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Analysis of Various Driving Cycle Effected the Battery State of Charge in Regenerative Braking of Electric Vehicle

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Abstract: The purpose of this study is to examine using Simcenter Amesim, the effect of various driving cycles on the battery state of charge (SoC) during regenerative deceleration in electric vehicles (EV). The battery SoC is a crucial parameter that impacts the overall performance and range of EVs. Regenerative braking, which converts kinetic energy into electrical energy during deceleration, plays a significant role in recharging the battery's state of charge. Simcenter Amesim, a comprehensive system simulation tool, is used to model the EV powertrain, which consists of the battery, the motor, and the regenerative braking system. Various driving cycles including urban, rural, and highway are simulated to depict a variety of driving scenarios and patterns. The simulations replicate real-world driving conditions using variables such as vehicle speed, acceleration, deceleration, and traffic conditions. The study investigates the influence of vehicle cycles on the battery SoC during regenerative braking. The simulations analyze the transfer of energy during braking events, including the energy captured and stored in the battery. The results are used to compare the battery SoC levels for various driving cycles and to evaluate the efficiency of regenerative braking in maintaining or increasing battery SoC.

Keywords: Simcenter Amesim, Electric Vehicle (EV), Driving Cycle, Battery State of Charge (Soc), Regenerative Braking System (RBS)

1. Introduction

Regenerative braking is a feature found in hybrid and electric vehicles that captures the energy from braking and converts it into electrical power for the vehicle's battery. Unlike traditional braking systems that waste energy as heat, regenerative braking recovers up to 70% of the kinetic energy that would otherwise be lost [1]. This improves energy efficiency and extends the vehicle's range. The captured energy can be used to power the vehicle's systems, assist in acceleration, or charge the battery. Factors like the car model, driving conditions, and behavior can affect the amount of energy recovered. Overall,

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regenerative braking is an important technology that conserves energy and makes hybrid and electric vehicles more environmentally friendly and cost-effective [2],[3].

Regenerative braking works by reversing the process that propels the car forward. In electric vehicles, the battery powers the motor, which generates torque to spin the wheels. When regenerative braking is activated, the spinning wheels drive the motor to act as a generator, converting the kinetic energy into electrical energy. This electrical energy is then sent back to the battery, reversing the flow of electricity. Removing the foot from the accelerator or pressing the brake pedal, automatically initiates the regenerative braking, which not only captures energy but also helps slow down the vehicle as the wheels consume energy by rotating the shaft of the electric motor. This process efficiently converts mechanical energy into electrical energy, maximizing energy conservation in hybrid and electric vehicles.

This project will go through Simcenter Amesim simulation software. It is used to model and simulate complicated multi-domain systems such as mechanical, electrical, hydraulic, and control systems. Engineers and researchers utilize Simcenter Amesim to analyze and optimize the performance of numerous systems, such as automobile powertrains, aircraft systems, and industrial equipment. A driving cycle is a defined pattern of vehicle operation that is used to simulate real-world driving scenarios. It includes variations in speed, acceleration, and deceleration that a vehicle encounters during normal use. Driving cycles are used in emissions testing and vehicle design to analyze how a vehicle performs under various driving conditions. Laminated lithium-ion batteries are a form of rechargeable battery that is widely used in portable gadgets and electric vehicles. They are made up of numerous layers of lithium-ion cells that are layered together and sealed in a laminate casing. Laminated batteries are well-known for their versatility, lightweight design, and simplicity of integration into various forms and sizes.

2. Methods

The methodology will provide a structured approach for simulating and analyzing battery SOC behavior under various driving conditions. It includes a phase cycle and simulation flowchart for a systematic approach.

2.1 Project Methodology

The phase cycle describes the various phases of the methodology, including the planning phase, the implementing phase, the evaluation phase, and the documentation phase, which serves as a validation and sensitivity analysis for the project. Based on Figure 1, Each phase is an essential component of the overall study and assures a logical progression of tasks.

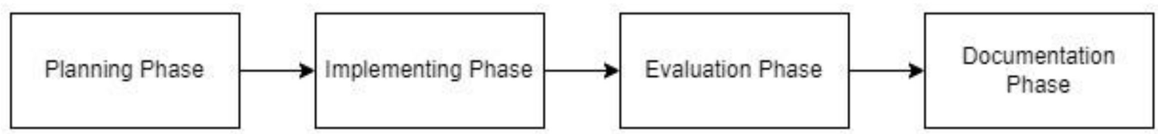

Figure 1: Phase Cycle

2.2 Flow Chart

Figure 2 will show the workflow of this project for the various driving cycles in regenerative braking of electric vehicles using Simcenter Amesim. This section will also demonstrate the process from the beginning to the end throughout the execution of this project.

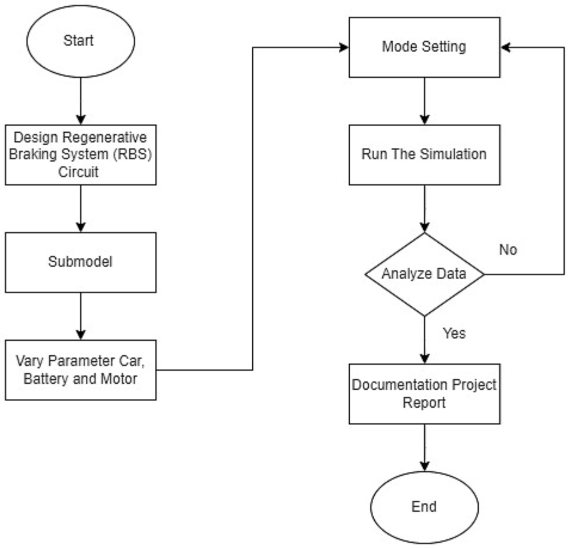

Figure 2: Flow Chart for Simulating Circuit

3. Results and Discussion

Simcenter Amesim simulation software has been used to install circuit simulation in this area. Based on Figure 3, the primary blocks applied in this project are the driver block, the vehicle control unit (VCU), the motor, the battery, the regenerative brake control, and the vehicle's block. Following that, each of the specified blocks must be connected to the proper port in the submodel section.

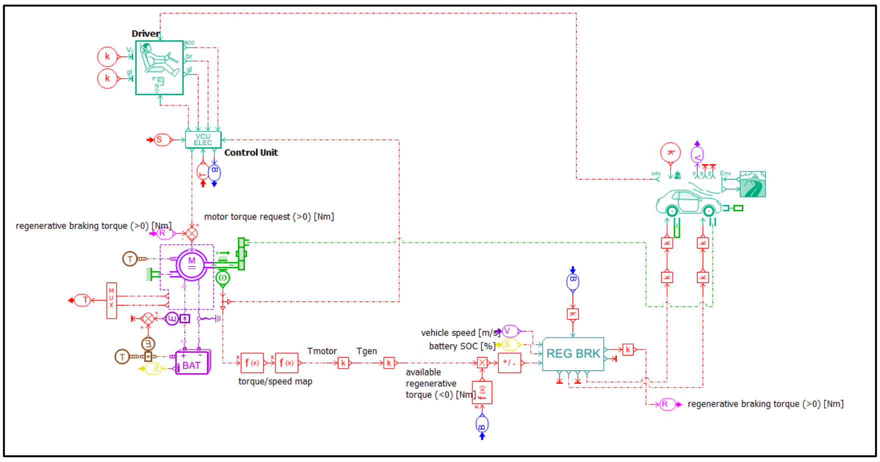

Figure 3: Circuit Simulation of Project

3.1 Driving Cycle Mode

A. 10-15 Mode

This mode was selected because it has a suitable speed limitation of 70 km/h, which is used to represent real driving scenarios in rural areas. Figure 4 shows this mode needs to take 650 seconds to complete a full cycle, which equals to 10.8 minutes. 10-15 modes have characteristics that are appropriate for the actual situations in rural areas, as shown by the fact that this route has a better balanced acceleration and deceleration to be employed in this project.

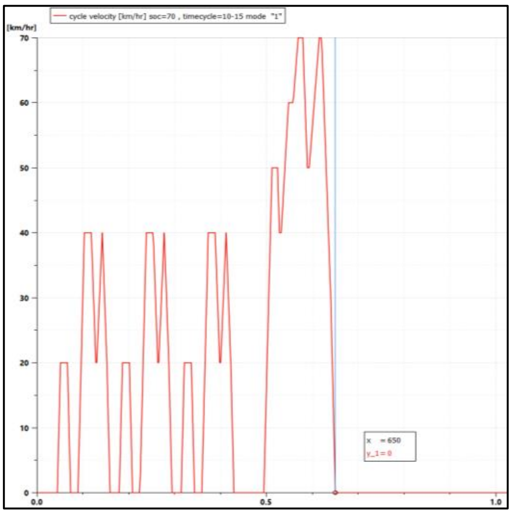

Figure 4:10-15 Driving Cycle

B. WLTC Mode

This mode was selected because WLTP consists of four driving phases which are low speed, medium speed, high speed, and extra-high speed. Figure 5 represents the real driving scenarios in urban areas. This mode needs to take 1795 seconds to complete a full cycle, which equals 29.9 minutes.

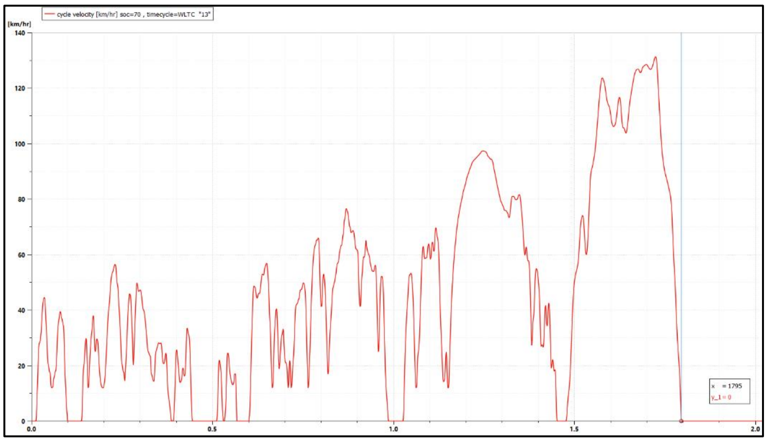

Figure 5: Worldwide Harmonized Light Vehicle Test Cycle (WLTC) Driving Cycle

C. HWFET Mode

This mode was selected because it represents constant-speed driving on a flat road without stops or significant changes in acceleration. Based on Figure 6, it takes 763 seconds to complete a full cycle, which equals 12.7 minutes. The test focuses on assessing a vehicle's efficiency in maintaining a consistent speed on the highway. It provides a basis for comparing the fuel economy of different vehicles in highway scenarios.

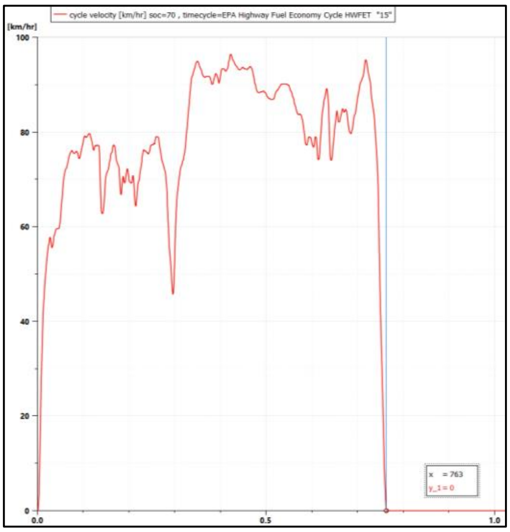

Figure 6: Highway Fuel Economy Test (HWFET) Driving Cycle

3.2 State of Charge (SoC)

A. 10-15 Mode

The maximum displacement value for one whole cycle for this mode is 4.165143 km. This analysis was carried out by creating an estimated shift of 50 km to achieve the project's objectives. Based on Figure 7, this mode will be performed for 12 complete cycles to achieve the expected distance of 49.98 km.

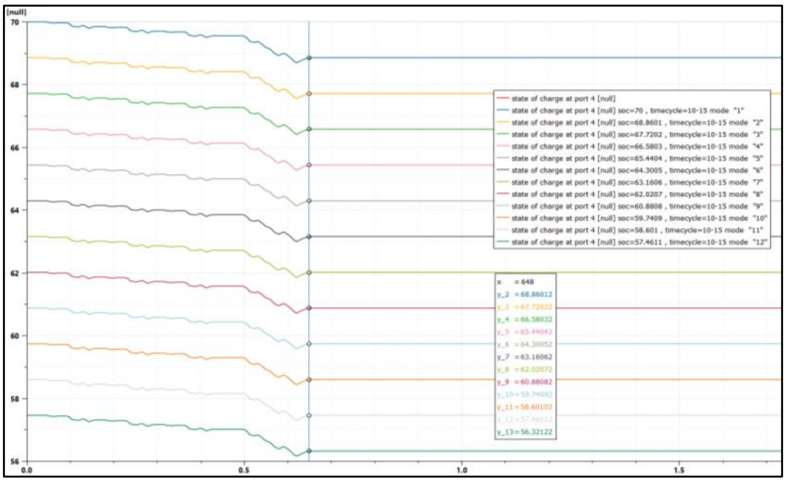

Figure 7: Regenerative Braking System for 10-15 Driving Cycle

For this project, the battery's state of charge (SoC) begins at 70%, which is neither too maximum nor too minimum conditions. It is configured to get the best results. Table 1 shows the state of charge (SoC) of this battery is 70% in the first cycle, and each SoC state up to cycle 12, which is 56.3212%. It was discovered that the state of charge (SoC) of this battery decreased by 0.27367% in each cycle.

Table 1: State of Charge (SoC) for 10-15 Driving Cycle Mode

Cycle	State of Charger (SoC)
1	70
2	68.8601
3	67.7202
4	66.5803
5	65.4404
6	64.3005
7	63.1606
8	62.0207
9	60.8808
10	59.7409
11	58.601
12	57.4611
13	56.3212

B. WLTC Mode

The maximum displacement value for one entire cycle for this mode is 23.26623 km. Figure 8 shows this mode will be used for 2 full cycles to cover an expected distance of 46.53 km.

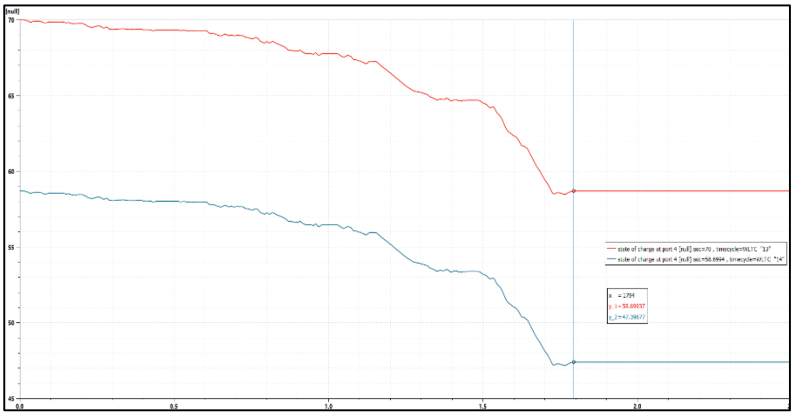

Figure 8: Regenerative Braking System for WLTC Driving Cycle

Based on Table 2, the state of charge (SoC) of this battery is 70% in the first cycle, 58.6994% in the second cycle, and 47.3988% in the final cycle. As a conclusion, of this research, it was found that the state of charge (SoC) of this battery decreased by 0.4857% in each cycle.

Table 2: State of Charge (SoC) for WLTC Driving Cycle Mode

Cycle	State of Charger (SoC)
1	70
2	58.6994
3	47.3988

C. HWFET Mode

The maximum displacement value for one entire cycle for this mode is 16.50243 km. As a result, figure 9 shows this mode will be used for 3 full cycles to complete an estimated distance of 49.51 km.

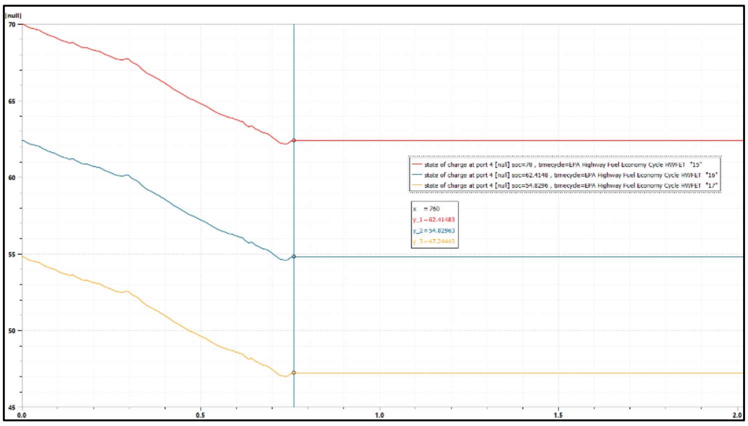

Figure 9: Regenerative Braking System for HWFET Driving Cycle

Table 3 shows the state of charge (SoC) of this battery is 70% in the first cycle, 62.4148% in the second cycle, 54.8296% in the third cycle, and up to 47.2444% in the fourth cycle. As a consequence of this research, it was found that the state of charge (SoC) of this battery decreased by 0.4596% in each cycle.

Table 3: State of Charge (SoC) for HWFET Driving Cycle Mode

Cycle	State of Charger (SoC)
1	70
2	62.4148
3	54.8296
4	47.2444

3.3 Discussion

A. 10-15 Mode

Figure 10 shows the situation in driving mode 10-15 and the state of charge (SoC) when the regenerative braking system is activated. As a result, a relationship can be created between the state of charge (y_1) and the cycle velocity (y_2), which occurs when y_2 is decelerating or running downhill. So, the regenerative braking process happens at y_1, and the generated electrical energy is stored in energy storage devices such as batteries. In addition, figure 10 shows that mode 10-15 has the highest regenerative braking process because this driving cycle has effective and balanced characteristics such as acceleration, deceleration, or stop position.

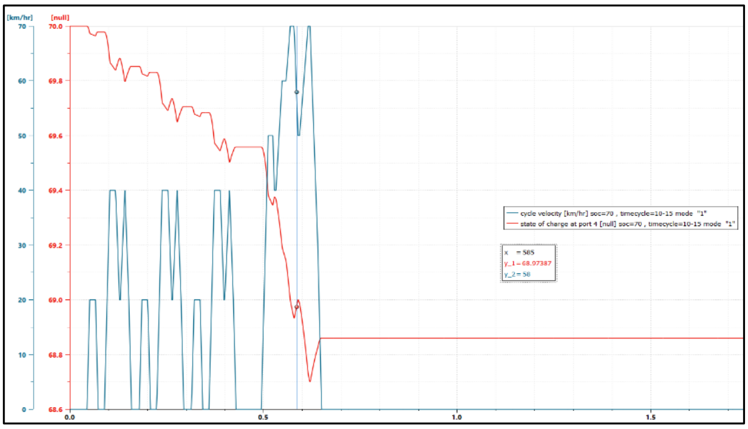

Figure 10: State of Charge (SoC) vs Velocity for 10-15 Cycle

B. WLTC Mode

Figure 11 shows the condition in WLTC driving mode as well as the state of charge (SoC) when the regenerative braking system is enabled. As a consequence, a relationship may be created between the state of charge (y_1) and the cycle velocity (y_2), which happens when y_2 is at low, medium, high, or extra-high speed. As a result, this part might demonstrate the real-world condition of the interaction between state of charge (SoC) and velocity in urban areas. Figure 11 further illustrates that mode WLTC has the lowest regenerative braking process since it has four driving phases which are low speed, medium speed, high speed, and extra-high speed. It can describe the condition of a vehicle during traffic jams, traffic lights, or typical driving.

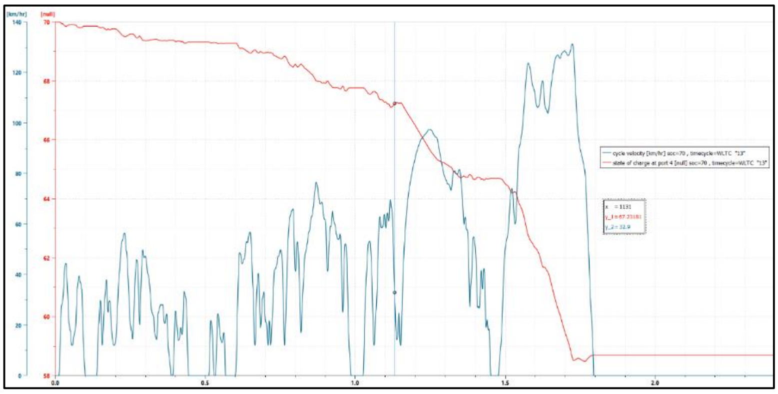

Figure 11: State of Charge (SoC) vs. Velocity for WLTC Cycle

C. HWFET Mode

Figure 12 shows the condition in the highway fuel economy test (HWFET) driving mode as well as the state of charge (SoC) when the regenerative braking system is enabled. As a consequence, a relationship may be created between the state of charge (y_1) and the cycle velocity (y_2), which happens when y_2 is maintaining speed. As a result, this part might demonstrate the real-world scenarios of the interaction between state of charge (SoC) and velocity on a highway. Figure 12 further illustrates that mode HWFET has the medium regenerative braking process since the mode focuses on assessing a vehicle's efficiency in maintaining a consistent speed on the highway. It can describe the condition of a vehicle while maintaining speed, changing lanes, or typical driving.

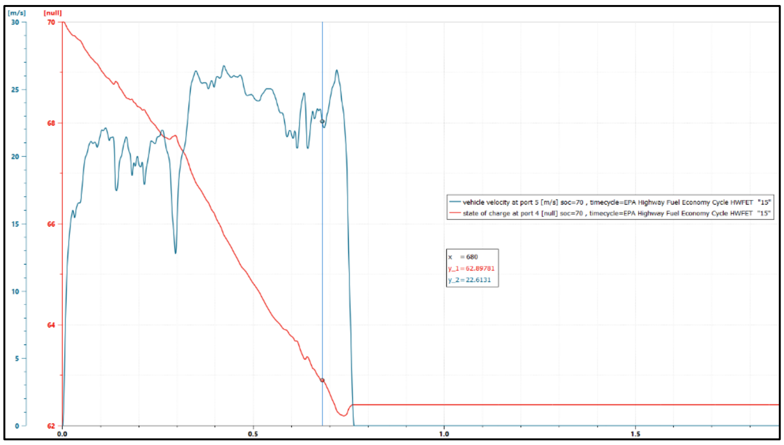

Figure 12: State of Charge (SoC) vs. Velocity for HWFET Cycle

4. Conclusion

The findings from this project determined that the 10-15 mode is the most efficient driving cycle for the Nissan Leaf. This is because, after conducting a simulation process in Simcenter Amesim, the

10-15 mode shows the most satisfactory results. This is evident as the state of charge value for the 10-15 mode is the highest at 56.3212% compared to 47.3988% for WLTC and 47.2444% for HWFET. The main factor that makes the 10-15 mode the best mode is due to the driving conditions that generate the best regenerative braking system.

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