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Battery SOC Estimation using Support Vector Machine

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Abstract: In recent years, there has been an incredible improvement in battery technology because of the occurrence of EVs and HEVs. However, the State-of-Charge (SoC) estimation remains a challenge in battery engineering. SoC is the ratio of available capacity and maximum possible charge that can be stored in a battery. SoC estimation is of prime importance with relation to battery safety and maintenance. This paper shows SoC estimation by optimisation SVM technique. Support Vector Machine (SVM) is a kind of learning machine based on statistical learning premises. An accurate SoC estimation can improve the performance of the battery and raise the security of the EVs. The SoC cannot only protect the battery, avoid overcharge or discharge, but also improve the battery life. Therefore, the aim of this study is correct sampling of voltage, current and temperature signals. In this project a SVM optimized by Particle Swarm Optimization (PSO) to boost SoC estimation accuracy.
Keywords: State-of-Charge (SoC), Support Vector Machine (SVM), Electrical Vehicles (EV)

I. INTRODUCTION

Energy created from conservative sources like coal and diesel is insufficient due to ever-rising demand for power. The exploitation of green energy is becoming progressively more significant in today's world. Creation of power from renewable energy sources to convene the gap of supply and demand is random in nature. Consequently, there is a need for storage of energy from renewable sources to make certain permanence of furnishings. Accordingly, Electric Vehicles (EVs) are presently the preeminent alternative for the environment in requisites of community and private transportation. EVs have gained receiving as little or zero secretion means of transportation.

Resultant batteries based on electrochemical theory are generally used for energy storage in fusion energy creation systems, portable devices, EVs etc. While batteries are furthermore fetching the crucial resource of power for various diminutives to huge power applications, it is obligatory to manage batteries to ensure their proficient operation.

As we know day by day, the number of vehicles for transportation is increasing around the world. Due to that a need for energy for that vehicle is also demanding.

The fuel utilization for transportation in developed countries like the U.S is about 70% of total consumption of oil in the U.S within a year [1]. Internationally, a growing middle class in developing countries like China and India is causing demand for passenger cars to expand and with it requirement for fossil fuel. By 2050, there may be as various as 1.5 billion cars on the road, compared to 750 million in 2010.

Owing to consumption of fossil fuel air pollution the problem is tremendously enhanced which is directly pretentious on human health. Bestowing to earlier research [2], developed countries like the United State particulate matter, volatile organic compound, carbon monoxide and lead were generated by combustion of fossil fuel in vehicles and remain in long term air. In addition to this CO_2 released by greenhouse effect. Gradually transportation performance improved hence, air pollution significantly increases in every single day [3].

To overcome the problems regarding the use of fossil fuel gives more concern to develop alternative, cost effective, eco-friendly EVs. Battery is an electrochemical energy storage device; the basic function of a battery is to convert chemical energy into electrical energy by simple electrochemical oxidation-reduction reaction.

Among several battery technologies, the most recognized and common rechargeable battery technologies are Lead-acid, Nickel-Cadmium, Nickel-Metal and Lithium-ion. The characteristics of different battery chemistries and noticeably specify the Li-ion batteries have superior performance. It retains high energy density and cell voltage compared to Pb - PbO_2, Ni-Cd and Ni-MH technologies [4].

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II. METHODOLOGY

Electric vehicles (EVs) are fitted with a high-voltage battery pack consisting of two or more modules, with two or more cells in each module. The smallest unit linked in parallel or in series to form one module is a cell. In a parallel or series configuration, a module is then linked to form one pack, called a battery.

In the past decade, the Battery Management System (BMS) and the accurate estimation State of Charge (SoC) have been thoroughly researched. SoC estimation not only provides information on battery performance, but also reminds the user of the battery's remaining useful energy. The block diagram of the work proposed as follows.

Block Diagram

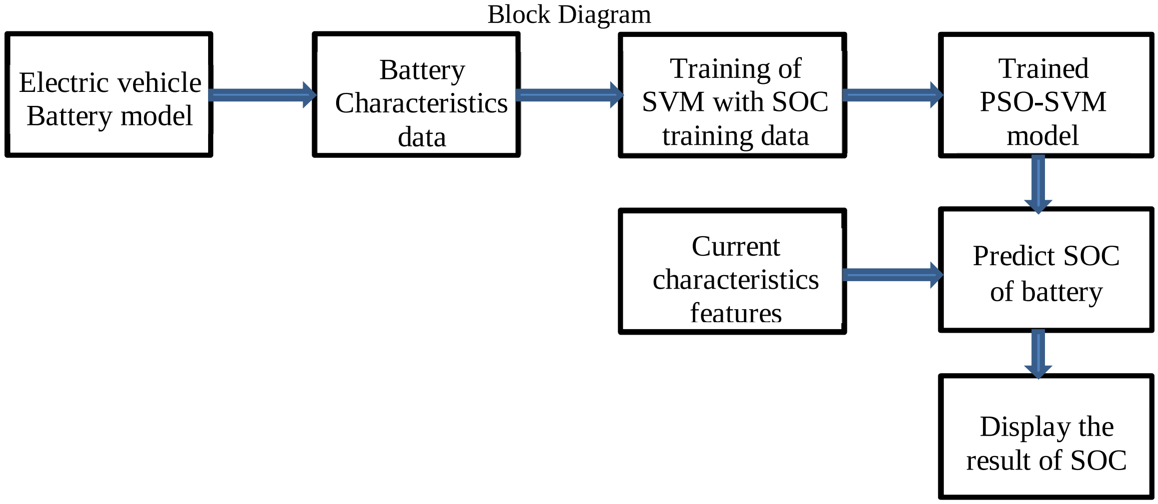

Fig 1: Block diagram of work

A. *Battery Characteristic Data*

The battery characteristics data is essential terms of interior resistance throughout charging-discharging cycles. This data can directly originate from characteristic graphs for specific battery models. The technique may contain design of the battery model and recording its performance in a simulation platform to gather the vital data.

When a load is applied, the voltage is measured between the battery terminals. The battery temperature is extraordinarily dependent on the season, where season can be interpreted to outside temperature. The highest temperature obtained in summer while lowest in winter season. The battery temperature is vital for batterysafety; gas venting, thermal runaway may lead to disclosure, explosion of battery. The foremost temperature for the performance of a Li-ion battery is almost 23℃owing to a trade-off between performance and security. The maximum temperature for batteries for safe work is less than 450C. At cold condition performance of Li-ion, battery drastically decreases. The minimum temperature for battery for safe work is more than -60C [5].

B. *Training of SVM with SOC Training Data*

1) *Training of SVM:* The pre-calculated SoC with respect to characteristics of, current, voltage and internal resistance of the battery used for training of SVM. The training depends on variability of the data contents. Hence, trial and experiment method is used to evaluate the endorsement tests of training requirements and data pre-processing. In the PSO optimized SVM bounds process, the fitness function used to estimate the quality of every particle, which must be calculated earlier searching for the optimal values of three SVM parameters. We must know about SOC of the battery model data. Once we have this SOC information, this information will be given to the SVM for training. The SOC will save and then load to the next coding i.e. regression model (analysis). After loading the SOC, if we give the input like voltage, temperature etc. we will get the SOC i.e. required SOC. The author [5] establishes the battery model in the math work called “get_modelData”. This "get modelData" call is in the data file for ode45. This "get modelData" from the data file will then simulate and plot the SOC. Our task is to first collect the data from the battery and train the SVM. In the base paper, SOC was predicted, and in the form of equations, the battery model is given. The SOC prediction equation gives the battery model in the "get modelData" file. The "get modelData" file in ode45 will run so that battery data is generated. This generated battery data is used for regression analysis like voltage, temperature etc. Once the regression model is delivered if we give the input like voltage, temperature to the model, we will get the SOC. By using the Extended Kalman Filter method, the battery model will simulate and predict the SOC. For SVM training, simulated data is used. SVM is used for SOC prediction. By loading two models regardless of details based on temperature and

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voltage, we can predict the SOC. Consider the battery specifics in the “alldata.mat” and two models are train and load. Another battery data is Alldata.mat, from which we want to see the temperature, time, current, voltage, and SOC. Time separation implies the difference between the time of the start and the time of the end. From that, we can obtain the time variables. Here we do not use current data but this current data is used later on. The current parameter is in the available standard battery data. If we need the load current value, then for real time estimation, we will use this current data in SoC. Consider we have a 12V battery, which has 20Amp capacity. How long will SoC stay after consuming every 1Amp current? For plotting the graph, we need this current. Current is dependent on the load circuit. Now we briefly discuss the load circuit. Load circuit means the Impedance in Ohm (Ω). If the impedance is decreased then current is increased. Similarly, if impedance is increased, current will be decreased. i.e. impedance is inversely proportional to the current. From the battery data we got the current data. This data is used in the formula for lifetime estimation of SoC. Now we have an existing SoC. Later on, the predicted data is compared with the SoC. The predicted data is estimated i.e. sochat, socbound, battdata, iterdata etc. sochat is the top value of SoC while socbound is the lower value of SoC. This sochat, socbound initialize the variables. Later on, we assign the values. We cannot predict the certainty of any battery. E.g., consider we have a 12V battery. It will charge up to 13.5V. After that we will start to discharge. The performance of the new battery is good, but after a year or month, we cannot guarantee the same performance. The battery data is formatted based on current, voltage and sigma. We take the battery data and then it is composed. The input data will be linearized. Variation will be checked after each input voltage, current and temperature. Then update the SoC and other model states. Our data has 40,000 readings and updates after each 1000 reading. That means (40,000/1000 = 40) 40 readings will get i.e. 0 to 100%. Now estimate the input SoC. The time scale is mentioned per hour at the time of plotting SoC. Then we check the error between actual SoC and predicted SoC. There are two types of errors. First is Time error and second SoC error. Here error means the comparison between minimum SoC value and actual SoC value. The error is approximately linearly equal to zero, but not exactly zero. It tends to zero.

2) *Testing Phase:* In electric vehicles during the progression of battery SoC estimation, SVM is used. Steps used in training a SVM model for SoC estimation are obtainable followed by the test procedures and results. Training steps include training data selection, pre-processing, and finding the optimal SVM parameters. Once trained model of SVM is obtained, the current state characteristics data will be used to predict the SoC state of the battery. Similarly, test steps also consist of selection and scaling operation of test data.

C. *Trained PSO-SVM Model*

1) *Particle Swarm Optimization – Support Vector Machine (PSO –SVM):* A Particle Swarm Optimization (PSO) algorithm can be used in order to improve the accuracy of the traditional Support Vector Machine (SVM). In this method Saturated And Mix-Delayed Particle Swarm Optimization (SMDPSO) algorithm, the evolutionary state will be determined by evaluating the evolutionary factor in each iteration, based on which the velocity updating model switches from one to another. Nature enthused algorithms are extensively used to crack the real world optimization problem. Hence, numerous researchers have compared the performance of nature-encouraged algorithms on several optimization problems. Thus, it is very simple in application and moderately effective technique. PSO fundamentally based on Swarm Intelligence. It rapid junction and lesser computational time make it worthy applicant for resolving higher dimensional optimization problem
2) *SVM Regression*

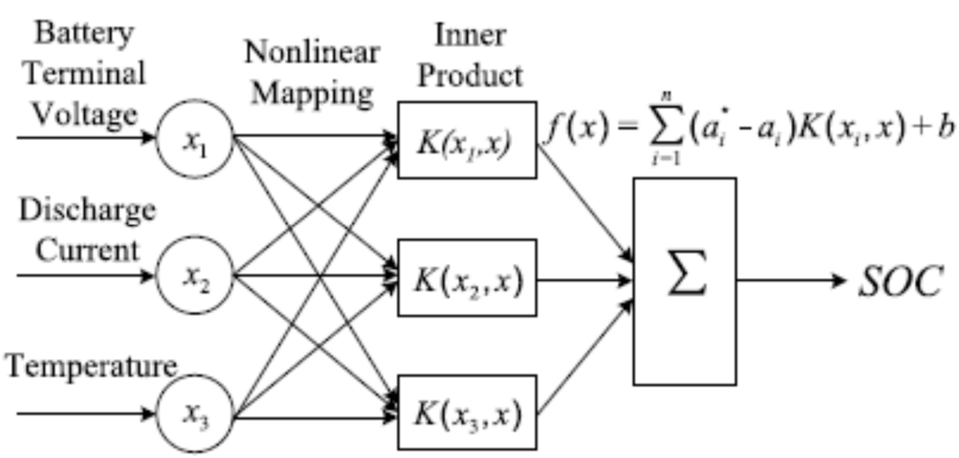

Fig 2: SoC simulation model of Support vector machine [7]

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SVM applied to the SoC estimate of lithium ion battery, with three outside characteristic parameters of battery, such as, battery terminal voltage, discharge current and temperature as inputs, battery SoC as the output, to develop a SVM model. In addition, the SoC prediction problem is transformed to a non-linear regression problem. A support vector machine SoC prediction model develops with discharge current, battery temperature, and battery terminal voltage, as inputs, as well as the battery SoC as an output. In the above figure, xi is the target support vector. K (xi; x) is the kernel function. In high dimensional space, the Kernel function can input low dimensional data. The model's ability to solve nonlinear problems can be greatly improved by choosing an acceptable Kernel function [7].

SVM was formerly established for pattern recognition, which represents decision borders in terms of a naturally minor subsection of all training examples, called the Support Vectors (SVs) [7].

III. RESULT AND DISCUSSION

To appraise the presentation of the SVM in battery SoC estimation, the PSO-SVM method is concurrently adopted in the estimation method as a baseline. The SVM needs the parameters: Voltage, Temperature and Current. The simulation results are presented in figures. The estimation error using the above method is also given, as shown in Figure 8.

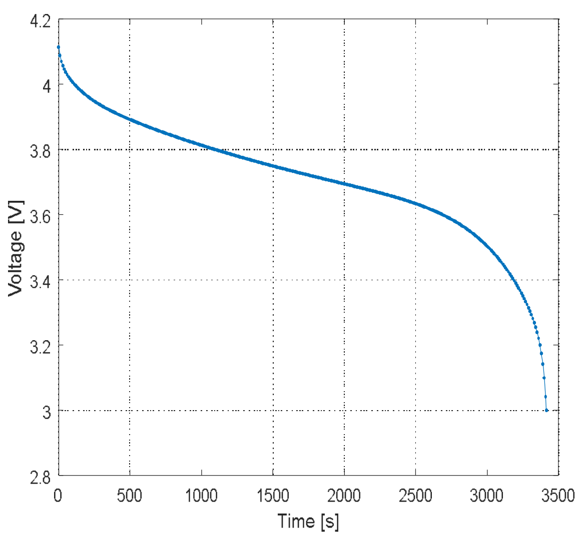

Fig 3: Time vs voltage

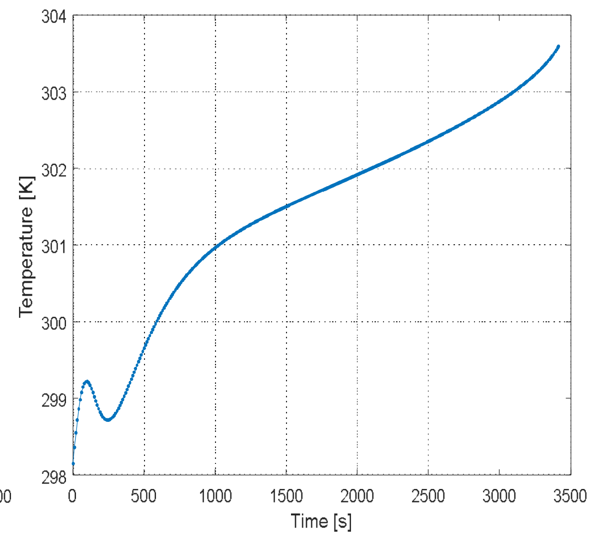

Fig 4: Time vs temperature

Time vs voltage graph Fig 3 demonstrates that consumption of battery voltage goes on decreasing with respect to time span, which is decrement in voltage. This graph is a constant load graph and shows that decreasing the voltage from 4.2V to 3V within 3500 seconds. The optimum voltage range of operation can be decided by the responding graph. The linearity of a voltage observed after 3.6V and further sudden decrement observed in voltage is battery capacity in terms of SoC goes beyond the limit and hence the consumption after 3.6V will stop. According to this graph, the voltage always decreases suddenly. That is the synthesis of battery activity, so that the battery is discharged at a specific limit and then the battery is charged again. It's really similar since mobile phones have a 0 percent battery, but the voltage is not going to be zero, practically. At certain limits it will be stated, e.g. 0V will be considered at 3.6V. This is a complete draining problem in that after the battery is to be recharged, the battery response stops of the linear decrement.

Fig 4 validates the graph of time vs temperature. Initially battery current sucks the maximum load so that initially current boost. For that current, the temperature deficition will be maximum. At the initial stage within 100sec, temperature will increase from 298K to quietly above 299K. As time passes, it will decrease and again it increases suddenly. It goes linearly increment because those after current are in steady state, since load is steady state. Still there is a need of cooling concern. Cooling can take care of increment in temperature but it cannot hold the temperature. Therefore, this graph concludes temperature increases from 300K to 304K in linear manner, which is a very slight change. This range of temperature is the accepted level of temperature of the battery.

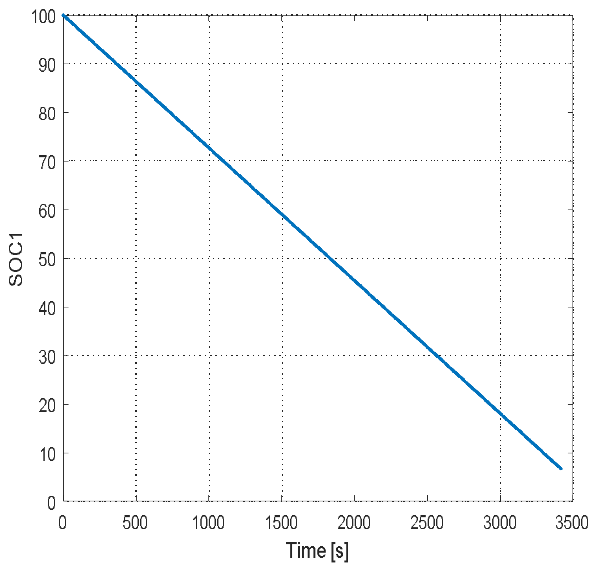

Fig 5: Time vs SoC1

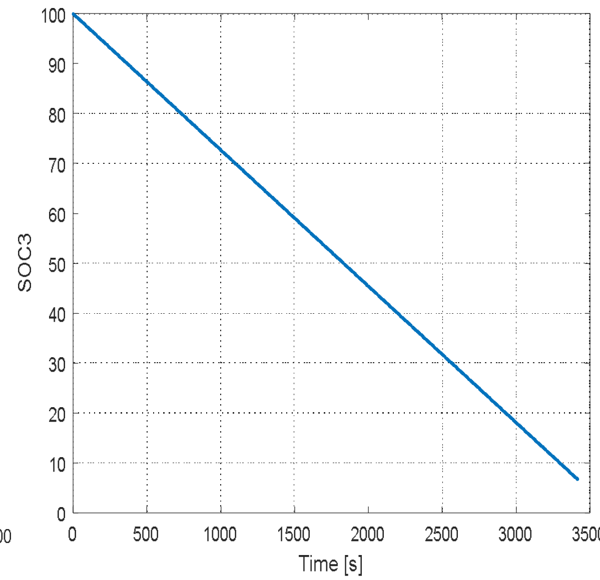

Fig 6: Time vs SoC3

Fig 5 and 6 represents the graph of time vs SoC1 and SoC3. Here, SoC1 is the anode, while the cathode is SoC. Now, 4.2V observed in the case of 100% and compared to the voltage graph, indicates that SoC is 100%. Within the time-span, it will go up to zero. Zero is considered within the same time at 3.3V from the voltage graph so that linear decrement SoC can be sent at constant load. The predicted SoC is this SoC.

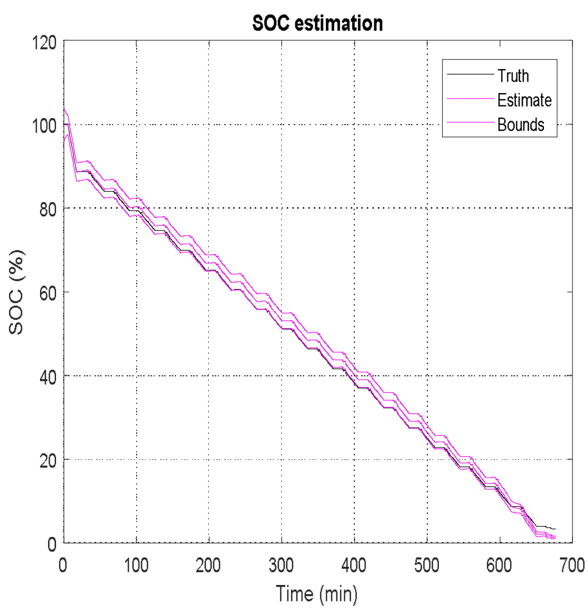

Fig 7: SoC estimation

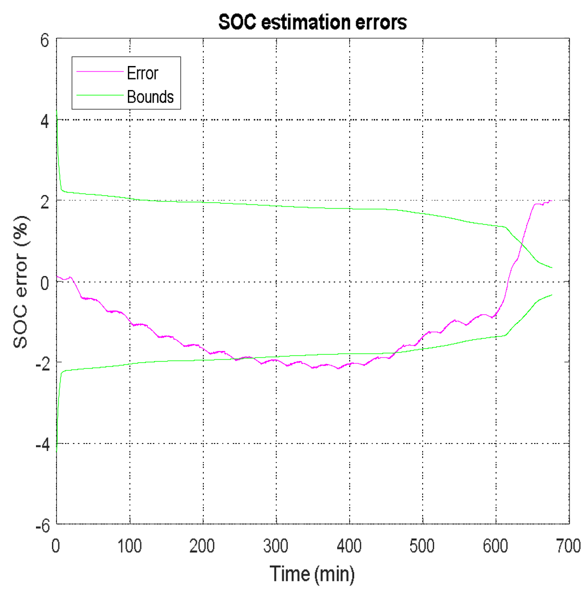

Fig 8: SoC estimation errors

Fig 7 demonstrates the graph of SoC estimation. The graph is time (min) vs SoC (%). The graph is a linearly decreasing slope of SoC; i.e. when time increasing the SOC will be decreasing. If the time is 300 that time, SOC is between 40 to 60% i.e. above the 50%. However, current increases, it will estimate the SoC with lifetime will be decreased.

SVM regression analysis also shows a similar kind of predicted SOC in which SOC predicted with respect to battery condition. Bound graphs are also plotted, i.e. actual calculated SOC and estimated SOC that plot this graph and are agreed near the real one.

Fig 8 demonstrates the graph of SoC estimation errors. The graph is time (min) vs SoC error (%). The graph says errors in the SoC prediction. Error is almost linearly equal to zero. It is level crossing bounding boxes. The error line is between -2 to +2 in %; i.e. ±2% tolerance is acceptable. The error line deviates above and below zero.

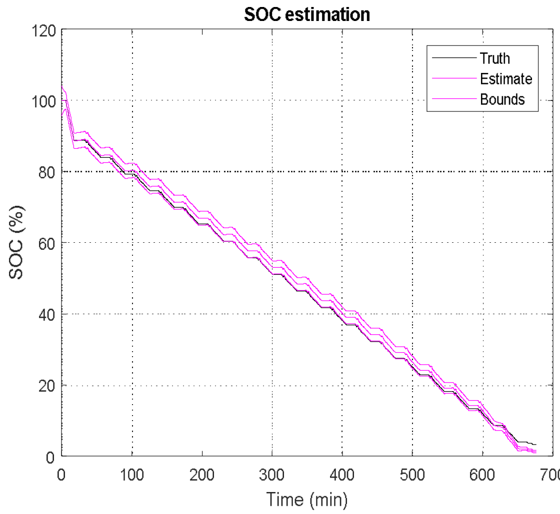

Fig 9: SoC estimation

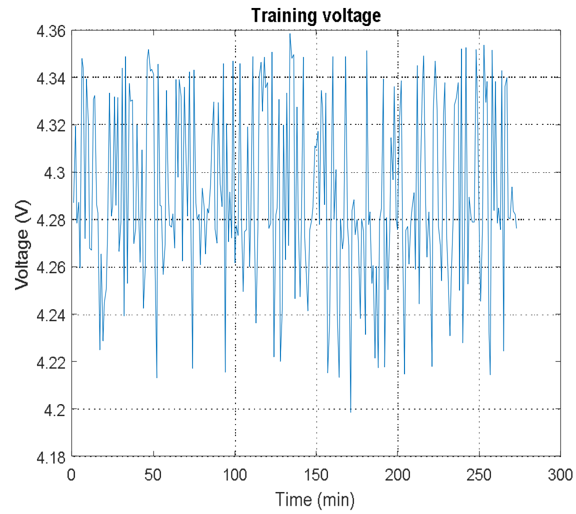

Fig 10: Training voltage

Fig 9 represents the graph of SoC estimation. The graph is SoC (%) vs time (min). The graph is a linearly decreasing slope of SoC; i.e. when time increases, the SoC will be decreasing. If the time is 300 that time, SoC is between 40 to 60% i.e. 50%. Though current increases, it will estimate the SoC. Lifetime, however, would decrease, i.e. 650. The shift in power is responsible for reducing the life of the battery. Reduce SoC in a fast way. If the current rises, the lifespan will be reduced.

SVM regression analysis also shows a similar kind of predicted SoC in which SoC is predicted with respect to battery condition. Bound graphs are also plot i.e. actual measured SoC and predicted SoC that are plotting this graph and near to the actual are accepted.

Fig 10 represents the graph of training voltage. The voltage should never be constant, high or low. It is a type of equation for inductive voltage. In the graph, voltage is used for SVM training. Large randomness in voltage is well predicted in such instances by SOC.

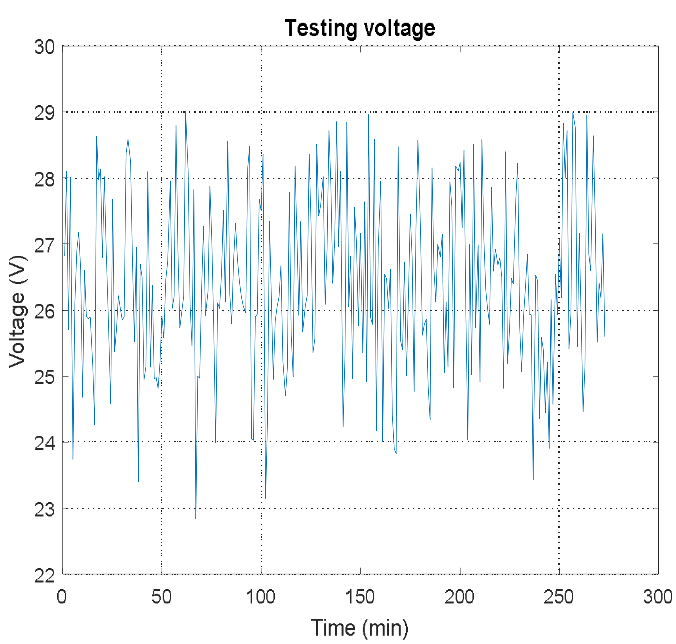

Fig 11: Testing voltage

Fig 11 represents the graph of testing voltage. The voltage should never be constant, high or low. It is a type of equation for inductive voltage. In the graph, what voltage is used for SVM training is plotted. Large randomness in voltage is well predicted in such instances by SOC. Both plots appeared in similar passion.

IV. CONCLUSION

Determining the SoC is principally significant for EV or portable devices. A battery is a nonlinear system. It is difficult to ascertain the correlation between the SoC and measurable battery parameters. This project represents a technique for estimating the battery SoC using the SVM. A novel battery modelling loom is projected to explicitly predict the battery performance. We gather the sample data, together with training data and test data. In sample data, the battery temperature and voltage are used as input variables to the SVM model and SoC as the output variable. The key intention of this project work was to formulate a SoC predictive model using the SVM. By using the characteristics data of the battery, train the Particle Swarm Optimized Support Vector Machine.

By using the Extended Kalman Filter method, the battery model will be simulated for SoC prediction. Briefly first take the battery model, second simulation and finally data will be generated. The simulated data is used for training of the SVM. Then SVM is used for prediction of SoC. Our results illustrate that the SVM is more precise in estimating the battery SoC. The developed model is able to predict the SoC quickly and fairly accurately using the right training data and propel kernel functions.

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