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On Controlling the Lithium-ion Battery Charging

Dina M. Khorshied, Ibrahim Ahmed, Ahmed Azzam

DINA@eaeat.edu.eg

Abstract– Battery stacks based on lithium-ion (Li-ion) cells are used in many applications on a wide scale. Battery Management System (BMS) is description of the state of the Battery according to a specific input to get multiple outputs which could be used in system control. This paper introduces the application, and control of a DC/DC buck converter in charging the Li-ion batteries. The main parameter that can be estimated to describe the state of battery charging capacity is State of Charge (SoC). SoC is estimated based on the battery open circuit voltage (OCV), and the Coulomb's counting method. SoC limits are controlled to avoid overcharging the battery. Pulse Adjustment (PA) control technique is applied to control the switching of the of the DC/DC buck converter used to charge the Li-ion battery. So ensures constant charging current at the beginning of the charging process, within permissible limits. Hence avoid excessive heating that may degrade or damage the battery. MATLAB/Simulink tool is used for design verification. Simulation & Practical results were encouraging. A mobile application is designed to monitor the battery charging/discharging parameters.

***Keywords*—**Li-ion batteries, Buck, SoC, PA, mobile application.

I. INTRODUCTION

Li-ion Battery is one of the most batteries used in the nowadays industries [1]. Compared to conventional technologies of batteries, Li-ion battery charges faster, and has a higher power density [2].

The use of battery outside or beyond its limits decreases its life [1]. Therefore, to increase the battery life, Battery Management System (BMS) plays an important role because all the battery parameters limits are handled by BMS. One of key component of battery management system is accurate state of charge (SoC) estimation, as SoC reflects battery performance. As the battery stores chemical energy, and this chemical energy is not directly accessed, so SoC estimation is very difficult [3].

The SoC of the batteries is still the basic factor to decide the power flow direction from the source to the & vice versa [4]. Almost all research works that deal with Li-ion batteries discuss SoC estimation issue, if not mainly specified in it. Ref. [5] discussed the enhancement of the accuracy of state-of-charge (SoC) estimation by introducing varies dynamic cell model methods. Also, Ref. [6] discussed that Artificial intelligence (AI) models, which are widely used for SOC estimation for lithium-ion batteries.

Ref. [7] also stated that it is very effective for estimating SoC to use the approach of neural network (NN) methods; involves constructing a dataset by selecting input features such as current, voltage, and temperature, and training the NN node parameters for a nonlinear mapping from input features of the SoC.

For charging the battery, DC/DC converter is introduced in this research work. Stabilizing the DC/DC converters is highly affected by its load type, either constant voltage load (CVL) or constant power load (CPL) [8]. Constant power loads (CPLs) commonly exist in power systems, whose negative impedance will obviously result in the low-frequency oscillation and even instability [9], one of the suitable and widely used strategies to control CPL destabilizing effect is the proposed PA technique.

Recently, Pulse Width Modulation (PWM) techniques have been widely used in the field of switch converter technology [10]. But due to poor stability and transient performance characteristics, some scholars put forward this kind of new control technique; PA, which is based on nonlinear control regulation [11]. Comparing with the conventional PWM, PA control technique has more excellent transient performance and stability [12].

Also, Internet of Things (IoT) is now widely used in many critical applications for advanced developments, such as; smart buildings, security, industrial automation, etc. [13]. According to this concept, this research work proposes a mobile application for remotely monitoring the battery operation.

This research paper is organized as follows, the overall system block diagram is introduced, the initial SoC estimation method is discussed. Controlling the battery SoC limits are illustrated using MATLAB/Simulink model. The application of uncontrolled DC/DC buck converter in charging the 18650 model Li-ion battery is introduced. Constant current control for DC/DC buck converter using PA technique is introduced, the MATLAB/Simulink model is illustrated. An experimental part dedicated to connect/disconnect the charging buck converter to the battery, according to its voltage level is introduced. Finally, the conclusion and future work are discussed.

II. SYSTEM BLOCK DIAGRAM

DC chargers convert the three-phase AC voltage into the desired DC voltage in two stages: an AC/DC rectification stage that converts the three-phase mains into intermediate DC voltage followed by a DC/DC stage which converts the intermediate DC voltage into a controlled DC voltage fed to the batteries [14].

The proposed system block diagram is illustrated below in Fig. 1. It starts mainly from the AC mains 220V AC, 50 Hz. AC/DC full wave rectifier circuit is design to converter the available AC voltage into DC voltage level. Then DC/DC converter is designed to control the output DC level according to the system requirements.

The DC/DC converter feeds the load and charge the battery until it gets charged (i.e., %SoC = 85), then the control circuit disconnect the DC/DC converter and the battery discharges in the load until %SoC=15, so the control circuit connects the DC/DC converter again, to charge the battery and feed the load and so on.

Each block will be discussed in details in the following paper sections. The initial % SoC is determined according to the battery open circuit voltage, as explained in the next section. Also, a block represents the mobile application is designed to monitor and display the battery parameters for the operator.

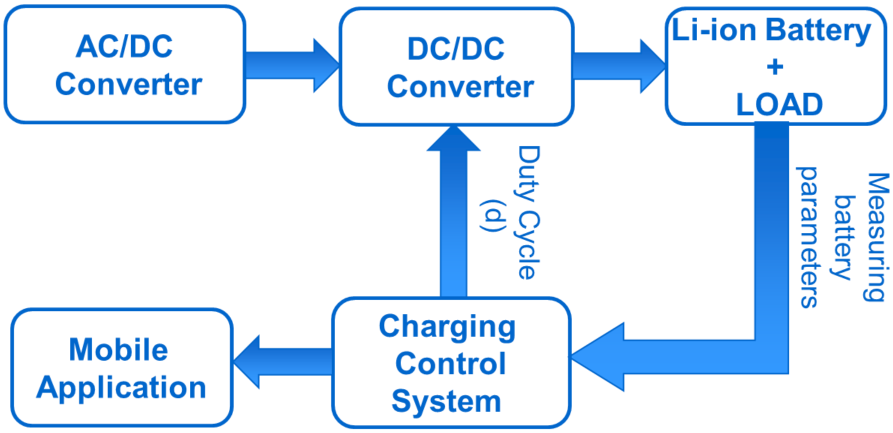

Figure 1: The proposed system block diagram.

III. SoC ESTIMATION

Generally, the SOC of a battery is defined as the ratio of its current capacity (Q(t)) to the nominal capacity (Q_n). The nominal capacity is given by the manufacturer, and represents the maximum amount of charge that can be stored in the battery [15]. The SOC can be defined as follows:

$$SoC = \frac{Q(t)}{Q_n(t)} \tag{1}$$

Estimating SoC can mainly be classified into four categories; direct measurement, book keeping estimation, adaptive system and Hybrid method. In direct measurement method, the voltage or impedance i.e., the physical properties of the battery are measured to estimate SoC. In book keeping estimation method, the charging current or discharging current is integrated over time to calculate the SoC. The adaptive systems as named suggest adapts by itself for various charging/discharging conditions for SoC estimation. The Hybrid method of SoC estimation uses combination of these three methods inheriting their benefits and has optimal estimation results [3]. Ref. [16] compared different SoC estimation methods, including the advantages, disadvantages and the input required for each method.

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Table (1): Properties of different SoC estimation methods

Method	Advantages	Disadvantages
Discharge test method Ampere-hour integral method	- Easy to implement - Accurate if the initial SoC value, the current measurement and the efficiency are precise	- Long time needed - offline - need accurate values of the initial SoC, measured current, self-discharge rate and the coulomb efficiency.
Open Circuit voltage method	- Easy to implement - Accurate	- Battery should be at rest. - Only suitable when SoC is very high or very low
Coulomb Counting	- Most general and simple method for estimating the SoC	- Sensitive to the current measurement - need accurate values of the initial SoC
Battery model-based SoC estimation method	- Needs no rest time - Insensitive of the initial SoC value	- Sensitive to the measure noise - Only suitable when SoC is very high or very low
Neural network model	- Suitable for all kinds of batteries	- Needs large amount of training data
Fuzzy logic	- Fuzzy thinking of human beings	- Not-accurate
Kalman Filter	- Accurate, dynamic - Insensitive of the noise and the initial SoC value error	- Complicated - Lots of computation - Instability if the gain is undesirable
Sliding mode control	- Accurate, robustness, dynamic - Insensitive of the noise, model error and the initial value error.	- Not easy to implement

The Coulomb counting method estimates SOC by measuring the discharging current of a battery and integrates the discharging current over time [15]. Coulomb counting method estimates SoC(t), considering the discharging current, I(t), and previously estimated SoC values, SoC(t-1). SoC is calculated by the following equation:

$$SoC(t) = SoC(t-1) + \frac{I(t)}{Q_n(t)}\Delta t \qquad (2)$$

The accuracy of the coulomb counting method is affected by the accuracy of initial SoC estimation, and measurement of the battery current (accuracy of current sensors). To overcome these drawbacks, the open circuit voltage method is applied to estimate the initial state of the charge [17].

The battery SoC indicates its estimated available charge. Ref. [17] proposed a solution for Li-ion battery SoC estimation based on an enhanced Coulomb-counting algorithm to be implemented for multimedia applications. This solution uses the Open-Circuit Voltage (OCV), thus having a piecewise linear SoC-OCV relationship, and performing periodic re-calibration of the battery capacity. So, it overcomes the main accumulative errors drawback of the Coulomb-counting algorithm. Practically, this solution has shown a reliable estimation since accuracy is less than 2% [17].

This equation used to estimate initial SoC for each segment:

$$SoC_i(t) = a * OCV - b \qquad (3)$$

For each segment, the coefficients a and b vary according to OCV intervals. These coefficients for each segment are given in Table 2, with their voltage range.

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Table (2): Piecewise linear relationship of SoC-OCV at 25°C

Segment	1	2	3	4	5	6	7	8
Voltage Range (V)	[3.3; 3.452]	[3.452; 3.508]	[3.508; 3.595]	[3.595; 3.676]	[3.676; 3.739]	[3.739; 3.967]	[3.967; 4.039]	[4.039; 4.132]
A	26.55	125	149	344	229.5	111.9	104.8	90.61
B	88.6	431.1	516.1	1225	800.9	359.9	332	274.7

The open circuit voltage (OCV) method is very common and simple methods to estimate the SoC. The OCV method falls under direct measurement category of SoC estimation by measuring the voltage across the battery when it is not connected to the load. The OCV method is suitable when the battery is at rest i.e., at neither charging nor discharging operation [3].

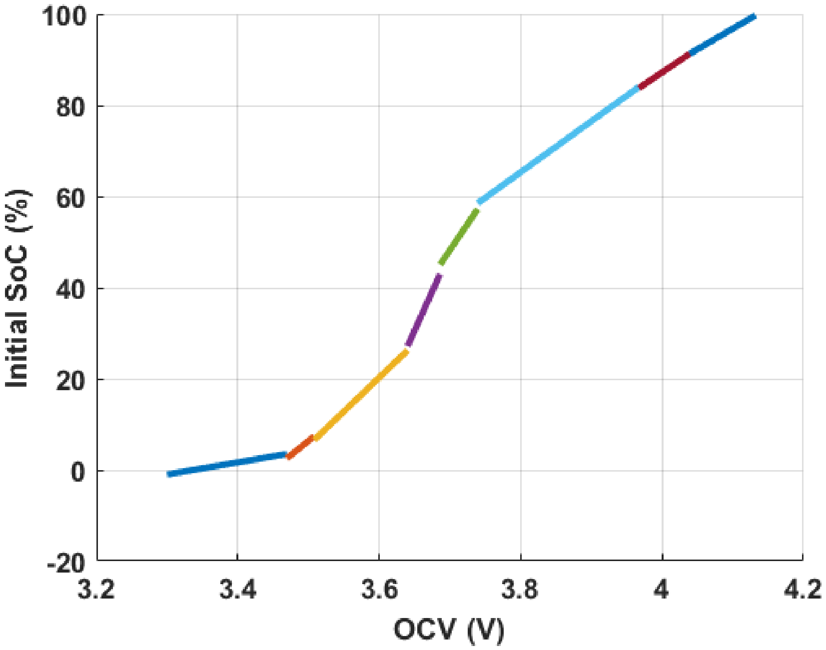

Figure 2: The piecewise linear relationship of SoC-OCV.

Ref. [17] experimentally proved the OCV-SoC proposed function, and also MATLAB m-file is used to verify this relationship as shown in Fig. 2.

For estimating the battery SoC, the coulomb counting method is used. It integrates the battery's current with time to calculate SOC, which is less complicated method, but limited by initial and cumulative errors [18]

IV. CONTROLLING SOC LIMITS

Always avoid to fully charging the battery, as it will create higher float voltage in the battery and will damage as well as decrease its performance. Also, deep discharging can damage the battery, as it creates metal plating, that will result in a short circuit. This makes the battery hard to handle, and there may be a chance of explosion. So many BMS are designed to stop the discharging at a particular point [1].

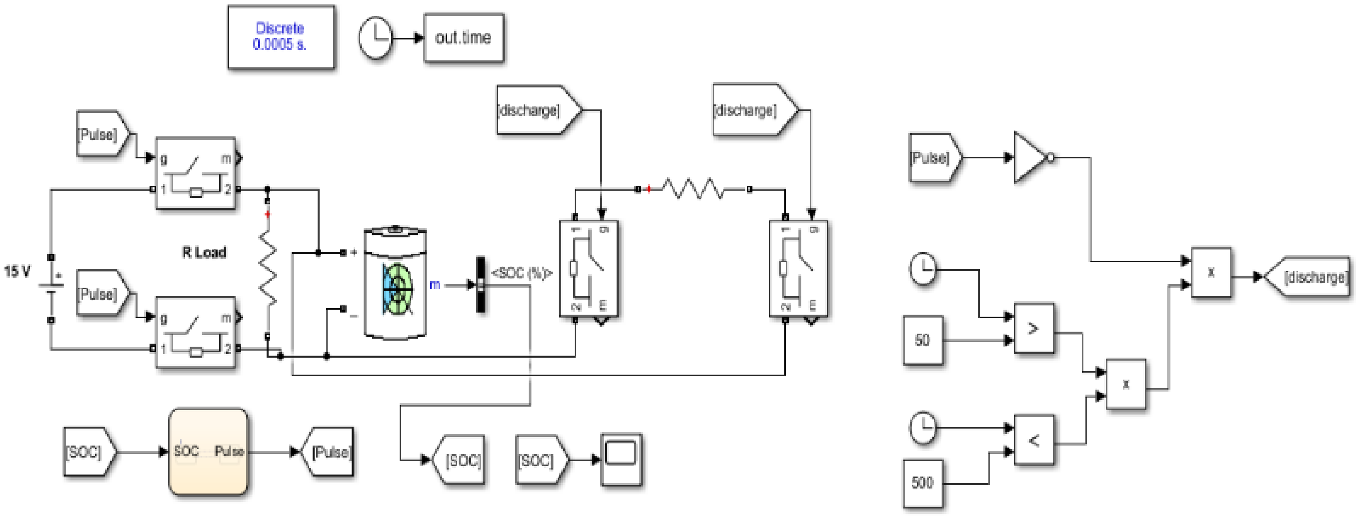

Figure 3: Simulink model illustrates the %SoC charging/discharging limits.

Fig. 3 illustrates a simple MATLAB/Simulink model showing the open-loop control of charging/discharging processes of a Li-ion battery. It toggles between both modes according to the battery SoC level; ranges from 15-to-85%, as shown in Fig.4. Considering that simulating and modelling a circuit having fixed charge / discharge percentage helps in improving the battery life as well as degradation of the battery [1].

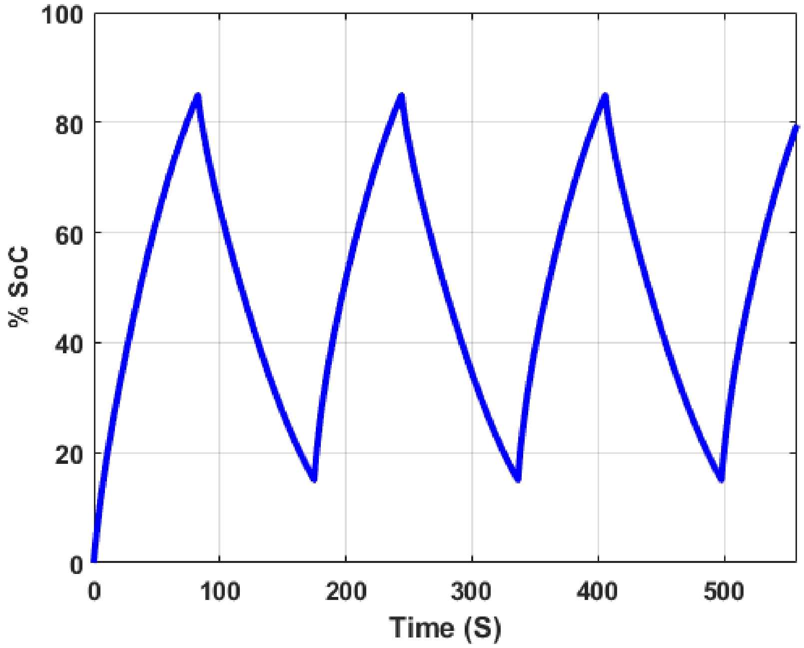

Figure 4: Simulink model illustrates the charging/discharging limits.

Figure 4 shows the state of charge (%Soc) limitations of Li-ion battery, where it gets charging up to 85% and then starts discharging till 15%. MATLAB/Simulink results show that the State of charge takes 69S to be 85%, and once it reaches the optimum value it starts discharging, and this process takes place until it reaches 15% in about 91S. This cycle is continued for the entire time period/run of the circuit.

V. BATTERY CHARGING CONTROL CIRCUIT.

Ref. [19] stated that, a good battery charger should have better input power quality (QA), high efficiency, reliability and high-power density. This paper discussed various topologies of power converters used in charging the electric vehicles (EV) Li-ion batteries.

Ref. [10] proposes the mathematical modeling for the buck converter according to the state space averaged (SSA) model, so the buck converter transfer function could be expressed as;

$$G_{vd}(s) = \frac{[C_{11}s + (A_{21}C_{12} - A_{22}C_{11})]\ V_g}{L[s^2 - (A_{11}+A_{22})s + (A_{11}A_{22} - A_{21}A_{12})]} \tag{4}$$

$$G_{vg}(s) = \frac{[C_{11}s + (A_{21}C_{12} - A_{22}C_{11})]\ D}{L[s^2 - (A_{11}+A_{22})s + (A_{11}A_{22} - A_{21}A_{12})]} \tag{5}$$

Where: $G_{vd}(s)$: The control – to - output TF & $G_{vg}(s)$: The line – to - output TF.

$$A_{11} = -\frac{1}{L}\left(R_L + \frac{R_O R_C}{R_O + R_C}\right) \tag{6}$$

$$A_{12} = -\frac{1}{L}\frac{R_O}{R_O + R_C} \tag{7}$$

$$A_{21} = \frac{1}{C}\left(\frac{R_O}{R_O + R_C}\right) \tag{8}$$

$$A_{22} = -\frac{1}{C}\left(\frac{1}{R_O + R_C}\right) \tag{9}$$

$$C_{11} = \frac{R_O R_C}{R_O + R_C} \tag{10}$$

$$C_{12} = \frac{R_O}{R_O + R_C} \tag{11}$$

According to the previous model, the proposed converter control-to-output T.F. and line-to-output T.F could be expressed as:

$$G_{vd} = \frac{2.4s + 29090}{0.00032s^2 + 1.226\,s + 3030} \tag{12}$$

$$G_{vg} = \frac{0.875s + 1061}{0.00032s^2 + 1.226\,s + 3030} \tag{13}$$

A MATLAB/Simulink tool is built to simulate the Li-ion battery charging/discharging processes using a DC/DC buck converter, instead of the DC source, as shown in Fig. 5. The Li-ion battery model 18650 is selected. The buck converter parameters are illustrated in table (3).

Table (3): The proposed buck converter parameters.

Variable	Parameter	Value
V_S (V)	Input voltage	12
V_{ref} (V)	Reference output voltage	4.2
f_S (kHz)	Switching frequency	25
L(μH)	Magnetizing inductance	320
R_L (Ω)	Inductance internal resistance	0.25
C (μF)	Output filter capacitance	330
R_C (Ω)	Capacitance ESR	0.25
R_O (Ω)	Load resistance	1

The initial SoC value is set to be 45%. It could be determined according to the battery open-circuit voltage, as previously discussed.

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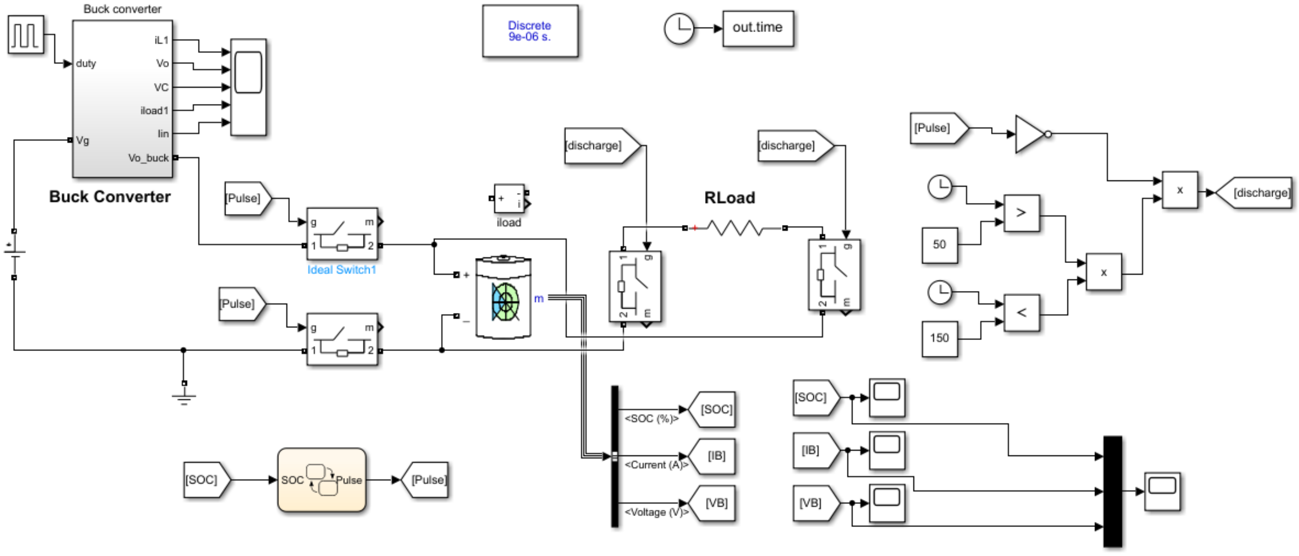

Figure 5: Simulink model illustrates controlling the battery charging process using open-loop buck converter

The synchronous buck converter MOSFETs have been derived using pulse generator as shown in Fig. 6, to allow the required energy transfer to charge the battery, and feed the load.

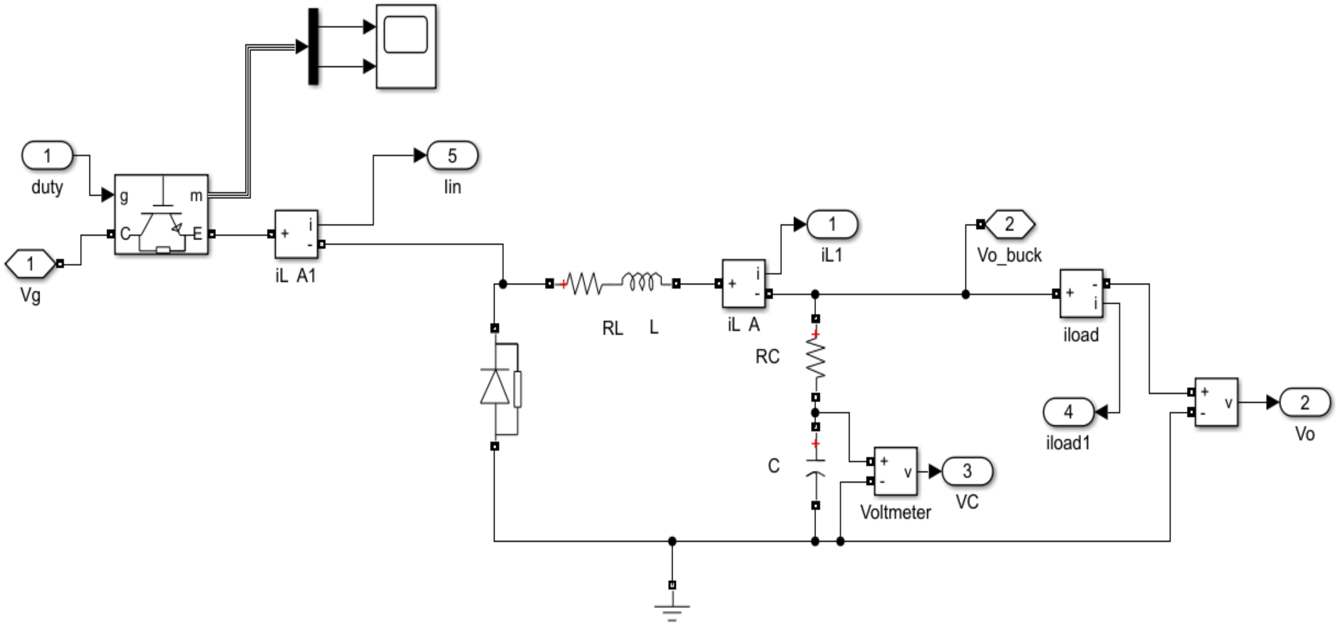

Figure 6: Simulink model for the charging buck converter.

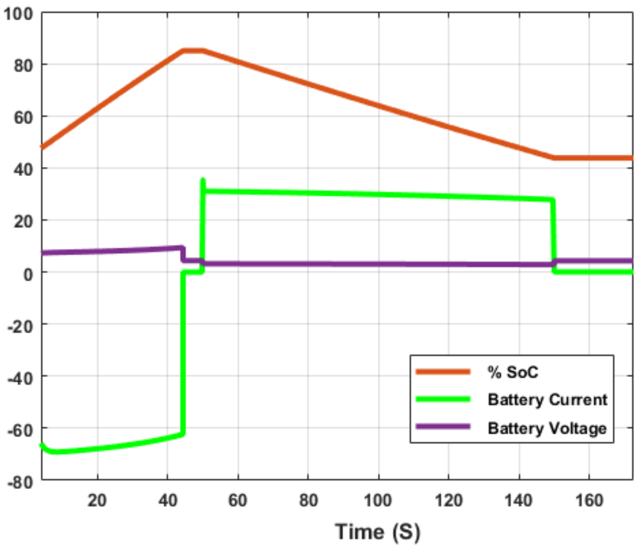

Figure 7: Battery main parameters for charging / discharging processes, when fed from an uncontrolled DC/DC power converter.

Figure 7 depicts the battery charging /discharging processes when using the DC/DC buck converter. It is obvious that, while the %SoC increases from 45% - to- 85%, the battery current was negatively charged, as the Li-ion battery is getting charging. When %SoC reaches 85, the battery charging current will be decreased to zero, as it gets fully charged. Then discharging process occurs, so the battery current will be positive, to feed the load, and the battery voltage is decreased to the battery nominal voltage; 4V.

But the battery current either while charging or discharging exceeds the nominal value. So, current control should be applied to limit the current within acceptable limits, and hence avoid damage the battery. Considering that, providing excessive current more than the cell rated value, could reduce battery life, or heat it up quickly, causing it to be damaged.

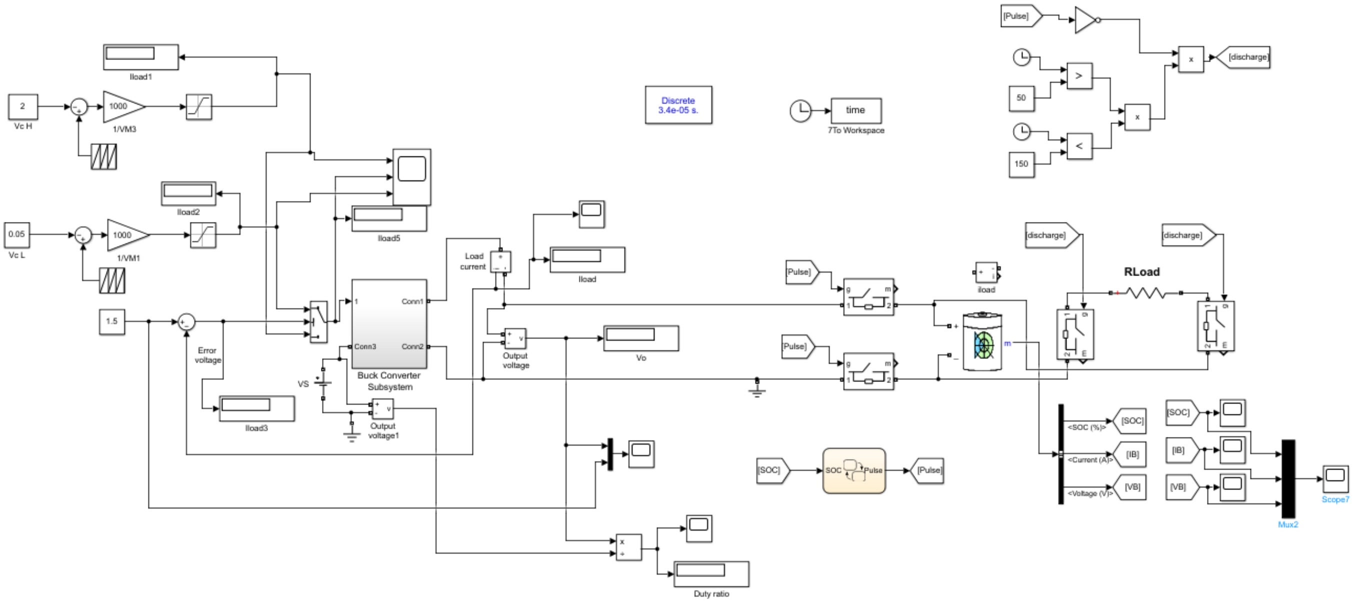

Figure 8: Simulink model for applying the PA control technique to the charging buck converter.

For the buck converter operating in continuous conduction mode (CCM), the duty cycle is expressed as:

$$D = \frac{V_o}{V_{in}} = \frac{I_{in}}{I_o} \qquad ()$$

Pulse adjustment (PA) control technique is used for current control. The main concept is that, high-power pulse or low-power pulse is selected to drive the power switch by sensing the output current of the DC-DC converter at the beginning of each switching period [12]. So, the proposed controller is applying two values of duty cycle; high duty cycle (D_H) and low duty cycle (D_L).

The controller toggle between the two values according to the measured current error signal. For negative error, which means that the output current exceeds the desired level, so apply D_H. Vice versa, for positive error, which means that the output current didn’t reach the desired level, so apply D_L. D_H is set to 66.67% and D_L 1.67%.

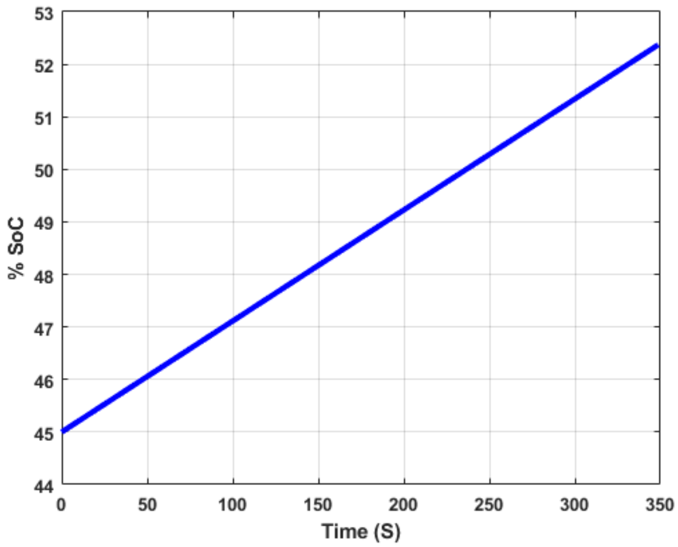

Figure 9: %SoC increase when charging the Li-ion battery using constant current, by applying PA control technique to the charging buck converter

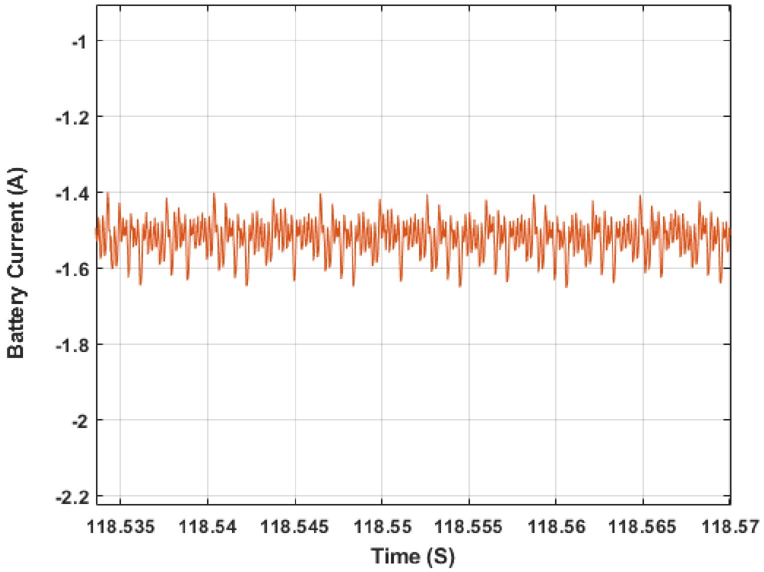

Figure 10: The constant current of 1.5A applied to charge the Li-ion battery by applying PA control technique to the charging buck converter

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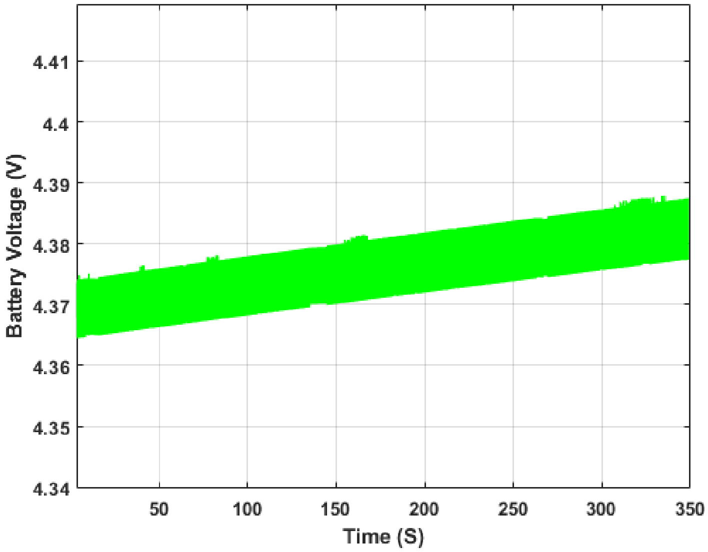

Figure 11: The rise of the built-up voltage across the Li-ion battery terminal when applying PA control technique to the charging buck converter

Figure 8, depicts the Simulink model for the current mode controlled buck converter, using PA control technique. The reference current for charging the battery is set to 1.5A. Simulation results show that, the battery is charging as the battery SoC increases with time. Also, the voltage is building up across the battery terminals as the battery get charged, as shown in Fig. 9, 11.

Figure 10 show that the constant current at 1.5A has 6-10% current ripples as it ranges from 1.4A-to-1.65A. Also, Fig. 11 depicts that the voltage waveform has ripples of 0.01V as it ranges from 4.377V-to-4.387V.

VI. EXPERIMENTAL WORK

At first, rectification process is needed to get the input charging DC voltage from the available 220V AC mains. Converting AC-DC using full-wave rectifiers are used to convert AC voltage to DC voltage. Using step-down transformer, and full wave rectification is the process of converting an AC signal to a DC signal, using bridge rectifier.

To assure pure constant output DC waveform, a filter circuit must be used to reduce the effect of the output pulsating DC output voltage. A capacitor is applied across the load terminals, to smooth the output voltage, and remove the over-imposed ripples of it, as illustrated in Fig. 12.

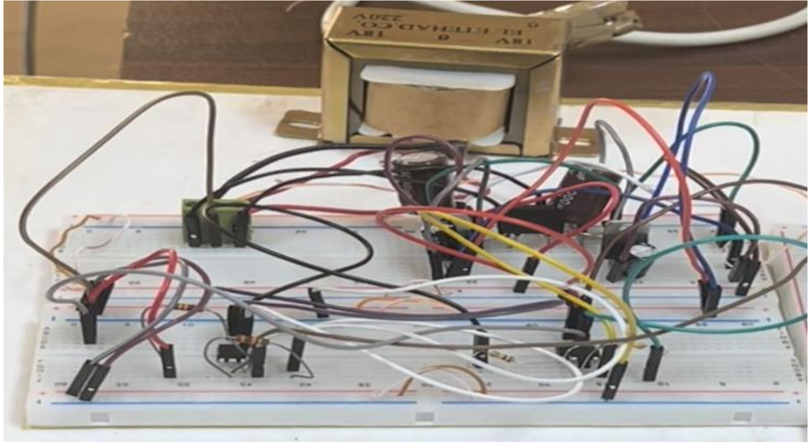

Figure 12: AC/DC full-wave rectifier circuit prototype.

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This 220VAC/12V DC rectification circuit output of 12V DC is to be applied to the DC/DC buck converter, used to charge the Li-ion battery.

The DC-DC buck converter; shown in Fig. 13, is used to charge one cell of 18650 Li-ion battery. The buck converter LC filter of 2A, 3.2mH inductor, and 50V, 330μF capacitor are used. Also, a IRF9540N MOSFET & 3A diode are used as the alternatively switching elements.

The input 12V DC is to be stepped down by the DC/DC buck converter to 4.2V to charge the battery. The Arduino Uno having ATmegaa328P microcontroller is used to control the on/off switching of the buck converter output to the battery. This is done according to the battery voltage level V_B. If $V_B < V_{min}$ so connect the charging circuit to the battery, allowing the battery to charge, and the voltage level to be built up on the battery terminals.

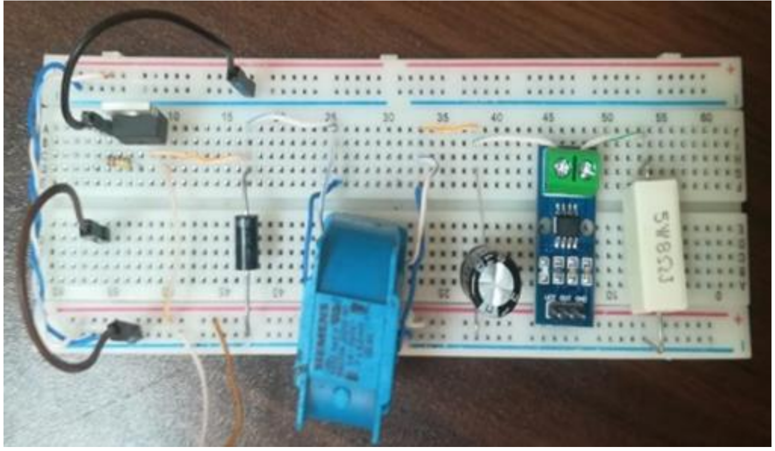

Figure 13: The buck converter prototype.

Then, when the battery voltage reaches Vmax, so disconnect the charging circuit to avoid overcharging the battery. For this proposed battery model, V_{min} is set to 2.7V, and V_{max} is set to 4.2V.

VII. MOBILE APP UIUX DESIGN

Of course, the battery is the most important component of the most modern device. Also, it is important to monitor the voltage level of the battery, as improper or excess charging/discharging may lead to damage of Battery or System Failure.

Most of the electrical/electronic device has a separate BMS system, that monitors all the properties of the battery like the voltage, current, temperature & auto cut-off system. This ensures the safety and proper handling of Lithium-Ion batteries.

Earlier BMS only monitors the condition of the battery and alarms the user via a battery indicator. But now due to the use of the Internet of Things (IoT), users can directly be notified remotely of any emergencies. So quick actions could be taken; just like check the battery status on their smartphones or Computer Dashboard from anywhere in the world.

In this research work, a mobile application is introduced as smartphones exist in our daily live, everyone has a smartphone. So, by developing a mobile application, it will very easy to monitor the battery status anywhere & anytime. The flow chart of the mobile application is depicted as shown below in Fig. [14].

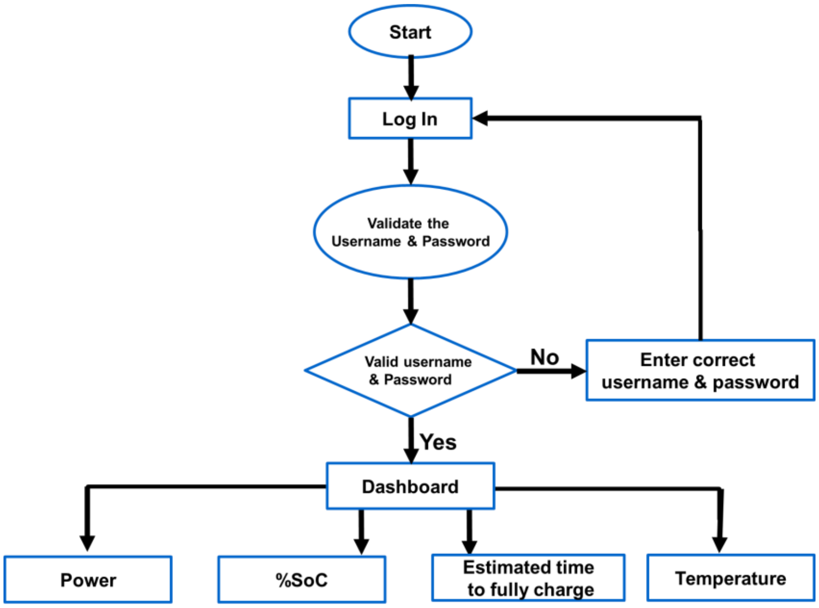

Figure 14: Mobile application design flow chart.

Figure 15 shows the screenshots of the proposed mobile application show mainly the 'login' screen, then a screen for monitoring the main battery parameters; the battery percentage SoC, total power and the estimated time. Extra monitoring features such as; the battery voltage, and current etc. may be added.

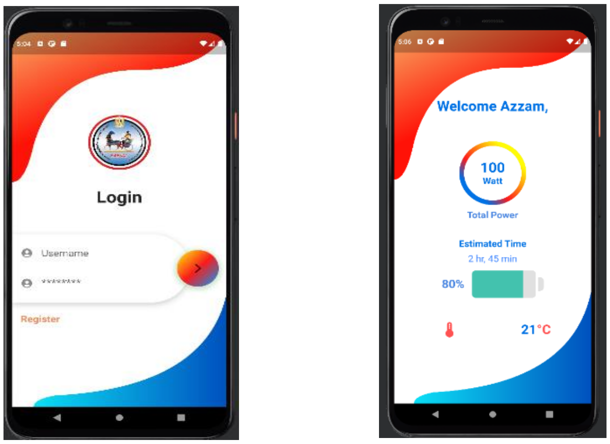

Figure 15: Mobile application interface.

VIII. CONCLUSION

This research work introduces the application of DC/DC buck converter for controlling the charging of the Li-ion battery. The pulse adjustment control technique is selected to be applied for constant current control of the battery charging. It should be considered that, at the beginning of the charging process, the charging current should be limited within its permissible limits, to prevent the battery overheating or damage caused by excessive currents. It is simple and could be easily implemented practically.

Also, a mobile application is very beneficial for monitoring the Li-ion battery status at any time. It could be modified to control applied on a wide scale for different BMS parameters.

IX. FUTURE WORK

This research work applies the PA control to control the buck converter used to charge the Li-ion battery. At the beginning of the charging process, constant current (CC) control is used to limit the battery charging current to permissible limits, that protect the battery from excessive heating that can degrade or damage the battery. After a while, when the voltage value is built-up across the battery terminals, the controller should supply the battery with constant voltage (CV); according to the battery datasheet. Also, a comparative study between the applied PA controller, and another control method is recommended, to study the merits and drawbacks of each controller. This is to be verified by simulation, then experimentally tested, as practical results validate the system design.

Also, for the mobile application, various controllers namely Raspberry Pi, Arduino Uno etc., could be used for monitoring and managing the environment that combines IoT with information systems [20]. It is recommended to applying the IoT technology, to add more features to the mobile application, to be interactively used, not just for monitoring.

X. REFERENCES

[1] Bhagat S., Archana C., Virendra Talele., Khade K., Budukh A., Bhosale A., Mathew VK. (2022), Simulation of Li-ion Battery using MATLAB-Simulink for Charging and Discharging. E3S Web of Conferences 353, 03001 https://doi.org/10.1051/e3sconf/202235303001

[2] Hassoune, A., Khafallah, M., Mesbahi, A., Nouaiti, A., & Bouragba, T. (2020). Experimental implementation of a smart battery charger for electric vehicles charging station. International Journal of Power Electronics and Drive Systems (IJPEDS), 11(4), 1689. https://doi.org/10.11591/ijpeds.v11.i4.pp1689-1699

[3] Suraj S., Narayan S. Manjarekar, Soumyabrata Barik. (2022). SoC Estimation and IoT based Delayed Charging of Electric Vehicles. Conference Paper. DOI: 10.1109/ICPC2T53885.2022.9776936.

[4] Abdelilah Hassoune, Khafallah, M., Asghar Mesbahi, & Tarik Bouragba. (2019). Optimization Techniques for DC Bus Voltage Balancing in a PV Grid System Based EVs Charging Station. 123–131. https://doi.org/10.77/978-3-030-05276-8_14.

[5] Ajao, Q., & Sadeeq, L. (2023). Dynamic Cell Modeling of Li-Ion Polymer Batteries for Precise SOC Estimation in Power-Needy Autonomous Electric Vehicles. *ArXiv (Cornell University)*. https://doi.org/10.48550/arxiv.2306.10654

[6] Lin, Q., Li, X., Tu, B., Cao, J., Zhang, M., & Xiang, J. (2023). Stable and Accurate Estimation of SOC Using eXogenous Kalman Filter for Lithium-Ion Batteries. *Sensors*, *23*(1), 467. https://doi.org/10.3390/s23010467

[7] Zhang, Z., Chen, S., Lu, L., Han, X., Li, Y., Chen, S., Wang, H., Lian, Y., & Ouyang, M. (2023). High-Precision and Robust SOC Estimation of LiFePO4 Blade Batteries Based on the BPNN-EKF Algorithm. *Batteries*, *9*(6), 333–333. https://doi.org/10.3390/batteries9060333

[8] Hossain, E., Perez, R., Nasiri, A., & Padmanaban, S. (2018). A Comprehensive Review on Constant Power Loads Compensation Techniques. *IEEE Access*, *6*, 33285–33305. https://doi.org/10.1109/access.2018.2849065

[9] He, W., Shang, Y., Namazi, M. M., & Ortega, R. (2022). Adaptive sensorless control for buck converter with constant power load. *Control Engineering Practice*, *126*, 105237. https://doi.org/10.1016/j.conengprac.2022.105237

[10] M.M. Abdel Aziz, Mahfouz, A., & Khorshied, D. M. (2012). SIMPLIFIED APPROACHES FOR CONTROLLING DC-DC POWER CONVERTERS. *International Journal of Engineering Science and Technology (IJEST), Vol. 4* (2).

[11] Abdel Aziz, M. M., Mahfouz, A. A., & Khorshied D. M. (2012). Embedded Real-Time Control for DC Multi-Converter Systems. International Journal of Engineering and Innovative Technology (IJEIT), Vol. 2(1).

[12] Ming Q., Jingchao L., (2016). Multiple Sets of Pulse Adjustment Control Technique Based on Input Voltage Feed-forward Compensation for DC-DC Converters. 5th International Conference on Environment, Materials, Chemistry and Power Electronics

[13] Elhoseny, M., Siraj, M., Haseeb, K., Nawaz, M., Altamimi, M., & Alghamdi, M. I. (2022). Energy-Efficient Mobile Agent Protocol for Secure IoT Sustainable Applications. Sustainability, 14(14), 8960. https://doi.org/10.3390/su14148960

[14] Elkeiy, M. A., Abdelaziz, Y. N., Hamad, M. S., Abdel-Khalik, A. S., & Abdelrahem, M. (2023). Multiport DC-DC Converter with Differential Power Processing for Fast EV Charging Stations. Sustainability, 15(4), 3026. https://doi.org/10.3390/su15043026

[15] Chang, W.-Y. (2013). The State of Charge Estimating Methods for Battery: A Review. *ISRN Applied Mathematics*, *2013*, 1–7. https://doi.org/10.1155/2013/953792

[16] Lu, L., Han, X., Li, J., Hua, J., & Ouyang, M. (2013). A review on the key issues for lithium-ion battery management in electric vehicles. *Journal of Power Sources*, *226*, 272–288. https://doi.org/10.1016/j.jpowsour.2012.10.060

[17] Baccouche, I., Manai, B., Jemmali, S., & Ben Amara, N. E. (2018). Implementation Of An Improved Coulomb-Counting Algorithm Based On A Piecewise SoC-OCV Relationship For SoC Estimation Of Li-Ion Battery. International journal of renewable energy research, Vol.8, No.1, 178-187. https://www.researchgate.net/publication/323837082

[18] Fu, Y., & Fu, H. (2023). A Self-calibration SOC Estimation Method for Lithium-ion Battery. *IEEE Access*, 1–1. https://doi.org/10.1109/access.2023.3266663

[19] Begum, M., Raveendhra, D., & Pakkiraiah, B.,(2023). Power Electronic Converter with Improved Power Quality for EV Charger Application. E3S Web of Conferences 391. https://doi.org/10.1051/e3sconf/202339101062

[20] Ramesh, P., N Vidhya, P T V Bhuvaneswari, & Parveen, S. (2023). I-SOEWM: IoT Based Solar Energized Weather Monitoring System. 16(20), 1505–1515. https://doi.org/10.17485/ijst/v16i20.287