ANN Optimized Hybrid Energy Management Control System for Electric Vehicles

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Abstract: The automobile industry is focusing on renewable power sources for driving Electric Vehicles (EVs), which results in the reduction of pollution. This paper presents an Artificial Neural Network (ANN) optimized hybrid Energy Management System (EMS), which was designed for solar Photovoltaic (PV) Electric Vehicles (EVs). In the proposed EMS, two DC-DC converters are utilized, namely a High Gain Interleaved Boost Converter (HGIBC) and a conventional boost converter. The main use of the HGIBC is to harvest maximum power from the solar PV panel which is accomplished with the help of a Model Predictive Controller (MPC) and the other DC-DC converter is used for maintaining the DC link voltage constant. The model predictive controller not only controls the parameters involved,but it can also predict a future change in these parameters, which cannot be performed by conventional controllers. The purpose of this paper is to proposea hybrid energy supply systemfor EVs based on a Battery and an Ultra-Capacitor. The energy of the battery and of the UC is controlled by an ANNcontrollerand also evaluated by means of a conventional PI controller. Based on the simulation results, it can be concluded thatthe ANN controller showed a better performance in comparison with the Proportional Integral (PI) controller. The entire structure wasanalysedfor various conditions of the State of Charge (SoC) of the Battery using MATLAB/Simulink.

Keywords: Electric Vehicle, Artificial Neural Network, EMS, HGIBC, MPC.

1. Introduction

The demand for sustainable energy sources has been increasing drastically for the last few years due to their remarkable benefits. The field of the automobile industry also shows a huge interest in the utilization of sustainable energy sources which leads to a reduction in usage of fuel resulting in a huge reduction in carbon emissions from the conventional electric vehicle (Ravipati et al., 2021). Solar Photovoltaic (PV) energy has been chosen as a source among the several sustainable energy sources due to its huge availability (Gulagi et al., 2020). Furthermore, PV energy is implemented along with the battery source. In modern technologies, multiple energy sources are integrated with proper control schemes. In this sense, to extract available power from the PV panel, different types of Maximum Power Point Tracking (MPPT) techniques have been investigated by the researchers (Kamran et al., 2020). The voltage obtained from the solar PV panel is not enough for driving electric vehicles. Therefore, it is necessary to introduce an intermediate stage which is called the DC-DC conversion stage for enhancing input voltage and this converter is acting as a bridge between the solar PV panel and power converter conditioning units (Lakshika et al., 2020). Various types of converters are used as intermediate DC-DC converters for electric vehicles such as isolated and non-isolated converters (Bairabathina & Balamurugan, 2020). Among the DC-DC converters, non-isolated converters are highly recommended for an electric vehicle due to the absence of a transformer, but their efficiency is inferior to that of an isolated converter (Chakraborty et al., 2019). Among the non-isolated converters, interleaved converter offers superior performance concerning the low ripple current, higher operating efficiency, smaller filtering requirements, and higher output voltage with lower duty cycles (Lipu et al., 2021). Therefore, interleaved DC-DC converter has been chosen for harvesting power from the solar PV panel. As itharvests maximum power from the PV panel, MPPT system is an essential part of the PV power system. To obtain maximum power from the PV panel under operating systems in different environments, an intermediate DC-DC converter is used for implementing different MPPT control algorithms (Raj & Praveen, 2022). Amongst MMPT control algorithms, Perturb and Observation (P&O) and Incremental Conductance (INC) achieve an excellent performance and are commonly applied for harvesting power from the Solar PV panel (Mohamed & Abd El Sattar, 2019). Even though the performance of such MMPT control algorithms has its drawbacks, and to overcome the drawback of such control algorithms, Fuzzy Logic MPPT (Muhannad Al Shareef, 2021),

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ANN MPPT, and Genetic Algorithm have been applied to track power from Solar PV panel (Baba et al., 2020). From the literature review, it is found that the static and dynamic response is poor in variable weather operating conditions. To improve dynamic response during weather changing conditions, high computational knowledge is essential. Hence, MPC has been used which predicts the variations in the future output based upon the past and present change in the voltage, current, and power parameters (Irmak & Güler, 2020). With consideration of manufacturing cost, control, and energy savings, different types of electric vehicles were manufactured such as Plug-in Electric vehicles (PHEVs), Hybrid Electric Vehicles (HEVs), Battery Electric Vehicles (BEVs), and Fuel Cell Electric Vehicles (FCEVs). The management of energy is a very difficult task, especially in battery-powered electric vehicles. A single energy source cannot fulfill the continuous load requirements as it is not available all the time and so auxiliary sources are required for reducing interrupted power supply problems. Two energy storage devices named battery and ultra-capacitor have been chosen for storing excess energy and delivering the energy during source off-state due to their advantages like higher specific power, lower charging time, good stability, and higher efficiency (Castro-Gutiérrezet al., 2020). In the source off-state, the storage devices should sustain the DC link voltage at a rated value and so to direct the flow of energy from the energy storage devices and to maintain the DC link voltage. For this bi-directional converters have been chosen which have certain advantages like allowing the flow of power in both directions therefore charging and discharging of the storage devices can be done based upon the input source which is not possible in unidirectional converters (Rojas-Dueñas et al., 2021). For controlling the operation of bidirectional converters to maintain constant DC links, an energy management technique has been proposed. An electric vehicle is greatly dependent on the limited electric power provided by way of a battery, the power flow control is essential in this context. To control power flow to the electric vehicles, various types of controllers are applied such as conventional PID, Fuzzy logic, and ANN controllers. The fuzzy logic controller is popular in the control of power flow to electric vehicles (Ishaque et al., 2021). In spite of that power flow performance depends on the membership functions, and optimal power is not assured. Hence, an ANN-based energy management system is applied to electric vehicles for smooth power control of batteries and ultra-capacitors (Yavasoglu et al., 2020). The simulation resultsfor the proposed EMS system are obtained in various operating conditions is shown in Figure 1 and verified through MATLAB/Simulink.

The rest of this paper is structured as follows. Section 2 presents the contributions and the proposed ANN EMS is described in Section 3. Section 4 set forth the MPC-MPPT control and Section 5 presents the ANN-EMS control system. Simulation results and comparative analysis of the proposed system and performance parameters are discussed in Section 6. Finally, Section 7 includes the conclusion of this paper.

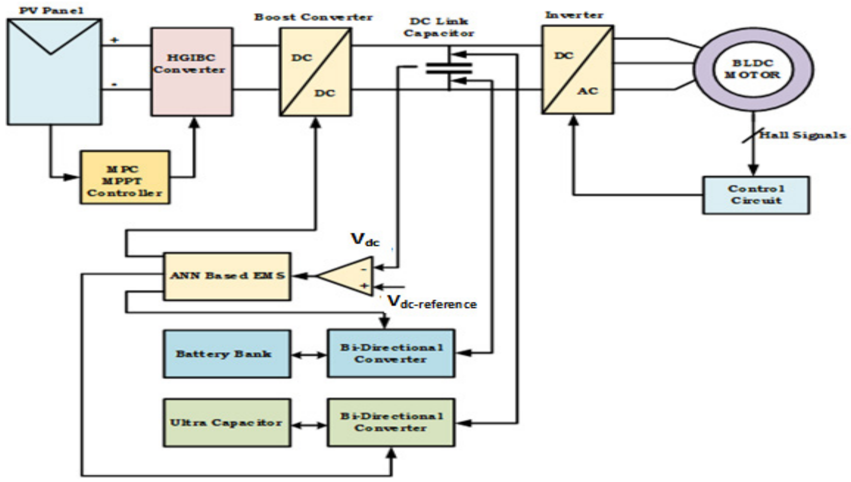

Figure 1. ANN-based Hybrid EMS

2. Contributions

The goal of this work is to provide a power management system that can act as a controller to coordinate power transfer between the battery banks, ultra-capacitors, MPPT-based PV panels, and the DC link in a Hybrid Electric Vehicle. Battery and Ultra-capacitor are used as backup sources for the proposed system. These energy storage devices are used to store excess energy from solar PV through bidirectional DC-DC converter and discharge the energy to the electric vehicle when required,as the PV power output has a variable nature and it depends on the amount of insolation and irradiance falling on the PV panel. There are many MPPT control techniques which have been discussed in the literature. In order to track maximum power from PV panels Model Predictive Controller (MPC) has been used. MPC controller not only controls the parameters involved but also predicts the future change in the PV parameters which maynot be performed byother MPPT controllers like PI and Fuzzy controllers. The hybrid EMS has been controlled with the proposed controller whose performance is tested in comparison with that of PI and ANN controllers where the storage devices are monitored with variation of gains in PI, and of weights in ANN where the neural network is estimated to improve the performance of energy storage devices better than the PI controller. To validate the results of the proposed system, a comparison is made with respect to current and power by using both PI and ANN controllers. The disadvantages of PI controller are that it givesriseto a higher maximum deviation, a longer response time and a longer period of oscillation. The ANN shows a better performance in comparison withthe PI controller in terms of solar output, UC power by 2.1% and also maintains a stable output The proposed system is implemented by using MATLAB/Simulink and simulation results are expressed for irradiation variation with MPPT controller and power coordination between PV cell, battery and UC.

3. The Proposed EMS System

The ANN-based hybrid energy management control system for an EV is shown in Figure 1. It consists of a HGIBC, maximum power point tracker, MPC controller, an energy management system based on an artificial neural network, boost converter, inverter, and Brushless DC Motor. When the solar rays are projected upon the panel, it generates DC electrical energy which is fed to the HGIBC. The interleaved converter boosts up the voltage from the solar panel upon obtaining the pulse from the MPPT fed MPC. A MPPT has been used for tracking the maximum output from the solar panel and to attain a fast dynamic response MPC has been used which predicts the future change in the employed variables with the help of past and present change in the variables. In the proposed Hybrid EMS, two DC-DC converters are used. The output of the high gain interleaved boost converter will be controlled by the MPPT fed MPC whose output is again fed to the boost converter. The boost converter again boosts the voltage which maintains the constant DC voltage at the link. The actual DC voltage at the DC-link is compared with the reference voltage ($V_{dc\text{-}reference}$) and then the error voltage is fed to the energy management system. This involves the usage of the Artificial Neural Network (ANN) for controlling the static and dynamic response of the bi-directional converters for continuous power flow to the electric vehicles (Wang et al., 2021). Two energy storage devices named battery and UC have been used which are connected to the inverter which converts the DC energy into three-phase AC energy. The output from the inverter drives the brushless DC motor. The bi-directional converters are used at the energy storage devices which buck or boost the supply based upon the DC-link capacitor voltage. The pulses for the bi-directional converters are fed from the energy management system for calculating the DC-link voltage. The relation between the input voltage and output potential of the interleaved boost converter can be given as:

$$\frac{V_o}{V_{in}} = \frac{1+D}{1-D} \tag{1}$$

D-duty cycle. The relation between input voltage and output voltage of the second converter at the DC link can be given as

$$\frac{V_o}{V_{in}} = \frac{1}{1-D} \tag{2}$$

The bidirectional converter is a converter that allows the flow of power in both directions from the source to the load and also from the load to the source. The proposed bi-directional converter allows the flow of power from the PV panel to the battery and UC where both storage devices charge. Also, with the help of a bidirectional converter, in the case of the absence of a source, the load will run with the discharging of the battery and UC. The operation of the bidirectional converter for boost mode and buck mode is shown in Figures 2 and 3, respectively.

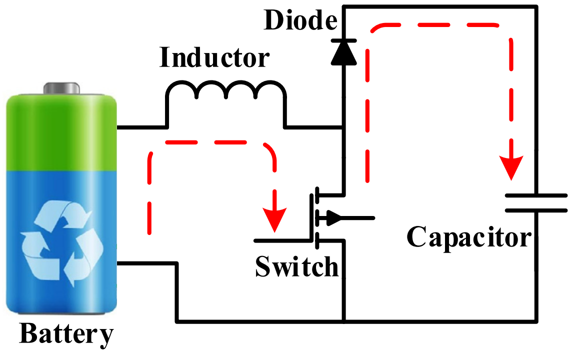

Figure 2. Boost mode

At the time switch is closed, the energy in the battery gets transferred to the inductor and the inductor charges, and at the instant, a switch is in off position, the diode is forward biased and the energy is transferred to the DC link which is boosted.

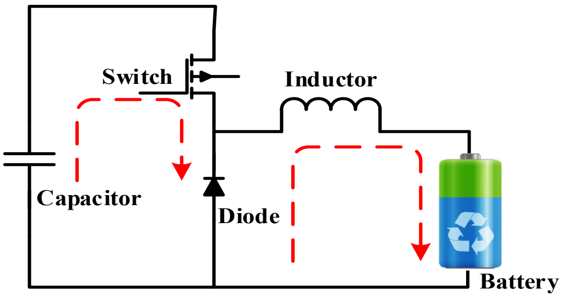

Figure 3. Buck mode

When the switch is closed, the energy across the capacitor is transferred to the inductor and then to the battery, and the buck operation is performed. At the instant switch is in off position, the diode is forward biased and the inductor is discharged through the battery.

4. MPC-MPPT Control

The energy from sustainable sources like wind force is changeable due to the rapid changes in climatic conditions. So, a tracker is necessary to sustain the output of the energy and provide a maximum output based on the varying weather conditions. Therefore, a maximum power point tracker is used which continuously tracks the voltage and current of the solar panel. Also, to manage the static and vibrant response of the tracker system, aMPChas been used to control the future variables and its block diagram is shown in Figure 4.

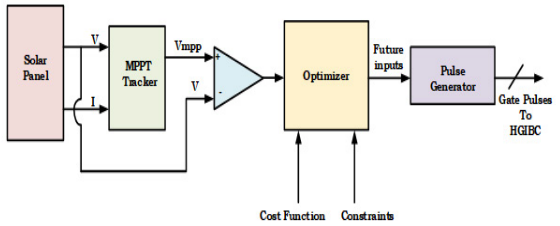

Figure 4. MPC-Based MPPT control

The solar PV panel generates a DC supply whose voltage and current parameters are directed to the tracker which tracks the maximum voltage. Then the maximum voltage of the solar panel is compared with the actual voltage obtained from the solar panel whose error is fed to the MPC which consists of an optimizer that aims to minimize the cost function using constraints. The MPC generates a future change in variables which are fed to the pulse generator providing gate pulses to the interleaved boost converter. The basic principle of MPC is optimizing the current parameters while controlling the future parameters and it is fulfilled by optimizing the time period. It can predict future actions and organize the system. This controller is based on the repetitive finite sphere emulation of the system and at the time of [t], the existing system situation is sampled and a cost-reducing approach is evaluated [t+T]. An online calculation is used to provide state trajectories that emerge from the current state, finding a cost minimizing control technique utill [t+T]. The controlling strategy starts from the first stage, then a sampling of the plant state occurs and the computations are continual from the novel present state, generating a new control, and predicted situation. The forecasted horizon keeps on shiftingforward and so it is also known as receding horizon power. The MPC procedure is as follows:

i. It confines the static and dynamic relations among the input, output, and the disturbance parameters;

ii. Reconstraints on the input and output parameters are measured in a methodical way;

iii. Control computations are synchronized with the finest setpoints.

Figure 5 represents the block diagram of MPC. The prediction controller consists of four variables namely measured output which is the actual output of the system, a measured variable which is the processed error, a measured disturbance which is the error between the two above-mentioned variables.

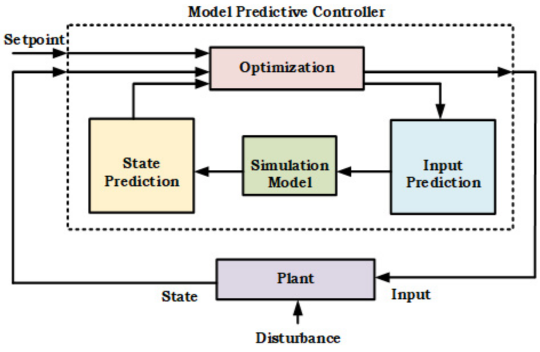

Figure 5. Block diagram of MPC

Equation (3) provides a nonlinear cost function for optimization and can be given as

$$F = \sum_{i=1}^{N} h_{x_i} (r_i - c_i)^2 + \sum_{i=1}^{N} h_{y_i} \Delta m_i^2 \tag{3}$$

where c_i is the i^{th} controlled variable, r_i is the i^{th} reference variable, m_i is the i^{th} reference manipulated variable, h_{x_i} and h_{y_i} are the weighted coefficients.

5. ANN-EMS Control System

The proposed ANN-based energy management system is designed for continuous power to the electric vehicles from battery and UC (Wahab et al., 2020). The proposed ANN consists of one input layer, one hidden layer, and one output layer containing one input and one output. The input at the input layer is the error value which is fed to the hidden layer through the activation function. The expression for the net input at the hidden layer can be given as:

$$X_{net} = \sum_{i=1} x_i w_i \tag{4}$$

where x_i is the input vector and w_i is the weighting vector. The net input at the hidden layer is passed through the tangential sigmoid activation function to the output layer and can be given as:

$$Y = \tan\left(\operatorname{sgn}\left(X\right)\right) \tag{5}$$

The net input at the output layer is passed through the linear activation function which can be given as:

$$Z = f\left(Y\right) = Y \tag{6}$$

Solar PV energy is available only at sunlight hours and cannot be available during the hours of darkness. Therefore, storage devices are required for storing the excess energy which can be utilized during the absence of solar energy. Two energy storage devices named lead-acid batteries and UC are used for storing energy with the help of bi-directional converters. The bi-directional converters operate with the gate pulses specific to the energy management technique. The energy management technique controls the DC-link voltage and also controls charging and discharging state of the energy storage devices. The flowchart for the energy management technique directs the charging and discharging states of the battery and UC. The block diagram of the hybrid power

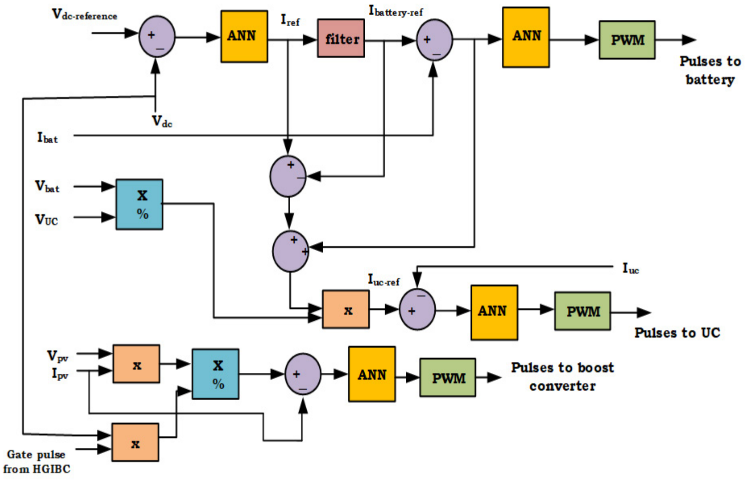

Figure 6. Hybrid EMS power storage control

storage control scheme is shown in Figure 6. The actual DC-link capacitor voltage will be evaluated with the reference capacitor voltage and the error will be fed to an ANN that processes the error. The reference battery current is generated. An error that is again compared with the actual battery current. Then the error between the rated battery current and real battery current is again fed to the ANN generating gate pulses to the bi-directional converter connected to the battery. The reference UC current is generated from the battery and UC voltages and also from the battery and UC currents. Then the reference ultra-capacitor current is evaluated with the real UC current and the error will be directed to the ANN which processes the error, where the processed error generates gate pulses to bi-directional converter connected to UC. The gate pulse to the boost converter at the DC-link is generated from the solar panel voltage, current, and also from the DC-link voltage, gate pulse of the HGIBC. The flow chart of hybrid EMS power storage control is shown in Figure 7.

6. Simulation Results and Discussion

The proposed ANN-based hybrid EMS has been simulated using MATLAB/Simulink while being subjected to the irradiations at different SoC conditions. The proposed hybrid EMS scheme has been simulated with an ANN controller with various irradiations and Figure 8 shows the I-V curves of the solar panels with G=250W/m^2, 500 W/m^2, 750 W/m^2 and 1000W/m^2.

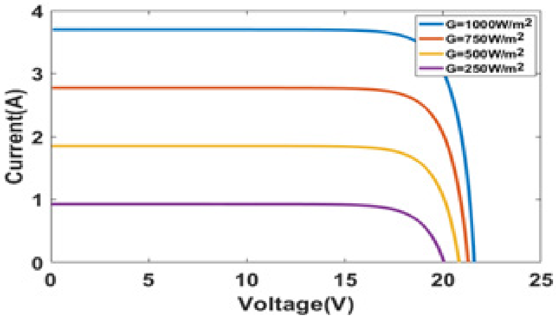

Figure 8. I-V curves of solar panel

Figure 9 shows the P-V curves of solar panel with G=250W/m^2, 500W/m^2, 750 W/m^2 and 1000W/m^2.

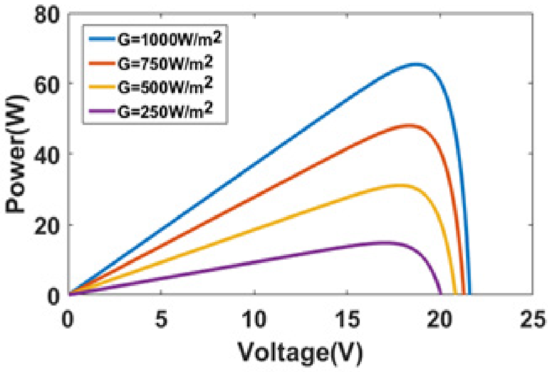

Figure 9. P-V curves of solar panel

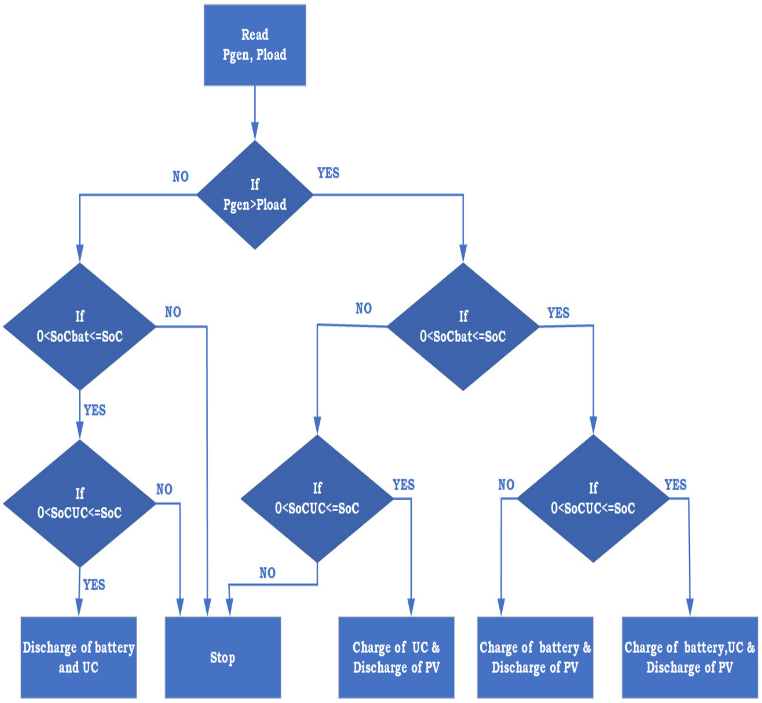

Figure 7. Flow chart of hybrid EMS energy storage control

The simulation results have been analyzed for various conditions of the State of Charge (SoC) of battery like SoC>50 with variable irradiations, 50<SoC>0 with variable irradiations andSoC<20with variable irradiations.

Test case (i): SoC>50 variable irradiations

The performance of the hybrid EMS has been evaluated for both battery and UC concerning various parameters. In test case (i), for the time periods from t=0 to t=0.6 seconds andsimilarly for t=0.6 to t=0.8 seconds and for t=0.8 to t=1 seconds, a change in irradiations from 250 to 500 W/m^2, from 500 to 750 W/m^2 and from 750 to 1000 W/m^2 has been provided. Figures 10 and 11 show the current and power through solar panel, battery current and power, the ultra-capacitor current and power, and the load current and power which are constant, respectively.

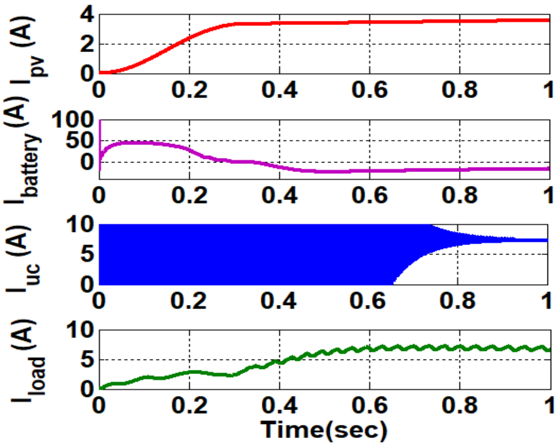

Figure 10. Test case (i)PVcurrent, Battery current, UC current, and load current

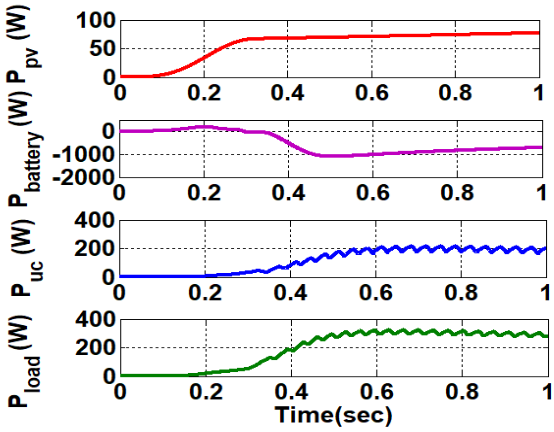

Figure 11. Test case (i)PV power, Battery power, UC power, and load power

Test case (ii): 50< SoC>0 variable irradiations

In test case (ii), for the time periods from t=0 to t=0.6 seconds andsimilarly for t=0.6 to t=0.8 seconds and for t=0.8 to t=1 seconds, a change in irradiations from 250 to 500 W/m2, from 500 to 750 W/m2 and from 750 to 1000 W/m2 has been provided.

Figures 12 and 13 show the current and power through solar panel which increases with the increase in irradiation, the current and power of the battery which initially discharges and with an increase in irradiations, it charges, the ultra-capacitor current and power which is reduced to rated value from a higher unstable value and the load current and power which are constant.

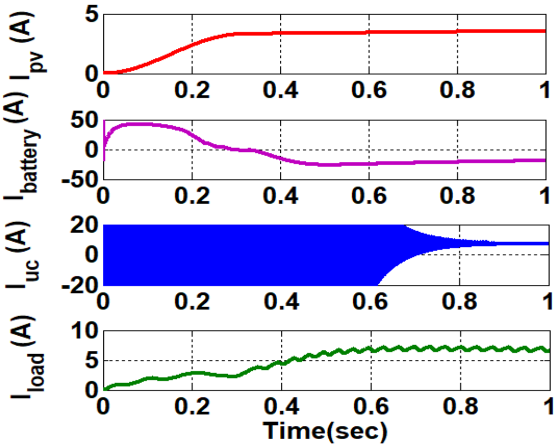

Figure 12. Test case (ii)PV current, Battery current, UC current and load current

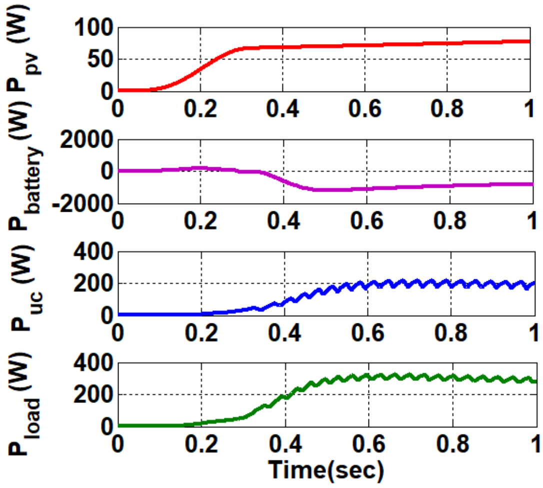

Figure 13. Test case (ii)PV power, Battery power, UC power, and load power

Test case (iii): SoC<20 variable irradiations

In test case (iii), for the time periods from t=0 to t=0.6 seconds and similarly for t=0.6 to t=0.8

seconds and for t=0.8 to t=1 seconds, a change in irradiations from 250 to 500 W/m^2, from 500 to 750 W/m^2 and from 750 to 1000 W/m^2 has been provided. Figures 14 and 15 show the current and power through solar PV panel which increases with the increase in irradiation, the current and power of the battery which initially discharges and with an increase in irradiations, it charges, the ultra-capacitor current and power and load current and power which are constant.

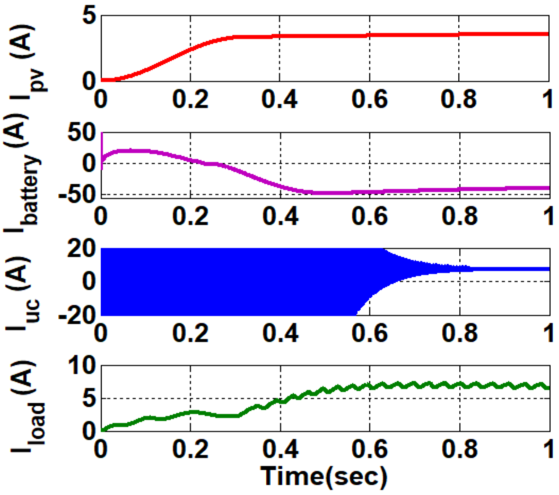

Figure 14. Test case (iii) PV current, Battery current, UC current and load current

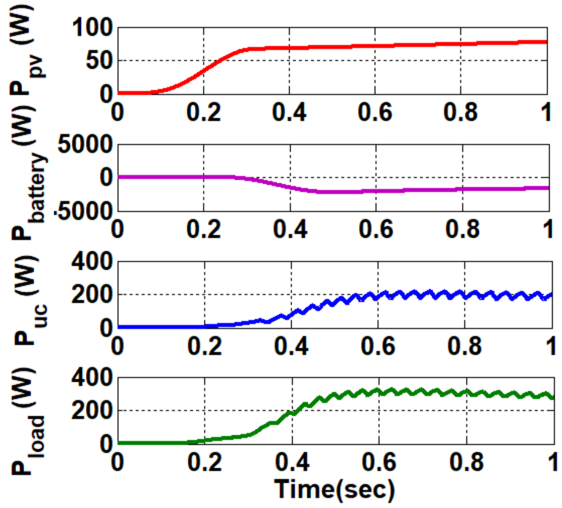

Figure 15. Test case (iii) PV power, Battery power, UC power, and load power

Hybrid EMS-Comparative Analysis

A comparative analysis for the Hybrid EMS has been made for various parameters using PI and ANN controllers.

Table 1. Test case(i) PI and ANN Based Hybrid EMS

Parameters	PI	ANN
I_{pv}	3.6A	3.62A
$I_{battery}$	Charging	Charging
I_{uc}	6.8A	6.83A
I_{load}	7.1A	7.11A
PV_{power}	75W	76.1W
$P_{battery}$	Charging	Charging
P_{uc}	295W	296.3W
P_{load}	350W	351.2W

Table 1 gives the comparison of the performance of the PI and ANN controllerfor energy managing purposes and also for SoC>50. With regard to the current through UC and power through UC, the ANN outperforms the PI controller.

Table 2 gives the comparison of the performance of the PI and ANN controllerfor energy managing purposes and also for 50<SoC>0, where the ANN shows better performance than the PI controller in terms of current through UC and power through UC.

Table 2. Test case(ii) PI and ANN Based Hybrid EMS

Parameters	PI	ANN
I_{pv}	3.65A	3.66A
$I_{battery}$	Charging	Charging
I_{uc}	6.83A	6.85A
I_{load}	7.25A	7.27A
PV_{power}	77W	79W
$P_{battery}$	Charging	Charging
P_{uc}	297W	298W
P_{load}	352W	353W

Table 3 gives the comparison of the performance of the PI and ANN controller for energy managing purposes and also for SoC<20, where the ANN shows superior performance to the PI controller in terms of current through UC and power through UC.

Table 3 .Test case(iii) PI and ANN Based Hybrid EMS

Parameters	PI	ANN
I_{pv}	3.8A	3.82A
$I_{battery}$	Charging	Charging
I_{uc}	6.91A	6.95A
I_{load}	7.29A	7.31A
PV_{power}	79W	79.5W
$P_{battery}$	Charging	Charging
P_{uc}	300.5W	300.9W
P_{load}	355W	356W

Comparison with Existing Work

The above tables show the comparison of PI and ANN controllers for various irradiations in terms of currents and also power values through the battery, ultra-capacitor, load and solar panel. Here, the neural network shows a better performance than that of the PI controller in terms of solar output and UC power by 2.1% (Saha & Dey, 2019) while the current through UC is lower with the PI controller.

7. Conclusion

This paper presents an Artificial Neural Network (ANN) optimized hybrid Energy Management System (EMS) which was designed for the effective power management control for EVs. In the proposed hybrid EMS, two DC-DC converters have been utilized for MMPT and to maintain the DC-Link voltage constant. AMPC has been applied to a solar PV panel for the harvesting of electrical power. The hybrid energy storage system was controlled through the proposed system whose performance was tested with a PI and ANN controller, where the ANN showed a better performance in comparison with the PI controller in terms of PV output and UC power by 2.1%, and also maintained a stable output. Based on the simulation results, it has been concluded that the ANN controller achieved a better performance in comparison with the Proportional Integral (PI) controller. The entire structure was analyzed for various conditions of the State of Charge (SoC) of the Battery using MATLAB/Simulink.

REFERENCES

Al Shareef, M. (2021) An Improved MPPT Method Based on Fuzzy Logic Controller for a PV System. *Studies in Informatics and Control*. 30(1), 89-98. doi: 10.24846/v30i1y202108

Baba, A. O., Liu, G. & Chen, X. (2020) Classification and evaluation review of maximum power point tracking methods. *Sustainable Futures*. 2, 100020.

Bairabathina, S. & Balamurugan, S. (2020) Review on non-isolated multi-input step-up converters for grid-independent hybrid electric vehicles. *International Journal of Hydrogen Energy.* 45(41), 21687-21713.

Castro-Gutiérrez, J., Celzard, A. & Fierro, V. (2020) Energy storage in supercapacitors: Focus on tannin-derived carbon electrodes. *Frontiers in Materials*. 7, 217.

Chakraborty, S., Vu, H. N., Hasan, M. M., Tran, D. D., Baghdadi, M. E. & Hegazy, O. (2019) DC-DC converter topologies for electric vehicles, plug-in hybrid electric vehicles and fast charging stations: State of the art and future trends. *Energies*. 12(8), 1569.

Gulagi, A., Ram, M. & Breyer, C. (2020) Role of the transmission grid and solar wind complementarity in mitigating the monsoon effect in a fully sustainable electricity system for India. *IET Renewable Power Generation*. 14(2), 254-262.

Irmak, E. & Güler, N. (2020) A model predictive control-based hybrid MPPT method for boost converters. *International Journal of Electronics*. 107(1), 1-16.

Ishaque, M. R., Khan, M. A., Afzal, M. M., Wadood, A., Oh, S. R., Talha, M. & Rhee, S. B. (2021) Fuzzy Logic-Based duty cycle controller for the nergy management system of hybrid electric vehicles with hybrid energy storage system. *Applied Sciences – Basel*. 11(7), 3192.

Kamran, M., Mudassar, M., Fazal, M. R., Asghar, M. U., Bilal, M. & Asghar, R. (2020) Implementation of improved perturb & observe MPPT technique with confined search space for standalone photovoltaic system. *Journal of King Saud University-Engineering Sciences*. 32(7), 432-441.

Lakshika, K. H., Boralessa, M. K. S., Perera, M. K., Wadduwage, D. P., Saravanan, V. & Hemapala, K. M. U. (2020) Reconfigurable solar photovoltaic systems: A review. *Heliyon*. 6(11), e05530.

Lipu, M. S. H., Faisal, M., Ansari, S., Hannan, M. A., Karim, T. F., Ayob, A., Hussain, A., Miah, M. S. & Saad, M. H. M (2021) Review of Electric Vehicle Converter Configurations, Control Schemes and Optimizations: Challenges and Suggestions. *Electronics*. 10(4), 477.

Mohamed, S. A. & Abd El Sattar, M. (2019) A comparative study of P&O and INC maximum power point tracking techniques for grid-connected PV systems. *SN Applied Sciences*. 1(2), 174.

Raj, A. & Praveen, R. P. (2022) Highly efficient DC-DC boost converter implemented with improved MPPT algorithm for utility level photovoltaic applications. *Ain Shams Engineering Journal*. 13(3), 101617.

Ravipati, S., Mani, V. & Yarlagadda, S. R. (2021) Efficient Control of Sensorless Hybrid Electric Vehicle Using RBFN Controller. *Studies in Informatics and Control*. 30(4), 87-97. doi: 10.24846/v30i4y202108.

Rojas-Dueñas, G., Riba, J. R. & Moreno-Eguilaz, M. (2021) Modeling of a DC-DC bidirectional converter used in mild hybrid electric vehicles from measurements. *Measurement*. 183, 109838.

Saha, R. & Dey, J. (2019) PV, battery and ultra-capacitor based hybrid energy storage system. In: *Proceedings of The 2019 IEEE 16th India Council International Conference, Indicon.* pp. 1-4.

Wahab, N. A., Yasin, Z. M., Salim, N. A. & Aziz, N. F. A. (2020) Artificial neural network based technique for energy management prediction. *Indonesian Journal of Electrical Engineering and Computer Science*. 17(1), 94.

Wang, H., Li, Y., Tian, Y. & Wang, C. (2021) *Model-Free DC Bus Voltage and Energy Management Control for Fuel Cell Hybrid Electric Vehicle*. Studies in Informatics and Control. 30(4), 19-30. doi: 10.24846/v30i4y202102

Yavasoglu, H. A., Tetik, Y. E. & Ozcan, H. G. (2020) Neural network-based energy management of multi-source (battery/UC/FC) powered electric vehicle. *International Journal of Energy Research*. 44(15), 12416-12429.