

## PROJECT COMPLETION REPORT

- Notes:
1. The PCR should be in bound form.
  2. Cover page should include the title of the project, file number, names and addresses of the investigation.

1. Title of the project: Machine-Learning based Battery Cell Balancing Mechanism for Two-Wheeled Electric Bikes for Improving Lifespan of Battery Pack
2. Principal Investigator(s) and Co-Investigator(s): Prof. ( Dr.) Asim Datta, Tezpur University and Dr. Manashita Borah, Tezpur University
3. Implementing Institution(s) and other collaborating Institution(s): Tezpur University , Assam and Agni Green Power Limited-Kolkata
4. Date of commencement: 22/11/2024
5. Planned date of completion: 31/12/2025
6. Actual date of completion: 31/03/2026
7. Objectives as stated in the project proposal:

- To design an intelligent cell balancing technique for Li-Ion battery pack in a two wheeled electric vehicle.
- To develop the framework of above by integrating machine learning with passive cell balancing technique.
- To test and validate the technique of intelligent cell balancing.

8. Deviation made from original objectives if any, while implementing the project and reasons thereof: No major deviation
9. Experimental work giving full details of experimental set up, methods adopted, data collected supported by necessary table, charts, diagrams & photographs:

### 9.1 Experimental Setup

The experimental setup was designed to implement and validate a machine learning-based passive cell balancing system. A Raspberry Pi 5 was used as the central controller. Voltage and current measurements were obtained using ADS1115 (ADC) and INA219 sensors, respectively, via the I2C communication protocol.

The balancing circuit consisted of IRLZ44N MOSFETs driven by an IR4427 driver, along with resistors for passive

discharge. A regulated 12V power supply was used to operate the system. This setup enabled real-time monitoring and control of individual battery cells.

## 9.2 Methods Adopted

The methodology involved both data-driven modelling and hardware implementation:

- Battery parameters (voltage, current, temperature, SoC) were collected over multiple charge–discharge cycles.
- Data pre-processing included noise removal, normalization, and time-series segmentation.
- A Bi-LSTM model was trained to predict voltage drift.
- The trained model was integrated with the hardware system for real-time operation.
- When imbalance exceeded a threshold, the controller activated MOSFETs to discharge the higher-charged cell.

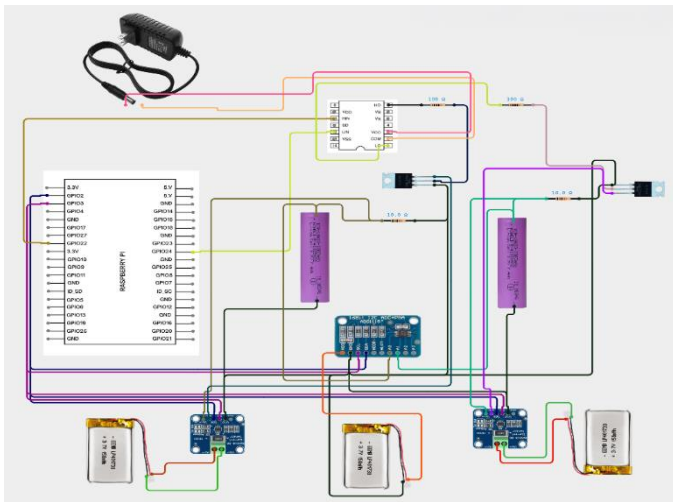


Fig.1. Circuit diagram of the proposed cell balancing system

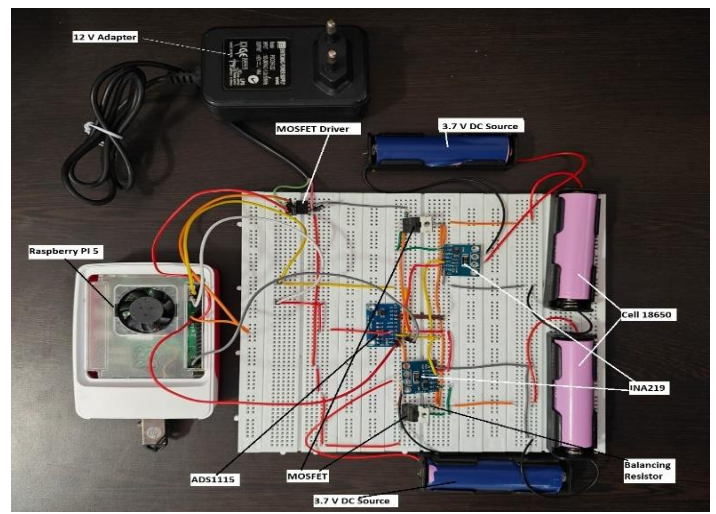


Fig. 2. Hardware implementation of the proposed cell balancing system

Fig. 1 illustrates the circuit diagram of the machine learning-based passive cell balancing system. The Raspberry Pi acts as the central controller and communicates with sensors such as INA219 (current sensor) and ADS1115 (ADC for voltage measurement) using the I2C protocol.

Each lithium-ion cell is monitored individually for voltage and current. Based on this data, the controller estimates the State of Charge (SoC) and detects any imbalance between cells.

The IR4427 MOSFET driver receives control signals from the Raspberry Pi and drives the MOSFETs accordingly. When imbalance exceeds a predefined threshold, the MOSFET connects the higher-charged cell to a balancing resistor, allowing excess energy to dissipate as heat.

Fig. 2 shows the practical hardware implementation of the proposed system on a breadboard. The setup includes a Raspberry Pi 5, INA219 sensors, ADS1115 module, MOSFET driver, MOSFETs, balancing resistors, and 18650 lithium-ion cells.

All components are interconnected using jumper wires, with communication established through the I2C interface. A 12V adapter powers the control circuitry, while the battery cells act as the energy source.

During operation, real-time data is collected from sensors and processed by the Raspberry Pi. Based on the predicted imbalance, the system activates the MOSFETs to discharge the higher-charged cell.

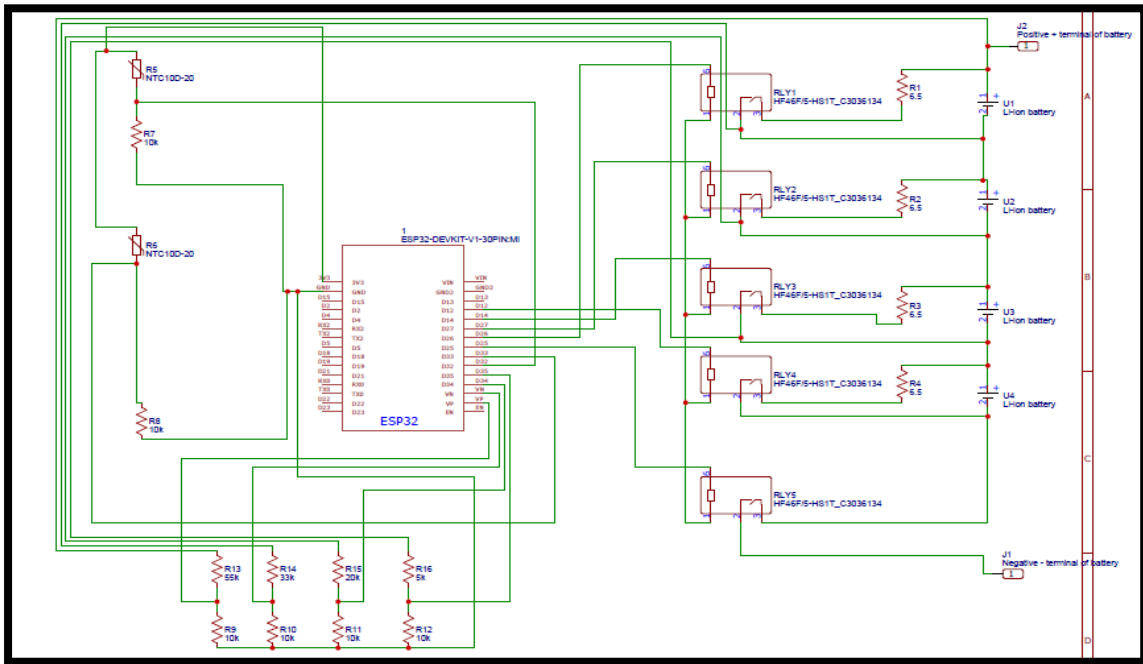


Fig. 3. Circuit diagram of Passive cell balancing system

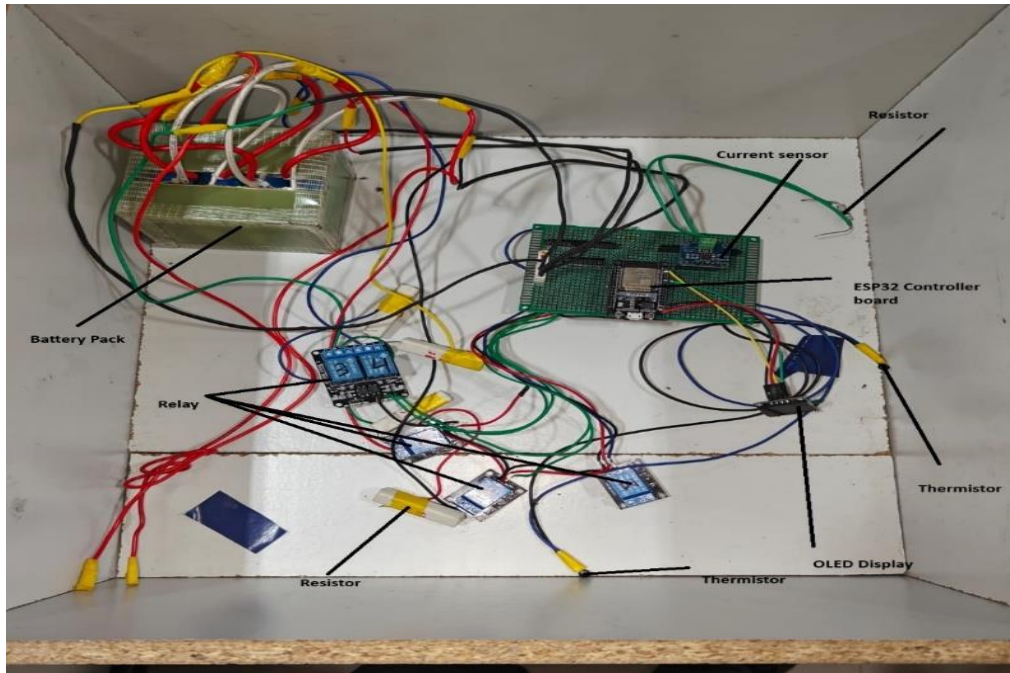


Fig. 4. Hardware Implementation of Passive cell balancing system

This figure demonstrates the real-time working prototype, validating the feasibility of the proposed low-cost and intelligent battery management system.

Fig. 3 shows the circuit diagram of the ESP32-based battery management and cell balancing system. The ESP32

controller is the central unit that monitors and controls multiple lithium-ion cells.

Each cell is connected through relay switches, which are used to control charging and discharging paths. Balancing resistors are connected across the cells to safely dissipate excess energy during imbalance conditions.

The circuit also includes thermistors for temperature monitoring and a current sensor for measuring real-time current flow. The ESP32 collects all sensor data and processes it to decide when to activate relays for balancing.

Fig. 4 shows the actual hardware setup of the proposed system. It includes an ESP32 controller board, battery pack, relay modules, current sensor, thermistors, resistors, and an OLED display.

The battery pack consists of multiple lithium-ion cells connected together. The relay modules control individual cells by switching resistive loads for balancing. The current sensor measures current, while thermistors monitor temperature to prevent overheating.

The OLED display provides real-time information such as voltage, current, and temperature. All components are connected using wires on a prototyping board.

### 9.4 Results and Analysis

The performance of the system was evaluated using graphical and statistical analysis:

- Training & Validation MAE vs Epochs: Shows continuous reduction, indicating effective learning.
- Training & Validation Loss Curves: Demonstrates stable convergence and minimal overfitting.
- Voltage Drift vs Time Plots: Illustrates battery behaviour under different temperatures.
- Actual vs Predicted Comparison: Confirms high accuracy of the Bi-LSTM model.

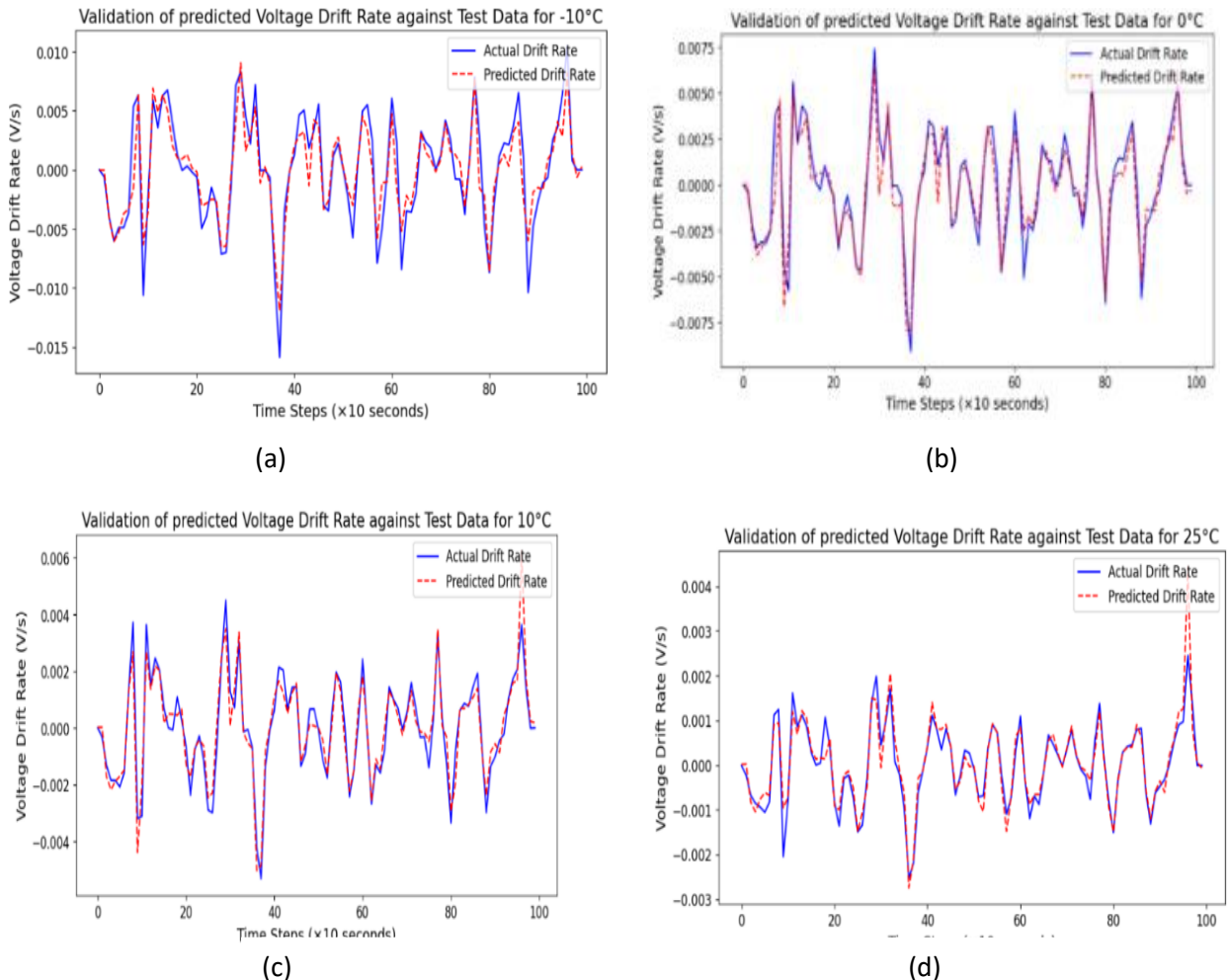


Fig.5. Validation and testing of predicted voltage drift rate using LSTM using experimental testing dataset at (a) -10°C, (b) 0°C, (c) 10°C, and (d) 25°C.

In Fig. 5(a), the model effectively follows sudden spikes and steep variations, showing high accuracy even during highly volatile regions. Fig. 5(b) highlights the model's ability to capture early transient behavior and high-frequency oscillations with minimal lag. In Fig. 5(c), the model successfully tracks peaks, troughs, and overall trends, though slight underestimation is observed at extreme values. Fig. 5(d) shows near-perfect phase synchronization with minor amplitude damping, indicating stable and consistent performance under normal conditions.

Fig. 6 shows that the trend is decreasing can be seen from the bar chart of the model's average prediction error for various temperatures: -10°C, 0°C, 10°C, and 25°C. The highest error is at -10°C with 0.000419 then the error goes down as temperature increases. The lowest error is at 25°C with 0.000129 it can be observed that the model's predictions improve at higher temperatures.

At the high temperature (25°C), the training set distribution results in improved ability to adapt and at the low temperature (-10°C) the measurement system and sensors are less precise or noisy at the end conditions resulting in the increased prediction error.

The model is forecasting decent accuracy, particularly at moderate and warm conditions that imply the model can generalize to a very large number of input conditions. The best performance of our model is at 25°C representing the most stable system dynamics while it performs poorly at -10°C showing absence of extrapolation to cold, noisy, and non-linear conditions.

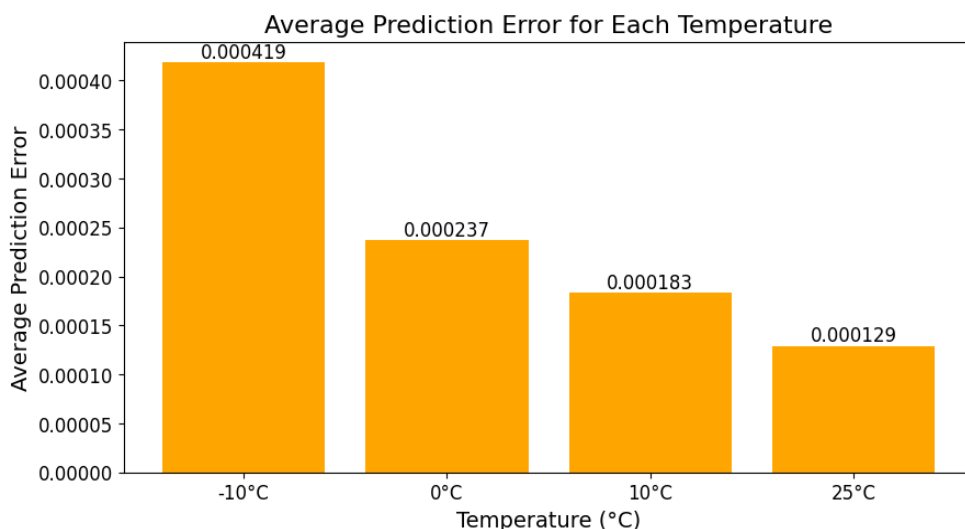


Fig. 6. Average prediction error for four different temperatures

Table 1

Model Performance Metrics (MAE, RMSE and R<sup>2</sup> Score) for training and four different

Dataset	MAE	RMSE	R <sup>2</sup> Score
<b>Training</b>	0.000118	0.000426	0.940533
<b>-10°C</b>	0.000419	0.001033	0.907527
<b>0°C</b>	0.000237	0.000622	0.928684
<b>10°C</b>	0.000183	0.000467	0.941455
<b>25°C</b>	0.000129	0.000324	0.941994

### 1) Trends in MAE

The training MAE is 0.000118, showing that the model fits the training data exceptionally well and serves as a reliable baseline. All testing MAEs are higher than the training MAE, which is both expected and normal,

meaning that the model generalizes effectively. At  $-10^{\circ}\text{C}$ , the MAE is the highest among all testing sets in Table 1, showing that the model's performance is suboptimal at this temperature. The remaining trends follow a similar pattern.

## 2) Trends in RMSE

The training RMSE is 0.000426, showing that the model fits the training data exceptionally well. However, all testing RMSE values are higher than the training RMSE, meaning that the model's performance is slightly suboptimal on unseen data. At  $-10^{\circ}\text{C}$ , the RMSE is 0.001033 in Table 1, showing that the model's performance is less than ideal. The remaining trends follow a similar pattern.

## 3) Trends in $R^2$ score

The training  $R^2$  score is 0.940533, showing the proportion of variance in the target variable explained by the model. The testing  $R^2$  scores are either close to or slightly higher/lower than the training score, meaning strong ability to adapt. At  $-10^{\circ}\text{C}$ , the  $R^2$  score is 0.907527 in Table 1, showing the model performs weakest at this temperature. The remaining trends follow a similar pattern.

## 10. Detailed analysis of results indicating contributions made towards increasing the state of knowledge in the subject:

- The Bi-LSTM model achieved high prediction accuracy with low MAE and  $R^2$  greater than 0.94, demonstrating strong capability in capturing nonlinear battery behaviour.
- The small difference between training and validation errors indicates good generalization and minimal overfitting, ensuring reliable real-time performance.
- Validation across a wide temperature range ( $-10^{\circ}\text{C}$  to  $25^{\circ}\text{C}$ ) confirms model robustness under varying environmental conditions, with only slight degradation at low temperatures.
- The work introduces a pre-emptive (predictive) cell balancing approach, shifting from conventional reactive methods to intelligent, data-driven control.
- Predictive balancing reduces unnecessary energy dissipation in passive systems, thereby improving overall energy efficiency.
- The Bi-LSTM model effectively captures temporal dependencies (past and future), enhancing voltage drift prediction compared to traditional LSTM models.
- The hybrid use of Coulomb counting and OCV methods improves the accuracy and reliability of state-of-charge estimation.
- Successful integration with Raspberry Pi, INA219, ADS1115, and MOSFET-based circuitry demonstrates real-time hardware feasibility.
- The system provides a low-cost and scalable solution suitable for two-wheeler electric vehicle applications.

## 11. Conclusions summarizing the achievements and indication of scope for future work:

- The project successfully developed an intelligent battery cell balancing system.
- The use of Bi-LSTM helped in predicting voltage drift early, making the balancing process smarter and more efficient.
- The system reduced energy loss and can help in increasing battery life and safety.
- It performed well under different temperature conditions, showing reliability in real-world situations.
- Combining Coulomb counting and OCV methods improved the accuracy of battery monitoring.

### Scope for Future Work:

- Use more advanced AI models for better prediction.
- Explore active balancing for higher efficiency.
- Add features like battery health (SoH) prediction and remote monitoring.

12. TRL Level: 4

13. Technologies developed as part of the project:

- A smart system that helps balance battery cells more intelligently.
- A Bi-LSTM prediction model that can detect voltage imbalance before it actually becomes a problem.
- A predictive balancing method that works in advance instead of reacting late, improving efficiency.
- A more reliable way to track battery charge using a combination of Coulomb counting and OCV methods.
- A working real-time prototype using Raspberry Pi, showing practical implementation.
- A simple but effective sensor setup to measure voltage and current accurately.
- A MOSFET-based balancing circuit to safely discharge extra energy from cells.

14. Status of translation readiness, along with any areas where assistance with translation may be required ( if applicable)

- The developed technology has reached a prototype validation stage, with successful testing.
- The system is partially ready for real-world application, especially for small-scale or controlled EV environments.

15. Table of Proposed outcomes Vs Achieved outcomes

Proposed Outcomes	Achieved Outcomes
Development of intelligent cell balancing technique for Li-ion battery pack	Successfully developed intelligent cell balancing system
Integration of machine learning with passive balancing method	Implemented Bi-LSTM based predictive model integrated with passive balancing hardware
Prediction of battery behaviour (voltage/SoC)	Achieved prediction accuracy upto ( $R^2 > 0.94$ ) for voltage drift and reliable SoC estimation
Validation under different operating conditions	Tested and validated across multiple temperature conditions (-10°C to 25°C)

16. S&T benefits accrued:

a. List of Research publications

S No	Authors	Title of paper	Name of the Journal	Volume	Pages	Year
1	Pranjal Ozah, Rajarshi Dutta, Jyotishmoy Deka, Ajoy Chetry, Pallab Jyoti Malakar, Manashita Borah, Asim Datta	Bi-LSTM Based Data-Driven Predictive Voltage Drift Modelling for Lithium-Ion Battery Cells for EV Applications under Different Temperature Conditions	Next Energy ( Elsevier)	Submitted		2026 ( Submitted)

Conference publications:

- i. C. Dutta, A. Dowerah, P. Ozah, and A. Datta. "Study and Analysis on a Solar PV-integrated Power Electronics Converter System for EV Battery charging." in 2025 IEEE Guwahati Subsection Conference (GCON), pp. 1-6. IEEE, 2025.
- ii. Rakesh, Sanjoy Debbarma, and Asim Datta "Optimal Integration of EV Charging Loads in the IEEE 9-Bus System for Improved Grid Performance " in the 2026 IEEE North-East India International Energy Conversion Conference and Exhibition, Sohra, Meghalaya, to be held during June 12 – 14, 2026. (Accepted)

b. Manpower trained on the project

i. Research Scientists or Research Associates – Pranjal Ozah (Project Associate)

ii. No. of Ph.D/MS produced ( one ongoing)

iii. Other Technical Personnel trained. 6 Nos.(B.Tech. students )

c. Patents filed, if any

17. Financial Position:

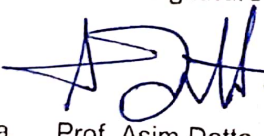
No	Financial Position/ Budget Head	Funds Sanctioned (Rs.)	Expenditure (Rs.)	% of Total cost
I	Salaries/ Manpower costs	350,000/-	3,49,161/-	34.95
II	Equipment	100,000/-	99,972/-	10.01
III	Supplies & Materials	200,000/-	1,99,964/-	20.01
IV	Contingencies	200,000/-	2,00,000/-	20.02
V	Travel	150,000/-	1,49,999/-	15.01
VI	Overhead Expenses	-	-	
VII	Others, if any	-	-	
	Total	10,00,000/-	9,99,096/-	100%

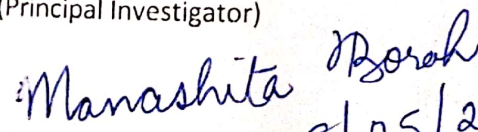
18. Procurement/ Usage of Equipment)

S No	Name of Equipment	Make/Mo del	Cost (FE/ Rs)	Date of Purchase /Installation	Utilization Rate (%)	Remarks regarding maintenance/
1	Battery Cell Balancing Tester/Demonstrator	A D Solution	99,120/-	01/04/2025	70%	done
2	Official Raspberry Pi 5 Case Red-White	MACFOS Ltd.	852/-	07/03/2025	50%	done

b) Plans for utilizing the equipment facilities in future  
For advancing research/project works

Name and Signature with Date:

  
08/05/2026  
a. Prof. Asim Datta  
(Principal Investigator)

  
08/05/2026  
b. Dr. Manashita Borah  
(Co-Investigator)



## GFR 12 – A

[(See Rule 238 (1))]

### FORM OF UTILIZATION CERTIFICATE FOR AUTONOMOUS BODIES OF THE GRANTEE ORGANIZATION

UTILIZATION CERTIFICATE for the period 1st January, 2026 to 31<sup>st</sup> March, 2026  
in the financial YEAR 2025-26 in respect of recurring/non-  
recurring GRANTS-IN-AID/SALARIES/CREATION OF CAPITAL  
ASSETS

1. Name of the Scheme: National Mission on Interdisciplinary Cyber Physical System.
2. Whether recurring or non-recurring grants: Both.
3. Grants position at the beginning of the financial year/ quarter Q6
  - (i) Cash in Hand/Bank : 17,319/-
  - (ii) Un adjusted advances: NIL
  - (iii) Total: 17,319/-
4. Details of grants received, expenditure incurred and closing balances: (Actuals)

Sanction Heads	Grants at the beginning of the quarter	Grant received during the Quarter			Total Available funds for the quarter Q6 (1+2)	Expenditure incurred in the quarters Q6(1st Jan., 2026 to 31st Mar., 2026)	Grants at the end of the quarter Q6, i.e. 31 <sup>st</sup> Mar. 2026
		Sanction No (i)	Date (ii)	Amount (Rs)(iii)			
	1	2			3	4	5
<b>Recurring</b>	17,291/-			-	17,291/-	16,415/-	876/-
<b>Non-Recurring</b>	28/-				28/-	-	28/-
<b>Total</b>	17,319/-				17,319/-	16,415/-	904/-

Component wise utilization of grants:

Grant-in-aid– General (Rs)	Grant-in-aid– Salary(Rs)	Grant-in-aid–creation of capital assets	Total (Rs)
16,415/-	-	-	16,415/-

Details of grants position at the end of the Quarter 6 ( i.e., after 31/03/2026)

- (i) Cash in Hand/Bank: Rs. 904/-
- (ii) Unadjusted Advances: NIL
- (iii) Total: **Rs.904/-**



**GENERAL FINANCIAL RULES 2017**  
**Ministry of Finance**  
**Department of Expenditure**

Certified that I have satisfied myself that the conditions on which grants were sanctioned have been duly fulfilled/are being fulfilled and that I have carried out the following checks to see that the money has been utilized for the purpose or which it was sanctioned:

- (i) The main accounts and other subsidiary accounts and registers (including assets registers) are maintained as prescribed in the relevant Act/Rules/Standing instructions (mentioning the Act/Rules) and have been duly audited by designated auditors. The figures depicted above tally with the audited figures mentioned in financial statements/accounts.
- (ii) There exist internal controls for safeguarding public funds/assets, watching outcomes and achievements of physical targets against the financial inputs, ensuring quality in asset creation etc. & the periodic evaluation of internal controls is exercised to ensure the ineffectiveness.
- (iii) To the best of our knowledge and belief, no transactions have been entered that are in violation of relevant Act/Rules/standing instructions and scheme guidelines
- (iv) The responsibilities among the key functionaries for execution of the scheme have been assigned in clear terms and are not general in nature.
- (v) The benefits were extended to the intended beneficiaries and only such areas/districts were covered where the scheme was intended to operate.
- (vi) The expenditure on various components of the scheme was in proportions authorized as per the scheme guidelines and terms and conditions of the grants-in-aid.
- (vii) It has been ensured that the physical and financial performance under **National Mission on Interdisciplinary Cyber Physical Systems (3645)** scheme has been according to the requirements, as prescribed in the guidelines issued by Govt. of India and the performance/targets achieved statement for the year to which the utilization of the fund resulted in outcomes given at Annexure – I duly enclosed.
- (viii) The utilization of the fund resulted in outcomes given at Annexure–II duly enclosed (to be formulated by the Ministry/Department concerned as per the requirements /specifications )
- (ix) Details of various schemes executed by the agency through grants-in-aid received from the same Ministry or from other Ministries is enclosed at Annexure–II (to be formulated by the Ministry/Department concerned as per the requirements/specifications).

Date:

Place:

Signature

Name.....

Head of the  
Organization

*[Handwritten Signature]*  
*30/12/20*  
 Registrar  
 Tezpur University

Signature

Name.....

Auditor

*[Handwritten Signature]*  
*30/12/20*  
 Finance Officer I/c  
 Tezpur University  
 Napaani, Tezpur

(Strike out inapplicable terms)

**REQUEST FOR ANNUAL INSTALMENT WITH UP-TO-DATE STATEMENT OF EXPENDITURE (General)**

Sanction Order No. IIT-H/HUB/Project/Mobility/2024-25/M2-021

date: 24/09/2024

2. Total Project Cost: 10 Lakh

3. Revised Project Cost:(if applicable) N/A

4. Date of Commencement: 22/11/2024

5. Statement of Expenditure: Recurring & Non-Recurring

6. (Month wise expenditure incurred during current financial year : up to 31/03/2026)

Month & Year	Nov. 2024	Dec. 2024	Jan. 2025	Feb. 2025	Mar. 2025	Apr. 2025	May 2025	Jun.2025	Jul, 2025	Aug. 2025	Sept. -Dec., 2025	Jan.-Mar. 2026	TOTAL (Rs.)
Manpower	-	25,161	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	84,000/-	-	3,49,161/-
Consumables	2,565	588		32,435	38,442	-	1,934	73,800	-	-	50,200/-	-	1,99,964/-
Contingencies	1361	3,441	879	28228	16,091	-	51,172	40,397	725	2336	51,906	3474/-	2,00,000/-
Travel	-	23,220	19,006	-	-	21,724	-	22,929	17,788	-	32,391/-	12,941/-	1,49,999/-
Equipment	-	-	-	-	99,972/-	-	-	-	-	-	-	-	99,972/-
<b>TOTAL</b>													<b>9,99,096/-</b>

7. Grant received in each Quarter & year:

Sanction Heads	1 <sup>st</sup> Quarter	2 <sup>nd</sup> Quarter	3 <sup>rd</sup> Quarter	4 <sup>th</sup> Quarter	TOTAL (Rs.)
Recurring	2,00,000/-	4,50,000/-	-	2,50,000	9,00,000/-
Non- Recurring	1,00,000/-	-	-	-	1,00,000/-

STATEMENT OF EXPENDITURE - GRANTS-IN-AID GENERAL (REVENUE) & Capital (Provisional)

**Statement of Expenditure (General)**

Sr. No.	Sanction Heads	Fund Allocated (Rs.)	Fund Released (Rs.)	Expenditure Incurred						Total Expenditure (Rs) (up to 31/03/2026)	Balance against Sanctioned (Rs.)	Requirement of fund up to Quarter Q6 (Rs.)	Remarks (if any)
				1st Quarter	2nd Quarter	3rd Quarter	4th & 5th Quarters (1 <sup>st</sup> July - 31 <sup>st</sup> Dec. 2025)	6 <sup>th</sup> Quarter (1 <sup>st</sup> Jan - 31 <sup>st</sup> Mar. 2026)					
I	II	III	IV	V	VI	VII	VIII	IX	X=V+VI+VII+VIII+IX	XI=III-X			
1	Recurring	9,00,000/-	9,00,000/-	56,336/-	2,25,071/-	3,01,956/-	2,99,346/-	16,415/-	8,99,124/-	876/-	9,00,000/-		
2	Non-Recurring	1,00,000/-	1,00,000/-		99,972/-				99,972/-	28/-	1,00,000/-		
	<b>Total</b>	<b>10,00,000/-</b>	<b>10,00,000/-</b>	<b>56,336/-</b>	<b>3,25,043/-</b>	<b>3,01,956/-</b>	<b>2,99,346/-</b>	<b>16,415/-</b>	<b>9,99,096/-</b>	<b>904/-</b>	<b>10,00,000/-</b>		

Name and Signature of Principal Investigator: 

Date: 25/03/2026


  
 Dept. of Electrical Engineering  
 Tezpur University  
 Assam, India

Signature of Competent Financial Authority:   
 Finance Officer I/c  
 Tezpur University  
 Assam, India

Note:

- Expenditure under the sanctioned heads, at any point of time, should not exceed funds allocated under that head, without prior approval of IIT - H DATA I-HUB FOUNDATION i.e. Figures in Column (IX) should not exceed corresponding figures in Column (III)
- Utilization Certificate (Annexure III) for each Quarter ending has to be enclosed along with request for carry-forward permission to the next Quarter.



Account Statement for the period 27/04/2026 to 27/04/2026

<b>Account Number</b>	00000030448821505	<b>Branch</b>	TEZPUR UNIVERSITY
<b>Address</b>	TEZPUR UNIVERSITY,NAPAM,TEZPUR,Sonitpur TEZPUR ASSAM-784028 IN	<b>Account Type</b>	SBCHQ-SURABHI-PUB- OTH-ALL-INR
<b>Account Name</b>	TEZPUR UNIVERSITY R& D	<b>MOD Balance</b>	1,16,27,231.00
<b>Drawing Power</b>	0.00	<b>Interest Rate(% p.a.)</b>	2.5
<b>Balance as on 27/04/2026</b>	3,646.23		

Date (Value Date)	Narration	Ref/Cheque No.	Branch Code	Debit	Credit	Balance
27-Apr-26 (27-Apr-2026)	CHQ TRANSFER NEFT UTR NO: SBIN226117810966 924055 IIIT H DATA I HUB FOUNDATION	924055 IIIT H DATA I HUB FOUNDATION	14259	904.00		2,742.23
27-Apr-26 (27-Apr-2026)	CHQ TRANSFER DD ISSUED 924054	924054	14259	506.00		2,236.23
27-Apr-26 (27-Apr-2026)	CHQ TRANSFER CHEQUE TRANSFER TO 924053	924053	14259	823.00		1,413.23
27-Apr-26 (27-Apr-2026)	TRANSFER CREDIT SWEEP DEPOSIT BY TRANSFER	SWEEP FROM 44834689266 TEZPUR UNIVERSITY R&	14259		13,142.00	14,555.23
27-Apr-26 (27-Apr-2026)	TO TRANSFER NEFT UTR NO: SBIN226117946631	TRANSFER TO 4697157044307	14259	13,694.00		861.23
27-Apr-26 (27-Apr-2026)	CHEQUE DEPOSIT 849379	TRANSFER TO 37854250831 TEZPUR UNIVERSITY RECU 849379	14259		2,206.00	3,067.23

\*\*This is a computer generated statement and does not require a signature.

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