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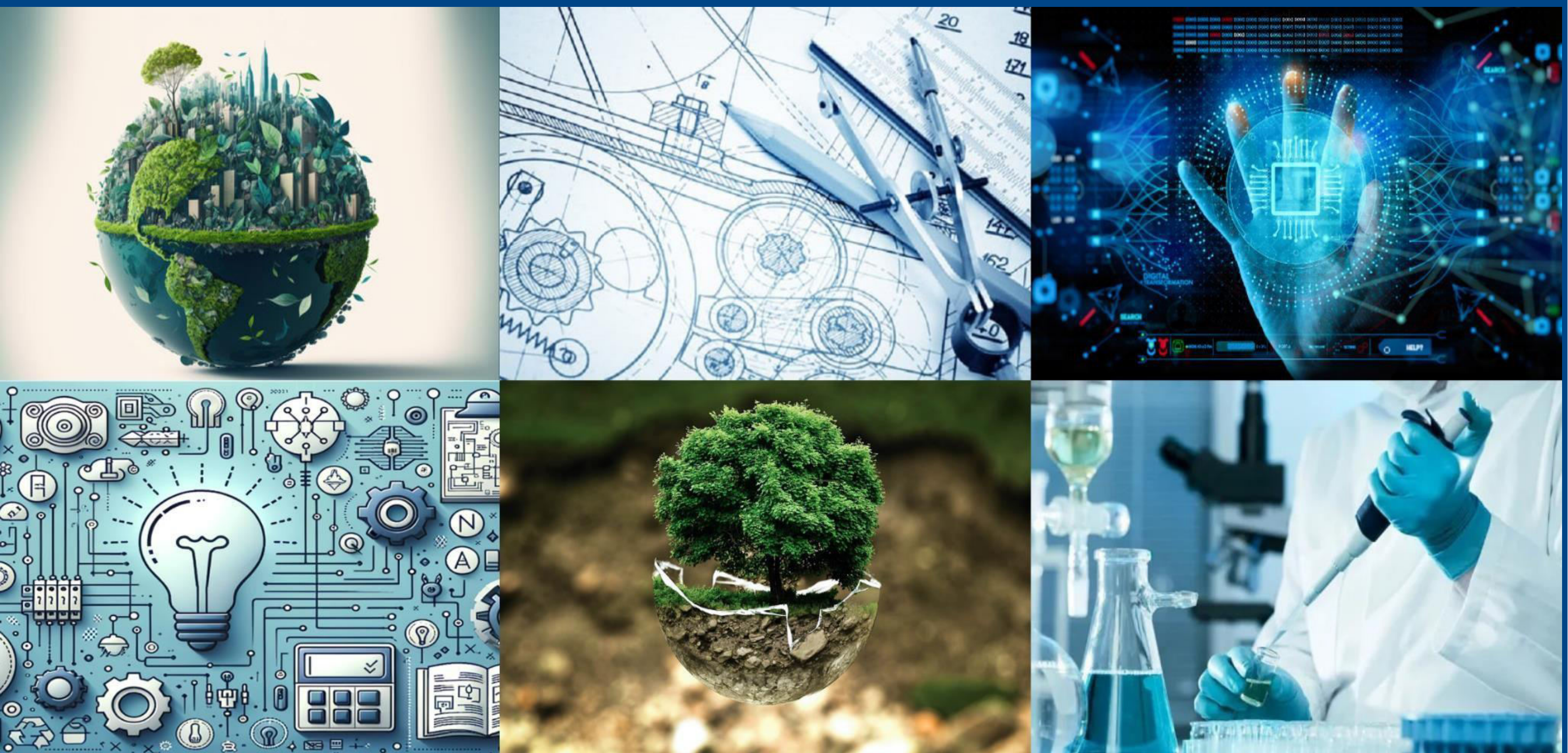

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Speed Control Performance Analysis of BLDC Motor using Multiple Input Sources for Electric Vehicle Application

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ABSTRACT: In the proposed research, three input sources—a Solar Photovoltaic (SPV), Battery, and Super Capacitor (SC)—are used to control the speed of a BLDC motor. The super capacitor is used to discharge energy to the BLDC motor as rapidly as possible so that it can attain the desired speed. The lithium ion battery and SPV are used to increase the electric vehicle's (EV) range. The energy can be released by the super capacitor in a matter of milliseconds. In order for the BLDC motor to obtain enough energy in a brief amount of time and to attain the maximum or predetermined speed as soon as feasible. Electric vehicles typically have poor pick times (maximum or predetermined speeds) or require longer times to attain their maximum speeds. The public becomes extremely afraid of buying electric vehicles as a result. The aforementioned disadvantage is removed in the proposed paper, making electric vehicles a rival to gasoline-powered automobiles. Two distinct methods are used to analyze the speed control performance of BLDC motors: (i) Battery-SPV combination; (ii) Battery-SPV-SC combination. The speed at which the motor reaches its specified speed is measured. The three-phase Voltage Source Inverter (VSI), which will drive the EV at a steady speed, is adjusted using basic PI controllers. The BLDC motor's performance is tested using MATLAB Simu-link for a range of fixed speeds and input source combinations. Performance features of the BLDC motor during speed control were examined and a hardware model was created.

KEYWORDS: BLDC motor, Speed control, PI controller, Super Capacitor, SPV, Battery.

I. INTRODUCTION

The use of electric vehicles is growing rapidly worldwide as a result of rising petrol prices and the fact that fossil fuels like petrol and diesel will run out entirely in another 30 to 40 years. Many well-known automakers have begun producing electric vehicles. Poor starting torque is the main issue with electric vehicles and the reason why people are afraid of them. Another explanation is the inability to travel upward, especially after applying a brake.

The above said draw will be mitigated or reduced in the proposed research paper. The super capacitor may only discharge for a brief period of time from these three sources before being reenergized by battery power. Therefore the vehicle can get more torque quickly and can move fast in up hills and bridges. It offers a lengthy life cycle and quick charging and draining capabilities. Continuous solar PV battery charging occurs. The car can travel farther (range) and the battery can provide power for a longer period of time.

Changing the input voltage applied to the BLDC motor allows it to be speed-controlled in the context of an electric vehicle application. The process involves linking a controller with feedback signal and a voltage source inverter (VSI). Here, three DC sources are used to power the VSI, which is typically powered by a DC supply; namely, solar photovoltaic cells, lithium-ion batteries, and super capacitors [01–03]. The BLDC motor's rotor is made entirely of permanent magnets, while the stator contains three sets of coils. As a result, unlike brushed DC motors, brushes are not needed [04-05]. This will decrease the complexity of the commutator-brush and boost efficiency. Usage for BLDC motors includes electric vehicle usage. A rechargeable battery that uses the movement of lithium ions between electrodes during charging and discharging is known as a lithium-ion battery. Because of their extended cycle life and high energy density, these batteries are frequently found in consumer gadgets. By reversibly adsorbing and desorbing ions at the interface between the electrode material and electrolyte, a super capacitor is an electrochemical energy storage device that can be used to store and transfer charge. Electrochemical capacitors and ultra capacitors are other names for super capacitors [06-09].

II. PROPOSED SYSTEM

2.1 Block Diagram.

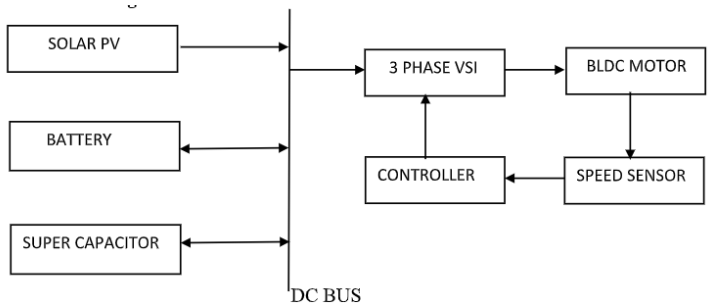

Fig 1; Block Diagram of proposed system

The proposed system's full operational overview is provided by the block diagram shown in Figure 1. It is made up of three sources: super capacitors, batteries, and solar photovoltaic. The three sources are linked to a single DC bus, and a three-phase voltage source inverter receives the DC voltage. The VSI will transform the DC into three phases of AC, which is then sent to the BLDC motor [10-12]. The hall sensor detects the speed of the BLDC motor and provides data to the controller. The controller will determine the mistake based on this feedback and provide the necessary gate signal to drive the VSI. Thereby, the BLDC motor's speed can be maintained at a predetermined level. The circuit's super capacitor is utilized to swiftly raise the BLDC motor's speed to its desired level [13-14].

2.2 Modelling of BLDC Motor;

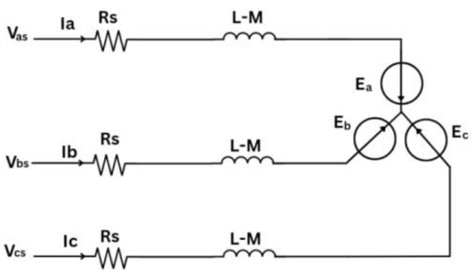

Fig 2; Equivalent circuit Model of BLDC motor

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The equivalent circuit model of a BLDC motor is shown in the figure 2. The mathematic modelling for the phase voltage, Back emf and Torque are given below.

$$\begin{bmatrix} Vas \\ Vbs \\ Vcs \end{bmatrix} = \begin{bmatrix} Rs & 0 & 0 \\ 0 & Rs & 0 \\ 0 & 0 & Rs \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} Laa & Lab & Lac \\ Lba & Lbb & Lbc \\ Lca & Lcb & Lcc \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \begin{bmatrix} ea \\ eb \\ ec \end{bmatrix} \quad \text{-- (2.1)}$$

Where V_{as}, V_{bs} and V_{cs} represents the phase voltage of stator;
R_s represents the stator resistance;
i_a, i_b and i_c denoted stator phase current.
Laa, Lbb and Lcc are self inductances;
L_{ab}, L_{ac}, L_{ba}, L_{bc}, L_{ca} and L_{cb} are mutual inductances.
Therefore; Laa = Lbb = Lcc = L
$L_{ab} = L_{ac} = L_{ba} = L_{bc} = L_{ca} = L_{cb} = M$

The stator phase currents are constrained to be balanced
$i_a + i_b + i_c = 0$ -- (2.2)

$$\begin{bmatrix} Vas \\ Vbs \\ Vcs \end{bmatrix} = \begin{bmatrix} Rs & 0 & 0 \\ 0 & Rs & 0 \\ 0 & 0 & Rs \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \begin{bmatrix} ea \\ eb \\ ec \end{bmatrix} \quad \text{-- (2.3)}$$

The Phase to phase voltages is;

$V_{ab} = R_s (i_a - i_b) + (L\text{-}M) \frac{d}{dt} (i_a - i_b) + e_{ab}$ -- (2.4)

$V_{bc} = R_s (i_b - i_c) + (L\text{-}M) \frac{d}{dt} (i_b - i_c) + e_{bc}$ -- (2.5)

$V_{ca} = R_s (i_c - i_a) + (L\text{-}M) \frac{d}{dt} (i_c - i_a) + e_{ca}$ -- (2.6)

The Back emfs are;

$$\begin{cases} ea = \frac{ke}{2} \omega m F(\theta e) \\ eb = \frac{ke}{2} \omega m F(\theta e - \frac{2\pi}{3}) \\ ec = \frac{ke}{2} \omega m F(\theta e - \frac{4\pi}{3}) \end{cases} \quad \text{-- (2.7)}$$

Where;
ω_m is the speed of the rotor
K_e – is a constant
Electrical rotor angle; $\theta_e = \frac{P}{2} \theta_m$

$\omega_m = \frac{d\theta m}{dt}$

Electrical Torque,

$T_e = \frac{kt}{2} \left[F(\theta e) ia + F\left(\theta e - \frac{2\pi}{3}\right) ib + F(\theta e - \frac{4\pi}{3})\right]$ -- (2.8)

The Mechanical part;

$T_e - T_L = J \frac{d\omega m}{dt} + B\omega m$ -- (2.9)

2.3 Super Capacitor Characteristics

Super Capacitor charging and discharging characteristics
Charging voltage and current;

$V_c(t) = V_{in} \{1 - e^{-t/RC}\}$ -- (2.10)

$I_c(t) = \left(\frac{V_{in}}{R}\right) e^{-t/RC}$ -- (2.11)

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Similarly the discharging voltage and current are;

$V_c(t) = V_s \left(e^{-t/RC}\right)$ -- (2.12)

$i_c(t) = \frac{Vs}{R}\left(e^{-t/RC}\right)$ -- (2.13)

III. CIRCUIT DIAGRAM

3.1 Circuit diagram with SC, SPV and Battery and Circuit Diagram with SPV and Battery

Figure 3 displays the circuit diagram for a BLDC motor's speed control system that includes a battery, SPV, and super capacitor. Using a three-phase voltage source inverter, the BLDC motor was powered from three sources. In the off-condition of the BLDC motor, SPV charges the battery supply and super capacitors under no load. The circuit diagram of speed control of BLDC motor with Battery and SPV is shown in figure 4. The BLDC motor was energised from three sources through 3 phase voltage source Inverter.

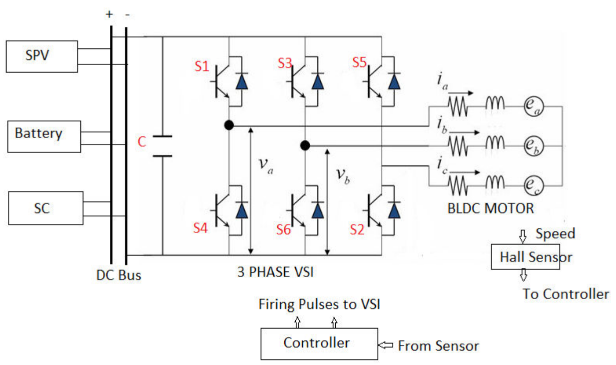

Fig 3; Circuit diagram with SPV, Battery and SC

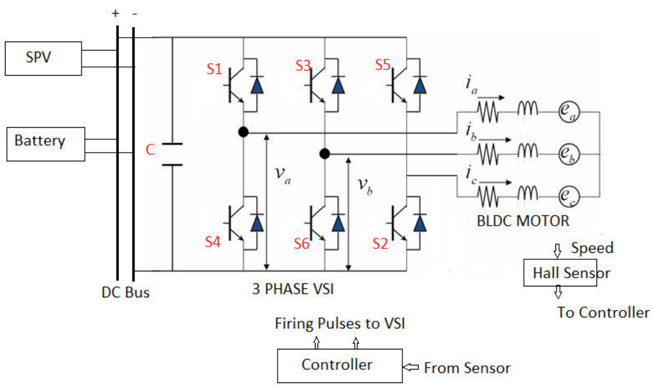

Fig 4; Circuit Diagram with SPV, Battery

3.2 Battery Sub-System

The specific role or task carried out by a component inside a larger system, such as the entrance control subsystem of a facility that consists of people, processes, and technologies to monitor and control the movement of people and materials, is known as a subsystem function. Because it distinguishes between high voltage and low voltage, this gadget is particularly helpful when using the battery pack at high voltages. The IMD detects voltage leakage, particularly in high voltage applications, and notifies the battery management system to stop the current flow. The second order thevenin equivalent circuit for battery is illustrated in the figure 5.

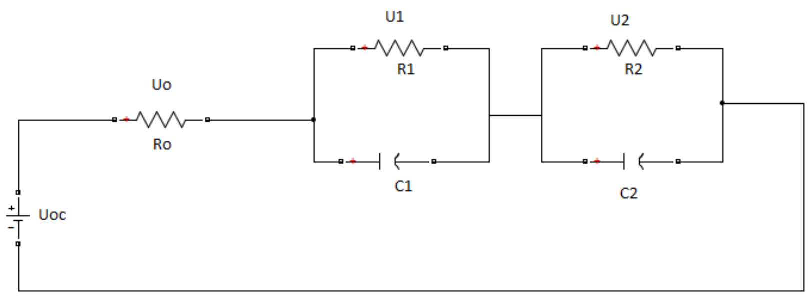

Fig 5; Second Order Thevenin Equivalent circuit model of Li-ion Battery

U_0 = Voltage across Ro
U_1 = Voltage across R1, C1 combination
U_2 = Voltage across R2, C2 combination
R_0 = Internal ohmic resistance of battery
R_1, R_2 = Polarisation resistance

C_1, C_2 = Polarisation Capacitance
U_{oc} = Source Voltage
U_o = Output Voltage
I_L = Load current

$U_o = R_o I_L$ -- (2.14)
$I_L = (U_1/R_1) + C_1 (dU_1 / dt)$ -- (2.15)
$I_L = (U_2 / R_2)+C_2(dU_2/dt)$ -- (2.16)
$U_L = U_{oc} - U_o - U_1 - U_2$ -- (2.17)

3.4 Solar PV subsystem

Photovoltaic systems are low maintenance, fuel-free, and emit no emissions. They are a good alternative for any energy system in a health facility when they are economically feasible. Facilities in remote locations without access to the grid should pay particular attention to PV systems. In Figure 6, the equivalent circuit of solar PV sub-system is displayed.

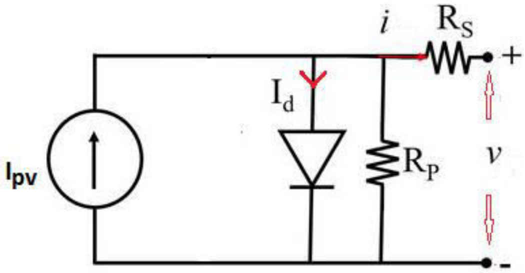

Fig 6; Equivalent circuit model of PV cell

Current generated by the solar cell, i_{pv}

$$I = I_{pv} - I_0 \left[\exp\left(\frac{V + R_s I}{V_t a} \right) - 1 \right] - \frac{V + R_s I}{R_P}$$

I_{pv} = Photovoltaic current
I_o = Saturation Current

3.5 Super Capacitor Sub-system

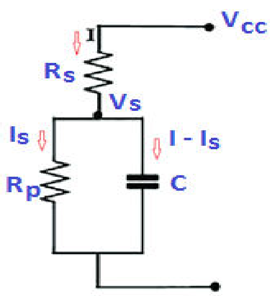

Fig 7; Equivalent circuit of Super capacitor

Rs = Effective series resistance
Rp = Leakage Resistance
Vs = Voltage across Capacitor

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Super capacitors are used in applications requiring many rapid charge/discharge cycles, rather than long-term compact energy storage: in automobiles, buses, trains, cranes and elevators, where they are used for regenerative braking, short-term energy storage, or burst-mode power delivery. The parameters below need to be defined before choosing the capacitor required; Required back up time, Required back up current, Minimum and maximum operating voltage, Operating temperature, Required dimensions, Mounting type. The equivalent circuit of super capacitor is shown in the figure 7.

IV. SIMULATION OUTPUTS

4.1 WITHOUT SUPER CAPACITOR

The output speed graph form with SPV and Battery sources is shown in figure 8. The motor speed reached the set speed 2000 rpm within 0.5 seconds. MATLAB simulink is used to get the output.

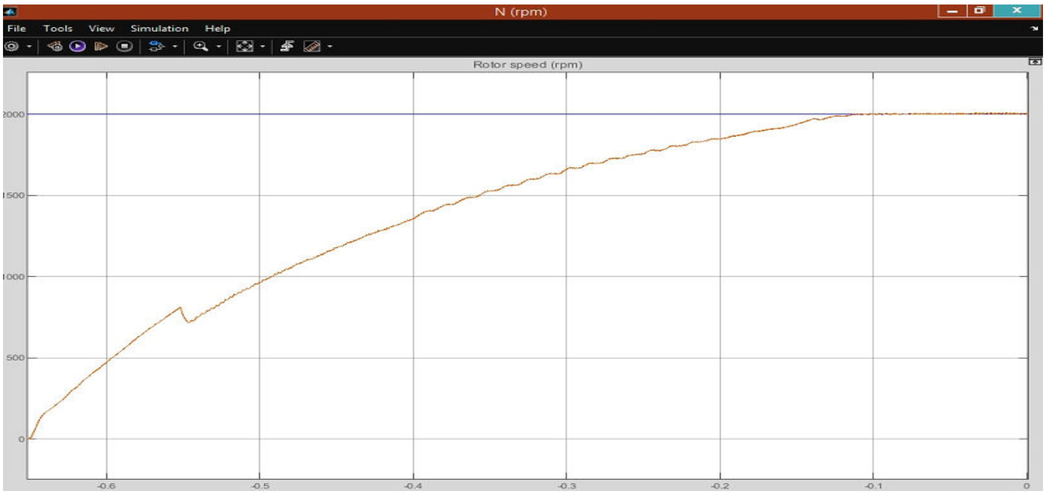

Fig 8; Simulation output of BLDC motor speed control with Battery and SPV

4.2 WITH SUPER CAPACITOR

The output wave form of the circuit with SPV, Battery and Super Capacitor is shown in the figure 9. Due to the fast discharge characteristics of the super capacitor, the output voltage or speed settle at set speed quickly. The motor reaches the set speed within 0.375 seconds. MATLAB simulink is used to get the output.

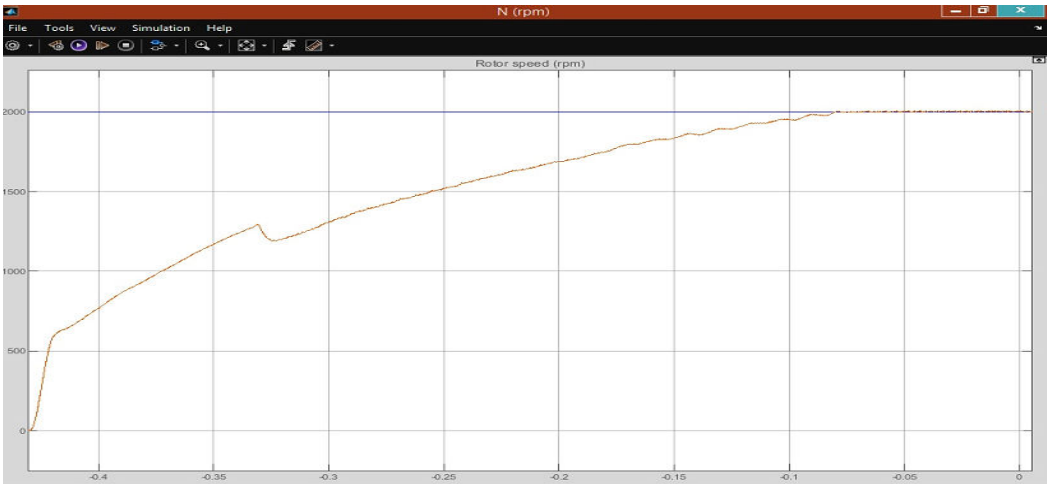

Fig 9; Simulation output of BLDC motor speed control with Battery, SPV and SC

4.3 FIRING PULSES

The firing pulses for the three phase Voltage source Inverter was designed using PI controller which is a powerful algorithm for the fast response. The voltage from hall speed sensor which is provided in the BLDC motor was taken as reference value to generate the gate pulse. So that the devices in the VSI can be turned ON at right time to settle speed of the BLDC motor at set speed with any delay. The pulse output wave form is illustrated in figure 11.

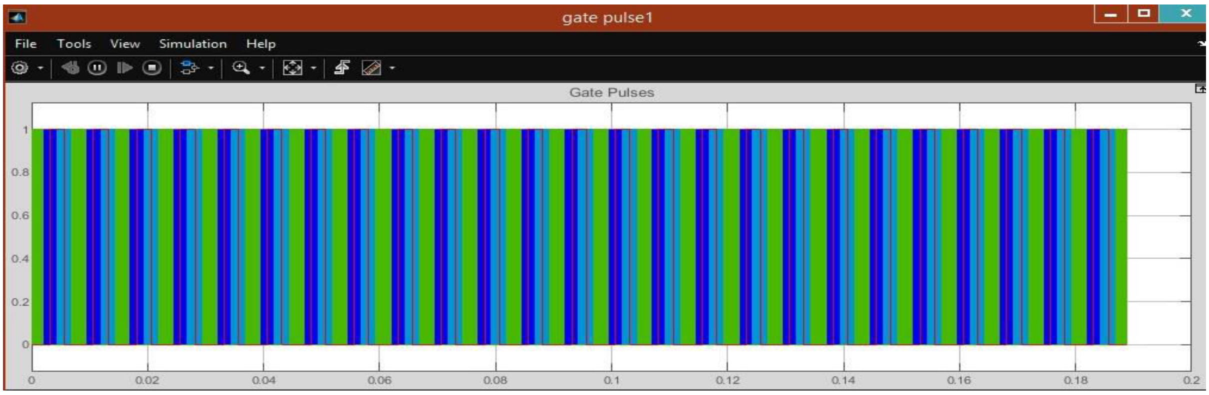

Fig 10; Gate pulses

4.4 PERFORMANCE COMPARISON

Table 1; Performance comparison with SC and without SC

Sl.No	Set Speed (in rpm)	Time Taken to reach set Speed (in rpm)	
		Without Super Capacitor	With Super Capacitor
1	2,000	0.5s	0.375s
2	1,500	0.45s	0.375s
3	1,000	0.4s	0.35s

IV. CONCLUSION

Two sets of sources were used to analyze the BLDC motor's performance during speed regulation using various set of input sources. Case (i): sources of batteries and SPV; Case (ii): sources of batteries, SPV, and SC. The BLDC motor performance was confirmed in both situations for a range of set speeds, and table 1 shows the results. Table 1 compares the analysis and times needed to reach the target speed in both scenarios. The best outcome in example (ii) was achieved using a super capacitor, which required less time to reach the desired speed. With SC, it took just 0.375 seconds to reach the 2,000 rpm target speed, while without SC, it took 0.5 seconds. The graphs illustrated in fig 8 and 9 are the evidence for the table 1.

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