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Closed Loop Speed Control of DC Machine with Using Dual Input DC-DC Converter for Electric Vehicle

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Abstract: *Renewable sources like PV, wind, fuel cell, battery, ultra-capacitor etc. are highly recommended in hybrid electric vehicle applications. Power electronic converters play an essential role in the incorporation of these green energy sources in to the vehicle system. Design and analysis of a non - isolated dual input DC-DC converter for the integration of nonlinear V-I characteristic DC sources for the vehicle propulsion system are discussed in this paper. Computer simulations of the DC-DC converter for integrating two input sources has been carried out in MATLAB/Simulink. Performance comparison has been carried out between the simulation results of the dual input DC-DC converter. The speed of the DC machine is controlled by a feedback loop control system. The controller used is PI controller which generates duty ratio for the dual switches to operate. This converter topology has low component count and offers simplicity in operation of two nonlinear V-I characteristic sources.*

Keywords: *Dual input DC-DC converter, Hybrid electric vehicle, hybrid energy, Super capacitor, and solar-PV.*

1. Introduction

The combustion of fossil fuels for energy purposes produces hazardous pollutants and greenhouse gases (GHGs). GHG emissions are the primary cause of rapid climate change, such as global warming and polar ice melting. CO2, NOx, CO, and methane are the most common GHGs. Figure 1 depicts GHG emissions from several consumption sectors, with transportation accounting for about 14% of total emissions. The number of automobiles on the road has expanded dramatically as a result of global development and expansion of several urban regions. [1] Of course, the vehicle's internal combustion engine is to blame for such a significant amount of transportation GHG emissions (ICE). Therefore, the decarburization of transportation will eliminate the CO2 emissions of the transportation sector. This has prompted current initiatives to replace ICE-based vehicles with sustainable and clean alternative power plants. One promising method to solving the above health and environmental issues is to electrify transportation. As a result, electric vehicles have been seen as a viable alternative to internal combustion engines (ICE). The EV promises zero car emissions, a reduced lifespan cost, increased safety, and the prospect of renewable energy. However, as compared to ICE vehicles, current EV technology has issues such as restricted range, high initial cost, and lengthier recharging time. In many metropolitan regions and developing countries, the restricted range of electric vehicles may not be a concern. [2] Even in these favourable places, however, the current dearth of requisite fast-charging stations provides a barrier to admission. Hybrid EVs are one option for solving the shortcomings of EVs (HEVs). HEV technology can be presented to overcome the drawbacks of both ICE as well as EV vehicles stated above. The hybrid electric vehicle (HEV) combines an internal combustion engine (ICE) with a battery-powered electric motor (EM), combining the benefits of both for transportation. In comparison to ICE or EVs, these features include minimal emissions, excellent dependability, great fuel efficiency, and long range.

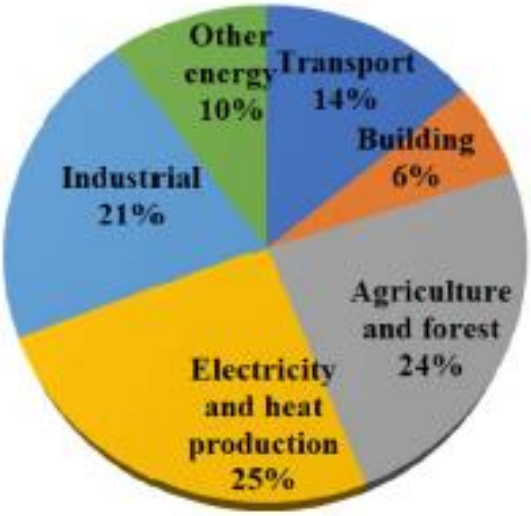

Fig. 1 Sectors responsible for the emission of GHG

With the increased attention towards energy efficiency and environmental pollution, alternatives with a small carbon footprint have found renewed interest in recent times. The traditional way to improve energy efficiency is to shift to all-electric. Transportation has begun to electrify its infrastructure, which is a major contributor to greenhouse gas emissions. Electric vehicles are the pioneers of electrified mobility, and this innovation is now advancing at a breakneck pace. Whereas the carbon footprint of an Electric Vehicle (EV) is still being discussed, it is seen as a viable solution for reducing gasoline expenditures. Electric vehicles (EVs) have a special ability profile that includes both power use and regeneration at various points during operation. Although pure electric vehicles (EVs) have a higher efficiency (68%) as well as lower cost than Fuel Cell (FC)-based EVs (30%), research on the latter has waned. [3] With the advent of new architectures, power electronics technology has a significant impact on electric car growth. Many on-board sources as well as storage units have been integrated in the advancement of the electric vehicle. In contrast to a primary source, high energy density ultra-capacitors are employed to extinguish as well as catch the intermittent demand. This has been observed that a battery with an ultra-capacitor energy storage device performs exceptionally well. A multi-port power converter is required to handle electricity from all sources while delivering a controlled voltage to the load. [4], In recent times, electric vehicles (EV) are gaining popularity, and the reasons behind it are many. The most eminent one is its contribution in reducing greenhouse gas (GHG) emission. The transportation sector emitted 25% of the GHG produced by energy-related industries in 2009. With enough adoption in the transportation industry, electric vehicles are likely to lower this. But this isn't the only reason that this century-old and once-dead concept is being brought back to life, in the form of a commercially feasible as well as accessible product. An EV is a vehicle that is silent, simple to run, and does not require the costly fuel that conventional vehicles do. It is quite beneficial as a mode of urban transportation. It uses no stored energy or emits any emissions while idling, is capable of frequent start-stop, offers total torque from start-up, and therefore does not necessitate a trip to the gas station. It is ideal for motorsport because of the instant torque. It is also beneficial in military applications due to its quietness as well as low infrared signature. The power sector is undergoing a transition, with renewable energy sources gaining traction. Smart grid, the next generation of electrical grid, has also been created. EVs are seen as a key component of this new power system, which includes renewable energy sources as well as an upgraded grid technology. All of this has rekindled interest in and development of this mode of transportation. [5]

1.1 Renewable Sources

Renewable resources are natural resources that are limitless and can be regenerated in a short amount of time. Renewable energy is energy produced from renewable natural resources such sunshine, wind, rain, waves, as well as geothermal heat (naturally replenished). For the planet Earth, the sun is a primary source of unlimited free energy (solar energy). New methods are presently being used to create electricity from solar energy gathered. These systems already have been proved and are extensively used as renewable sources to non-hydro technology around the world. [6] Another important aspect of solar research is the present push to reduce global carbon emissions, which has become a major worldwide environmental, social, as well as economic challenge in recent times. The installation of 113,533 household solar systems in California, for example, resulted in the reduction or avoidance of 696,544 metric tonnes of CO2 emissions. As a result, solar technology adoption would considerably minimise and alleviate difficulties such as energy security, climate change, unemployment, and so on. It is also expected that, because it does not required the use of gasoline, it will play a significant role in the transportation industry in the future. [7]

Policies, investments, as well as support (such as research money) for solar technology from a variety of governmental as well as non-governmental groups have contributed to lay a firm foundation for the use of this renewable energy system. Although rewards & rebates can be effective motivators for market development, there are increasing initiatives to lessen the budgetary impact of these regulatory incentives. Solar power subsidies, on the other hand, have already been drastically reduced in many nations, potentially slowing the industry's growth. Policies are shifting to facilitate the development of solar power systems for large-scale power generation in order to avert this potential drop. Additionally, household solar producers should be given higher subsidies than utility-scale generators. [8]

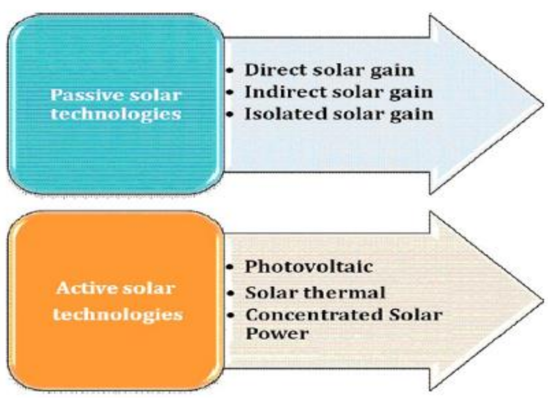

Fig. 2 Classification of the present solar energy technologies

2. Methodology

The analysis and design of a dual input non-isolated DC-DC converter topology for EV applications are provided in this work. Figure shows the EV's schematic diagram, which includes two DC input sources, a dual input DC-DC converter, and a DC motor drive. In comparison to other topologies, this DC-DC converter is both flexible as well as straightforward in terms of input source choices. Both closed loop as well as open loop systems are simulated and studied in this research. Following a thorough examination, it was determined that a closed loop system is in operation, which creates the needed output DC voltage in accordance with the user's reference. Fuzzy logic controller is employed in this closed loop system.[8]

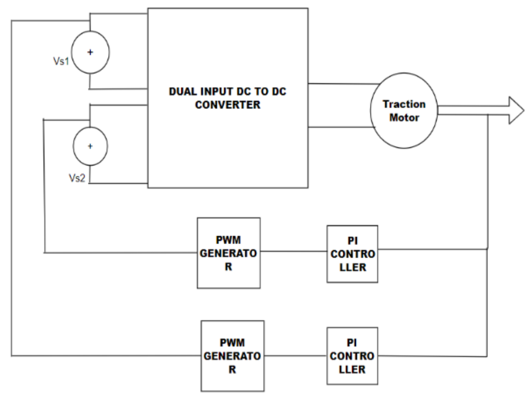

Fig.3 Block Diagram of Electric Vehicle system

2.1 PI Controller

Because of their many advantages, PID (Proportional-Integral-Derivative) controllers are still the most commonly utilised controller architectures in control loops today. Because of the noise in the control process, the derivative effect is rarely used. As a result, PI (Proportional-Integral) controllers are frequently used instead of PID controllers. The majority of PID controllers used in industrial applications are PI controllers, according to reports. PI controllers need the calculation of two parameters and produce satisfactory results in most control systems.[4] Different designed controller may be important to measure the response of the control system. To acquire the best controller parameters, optimization algorithms have been devised. These strategies are used to find the controller parameters that give the optimal response. In various control systems, any of these tuning strategies can provide distinct results. As a result, claiming that one method is the optimum controller tuning method is untrue. Calculation of controller settings that keep systems stable is a critical subject for which several methods have been established.[4] Control systems are employed in a variety of ways, from our daily lives to a wide range of industrial applications. The selection of the appropriate controller type is critical for meeting the design goals. Simple structured controllers are preferred in most situations. Because of their simple structure and reliable performance qualities, PID controllers are frequently used in industry. More than 90% of the controller structures utilised in the industry are PID controllers. Although it creates measurement noise in the process control, the derivative component of the PID controller is rarely used. PI controllers are favoured over PID controllers in certain processes.[4]

2.2 Optimization method

A PI controller is described by the transfer function:

$$K(s) = k_p + \frac{k_i}{s} = \frac{k_p(s + k_i/k_p)}{s}$$

To the feedback loop, the PI controller adds a pole at the origin (an integrator) and a finite zero. Because the integrator compels the error to a constant input to go to zero in steady-state, the PI controller is often utilised in servomechanism design. In the complex s-plane, the controller zero is usually close to the origin. A closed-loop system pole with a large time constant is added when a pole–zero pair is present. The zero location can be changed to keep the slow mode's impact to the overall system responsiveness to a minimum.[9] Proportional integral (PI) controllers are another name for integral controllers. It's a controller that combines proportional and integral control actions into one. As a result, it is known as a PI controller. In a proportional-integral controller, both proportional and integral controllers are used to govern the system. This combination of two separate controllers results in a more efficient controller that eliminates the drawbacks of each of them individually.[49] The control signal is proportional to both the error signal and the integral of the error signal in this scenario. The proportional plus integral controller is represented mathematically as:

$$m(t) = K_p\, e(t) + K_i \int e(t)$$

The figure below represents the block diagram of the system with PI controller:

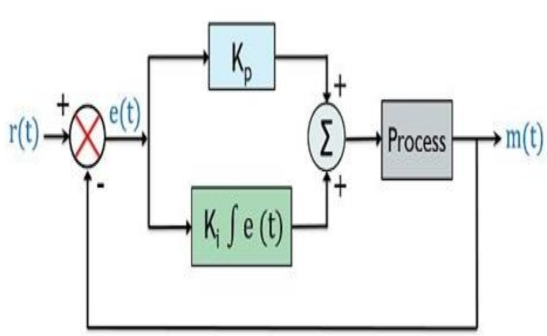

Fig. 4 Control System with PI Controller

The goal of PI controllers is to reduce steady-state error. The type number must also be raised to lead to a reduction in steady-state error. It's worth noting that the existence of a ‘s' in the transfer function determines the controller's type number. The foregoing equation plainly shows that the transfer function's power of 's' has increased significantly. This suggests an increase in the type number, which leads to a decrease in steady-state error. Whenever the PI controller is absent from the control system, the numerator will be devoid of ‘s,' resulting in the absence of zeros in the transfer function.[50] .So, by introducing PI controllers in a control system, the steady-state error of the system gets extremely reduced without affecting the stability of the system.

3. Simulation Model and Result Analysis

3.1 Open Loop Model

Figure 5 shows the proposed model consisting of two DC source at different voltage levels. The duty ratio of the switches S1 and S2 are changed so as to control the output voltage. The DC voltage amplitude of the two sources is depicted in figure 5 Figure 6 shows the output voltage and current of the DC motor and Figure 7 shows the inductor voltage and current, when the duty ration of the switch S1 and S2 is fixed. Depending on the ON and OFF time of the switches S1 and S2, the inductor either charges or discharges. Figure 9 gives the DC motor characteristics, whose speed settles at 2600 rpm and electromagnetic torque at 2.1 Nm for an output voltage of 155V.

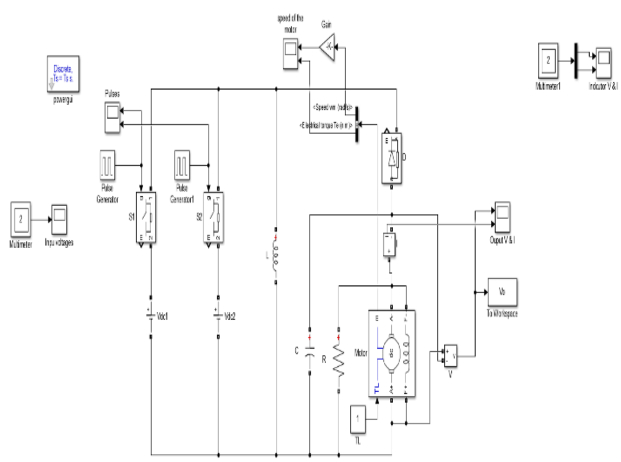

Fig. 5 Open loop model of the proposed system

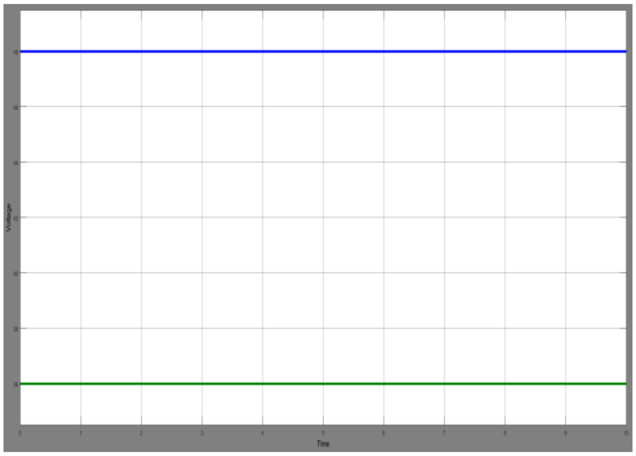

Fig. **Error! No text of specified style in document.** Input voltage of the two DC sources

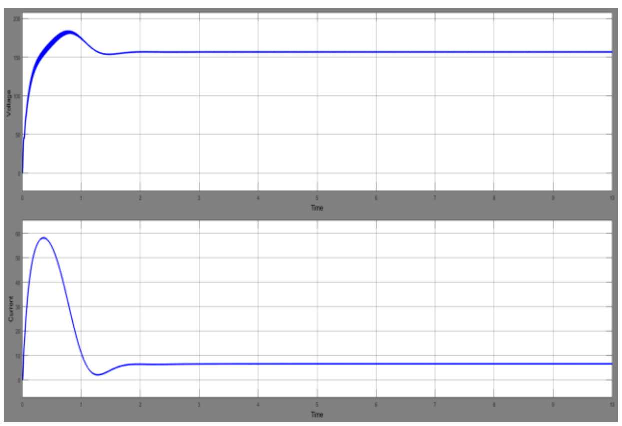

Fig. 7 DC motor output voltage and current

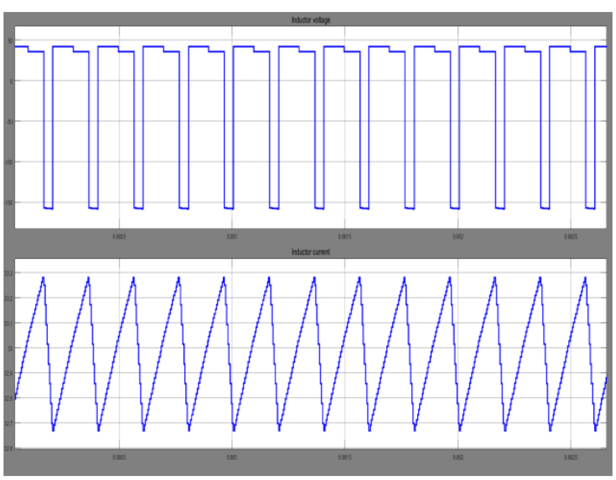

Fig. 8 Voltage and current of resonant inductor

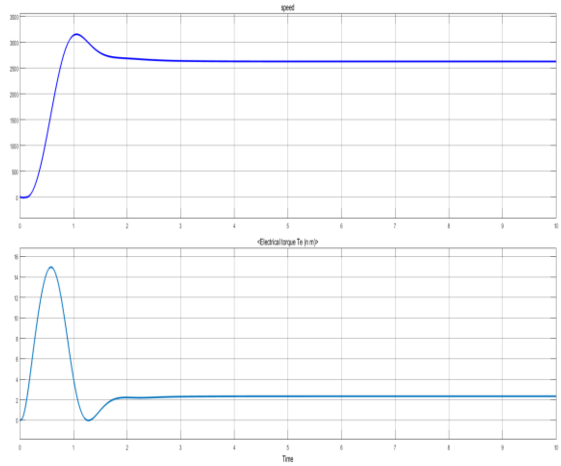

Fig. 9 DC motor characteristics

3.3 Closed Loop Model

Figure 10 shows the proposed model consisting of two DC source at different voltage levels along with voltage feedback from the output of the circuit. The reference voltage is taken as 250 V. The DC voltage amplitude of the two sources is depicted in figure. Figure 11 shows the inductor voltage and current, when the duty ration of the switch S1 and S2 is fixed. The ON and OFF time of the switches S1 and S2, determines the inductor charging or discharging. Figure 12 depicts the DC motor output voltage and current. It can be seen that the voltage settles at 250 V based on the reference voltage value. Figure 12 depicts the DC motor characteristics, which shows for 250V output voltage the speed is settled at 2750rpm and electro-magnetic torque at 2Nmt.

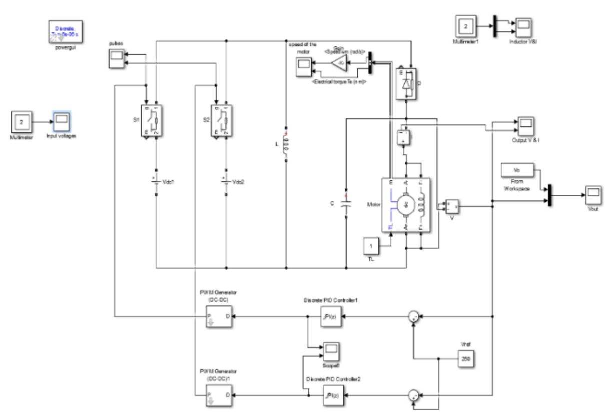

Fig. 10 Closed loop model of proposed topology

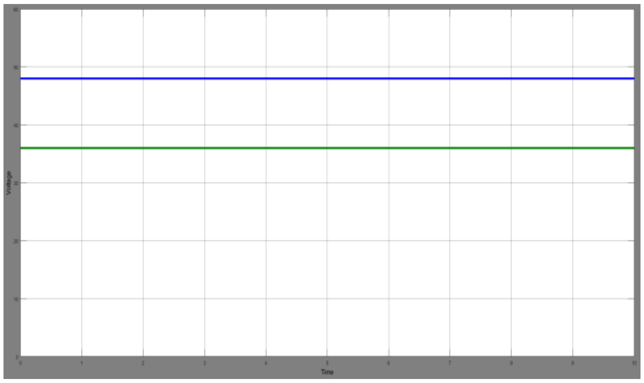

Fig. 11 Input voltage of two DC sources

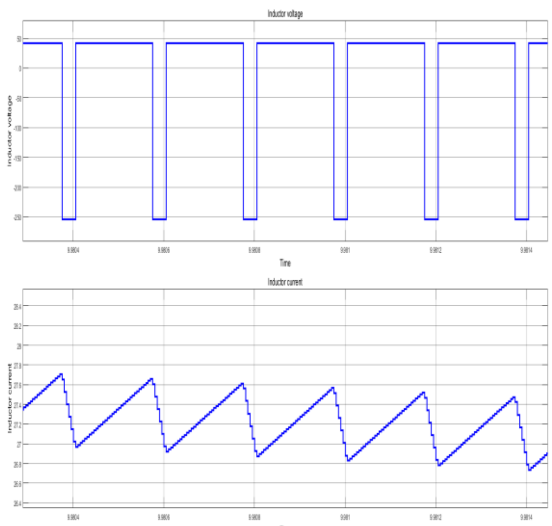

Fig. 12 Inductor voltage and current

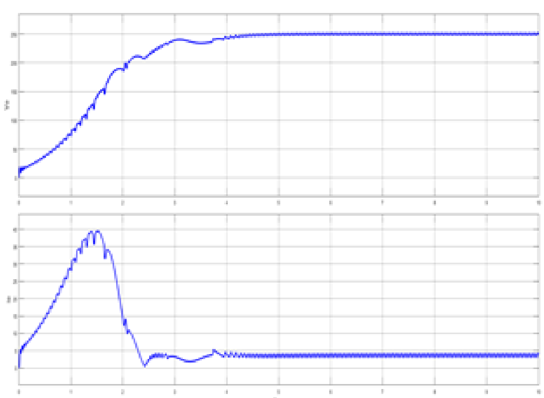

Figure 13 Output voltage and current of DC motor

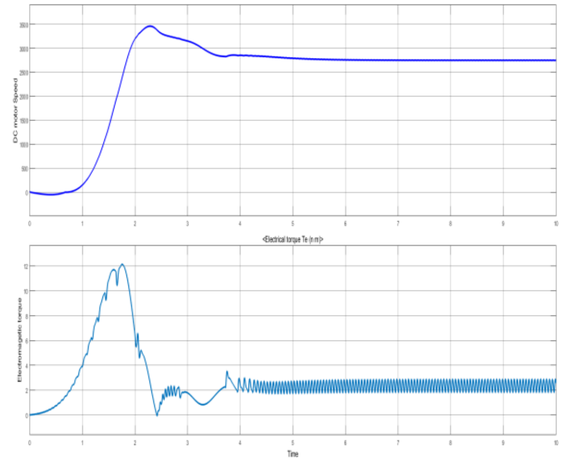

Fig. 14 DC motor characteristics

3.4 Comparative Analysis of Open & Closed Loop Model

The below figure 15 depicts the comparative analysis between the output voltage of open loop & closed loop controllers of the proposed model.

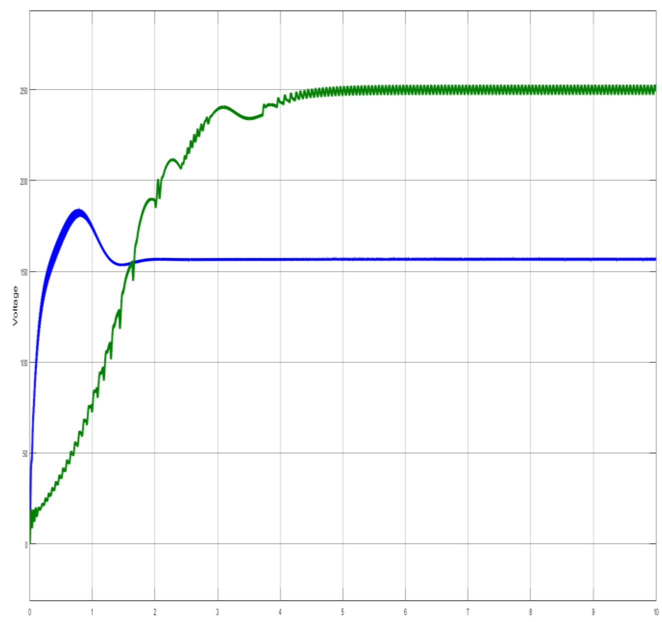

Fig. 15 Output voltage comparison between open loop control and closed loop voltage control

4. Conclusion

As seen from the graphs generated by the modelling of the proposed circuit topology, the closed loop system generates the required output DC voltage as per the reference given by the user. Even the input voltages of the DC sources are uneven the output voltage is stabilized to a constant voltage level operating the DC motor. The maximum voltage generated by the open loop controller with maximum duty ratio of 0.85 is 155V. Whereas for closed loop control, the output voltage is controlled as per the reference value, settled at 250V. However, the output voltage settles slower at 250V for the closed loop control and settles faster open loop controller.

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