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Design and Simulation for Energy Harvesting System with Regenerative Breaking in Induction Motor

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***Abstract*--The railway is the most popular mode of transportation in India. The majority of the railway line is electrified, which raises electricity usage. The traction system is the system that provides a vehicle's propulsion by obtaining the driving force or tractive force from various devices such as electric motors, steam engine drives, diesel engine dives, and so on. Electric traction systems are available in a broad range of configurations around the world, depending on the type of railway, its location, and the technology available at the time of installation. Many of the installations that can be seen now were established up to long years ago, some when electric traction was still in its beginnings, and this has had a significant impact on what can be seen today. The development of railway traction has accelerated dramatically in the last 20 years. This has happened at the same time as the advancement of power electronics and microprocessors. Electric traction is one of the capable technologies for improving transportation efficiency and performance. When compared to non-electric traction systems, electric traction systems have significant advantages. All alternative footing frameworks, such as steam and inner combustion motor type frameworks are superior to the electric traction framework. It has a few advantages over other frameworks, including quick start and stop, high efficiency, contamination-free operation, ease of use, and simple speed control With the advancement of electrical drives for stability structures, this zap of footing has becoming increasingly well known in a number of footing administrations, including metro and urban railroads. An induction motor is an AC electric machine in which the electric current in the rotatating parts needed to create torque is obtained by electromagnetic induction from the magnetic field of the stator winding. In recent years, regenerative braking has been promoted as a possible way to re-establish energy while braking. Because kinetic energy is dissipated in the form of both the power used to apply the brake and the power lost as heat in the break, a large quantity of kinetic energy is accessible during train braking. Regenerative braking can be used to save this energy. Instead of using a traditional frictional braking system, regenerative braking employs a new mechanical mechanism, in which a generator is mechanically attached to the wheel when the brake is applied. The generator functions as a massive load, causing the vehicle/train to come to a halt. In this research work the design methodology of Electrical motors, analysis and control techniques, PI Controllers are discussed and a new simplified methodology has been designed. The simulation result shows the significance improvement in the performance parameters.**

I. INTRODUCTION

Electric traction can be considered as one of the capable technology to amend efficiency & performance of transportation. All other footing frameworks, for example, steam and inside ignition motor type frameworks, are less efficient than the electric traction framework.It has a few advantages over other frameworks, such as a quick start and stop, exceptionally proficient, contamination free, simple to deal with, and simple speed control.With the introduction of electrical drives for footing frameworks, this zap of footing has become well-known in a few footing administrations, such as metro or rural railroads.An induction motor is an electric machine in which the electric current in the rotating part used to generate torque is obtained by electromagnetic induction from the stator winding's magnetic field.In recent days, regenerative braking has been deliberately used as a promising aspect to re-establish energy during the baking process. In this report template methodology of Electrical motors, analysis and control techniques, PI controllers are discussed, and a new simplified methodology has been built. The simulation result demonstrates a significant improvement in the performance parameters. Today because of, in relation to complete warming and go higher of pollution list of words in a book earth is having experience those possibly taking place in addition and answers to get changed to other form its damaging effect, where the electric vehicles offer a great chance of an emission-less vehicle over inside combustion engine vehicle. Commonly, Inside Combustion Engine (ICE) vehicles were one and only using the machine-like brake in which kinetic energy is provided to loose living in heat because, in relation to not being in harmony.Occasionally, half of all power used for traction is wasted in heat by machines such as brakes. In the common vehicle, losses of 30.77 percent and 17.44 percent come to mind during braking and deceleration, respectively [1]. In addition to its anti-lock braking System (ABS), hydraulic actuators are used in vehicles with low power for a given time doing work well [2].

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Modern Electric Traction-

The economy is progressively switching to electric vehicles (EV) instead of traditional vehicles that run on fossil fuels, which has generated a rise in interest in regenerative braking. The kinetic energy generated by the motor during the deceleration, or braking, process is used in regenerative braking. As a result, recovering braking energy is an excellent method for increasing an EV's driving range [1]-[4]. Typically, all braking energy is wasted in the form of heat due to friction losses in normal cars. The motor is used as a generator in RB, and the kinetic energy is gathered by using the appropriate switching schemes on the power converter switches. This energy can be stored in an ultracapacitor bank or used to charge the vehicle's battery [5]-[8]. Depending on the required power, a hybrid energy storage system can alternate power generation and storage between an ultracapacitor and a battery. Knowing the system's characteristics is critical for determining the amount of energy harvested against that generated. The power battery pack (typically in series as an energy-storage unit), the driving motor [may include induction motor (IM), brushless direct-current motor (BLDCM), and switching reluctance machine (SRM) [7], etc.], and the power converter controller make up a pure electric vehicle (PEV). The brushless direct-current (DC) motor has several benefits over other brush DC motors, IMs, and switch reluctance machines among all the driving motors. Its advantages include a simple structure, high efficiency, electronic commutating mechanism, high starting torque, quiet operation, and a wide speed range, among others. As a result, brushless DC motors are commonly employed in electric vehicles [8, 9]. Mechanical brakes are used in traditional electric vehicles to increase wheel friction for deceleration. As a result, the kinetic energy of braking is squandered. With this in mind, this study will look at ways to transform kinetic energy into electrical energy that may be used to recharge the battery pack. Regenerative braking can thus provide both electric braking and energy savings.

II. Overview Of System

Gaurav A. Chandak and Bhole explained that amongst numerous groups of Electrical motors, for the electric vehicle contingent on the obligation of torque-speed characteristics, slow or high speed proposal usually permanent magnet synchronous motor, brushless DC motor are extensively chosen . The settling of motors is also a significant part of reformative breaking, and the design of the controller is dependent on it.

The obverse wheel drive control, autonomously determined front and rear wheel control, and in wheel control are a number of regulator methods in the foundation of motor placement, the plan of drive train, and torque specifications of EVs [5]. Yong Hua and Shi-Yin Qin Even though reformative braking is possible, mechanical braking is needed in any electric vehicle, according to some. It is mostly for two reasons: first, for fast braking, when reformative braking fails, or in a disaster when reformative braking is insufficient to stop the vehicle, and second, if a battery is fully charged at that time mechanical brakes can be used to avoid battery from injury [6]. The electric vehicle has a number of control methods and a controller. It includes a vehicle control unit (VCU), a machine control unit (MCU), and a battery management system (BMS). Other components receive switch signals from the VCU. The braking force delivery between mechanical and reformative braking force is authoritative and calculated by regulators while regulatory a braking operation. In [7], author described a technique for reformative slowing in which the IM is used in conjunction with negative slipup to obtain breaking torque. Also, regulatory supply voltage approves out demo of Renewal during slowing of electric vehicle. The writer proposed a scientific model with a Dahlander connected winding that has the ability to work in two dissimilar numbers of poles as well as two different synchronous speed levels [8]. Used by the author Park alteration to obtain the scientific model and shown that the entire energy restored in braking can be planned after a reformative braking scenario is achieved both four-sided and trapezoidal rules are castoff and criss cross with the result. In [9], the author examines two reformative breaking approaches and demonstrates that by switching the switching order, motor torque can be regulated and energy can be increased. The difference between the reformative plugging mode and the reformative mode comes down to the fact that the reformative plugging mode has a higher arraigning ability than the reformative mode, resulting in better competence.

2.1 Electric Traction

The electric traction device is the most efficient of all the other types of transportation systems, such as steam and internal combustion (IC) engines. The traction system is a system that causes the propulsion of a vehicle in which tractive or driving force is obtained from various devices such as diesel engine drives, steam engine drives, electric motors, and so on. The traction or locomotive can also be described as the railway vehicle that provides the necessary traction power to move the train.

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This traction power may be diesel, steam, or electric. The traction system can be classified as:
i. Non-electric ii. Electric traction systems.

2.2 Electric Braking

Electrical braking is most often used to bring a motor-controlled unit to a complete stop or to keep the driven unit's speed under control during deceleration. Electric braking is used in applications where regular, fast, precise, or emergency stops are needed. Electric braking allows for a smooth stop with minimal inconvenience to passengers.When a loaded hoist is lowered, electric breaking keeps the speed within safe bounds. Otherwise, the machine or drive speed would reach dangerous levels.

Types are three types of electric braking

i. Regenerative braking.
ii. Dynamic or Rheostatic braking.
iii. Plugging or reverse current braking.

2.2.1 Regenerative Braking

Regenerative braking is an energy recovery mechanism that slows down a moving vehicle or object by converting its kinetic energy(KE) into a form that can be used right away or stored until it is required. The electric traction motor in this mechanism uses the vehicle's momentum to recover energy that would otherwise be lost to the brake discs as heat. This contrasts with conventional braking systems, in which excess kinetic energy is converted to unwanted and wasted heat due to friction in the brakes, or with dynamic brakes, in which the energy is recovered by using electric motors as generators but is immediately dissipated in the form of heat in resistors.In addition to improving the vehicle's overall efficiency, regeneration will significantly prolong the life of the braking system since the mechanical parts do not wear out as quickly. Moving vehicles have a lot of kinetic energy, and when brakes are applied on the system to slow a vehicle down, all of that kinetic energy (KE) has to go somewhere. Back in the Neanderthal days of internal combustion engine cars, brakes were solely friction based and converted the vehicle's kinetic energy into wasted heat in addition to decelerate a car. All of that energy was simply lost to the somewhere in environment.

2.3 Induction Motor

An induction motor, also known as a asynchronous motor, is an electric motor in which the electric current in the rotor used to produce torque is obtained by electromagnetic induction from the stator winding's magnetic field.

In the manufacturing industry, a motor's rotor may be either wound or squirrel-caged.Since they are self-starting, reliable, and economical, three-phase squirrel-cage induction motors are commonly used as industrial drives.

Single-phase induction motors are commonly used for smaller loads, such as household appliances like fans. While traditionally used in fixed-speed service, induction motors are increasingly being used in variable-speed service with variable-frequency drives (VFD).In variable-torque centrifugal fan, pump, and compressor load applications, VFDs give especially important energy savings opportunities for current and prospective induction motor Squirrel-cage induction motors are commonly used in both fixed-speed and variable-frequency drive applications.

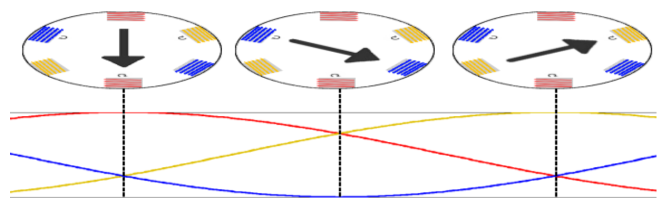

Figure **: A three-phase power supply provides a rotating magnetic field in an induction motor**

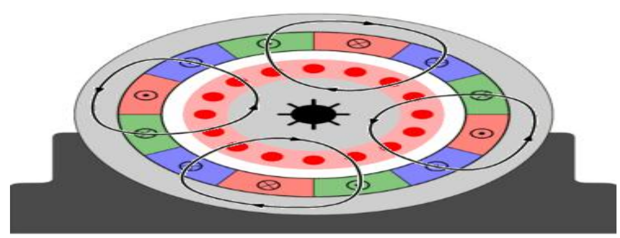

Figure : Inherent slip - unequal rotation frequency of stator field and the rotor

The power supplied to the motor's stator creates a magnetic area that rotates in synchronous motors in both induction and synchronous motors. A synchronous motor's rotor turns at the same rate as the stator sector, while an induction motor's rotor rotates at a somewhat slower speed than the stator field.The magnetic area of the induction motor stator is thus changing or rotating relative to the rotor. When the latter is short-circuited or closed through external impedance, this induces an opposing current in the induction motor's rotor, in effect the motor's secondary winding. The rotating magnetic flux induces currents in the windings of the rotor, in a manner similar to currents induced in a transformer's secondary winding(s).

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The induced currents in the rotor windings in turn create magnetic fields in the rotor that react against the stator field. In accordance with Lenz's Law, the magnetic field generated will be directed in the opposite direction as the change in current through the rotor windings. The rotor speeds up until the magnitude of the induced rotor current and torque balances the applied mechanical load on the rotation of the rotor. Since rotation at synchronous speed will result in no induced rotor current, an induction motor always runs slightly slower than synchronous speed. For standard Design B torque curve induction motors, the difference, or "slip," between actual and synchronous speed ranges from about 0.5 percent to 5.0 percent. The induction motor's essential character is that it is created exclusively by induction, rather than being separately excited as in synchronous or DC machines, or being self-magnetized as in permanent magnet Motor. The speed of the physical rotor must be lower than that of the stator's rotating magnetic field for rotor currents to be induced; otherwise, the magnetic field would not be moving relative to the rotor conductors and no currents would be induced. As the rotor's speed falls below the synchronous speed, the rotation rate of the magnetic field in the rotor increases, inducing more current in the windings and producing more torque. The ratio between the rotation rate of the magnetic field induced in the rotor and the rotation rate of the stator's rotating field is referred to as slip. The speed drops and the slip increases enough under load to generate sufficient torque to transform the load. Industry motors are often referred to as asynchronous motors for this purpose. An induction motor can be used as an induction generator, or it can be unrolled to form a linear induction motor that can generate linear motion directly. The rotor speed in the generator mode is higher than in the driving mode, which is a feature in comparison to the grid. After that, active energy is sent to the grid [2]. Another disadvantage of the induction motor generator is that it consumes a significant amount of magnetising current (=20-35%).

2.3.1 Working Principle of Induction Motor

The induction motor is a motor that works on the principle of electromagnetic induction. Electromagnetic induction is the phenomenon by which the electromotive force induces across the electrical conductor when it is placed in a rotating magnetic sector.The motor's stator and rotor are two essential components. The stator is the statorial part of the motor, and it carries the overlapping windings, while the rotor is the rotatinal part and carries the main field winding.

The stator's windings are evenly spaced from one another, with a 120° angle between them.The induction motor is the single excited motor, i.e., the supply is applied to only one part, i.e., the stator. The word excitation refers to the process of inducing the magnetic field on the parts of the motor.When the three-phase supply is given to the stator of the motor, the rotating magnetic field produced on stator. The figure 9 shows the rotating magnetic field in the stator:

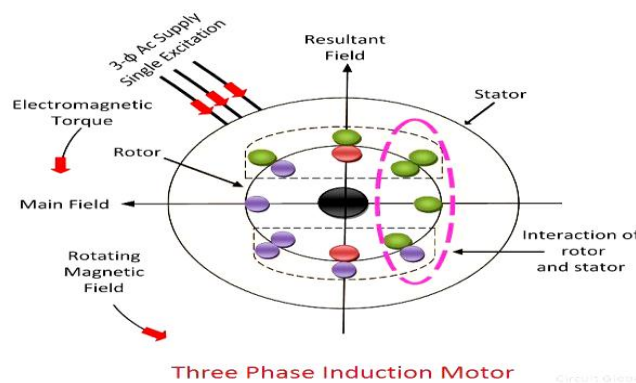

Figure: Three phase Induction motor

Consider the fact that the rotating magnetic field induces in the anticlockwise direction. There are moving polarities in the rotating magnetic sector. The magnetic field's peculiarities differ depending on the positive and negative half cycle of the supply .The magnetic area rotates due to the change in polarities. The rotor's conductors are statinary. The stationary conductor cut the stator's rotating magnetic area, and the EMF induces in the rotor due to the electromagnetic induction. This EMF is known as rotor induced EMF, and it occurs as a result of the electromagnetic induction phenomenon. The rotor's conductors are short-circuited, either by the end rings or by the aid of the external resistance. The relative motion between the rotor conductor and the rotating magnetic field induces the current in the rotor conductors. The flux is induced on the conductor due to current flows through the conductor. The direction of rotor flux and and rotor current both are same. We now have two fluxes, one as a result of the rotor and the other as a result of the stator. These fluxes interact with one another. The rotating magnetic field and the electromagnetic torque are in the same direction. As a result, the rotor begins to rotate in the same direction as the rotating magnetic field.The rotor's speed is always slower than that of a rotating magnetic field or a synchronous speed. The rotor attempts to run at the rotor's speed, but it still slips away.

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As a result, the motor never runs at the speed of the rotating magnetic area, and this is why the induction motor is also known as the asynchronous motor.

2.4 V/F Control Of Induction Motor

Synchronous speed can be regulated by changing the supply frequency. The voltage induced in the stator is, where f is the supply frequency and Φ is the air-gap flux. We obtain terminal voltage $1 \propto \Phi f$, so we can neglect the stator voltage drop. Thus, lowering the frequency without changing the supply voltage would result in an increase in the air-gap flux, which is undesirable. When the frequency is changed to control speed, the terminal voltage is also changed to keep the V/f ratio constant. Thus, maintaining a constant V/f ratio ensures that the motor's maximum torque is available for changing speeds. As shown in figure, when V/f ontrol is implemented, the maximum torque remains the same for a variety of frequencies within the operating area. Thus, keeping the V/f ratio constant allows us to maintain a constant maximum torque while controlling the speed according to our needs.

2.4.1 Control Principle

The V/F control principle is to make a circuit called a voltage-controller oscillator with oscillator frequency. When subjected to a change in voltage, its capacity will change, and the change in capacity will cause changes in the oscillation frequencies, resulting in variable frequency. This controlled frequency is used to monitor the frequency of the output voltage in order to achieve speed changes in the regulated electric motors.

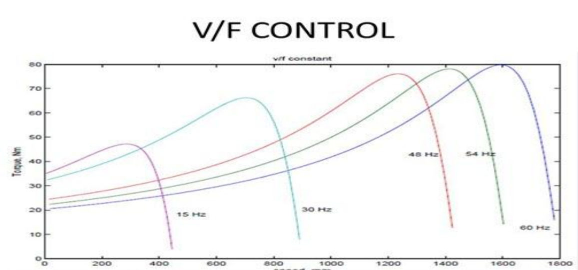

Figure : V/F Control of Induction motor.

2.5 Torque Speed Characteristic of an Induction Motor

The curve plotted between the torque and the speed of the industry motor is known as Torque Speed haracteristic. The torque equation is shown in the diagram below.

$$T = \frac{k\, s\, R_2 E_{20}^2}{R_2^2 + (sX_{20})^2} \quad \ldots\ldots\ldots\ldots (1)$$

When the torque is maximum, the rotor speed is expressed by the equation shown below.

$$N_M = N_S\,(1 - s_M) \quad \ldots\ldots\ldots\ldots (2)$$

The curve shown below in figure, the Torque Speed Characteristic.

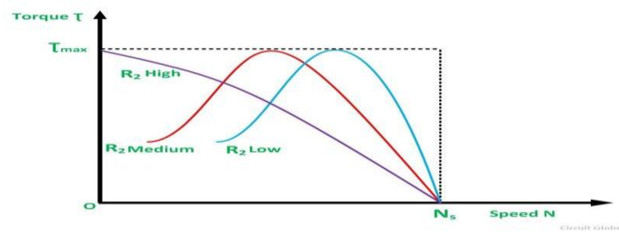

Figure: Torque speed characteristics of motor

The maximum torque is independent of the resistance of the rotor. However, the exact location of the maximum torque T_{max} is dependent on it. The greater the value of the R2, the greater the value of the slip at which maximum torque is attained.

III. Introduction Of Design

The architecture of our device is depicted in Figure 13. The aim of the battery is to provide DC supply to the bidirectional switch. In modular multilevel inverter configuration, bidirectional switches are usually used for together generation and regeneration. This DC output is going to an inverter, and an inverter converts DC supply to AC supply with a constant frequency. The role of a filter in this case is to pass a specific frequency signal while rejecting other frequency signals. Then it's passed on to the induction motor. Current transformer is used as a measuring device or to measure current in this case.

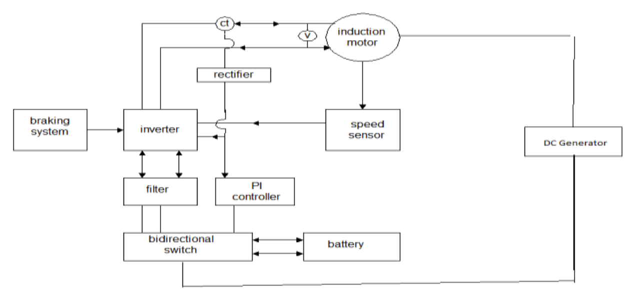

Figure : Modelling of system.

A speed sensor is used to detect the speed rate of induction. When we apply break to the motor or when supply is cut off from the motor.

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When the motor does not come to a complete stop and any power is wasted, we want this power to be store in battery. Motor shaft is connected to DC generator, and the output of this DC generator is fed to the battery through switch. The PI / Intelligent Controller is checking the status of the motor. The rectifier is used in the centre of the current transformer and the PI controller to convert AC to DC which is stored in battery.

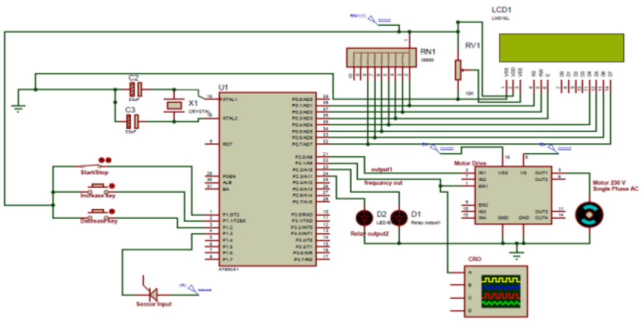

Fig.: Interfacing of Motor with Microcontroller

Figure depicts the motor's interaction with the microcontroller. In the interfacing, a variety of relays and motors with LCD are used. The application of reverse voltage to the moving DC motor for a brief period is probable for the unexpected break in both directions. The speed control of the motor is attained with the PWM pulses produced by the microcontroller as well. We can control the speed of DC motor using mechanical or electrical methods, but they require a large amount of hardware to design, while the microcontroller-created scheme provides an easy way to control the speed of DC motor. In the interfacing with the microcontroller, a single-phase motor with 230V supply is connected. At D1 and D2, the relay output can be measured. The motor, LCD, and motor drives are connected to the microcontroller's external ports, as shown in the diagram above. Figure 15 depicts the flow chart of the working principle of motor interfacing with a microcontroller, while figure 16 depicts the working mechanism of sensing.

3.1 Flow Chart of Microcontroller Program

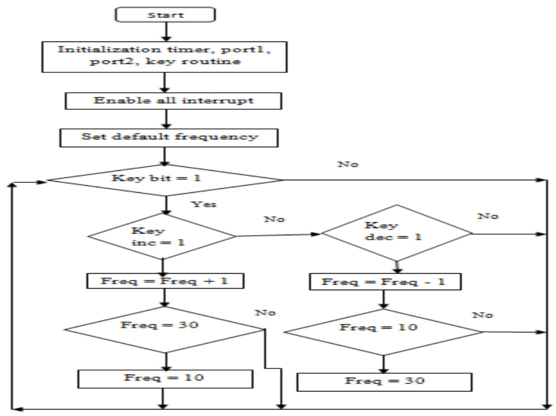

Figure : Flow chart of Microcontroller program

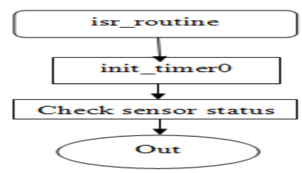

Figure : Flow chart of sensor working

First, we start the timer and the ports in our built framework. All interrupts should be allowed. Every interrupt has its one-of-a-kind interrupt handler. The number of hardware interrupts is insufficient in comparison to the number of interrupt request (IRQ) positions to the processor, but there may be hundreds of dissimilar software interrupts. The default frequency of the crystal. Now check key bit; if key bit is 1, increment key by 1; otherwise, return to checking the same value. If you type in incremented, increase the frequency by 1 as shown in figure. The function of crystal frequency will be the sapping of values between 30 and 10. For sensor, start the interrupt subroutine, then start timer 0 and keep checking the sensor status for parameter measurement.

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IV. Discussion

Figure 17 depicts the configuration of the proposed framework in Simulink software. Simulink is a graphics and simulation environment that is used to design systems and test the responses of each section. The system is made up of the same blocks that are used in our system's block diagram, such as the battery, voltage controller, and rectifier, filter, and so on. the motor's output, such as speed, torque, motor current, auxiliary winding current, and so on are shown by using scope. The PWM signal generator unit's function is to generate pulse width modulating signals. The speed is measured in rad/sec.

4.1 Simulation Model Of Energy Harvesting With Regenerative Braking For Induction Motor.

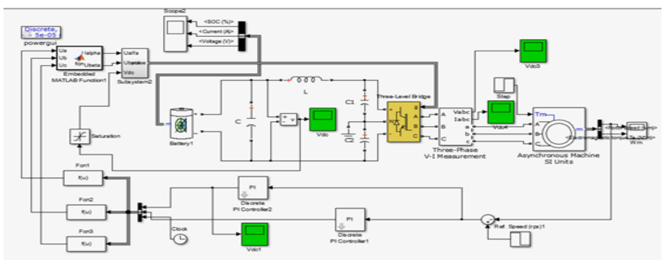

Figure: Design of system in Simulink

V. Simulation Result Analysis

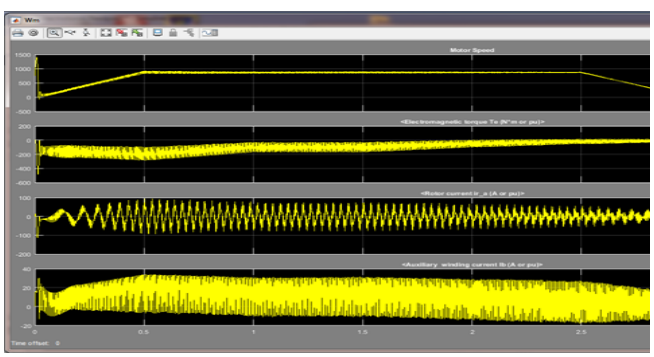

Figure : Simulink Waveform for Motor Charactristic

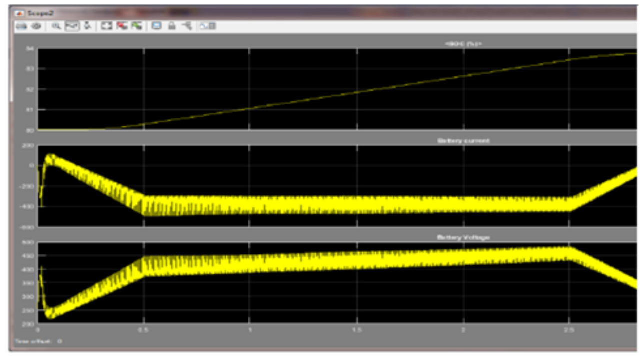

Figure: Performance of the designed system

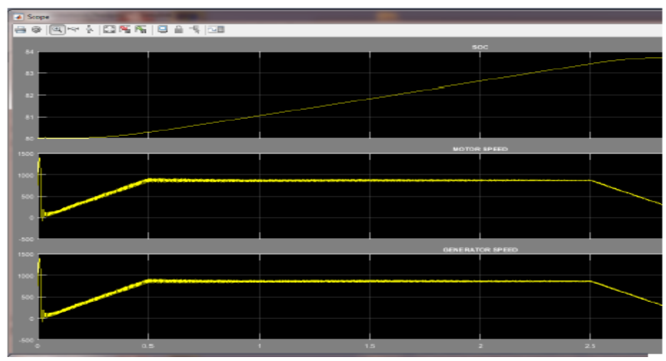

Figure: Performance of Battery system

Initially, the motor's speed will increase slightly; but, as soon as the motor rotates to its constant speed, the rotor's speed in the motor will remain constant. At the same time, the electromagnetic torque slowly increases with respect to time. As torque increases, the power speed decreases for a continuous flow. There is torque proportion and current direct proportion. As a result, if torque increases, all currents increase, and vice versa. The motor and generator speeds will be the same with regard to time, as seen in the above figure. A battery generates electrical power by converting chemical energy into electrical energy. As this reaction decelerates, the battery voltage will decrease. As a general rule, batteries have a static voltage, but big or new batteries tend to have a low internal resistance, allowing them to carry a large current, while small or ancient batteries tend to have a high internal resistance, limiting their ability to carry a large current.

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VI. CONCLUSION

The wear of the brakepads can be reduced with regeneration breaking. Outspread the electric vehicle (EV) driving set and decrease the reservation cost significantly. The operating principle and corresponsing power circuit of EVs below regenerative braking control are explained. When it comes to improving the vehicle's overall efficiency, regeneration will significantly extend the life of the braking system because its amounts do not wear out as quickly. We can claim that by lowering the action costs of supplying energy to train stations, we can give advanced economic reimbursements.The mounted storing batteries are used in the projected regenerative braking system. The topology and control policy for battery chargers on high-speed electric trains or vehicles, which can supply train or vehicle-mounted electric equip mentor can be tranported to remote location where electric energy is not reachable. By converting kinetic energy into electric energy, regenerative braking improves the energy efficiency of rail transportation. Simulation authenticates the recommended controller's performance.The projected scheme could achieve good dynamic performance and healthy stability, and the driving range could be improved by the projected controller, which legitimises the precision and possibility of regenerative braking for battery powered EVs

Future Scope

Many researchers are currently working on the use of various AC and DC motors in electric transmission systems. The Simulink results show significant improvements in torque, generation speed, and motor speed, among other things.

Various induction motors can be used to improve the performance. Through implementing this engineered device on hardware, the results can be checked to see if the motor speed is synchronised with simulation and if the hardware results are right. One should operate on a device where the friction at the rotor part must be reduced so that the power dissipation is reduced as compared to the current system.

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