Li-Ion Battery Pack Testing By using Artificial Neural Network

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***Abstract*—Industry 4.0 refers to a new kind of Industrial Revolution that mainly concentrates on internet of things (IOT), automation, machine learning, cloud computing and real-time data analysis. In industry 4.0 several machines create a huge amount of data like testing equipment's, sensors, manufacturing equipment's. By using big data analysis methods and machine learning techniques we can analyze and predict the performance**

In this paper, we collect data from the li-ion battery pack testing equipment. This equipment collects a different type of data from battery pack. By using big data analysis, we are analyzing the performance of batch of battery packs and by using artificial neural network (ANN) we are predicting the battery pack is pass or fail. And finally, we compared ANN with different machine learning models. ANN gave good results with compare other models. This prediction results helps to reduce one step testing results in battery pack manufacturing process.

***Keywords*—Big data analysis, Li-ion battery pack, Artificial neural networks, Decision tree.**

I. INTRODUCTION

From the past ten years, global climate changed and the greenhouse effect have bring about more impact on the Earth's environment, which has inspirited and moved the research and development of the storage systems and energy sources universally. Among the several energy storage devices, the Li-ion battery has been obtain universally implemented in electronic products and considered as the main energy source for electric vehicles and other applications [1]. Compared to others such as lead-acid and Ni-H batteries, the Li-ion battery is the better energy storage device due to its higher energy density, higher power density, longer cycle life, and lower self-discharge rate. The Li-ion battery usage is the increasing quickly and most widely used battery in consumer low-power applications and high-power applications. In the low power field on applications, such as mobile phones, cameras, laptops and other electronics and in high-power applications like as electric vehicles (EV), e-bikes, drones and other applications.

Even the electrical execution of Li-ion batteries, such as energy density and capacity rate is raised importantly [2]. Different shapes of lithium-ion batteries (LIB) are energy storages for the different applications. The different shapes can be divided into cylindrical shape, prismatic and pouch. The manufacturing process of li-ion cells discussed. Li-ion battery packs are frequently designed and manufactured as the cells connected into module and modules connected as a pack. The actual design of pack is mainly in how the required pack capacity and power is achieved [3]. Battery packs used for electric mobility applications consist of a large number of single individual battery cells are interconnected as a pack. The connection type may single battery cells connected as series and parallel [4].

II. JS POWER PACK MANUFACTURING PROCESS

Js power is the Taiwan's li-ion battery pack manufacturing company. Their main products are the battery packs for different applications. The battery packs for robots, drone, UPS, 5G telecom towers, automated agricultural machinery, wearable devices, e bikes and power banks. the manufacturing of battery pack in js power is discussed in below Fig: [1].

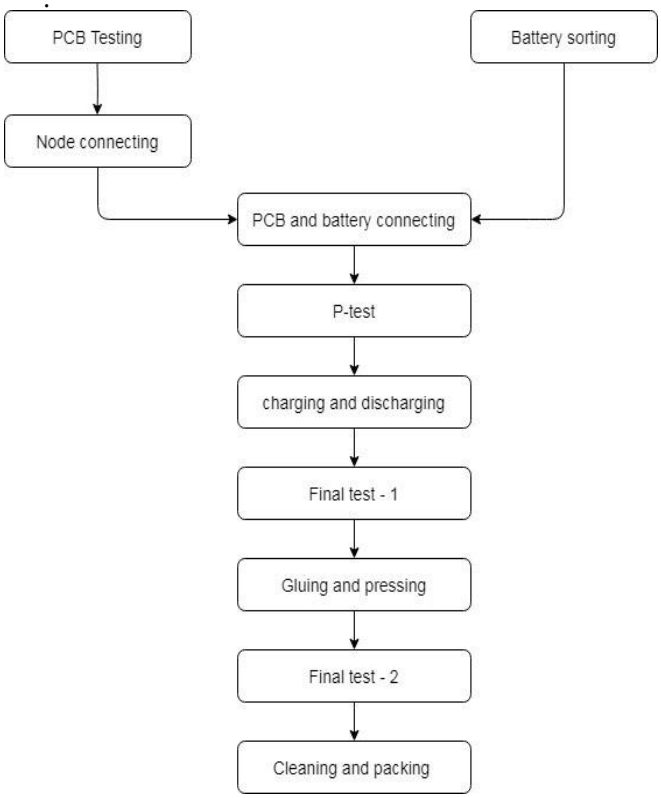

Fig:1 Manufacturing process of li-ion battery pack at js power.

Battery packs will manufacture depending on customer specifications. The Cell sorting is a process of identifying and grouping the cells with similar parameters and characteristics so that they have similar performance

during operation cycles. Cell sorting is the most critical step to assure safety of the battery pack. In PCB (printed circuit board) testing will check the parameters over charging protection, over discharging protection, over current protection, under current protection and short circuit protection will check the PCB. After PCB will go to wire (cathode, anode) connection. This process batteries will connect to the series or parallel depending on pack requirement. The batteries will connect through spot welding process. After connecting batteries PCB boards will connect through soldering. In the p-test we will check the main parameters of the battery like voltage, internal resistance, charging current, charging voltage. In this process battery packs will charge and discharge to see the performance. Charging/discharging (cyclic process) strategy will successfully checks the occurrence of irregularities such as over charge, over-heating and over-discharging. In our research we are collecting the parameters from the final test1 and 2 same tests will do two times. Between test 1 and test 2 will cover the battery pack by using glove and pressing.

In the final test 1 and 2 will do the depending on customer requirement. The customer will give some specifications to depending on their application. In final test will check the main parameters voltage of pack, voltage of each cell, voltage difference between each cell, Current, full charge capacity, charging voltage, full charging capacity. In this final testing stage we are collecting data of final testing results of battery packs.by using the decision tree and artificial neural networks we are predicting the battery pack is pass or fail depending on the final pack testing speciation parameters. Decision tree method used for the classification system based on multiple covariates or for improving prediction techniques for a target variable based. Tree method classifies a population into a branch-like segments that construct an inverted tree with root node, decision nodes, and terminal node or leaf nodes [5]. and we are using artificial neural networks to predict the output. A neural network is a system is designed to operate like a human brain it analyzes and processes instruction. ANN has the self-learning ability that enable them to make better results as more data becomes available [6]. ANN is using widely in different applications Optimization and Classification, Modeling and Identification, Process Control, pattern recognition [6][7]. Decision tree and ANN is explained in next section and finally we discuss about results and comparison with other models.

III. METHODOLOGY

In this section we are discussing about data collection and methods using. Data collected from the final testing station and discussing about decision tress and ANN. In the final testing station, we collected 100 packs data for sample.in this data is different parameters of the battery. The parameters are the pack voltage, each cell voltage, each cell voltage difference, fully charge capacity, and final test result pass or fail. Each cell voltage is in pack we will connect two or many numbers of cells depending on customers requirement. So, we are collecting each cell voltage also. And each cell voltage difference is we need to maintain cell difference properly. If the cell difference is more battery pack will cause the cell balancing problem. If inside pack cells will not maintain proper balance. automatically cause the performance of the battery pack. As per the industrial team in js power maintaining under 10 millivolts difference. If cell difference is more than 10 millivolt difference pack is failed. We collected 100 packs parameters data each data has we will maintain minimum range and maximum range. If the battery pack parameters exceed that range that pack is fail. The minimum and maximum ranges will change depending on application or customer. We are using decision tree and ANN to predict the results depending on parameters.

A. Decision tree

Decision tree is the one of the mostly using predictive model for the data mining and machine learning techniques. Decision tree is a decision-making strategy using for both classification and regression. The structure of the decision tree is like a tree structure shown in fig 2. classification tree is the target the data classify different types. regression tree represents if the data is same manner, they predict the continuous data values. Decision tree is capable to handle multiple output problems. Root node is splits data into two or more sets depending on attribute. Attribute selection is depending on the attribute selection method (ASM).ASM is the method is used for data reduction. There are two main ASM techniques Gini index and information gain. Branch or subtree is entire part or side of the decision tree. The splitting of the tree nodes into sub nodes depend on the if-else conditions. After root node is splits into sub nodes the sub node will slits more further nodes is called the decision node. Leaf or terminal node indicates the end of the decision tree. The terminal node cannot split into other nodes. Pruning is the technique removing sub nodes from the tree. There are different types of pruning techniques like Critical Value Pruning, Reduced Error Pruning, Minimum error pruning, Cost Complexity Pruning (CCP), Pessimistic Error Pruning (PEP), Error Based Pruning (EBP) detailed explained in [8].

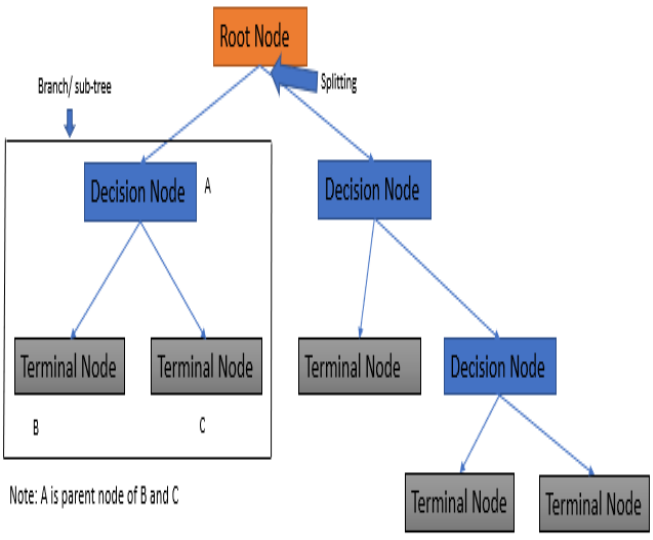

Fig:2 Basic architecture of Decision tree

For simulation we are using orange machine learning and big data mining open-source toolkit. csv file is imported in orange software and selected target as the results after we trained the model by using decision tree. Training data results is shown in the results section. Once after training we given

parameters testing file without results column ok or fail data. We select target as the results. After we added prediction widget to predict the test results. We got results but some battery packs it is showing wrong data. Results is discussed in results section. So, we are trying to implement the ANN to get better prediction results.

B. Artificial Neural Network (ANN):

Next, we are predicting the pack test result (ok or fail) depending on the cell parameters. ANN is using to predict the test result. Basic architecture of ANN is shown fig.5[9]. ANN is layer structure each layer has number of nodes each node is connected with other nodes. Each node has some weight transfer function is used for the calculate weighted sum of the inputs and the bias. Different layers are the input layer and layer between the input layer and output layer is called hidden layer and final layer is called output layer. In the input layer as the first layer of an ANN that receives the input information as various forms like text, image pixels, audio etc. In hidden layer is one or more hidden layers depending on the application. In this layer only performs different mathematical calculations. Output layer is connected with hidden layer gives the results from the hidden layer or input layer. Neural network will work on the train and test flow. our neural network we need to train some examples which contains as known input and output this data is stored in the net itself. In testing phase just give input, output will predict the neural network.

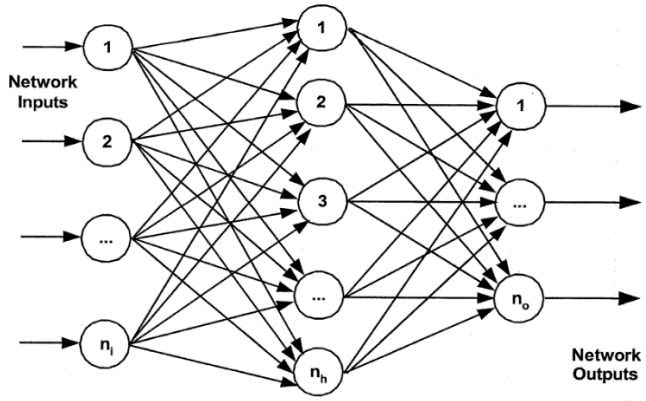

Fig:3 Basic architecture of ANN

In the neural network activation functions playing important role. The activation function role is node should be activated or not. There are different types of activation functions in hidden layers linear activation function, non-linear activation function, binary step function.The modern neural networks are mostly using the nonlinear activation functions because it creates complex model between input and output layers. nonlinear activation functions are the sigmoid, hyperbolic tangent(tanH), ReLU (rectifier linear unit), SoftMax [10]. There are various types of neural networks feed forward neural network, recurrent neural networks (RNN) and convolutional neural network (CNN) briefly discussed in [11].

We import data from the final pack chitai testing equipment. Firstly, we train our neural network with our old input and output results data. 85 percentage data we are training and 15 percent data is used for testing. Testing data is we give input parameters are pack voltage, cell1 voltage, cell2 voltage, difference between cell 1 and 2, and fully charge current and the output of the neural network is battery pack is ok or fail. The results of ANN is discussed below section.

IV. RESULTS

The ANN model got the good results to predicting battery pack is ok or fail depending on the customer requirement. In this experiment we are using two hidden layers. Results are discussed in Fig:4 by using ReLU activation function and 60 number of hidden neurons in each layer we got 93.8 % classification accuracy (CA) results in while testing. In 100 hidden neurons in ReLU function got 93.8 % CA. In 150 neurons each hidden layers we got same CA. In 200 hidden neurons also we got 100 % CA. The results with compare with tanh activation function in Fig:5 ReLU function getting good accuracy compare with tanh. So, in this model we used ReLU activation function with two hidden layers and each layer has 200 neurons.

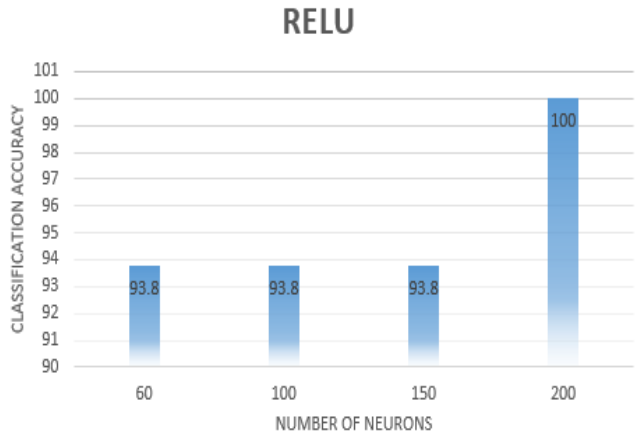

Fig:4 Result of classification accuracy at different hidden neurons in Relu.

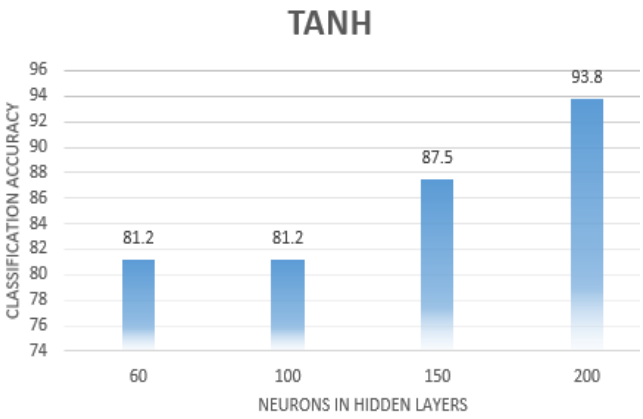

Fig: 5 Result of classification accuracy at different hidden neurons in Tanh.

Results compared with other models

The ANN results are compared with different models' decision tree and logistic regression models Fig:6. ANN model with 200 neurons Relu function getting best results. The final output of battery pack prediction ok or fail also ANN is showing best result compared to the decision tree. Final test pass or fail prediction results of pack is shown

in table:1 ANN got best prediction results compare with other models.

Model	AUC	CA	F1	Precision	Recall
Neural Network	1.000	1.000	1.000	1.000	1.000
Tree	0.750	0.875	0.859	0.893	0.875
Logistic Regression	0.500	0.812	0.767	0.850	0.812

Fig: 6 Results of different models.

	Neural Network	Tree	Logistic Regression	test result
1	0.00 : 1.00 → OK	0.03 : 0.97 → OK	0.04 : 0.96 → OK	OK
2	0.00 : 1.00 → OK	0.03 : 0.97 → OK	0.07 : 0.93 → OK	OK
3	0.00 : 1.00 → OK	0.03 : 0.97 → OK	0.02 : 0.98 → OK	OK
4	0.00 : 1.00 → OK	0.03 : 0.97 → OK	0.06 : 0.94 → OK	OK
5	0.00 : 1.00 → OK	0.03 : 0.97 → OK	0.04 : 0.96 → OK	OK
6	0.99 : 0.01 → FAIL	0.03 : 0.97 → OK	0.02 : 0.98 → OK	FAIL
7	0.00 : 1.00 → OK	0.03 : 0.97 → OK	0.02 : 0.98 → OK	OK
8	1.00 : 0.00 → FAIL	0.03 : 0.97 → OK	0.00 : 1.00 → OK	FAIL
9	0.00 : 1.00 → OK	0.03 : 0.97 → OK	0.05 : 0.95 → OK	OK
10	1.00 : 0.00 → FAIL	1.00 : 0.00 → FAIL	0.48 : 0.52 → OK	FAIL
11	0.00 : 1.00 → OK	0.03 : 0.97 → OK	0.07 : 0.93 → OK	OK
12	0.00 : 1.00 → OK	0.03 : 0.97 → OK	0.08 : 0.92 → OK	OK
13	0.00 : 1.00 → OK	0.03 : 0.97 → OK	0.05 : 0.95 → OK	OK
14	1.00 : 0.00 → FAIL	1.00 : 0.00 → FAIL	1.00 : 0.00 → FAIL	FAIL
15	0.00 : 1.00 → OK	0.03 : 0.97 → OK	0.08 : 0.92 → OK	OK

Table: 1 Final pack prediction result

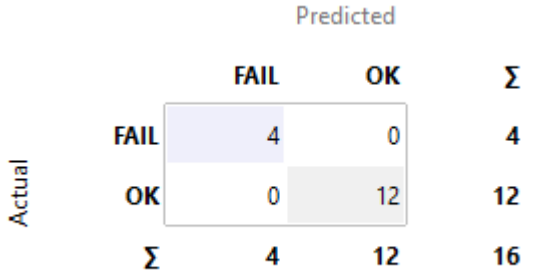

Fig:6 confusion matrix results

The above figure we can observe the pack each cell difference is more than 10 mv pack is fail still decision tree is showing pack is pass and ANN is showing correct results and got good results confusion matrix results is shown in fig:6

V. CONCLUSION

In this research ANN is using li-ion battery pack test station to predict the output of pack is ok or fail depending on customer requirement. ANN model is giving best results to compare tree and logistic regression.

FUTURE WORK

Depending on this research results we are trying to implementing ANN at the charging/discharging station (cyclic process). Our future work is trying to predicting the final test 1 results at charging/discharging station itself. By this research we can skip the final test-1 station. No need testing at the final test 1. Directly we can continue to the gluing and pressing process.

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