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Microgrid Designing for Electrical Two-Wheeler Charging Station Supported by Solar PV and Fuel Cell

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Abstract

Background/Objectives: One of the main objectives of this work is to design a microgrid for charging station of electric two-wheelers, which contains a public grid, fuel-cells (FCs) & solar PV plants as power sources. **Methods/Statistical analysis:** This work has used 6 kW Proton Exchange Membrane Fuel-Cells (PEMFC) and 6 kW solar PV plant with electric grid as a power source to incorporate a microgrid. The charging of EV battery is tested during different modes of operations and compared to each other. **Findings:** This paper describes that microgrid is eco-friendly and the use of solar PV & FCs in microgrid systems makes it more reliable & environment sustainable with power-efficient technologies simulated with MATLAB Simulink. **Novelty/Applications:** The proposed arrangement helps to create an efficient, low-cost, locally resilient microgrid. This will reduce the dependency on the electric grid during peak load time which is an imminent concern in cosmopolitan cities and which is novel contribution of this paper. This arrangement is also helpful when grid power is unavailable. The model was found to be satisfactorily charging the batteries used for two-wheeler and the charging rates of each method are compared to one another.

Keywords: Solar PV; FuelCell; Battery Charging; Electric Vehicles (EV's); Microgrid

1 Introduction

The charging infrastructure in developing countries is at developing stage. To endorse EV's development, fast-charging stations installation is required in which batteries of EV's can be charged. Although, Fast charging has some shortcomings of high-power demand and it has some adverse effect on public grid. Renewable sources can be used as power source at high power fast charging stations to counter these issues^(1,2). These stations can reduce the dependency on the grid for charging. RE-based charging stations can also be used as a microgrid concept which will be beneficial at remote locations⁽²⁾. FC and solar PV are the out-most capable RE source power-producing mechanisms. Out of various renewable energy sources FC has been attracting power engineers because of its cleanliness, high efficiency and profitable power supplied to consumers. The output of FC is DC in nature which can also be directly connected to the solar PV output and

it can also work as backup when standalone loads are considered^(3,4). Battery storage can be used for active regulation and balancing purposes of voltage in^(5,6). Microgrid possesses 1. A Conventional public grid, 2. Battery storage, and 3. RE-based DG sources with reliable and efficient architecture that reduces the energy cost mostly in urban zones⁽⁷⁾. The charging station based on DG source integrated with microgrid concept has potential in research and study for optimization of EV infrastructure that is the main motivation of this paper.

During past years, several researchers have reported papers of EV charging with public utility (grid) electrical supply^(3,4,6,8–12). Various researchers have also worked on EV charging methods and optimization^(5,6). Solar PV-based charging method is used for charging stations in^(13–15). Vehicle to grid method was proposed in⁽¹⁶⁾ to sell energy back to the grid, the same type of arrangement was proposed in⁽⁷⁾ to inject excess energy to the grid. Paper⁽¹⁷⁾ claimed fast functioning outcomes and appropriate application at the lower temperature & reported PEMFC is suitable for backup power with PV source. The architecture of FC can be understood from the reference paper⁽¹⁶⁾. The operation, control, and performance of the PV-FC hybrid system were demonstrated in⁽¹⁸⁾. A comparative study of AC and DC microgrid concept was reported by⁽¹⁹⁾ and it is concluded that DC is more beneficial. PV-based energy management algorithm was proposed in⁽²⁰⁾. Charging parameters related to EV controlling at peak time to diminish stress on the grid were proposed in⁽²¹⁾ but this study didn't specify when the grid was connected. The most popular battery used in EV is Li-Ion due to its energy density and charging cycles⁽¹⁹⁾. A study described PE-based DC-DC and AC-DC converters having integration with DC link in which DC bus is employed to integrate all the elements used and interface is made feasible by means of PEC's⁽²²⁾.

This paper proposes a microgrid for charging the electrical two-wheeler powered Li-Ion battery, with RE-based DG energy sources rather than grid-connected charging station. This proposed arrangement helps to create an efficient, low-cost, locally resilient microgrid. This will reduce the dependency on the electric grid during peak load time which is an imminent concern mainly in cosmopolitan cities and this makes the novel contribution of this paper. It works during any faulty period, contingency condition, or grid failure. It will support the vehicle rental agency to enhance the reliability and provide continuous facility to the end-user of vehicles. The charging of an array of two-wheelers will be possible in the parking area with charging docks which will reduce greenhouse gas emissions and saves fuel costs. The used bike specification is commercially available named as ATUM 1.0 with 100 km range and 1 unit of energy is needed for charging, which costs around 7-10 INR⁽²³⁾.

2 Methodology and System Arrangements

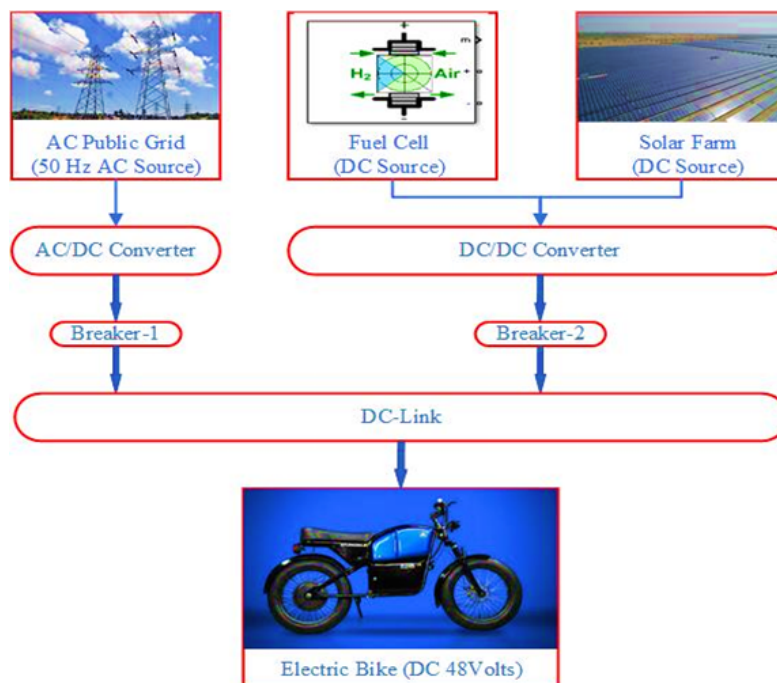


Fig 1. Hybrid Microgrid Arrangement.

In this study, the projected arrangement is mainly based on a DC microgrid consisting of 6 kW FCs and solar PV of 6 kW with the public grid as power sources. All these power sources are converted to DC using converters and centrally linked to charging station with breakers B1 and B2 which facilitates battery charging for EV's as shown in Figure 1. This arrangement uses the public grid as a secondary power source raising the excess sale of energy. This arrangement works in three modes for flexible operation of the system is shown in Table 1 and described below. Mentioned modes of operation are modelled in MATLAB software to check the feasibility of prototype arrangement. The comparative result analysis for all the working modes is done on the basis of their output voltage and charging battery SOC.

During Grid Connected Mode of operation, the breaker B1 is closed and B2 is isolating the renewable power sources. The charging of vehicles will be through the public grid. However, this mode is considered for emergency periods. Hybrid Mode of operation integrates public grid and renewable sources connected to the grid to charge EVs. During the charging, the DG provides generated surplus extra power to the utility grid also.

Table 1. Operating approaches of microgrid arrangement.

Breaker	Grid Associated Mode	Hybrid Mode	Autonomous Mode
B1	ON	ON	OFF
B2	OFF	ON	ON

Autonomous mode can be used when public grid failure/fault happens and grid breaker B1 opens. The power to charging station is fed independently from DC microgrid and power outages can be reduced. It is helpful to loads when the grid is unavailable during contingency periods.

3 Solar Powered Charging Station (Mathematical Modeling)

Mathematical modeling of the proposed system with its input and output components is determined for microgrid architecture. A PV array, FC, and public grid is available with PEC in microgrid. Modeling helps to obtain operational characteristics of connected components for the easy integration of the components and energy flow analysis^(24,25). The electric bike charging at the output side is modeled as Li-Ion batteries for the computation of parameters. The model performance was tested based on charging equations of SOC and voltage behaviors. A brief description of the mathematical modeling of the system is given below:

3.1 PV Array

The solar PV array is considered the most essential and prerequisite sustainable resource due to its free and abundant availability in the atmosphere. The solar power in the model mainly depends upon irradiance and ambient temperature. Solar cell radiation is measured by air mass, incident angle, and radiation to measure cell power (S) given in equation 1 below:

$$S = M(G_b R_b(\tau\alpha)_b) + G_d(\tau\alpha)_d \frac{1 + \cos\beta}{2} + G\rho g(\tau\alpha)_g \frac{1 + \cos\beta}{2} \quad (1)$$

Output power of solar PV is dependent on temperature and irradiance as equation 2.

$$T_{mod} = T_{air} + K_T G \quad (2)$$

Temperature affects the output power of the cell and as temperature goes down the current increases and voltage collapse at a higher rate than current increases. Thus, overall efficiency goes down. This phenomenon can be understood by the formula given in equation 3.

$$\eta_{cell} = \frac{I_{max} * V_{max}}{P_{in}} \quad (3)$$

$$P = P(S, T_{mod}) \quad (4)$$

Equation 5 gives the output power of PV cell in kWh:

$$P = \frac{P_{peak} * S}{1000} \quad (5)$$

The DC/DC converter for power extraction to match the DC bus voltage of the microgrid employed, that gives input-output relation as in equation 6.

$$V_{dc} = \frac{1}{1-D} V_{pv} \quad (6)$$

3.2 FC

It is an electromechanical conversion device, in which electrical energy is produced from chemical energy with water and heat as byproducts using H₂ energy. In existing research, PEMFC is used due to its low-temperature operation suitability and quick response. FC output voltage (V_{FC}) is given by oxidized fuel and electricity is generated as given in equation 7 & power (P_{FC}) is given by equation 8 as:

$$V_{FC} = E - V_{act} - V_{\Omega} - V_{con} \quad (7)$$

$$P_{FC} = N * V_{FC} * I_{FC} \quad (8)$$

The electrical FC efficiency is given by equation 10.

$$\eta_{FC} = \frac{P_{FC}}{M_{H_2} HHV_{H_2}} \quad (9)$$

Nearly, a FC can yield 0.6–0.75 V and the power and voltage level can fluctuate from 2 kW to 50 MW and a couple of volts to 10 kV⁽¹⁰⁾, individually relying upon the connections and picked arrangements plan. The important task in making FCs widely utilized in the DG market is to make them all the more financially serious with the innovations.

3.3 DC/DC Converter

The DC/DC boost converter is needed to boost the generated DC voltage for the conjunction of the required microgrid voltage level. The parameters needed for the computation of power stages are given in equations.

$$D = \frac{1 - V_i(\min) * \eta_c}{V_o} \quad (10)$$

The switching current is derived by the duty ratio of the switch, the switching current and inductor value respectively are given below.

$$I_s(\max) = \frac{\Delta I_L}{2} + \frac{I_o(\max)}{1-D} \quad (11)$$

$$L = \frac{V_i}{\Delta I_L} * \frac{(V_o - V_i)}{f_s * V_o} \quad (12)$$

The input capacitor value mainly depends upon output voltage & current which is employed to attain the essential ripple output voltage which is given below.

$$C_o = \frac{I_o(\max) * D}{f f_s * \Delta V_o} \quad (13)$$

3.4 Modeling of Electrical Vehicle

The electric bike mainly consists of a battery for the power supply source during the running time which leads researchers to develop a battery model for proper mathematical calculations and predictions. The main concern of EV's is their charging behavior with required battery chemistry. The reason to select Li-Ion batteries is that these have a higher coulombic efficiency value than other available batteries. The SOC of battery is characterized as the charging remaining capacity to full charged

capacity as in equation 14:

$$SOC = \frac{Q - Q_{min}}{Q_{max} - Q_{min}} \quad (14)$$

The SOC formula is given by equations 15 & 16.

$$SOC = SOC_0 - \frac{1}{SOC_0} \int i dt \quad (15)$$

$$SOC_v = \frac{1}{a_1} (V_{oc} - a_0) \quad (16)$$

The current-based SOC is denoted by coulomb counted method as in equation 17.

$$SOC_i = \frac{1}{C_p} \left(C_p - \int i dt \right) \quad (17)$$

The systematic correction factor (η) is given below.

$$\eta = \left(1 - \frac{SOC_0}{100} \right) \quad (18)$$

The final equation of SOC can be presented using equation 19.

$$SOC = w * SOC_v + (1 - w) (SOC_i - \eta) \quad (19)$$

Here, w is an additional weighing factor. A Li-Ion battery consists of series resistance, capacitance for ohmic resistance drop, and storage capacitance respectively. The terminal voltage, given by equation 20.

$$V_t = V_{OCV} - V_1 - V_2 - V_3 \quad (20)$$

The SOC of the battery can also be calculated at any time as equation 21.

$$SOC_t = SOC_{initial} - \frac{1}{3600} \int_{t_0}^t i_{battery}(t) dt \quad (21)$$

The battery pack with the terminal output voltage of 48V is directly coupled to the motor drive. The SOC of the battery is presumed to range between 30% to 100%, with an initial SOC of 80%.

4 Designing of Proposed Charging Station for E-Bike

The proposed microgrid for rental bike charging with a 27 Ah battery is designed in Simulink, which is powered by solar PV, FC, and grid. The simulation model is shown in Figure 2 which contains solar PV, public grid, FC, power electronic converters, and bikes battery as load for performance evaluation of charging characteristics. Parametric characterization is used for the customization of these subsystems for the development of a multi-dock charging microgrid.

Solar PV block from Simulink library is used for model development with 25°C temperature and 1000 W/m² irradiance for simulation. The PV array used with 10 parallel strings with 2 series associated cells to each string constituting 6 kW. A PEMFC FC of 6 kW is directly connected to a DC link with a DC-DC boost converter. The model using H₂ as the fuel and O₂ as an oxidant with a cell efficiency of 55%.

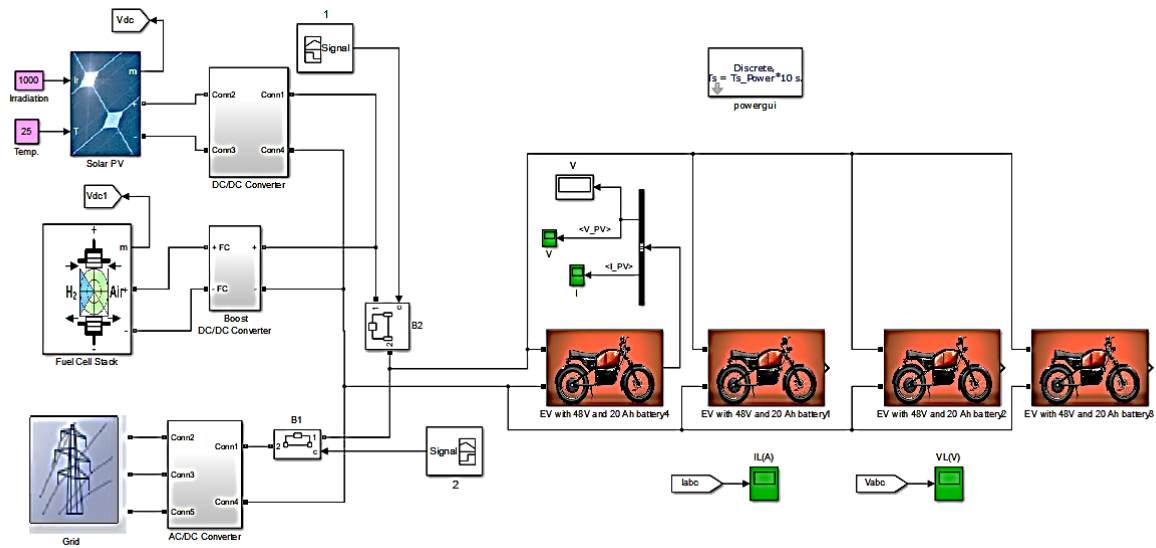


Fig 2. Simulation model of Microgrid arrangement for charging.

Boost converter is employed in the microgrid to step up DC voltage for required grid voltage level with solar PV and FC stack. The P&O MPPT controller is employed to obtain maximum power. The converter has an inductor of 5 mH, the input capacitance of 0.5 μ F and 12 mH respectively. A standard three-phase grid with 220 V and 23000 MVA at 50 Hz is utilized for model realization. The connection of the grid is supported with three-phase AC to DC voltage source converter. The VSC controller works as a regulator in the circuit with feedback of grid current and voltage.

The battery of newly launched electric two-wheelers ATUM 1.0 is considered to be the load that is less costly and suitable for the Indian market and customers. The battery employed is Li-Ion, commonly used in various applications. Specifications of the battery are given in Table 2. Aging and temperature effects are not considered under this study and battery block is taken from the Simulink library of MATLAB.

Table 2. Electric two-wheeler battery model.

S. No.	Parameter	Value
1	Nominal Voltage	48 V
2	Battery Capacity	27 Ah
3	Battery Energy	1300wh
4	Optimal Charging Time	3-4 hours
5	Battery Life Cycle	1000 Cycles
6	Initial Battery SOC	40%

5 Result Discussion

MATLAB was used for validation of DC microgrid model for charging of plug-in electric two-wheeler. The charging station was taken as a standalone microgrid with three modes of operation; grid associated, hybrid and autonomous mode. The grid is directly connected to the two-wheeler charging point which is a block-set of 27 Ah battery. The model was run for a three-second operation (1 second for grid as-associated mode, next 1 second for hybrid mode, and last 1 second for autonomous mode) and SOC variation is evaluated by reducing the battery response time. The model was run on accelerator mode with just a time algorithm. The charging profile of the used battery block system is shown in Figure 3.

During Grid Associated Mode of operation, only the public grid is connected while the DG source is isolated. Figure 3(a) shows the charging SOC and voltage profile during grid associated mode in which the charging rate is around 0.1287% per second during response accelerated mode. The output voltage during this mode is fluctuating between the ranges 43.736 to 56.981 which contains ripple in output voltage because during rectification AC waveform ripple was not fully suppressed. Ripple

content in waveform incurs some reduced power loss efficiency and this ripple can be removed by using filters or improved regulator at the output. The capacitor can also be employed to reduce the same.

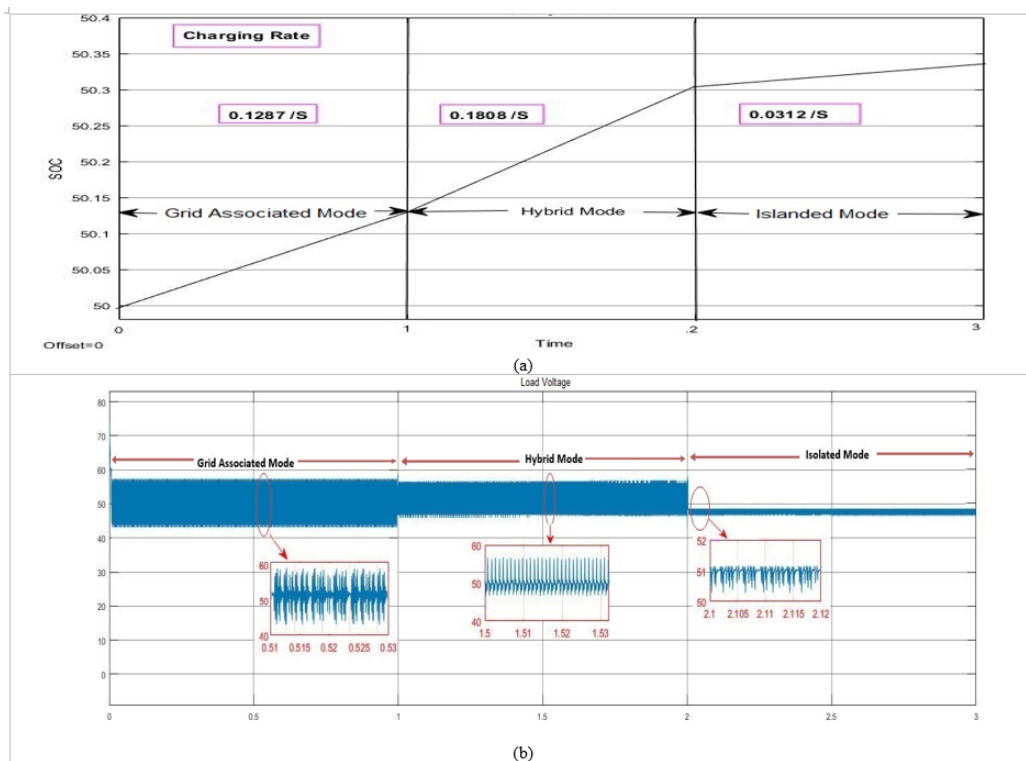


Fig 3. Simulation model of Microgrid arrangement for charging.

The battery charging rate is around 0.1808% per second with an injection of DC sources FC and solar PV which can be noted from figure 3(a) during hybrid mode. Hence, the ripple in voltage profile is less than compared to grid associated mode and the range of output voltage ranges between 46.927 to 54.712 V.

Islanded Mode works when the grid is not available due to fault or abnormality i.e. solar PV & FCs are being employed. The battery charging rate is around 0.0312% per second. The voltage ripple is also very less because only DG sources are working and the major AC source (public grid) is disconnected. The output ripple voltage range is around 47.106 to 48.293 V. Simulink model, efficiency & reliability of charging station is also improved during the off-grid period.

6 Conclusion

Electric vehicles are more popular due to less running costs and they doesn't emit environmental polluting agents. Electric two-wheelers have been more pocket-friendly as they can run for a 100 km distance with only 1 kWh of electric energy consumption. Market of electrical vehicles is growing rapidly but the lack of charging stations affects it negatively. This paper is devoted to design a charging station powered by a public grid as well as FC & solar PV-based RE sources. The study presents mathematical modeling of individual components along with a complete integrated arrangement. The proposed work is simulated and implemented in MATLAB and its feasibility is tested with RE sources. The islanded mode of operation also reduces the power burden on the public grid and it can also be used during grid failure or unavailability. The implemented model has an ideal electric two-wheeler Li-Ion battery with its parameters to charge it. The proposed model has the feasibility of charging methodology by integrating the renewable sources into the system. This manuscript haven't considered any method for cost analysis, vehicle dynamics, and battery management system.

The future scope of this work can also be extended for reducing the ripple in output voltage by using filters or other arrangements. The optimization methods can also be implemented for power flow, cost analysis and economic analysis can also be performed for the charging station.

7 Acknowledgement

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8 Nomenclature

List of Symbols	Column1	Vo	Voltage output
	Cell Power	Vi	Input voltage
w/m ²	Electric Solar Power Output	Io	Output Current
G	Solar Radiation	fs	Switching Frequency
	Beam		Efficiency of converter
D	Diffuse	Q	Currently stored charge
Pg	Ground	Qmax	Maximum charge in battery
M	Air Mass Modifier	Qmin	Minimum charge in battery
B	Angstrom Turbidity Constant	SOC0	Initial SOC
Rb	Ratio of beam Radiation	SOCv	Voltage based SOC
Tα	Fraction absorbed by absorber plate	a0	Terminal voltage at 0% SOC
Tmod	Temperature of Module	a1	Terminal voltage at 100% SOC
Tair	Temperature of Air	Cp	Battery capacity in Ah
KT	Clearness Index of Location	H	Systematic correction factor
Vmax	Maximum voltage	R0	Ohmic resistance drop
Imax	Maximum current	Cs	Storage capacitance
Pin	Input Power	Rd	Diffusion resistance drop
kWh	Power of Cell	Cd	Diffusion capacitance
Vpv	PV Array Voltage	Vt	Terminal voltage
Vdc	DC Bus Voltage	Vo	Output voltage
IL	Ripple current		
D	Duty Ratio	Abbreviations	
VFC	Fuel Cell Output Voltage	INR	Indian rupees
mH	Mili henry	VSC	Voltage source converter
E	Internal voltage of fuel cell	DG	Distributed generation
	Activation voltage	PE	Power electronics
Vcon	Concentration Voltage	DC	Direct current
PFC	Fuel Cell Output power	PV	Photovoltaic
	number of cells	PEMFC	Proton exchange membrane fuel cell
IFC	Fuel cell current	Li-Ion	Lithium-ion
MH2 (kg/s)	mass flow rate	EV	Electric vehicle
HHVH2	higher heating value of the hydrogen	SC	supercapacitor
Ah	Ampere-hour	CAGR	Compound annual growth rate
fs	Switching Frequency	AC	Alternating current
	Efficiency of converter	PEC	Power electronics converter
Vi	Input voltage	SOC	State of charge
Io	Output Current		

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