervious to perturbations and changes in parameters. The SMC's goal is for the system's output to track to the intended reference and generate a signal ('u') that minimizes tracking error. By switching between stable and unstable paths, the system arrives at the sliding surface, where error converges to zero.

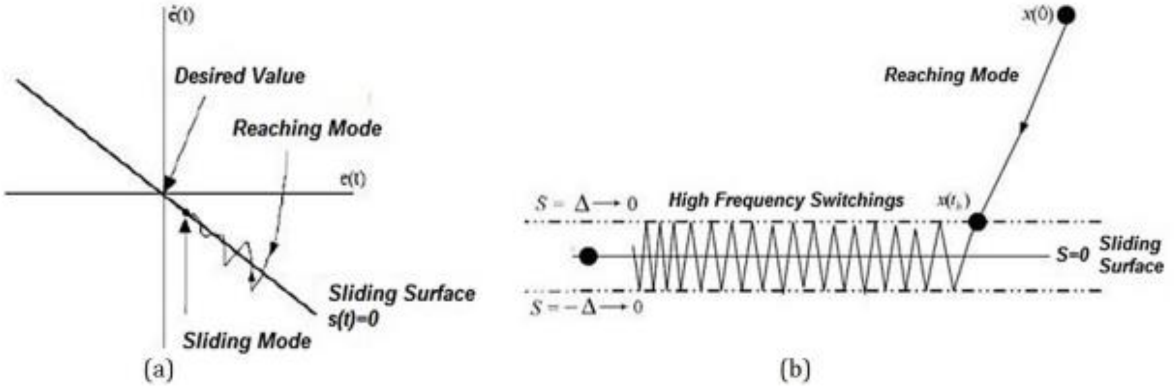

Fig. 2.2. (a)Phase portrait of sliding mode control, (b) Sliding surface, reaching mode and high frequency switching.

2.1.2 Classification of Sliding mode control

Sliding mode control can be classified into the following modes (Kumar and Dohera,2015): -

(a) Continuous-time Sliding Mode
(b) Discrete Time Sliding Mode and
(c) Sampled Data Sliding Mode

Continuous-time Sliding Mode.

Originally, sliding mode was intended to be a system motion for dynamic systems whose fundamental open-loop behavior could be sufficiently represented by ordinary differential equations. The continuous-time domain also defines the discontinuous control action, often known as variable structure control (VSC). Ordinary differential equations with discontinuous right-hand sides regulate the VSS, which is also defined in the continuous-time domain. The sliding mode manifold, or just sliding manifold, is the manifold of the state-space of the system on which sliding mode occurs.

Discrete Time Sliding Mode

Because microprocessor technology is getting cheaper, it is only a matter of convenience to build the feedback loops in discrete time. The continuous-time domain still serves as the foundation for the feedback design's conceptual framework. When it comes to sampled data control, the sampling rate selection is an instantaneous and crucial design decision for control engineers. Unfortunately, desired closed-loop bandwidth in continuous time SM does not offer any helpful recommendations for sampling rate selection. One major issue with SMC is chattering, which can be resolved by building asymptotic or sliding mode observers. Observers for any real-world control implementations are probably built in discrete time. However, because the idea of continuous-time sliding mode is still used, the sample rate needs to be somewhat large for these observer-based designs to function.

Sampled Data Sliding Mode

We will restrict our conversation to plant dynamics that are well-represented by finite dimensional ordinary differential equations, and we will make the assumption that the closed-loop system a priori bandwidth has been established. It is expected that the feedback controller is implemented in a discrete-time format. Rejection of exogenous shocks and insensitivity to large parameter uncertainty are features of the desired closed-loop behavior. Invoking DSM in the design is not worth it if there is no such demand on the closed-loop performance. Applying standard design guidelines for sampled data control systems, It is acceptable to assume that we will only include the dominant modes of the plant in the discretization of the continuous-time plant, provided that their corresponding corner frequencies fall well within the sampling frequency. In fact, this is always possible thanks to antialiasing filters that, prior to sampling, attenuate the plant outputs at frequencies higher than the sampling frequency. It is assumed that the dynamics of the actuator operate at frequencies higher than the sample frequency. Alternatively, actuator dynamics will have to be handled as part of the dominant plant dynamics. Thus, all the undesirable parasitic dynamics manifest only in the between sampling plant behavior, which is essentially the open-loop behavior of the plant since sampled data feedback control is applied. Clearly, this removes any remote possibilities of chattering due to the interactions of sliding mode control with the parasitic dynamics.

CONCLUSION

Significant progress has been made in the area of DC motor control with this work, particularly in relation to separately excited DC motors (SEDCMs). By employing Sliding Mode Control (SMC), we have expanded the possibilities for speed regulation and created a cutting-edge system that can adapt quickly to external disturbances and shifting operating conditions. The results of the study's experiments show how resilient and effective the recommended SMC-based control strategy is. The SEDCM performs better in terms of overall stability, disturbance rejection, and speed tracking when the designed control system is implemented. Because of its ability to lower uncertainty and maintain precise control even in the face of unpredictable external stimuli, the system is a leader in the development of robust DC motor control systems.Moreover, this study's expertise provides openings for real-world applications where precision and adaptability are essential. Since the recommended control approach enhances energy economy, system dependability, and speed regulation, it may be beneficial for sectors requiring high-performance DC motors.As this study draws to a close, it is evident that sliding mode control as it relates to separately excited DC motors still has a great deal of potential for advancement and practical applications. With its solid foundation for future study, invention, and application of complex control systems in engineering applications, this work ushers in a new era in the development of DC motor control technology.

REFERENCES

1. Ambesange, S. Kamble,Y and More,D.(2013). “Application of Sliding Mode Control for the Speed Control of DC Motor Drives,” in 2013 IEEE Internatioanal Conference on Control Application (CCA), , no. 1, pp. 832–836.
2. Ananthababu, P., & Reddy, B. A.(2009). Control of PMDC motor using fuzzy PI controller. Proceedings of International Conference on Control, Automation, Communication and Energy Conservation (pp. 1-4).
3. Ang,K, Chong, S. Member,T and Li,Y.(2005) “PID Control System Analysis , Design , and Technology,” IEEE Trans. Control Syst. Technol., vol. 13, no. 4, pp. 559–576.
4. Dursun,H and Durdu,A(2016). “Speed Control of a DC Motor with Variable Load Using Sliding Mode Control,” Int. J. Comput. Electr. Eng., vol. 8, no. 3, pp. 219–226, Babu,K and Amaresh,K(2011). “Sliding Mode Speed Control of a DC Motor,” in 2011 International Conference on Communication

Systems and Network Technologies, , no. June, pp. 387–391.

5. Huang, G. (2008). PC-based PID speed control in DC motor. Proceedings of International Conference on Audio, Language and Image Processing (pp. 400-407).