

# Start-Stop Moment Optimization of Range Extender and Control Strategy Design for Extended -Range Electric Vehicle

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**Abstract.** Range extender is the core component of E-REV, its start-stop control determines the operation modes of vehicle. This paper based on a certain type of E-REV, researched constant power control strategy of range extender in extended-range model, to target range as constraint condition, combined with different driving cycle conditions, by correcting battery SOC for range extender start-stop moment, optimized the control strategy of range extender, and established the vehicle and range extender start-stop control simulation model. Selected NEDC and UDDS conditions simulation results show that: under certain target mileage, the range extender running time reduced by 37.2% and 28.2% in the NEDC condition, and running time UDDS conditions were reduced by 40.6% and 33.5% in the UDDS condition, reached the purpose of meeting the vehicle mileage and reducing consumption and emission.

## 1. Introduction

Electric vehicles which has a kind of energy-saving, environmentally friendly, independent of oil resources and smooth operation, quiet and other advantages of clean energy vehicles, is one vital way of solving the current environmental pollution and energy crisis which are the two major problems [1-2]. However, due to the lower specific power and power density of the current power battery, the pure electric vehicle (BEV) has a long charging time and a shorter driving range problem, which limits its large-scale commercial promotion [3]. The Extended-Range Electric Vehicle (E-REV) is equipped with a Range Extender (RE) which consisting of a small displacement engine and a generator on a pure electric vehicle, it can effectively extend the vehicle's driving mileage, as a smooth transition from a traditional car to a pure electric car, the extended range electric vehicle (Extended-Range Electric Vehicle, E-REV) has become an important branch of the current electric cars and drawn more and more attention.

For the E-REV power system, on the basis of meeting the whole vehicle dynamic performance, the coordination with the mechanical and electrical components affect the fuel economy. It is the key problem in E-REV development that how to coordinate the energy distribution between the power battery and the Range Extender, so that the vehicle system has the highest efficiency [4]. Range extender is the core component of E-REV, its start-stop control determines the operation modes of vehicle. Since the E-REV power systems use structure in series, the engine only used for power generation, and not directly output power to drive the vehicle, thus the engine can be adjusted in the vicinity of the optimum operating point stable operation, in addition, it is expected that on the basis of meeting the mileage of the vehicle, it can reduce the excess power of the extended range, save unnecessary fuel consumption, and achieve the best fuel economy and emission [5].

In order to minimize the use of extenders, this paper based on studying the constant power control strategy of the extended range, taking the target mileage as the constraint condition and combining the



different driving cycle conditions of the vehicle, correcting the range extender power battery SOC (State of Charge) value, optimizing the start and stop control strategy to reduce the number of its start and stop and running time which to meet the car mileage while reducing fuel consumption and emissions purposes. Finally, based on ADVISOR platform and MATLAB software, the E-REV vehicle and RE start-stop control simulation model is established to verify the feasibility and effectiveness of control optimization.

## 2. E-REV Overall Designing

### 2.1. E-REV Structure and Vehicle Parameters

The basic structure of a typical E-REV is shown in Figure 1. Wherein, engines and generators connected coaxially to form extended-range system is essentially a generator set. When the battery is fully charged, the range extender is turned off and the car is running in pure electric mode. Only when the battery is low, the range extender starts and the vehicle runs in extended mode [6].

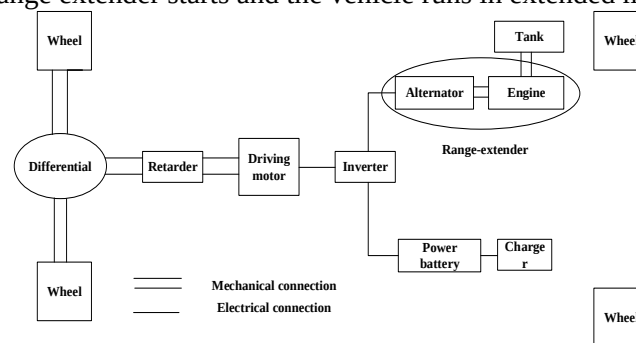


**Figure 1.** Basic structure of E-REV

In this paper, an example of a certain type of electric vehicle in the laboratory is selected, and the basic parameters of the selected vehicle are as shown in Table 1.

**Table 1.** Model parameters

| Parameter name                    | Value          |
|-----------------------------------|----------------|
| Vehicle length, width, height /mm | 4498×1798×1430 |
| Axis number                       | 2              |
| Driving form                      | 4×2 FW         |
| Curb weight m1/Kg                 | 1715           |
| Full load mass m/Kg               | 2015           |
| Wheel radius r/m                  | 0.314          |
| Windward area A/m <sup>2</sup>    | 2.0            |
| Drag coefficient C <sub>D</sub>   | 0.29           |

When the basic parameters of the vehicle are determined, performance index is shown in Table 2 .

**Table 2.** Performance indicators

| Category              | Parameter name                                 | Value |
|-----------------------|------------------------------------------------|-------|
| Performance parameter | Maximum speed V <sub>max</sub> /km/h           | 161   |
|                       | 0-100Km/h Acceleration time t <sub>a</sub> /s  | 9     |
|                       | 30Km/h climbing gradient α <sub>max</sub> /%   | ≥30   |
|                       | Pure electric driving range d <sub>1</sub> /km | ≥60   |
|                       | Total mileage d/km                             | ≥500  |

## 2.2. E-REV Power System

The E-REV powertrain consists of a power drive system (drive motor, gear unit, differential), energy storage system (power battery) and extended range system (engine, generator). According to the data of Table 1 and 2, the key components of the power system are selected. The main parameters are shown in Table 3.

**Table 3.** Parameters of power system component

| Parameter type                         | Value                        |
|----------------------------------------|------------------------------|
| Motor type                             | Permanent magnet synchronous |
| Rated power (kw)/ Rated speed (r/min)  | 45/4000                      |
| peak power (kw)/ Maximum speed (r/min) | 75/9000                      |
| Rated torque (N.m)                     | 150                          |
| Peak torque (N.m)                      | 240                          |
| Rated voltage (V)                      | 300                          |
| Power battery type                     | Lithium iron phosphate       |
| Capacity (A.h)                         | 60                           |
| Rated voltage (V)                      | 288                          |
| SOC range (%)                          | 30-90                        |
| Engine type                            | Inline four cylinder         |
| Displacement (L)                       | 1.3                          |
| Rated power (kw)/ Rated speed (r/min)  | 38/3500                      |
| peak power (kw)/ Maximum speed (r/min) | 55/6000                      |
| Maximum torque (N.m)/speed (r/min)     | 130/4250                     |
| Generator type                         | Permanent magnet synchronous |
| Rated power (kw)/ Rated speed (r/min)  | 35/4000                      |
| peak power (kw)/ Maximum speed (r/min) | 60/9000                      |

## 3. Analysis of Traditional E-REV Control Strategy

### 3.1. E-REV Energy Management Strategy

The energy management strategy of E-REV can be divided into Depleting Charge period and Charge Sustaining period. During the charge depleting period, the vehicle vehicles rely only on the power of battery, equivalent to pure electric driving, during charge sustaining period, the extender system began to start and power generation vehicle mainly rely on electricity to drive the car [7]. According to the upper and lower threshold SOC of power battery, based on rules of logic threshold switching control strategy to achieve a smooth transition of two period.

In order to ensure the drive motor within normal working voltage, while ensuring the performance of the power battery and prolong the life. In this paper, the SOC is set to 90%-30%.

### 3.2. E-REV Range-Extender Control Strategy

The E-REV range extender uses a constant power control strategy: According to the threshold of the battery SOC, it determines the opening and closing of the range extender .The control effect shown in Figure 2, first set the upper and lower limits of SOC, when the battery SOC over the upper limit SOC<sub>max</sub>, the range extender is off, the power battery provides the energy requirements of the motor; when the battery SOC below the lower limit SOC<sub>min</sub>, the range extender is on, and works in the optimal efficiency point, which driving the generator running power, to drive the motor providing

energy to ensure that the vehicle continues to run, the excess energy will be used to recharge power battery; when the battery SOC is located between the upper and lower limits, Range extender maintain the working state before the last moment [8]. The advantage of this control strategy is that the engine is easy to be controlled, it can maintain low fuel consumption, high efficiency constant power output, effectively avoid the engine frequent start and stop and power fluctuations.

### 3.3. Selection of Engine Operating Points

Figure 3 is the curve of engine equivalent fuel consumption rate. E-REV uses tandem type power system, there is no mechanical connection between the engine and the transmission system, the engine output is disconnected with the ground load, and always working in low fuel consumption and low load, in the high fuel economic area. using direct start-stop technology to cancel the engine idle controlling, so that the engine starting work in the speed and torque respectively 3500r/min and 50N.m with constant speed and constant torque condition (Figure 3 point), improving the efficiency of the engine, also reducing exhaust emissions. Engine power can be calculated at this time the engine output is constant power 18.3kW, It can meet the power demand of two driving conditions of the city streets and urban and highway combination.

### 3.4. Simulation Analysis of Traditional E-REV Control Strategy

Under the traditional E-REV control strategy, three typical driving cycle conditions NEDC, UDDS and CUDC were selected to simulate. Under different conditions, the battery SOC value with the car mileage changes shown in Figure 4.

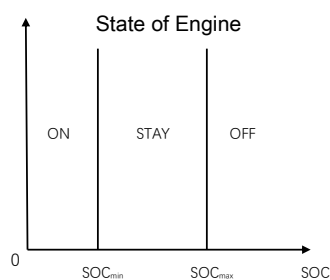


**Figure 2.** Constant power control strategy.

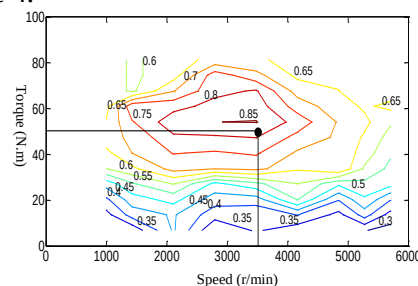


**Figure 3.** Engines equivalent fuel consumption curves.

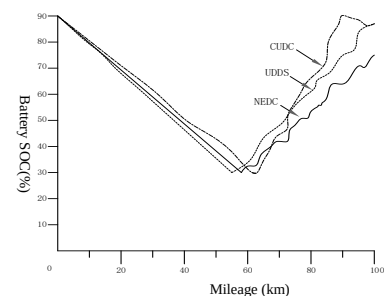


**Figure 4.** Relationship between SOC and mileage.

As is shown in Figure 4, in three different driving cycles, battery SOC value with the vehicle mileage increases continuously decline, before dropping to the 30% threshold, the range-extender is off, it indicated that the car meet various driving cycles of power demand in the period. Due to the different conditions of driving cycle, the power for vehicle's demand  $P_{req}$  are different, the battery SOC change rate is not the same, so the pure electric driving mileage  $S_{are}$  is different. but commonly in about 60km [9]. When the battery SOC value down to the lower limit, the range extender is on, extended range engine drive the generator power generation, on the one hand to drive the motor to provide energy to ensure that the vehicle continues to drive, on the other hand for the power battery charge, battery SOC is up until reach the upper limit, the range extender is off.

According to statistics from China's Ministry of Transportation, it shows that the average daily mileage is less than 60km. Therefore, E-REV basically rely on its own battery power energy to meet the daily needs of people to work and travel without starting the range extender system.

## 4. E-REV Control Strategy Optimization

### 4.1. Optimization of the Control Strategy of the Range- extender Starting and Stopping time

When the E-REV target distance  $D$  ( the mileage adjacent to the two external charging ) is greater than that of the pure electric vehicle mileage  $S_{are}$ , target distance will affect the range-extender start-stop times and running time, thus has impact on the vehicle's fuel economy, in order to reduce the start-stop

times and running time, it should make full use of battery energy[10]. Therefore, when the E-REV is having long-distance travel, it should be reasonable for start-stop time for the range-extender.

According to the original control strategy, the relationship between the SOC value of the battery and the working state of the range-extender with the mileage is shown in Figure 5. In initial stage, the vehicle is maintaining pure electric mode, when battery state of charge (SOC) down to the lower threshold value, start the range-extender and enter the road charging mode until the battery state of charge (SOC) reaching the upper threshold, then the range-extender closed. To shorten the range extender running time, two methods can be used to optimize the original control strategy [11].

For starting the range-extender in advance during pure electric mode, in pure electric driving mode, when the SOC value falls to O point, start the system in advance, the simulation results shown in Figure 6. For stopping the range-extender in advance during the road charging mode, in the charging mode, when the SOC value is increased to point C, range-extender is stopped in advance and the simulation results as shown in Figure 7.

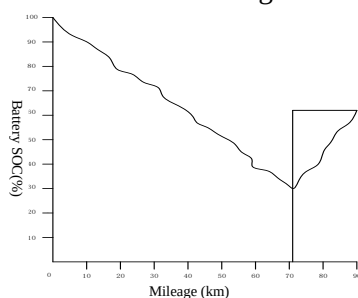


**Figure 5.** Original control strategy.

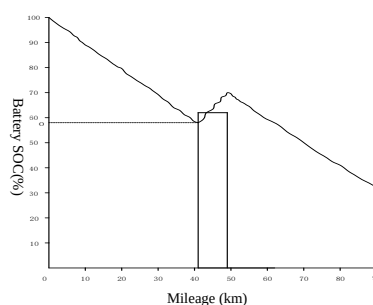


**Figure 6.** Open range extender advance.

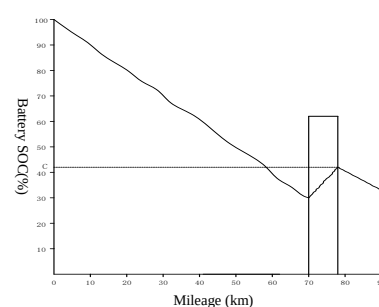


**Figure 7.** Close range extender advance.

In conjunction with Figure 8 and Figure 9, when the target distance is constant, these two optimization methods for start and stop time can be shortened range extender running time and the range extender power can just to run out before the next external charge [12]. The optimization strategy can make full use of battery energy, shortening range extender running time, reduce fuel consumption and cost savings.

When the engine is working in a particular point with a constant power output, the difference between the initial value of the battery SOC, the length of the target mileage, driving cycle conditions and other factors will affect the battery SOC decreasing speed, resulting in different start and stop times for range extender and different running time. Therefore, a combination of different driving cycle conditions is needed, to determine the range extender start and stop time.

The initial battery SOC value is set to 90%, with parameters  $k_1$ ,  $k_2$ ,  $k_3$  respectively SOC is dropped to 30%; starting range extenders SOC charged from 30% to 70%; Close range extenders after SOC decreased from 70% to 30% during these three mileage capacity ratios. According to results of simulation on three previous typical driving cycle conditions, the parameters  $k_1$ ,  $k_2$ ,  $k_3$  values are shown in Table 4.

**Table 4.** Mileage than capacity with different cycle conditions

| Cycle condition | Mileage capacity ratio |       |       |
|-----------------|------------------------|-------|-------|
|                 | $k_1$                  | $k_2$ | $k_3$ |
| NEDC            | 0.87                   | 0.75  | 0.78  |
| UDDS            | 1.06                   | 0.66  | 0.93  |
| CUDC            | 1.07                   | 0.43  | 1.05  |

In pure electric driving with starting the range-extender in advance, the target distance  $D$  is obtained when the range extender to start in advance. During the charging process, stop the range-extender in advance. Based on the numerical value of Table 4, the SOC of the starting and stopping time of the range-extender with different cycle conditions can be modified.

#### 4.2. Comparison of simulation results before and after control strategy

To verify the effectiveness of the optimized control strategy, selecting the NEDC and UDDS two cycle conditions are simulated, battery SOC<sub>s</sub> value is set 90% and target D values of mileage is 100km. According to equation (3) and (5), drawn NEDC conditions SOC RE<sub>on</sub> and SOC RE<sub>off</sub> were 39.2% and 60.6%, and the simulation results shown in Figure 8.

By Figure 8, under the NEDC cycle condition target mileage is 100km, according to the original control strategy (a), the range-extender is running 2890s, after optimize control strategy, during pure electric vehicle driving (b), open the range-extender in advance, the total running time is 1806s, during driving charge period (c), shut down the range-extender in advance, accumulating the run time is 2068s, that is reduced by 37.2% and 28.2% respectively. The results of the specific comparison are shown in Table 5. According to above, UDDS conditions SOC RE<sub>on</sub> and SOC RE<sub>off</sub> were 46.2% and 51.2%, and the simulation results shown in Figure 9.

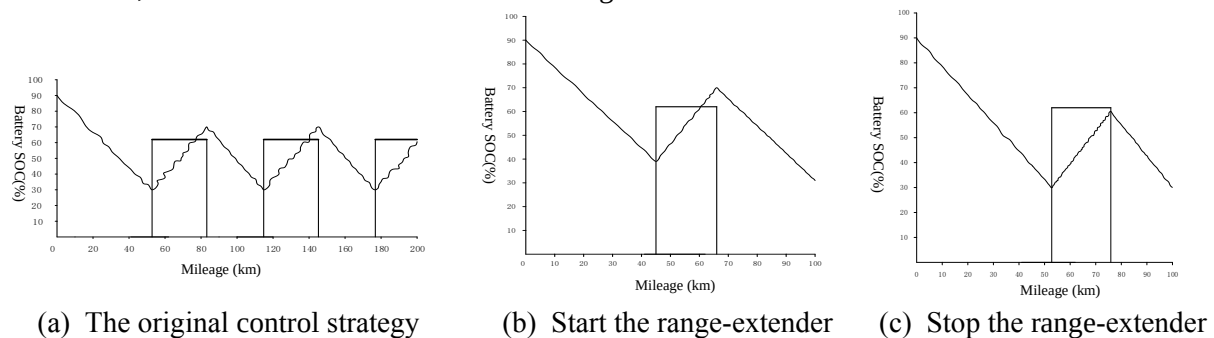


**Figure 8.** Simulation results of the NEDC conditions

**Table 5.** Comparison of before and after optimization for NEDC condition

| Control Strategy             | SOC Control parameters/%                                  | RE running time | Reduce RE running time /% |
|------------------------------|-----------------------------------------------------------|-----------------|---------------------------|
| Traditional control strategy | 30 (SOC <sub>RE_on</sub> )<br>70 (SOC <sub>RE_off</sub> ) | 2890            | -                         |
| RE Start early               | 39.2 (SOC <sub>RE_on</sub> )                              | 1806            | 37.2                      |
| RE close early               | 60.6 (SOC <sub>RE_off</sub> )                             | 2068            | 28.2                      |

By Figure 9, under the UDDC cycle condition target mileage is 100km, according to the original control strategy (a), the range-extender is running 2560s, after optimize control strategy, during pure electric vehicle driving (b), open the range-extender in advance, the total running time is 1516s, during driving charge period (c), shut down the range-extender in advance, accumulating the run time is 1708s, that's reduced by 40.6% and 33.5% respectively. The results of the specific comparison are shown in Table 6.

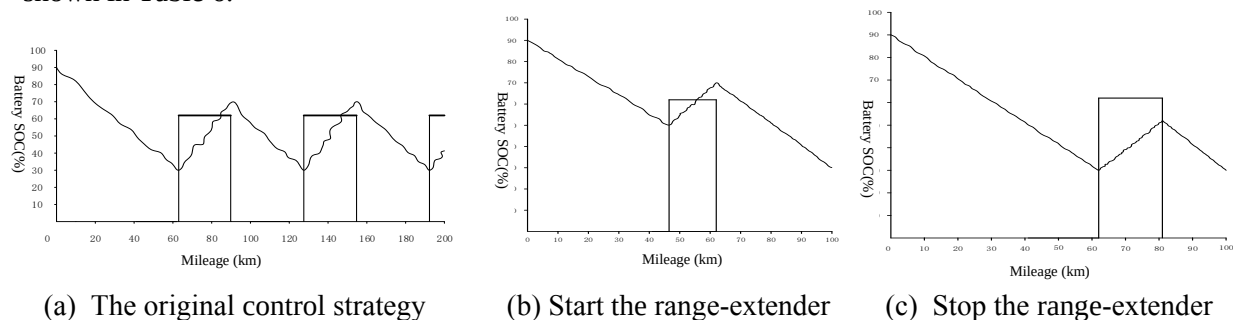


**Figure 9.** Simulation results of the UDDS condition

According to Figure 8 and 9, after optimize the control strategy, the running time of two cycles conditions are significantly reduced while reaching the target mileage, besides the power that charged into the battery can basically run out, making full use of the energy of the battery at the same time also ensuring that the car charging power through the outer supply to prepare for the next driving.

**Table 6.** Comparison of before and after optimization for NEDC condition

| Control Strategy             | SOC Control parameters /% | RE running time | Reduce Rerunning time /% |
|------------------------------|---------------------------|-----------------|--------------------------|
| Traditional control strategy | 30 ( $SOC_{RE\_on}$ )     | 2560            | -                        |
|                              | 70 ( $SOC_{RE\_off}$ )    |                 |                          |
| RE Start early               | 46.2 ( $SOC_{RE\_on}$ )   | 1516            | 40.6                     |
| RE close early               | 51.2 ( $SOC_{RE\_off}$ )  | 1708            | 33.5                     |

## 5. Summary

Footnotes should be avoided whenever possible. If required they should be used only for brief notes that do not fit conveniently into the text.

The range-extender electric vehicle technology has been generally recognized by the industry, the E-REV's start-stop control determines the mode of the car. Using the two methods that during pure electric driving start and stop the range extender in advance to reduce the running time when the target mileage is constant, and correcting the value of the battery SOC to precisely control the start and stop time.

The simulation results show that the control strategy is validated after the optimization of the control strategy. Under the condition of meeting the mileage of the vehicle, the running time of the extender is reduced by 37.24% and 28.2% respectively in the NEDC working condition, and in the UDDS operating conditions were reduced by 40.6% and 33.5% respectively, improving fuel economy and reducing emissions.

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