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Original Article

Design and Performance Analysis of Multilayer Neural Network-based Battery Energy Storage System for Enhancing Demand Side Management

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Abstract - *Fossil fuel-based power plants are harmful to the environment because it releases greenhouse gases. Also, the availability of fossil fuels is going to run out in the near future. Hence, Renewable Energy Sources (RES) play a vital role in power generation to meet the required energy demand. Since RES are ubiquitous, the earth's surface is blessed with a huge amount of energy resources. The electrical energy from RES is harnessed using suitable energy conversion devices such as solar PV, wind turbine, water turbine, etc. However, RES is seasonable and not available in a unique manner in all areas. Therefore, interconnecting to the grid is a crucial task that may raise stability issues. Hence, an accurate Demand Side Management (DSM) system is required to maintain grid stability. Moreover, DSM can reduce peak energy consumption from the grid using an accurate DSM system. The proposed system has Artificial Neural Network (ANN) based battery storage system. ANN controls the battery by using certain critical parameters such as the off-peak period, peak period, and state of charge of the battery. The ANN-based management system has been developed in MATLAB Simulink. From the results obtained, it is understood that the battery management system supplies the electrical energy to the grid during peak periods, reducing the burden on the main grid and storing the electrical energy during an off-peak period. Hence, the required size of generating units is reduced; therefore, ANN-based DSM optimizes the cost.*

Keywords - *Artificial neural network, Battery energy storage system, Demand side management, Microgrid.*

1. Introduction

Due to the rapid growth of population and industrialization, the demand for electrical energy has increased rapidly. Traditionally most power-generating units produced electrical energy from fossil fuels such as coal and diesel [1]. In developing countries like India, much electrical energy is generated from coal-based power plants. According to Indian government data, more than 60% of electrical energy was generated from coal-based power plants. However, many initiatives have been carried out on power generation to meet the Paris agreement. Coal-based power plants harm the environment because fossil fuels emit greenhouse gases such as NOx, Cox, and sulphur during the burning process [2]. Besides depletion rate of fossil fuels is very high. Hence, traditional fuels cannot satisfy future energy demands.

Consequently, Renewable Energy Sources (RES) are getting high attention in power generation as they are omnipresent and environmentally free [3]. Using suitable energy conversion devices or techniques, this electrical energy has been harnessed from natural resources such as sun, wind, and hydro. Usually, RES generates electrical energy and utilizes it to meet the local load; hence it can be called decentralized power generation. However, RES varies seasonably; therefore, interconnecting DC with the grid causes stability issues [4]. In conventional power systems, power flow is in unidirectional and top-down approaches. The limitation of RES is that only small-scale power generation can be integrated. But integrating a larger number of power generation units into the existing grid is difficult [5].

So existing grid cannot be able to satisfy future demands. Furthermore, maintaining power demand and supply at a balanced condition is crucial since the grid's load continuously increases over the years. Consequently, many technologies have been incorporated with existing power systems to maintain power system stability. The microgrid can interconnect RES with the utility grid. The Micro gird formed by the various distributed energy systems is interconnected [6, 7]. The Flywheel Energy Storage System with wind and solar power systems working in micro-grids is explained in [15]. Integration of the energy storage system in the power system is explained in [17]. A smart energy storage system for electric vehicles is discussed in [18]. The micro-grid system's electric vehicle used as a storage device is explained in [19]. Energy Storage Battery System for a Wind-Hydro Hybrid System was explained in [27]. A review of demand-side management is detailed in [22]. The residential Demand Side Management model and its optimization were discussed in [23]. The impact of demand-side management on the optimal sizing of battery energy storage systems is explained in [24]. A review of battery energy storage system technologies was demonstrated in [25]. All these methods have their limitations on the stability issue of micro-grid. From the literature findings, it was understood that an accurate Demand Side Management (DSM) System is required to maintain the grid stability and reduce peak energy consumption from the grid. The significance of a microgrid is that it has a separate control mechanism for controlling electrical quantities such as voltage, current, and power. To enhance the microgrid availability, this article proposed a multilayer neural network-based battery energy storage system that has been incorporated into an existing system. The battery storage system stores the electrical energy at light load and supplies the excess demand to the grid during peak load. However, a smart grid has been developed to improve the power system stability for a larger electrical network.

A smart grid refers to an intelligence grid which means it can integrate the electrical network intelligently [8]. A smart grid has a generation unit, transmission network, distribution network, and end users. Integration of RES in smart grid applications is elaborated in [26]. The key components of smart grids are sensors that can be used to sense the electrical quantities and communication devices that can be used to transfer sensed signals to the master control unit [28]. In addition, not only these two components but also according to the requirement, smart devices are incorporated with the electrical network in the smart grid.

The sensing methodology and communication types of equipment are frequently updated with technology developments. The primary role of a smart grid could prevent outages since smart grids are enabled with sensors that sense the electrical quantity when it reaches the threshold value. It shares the grid's condition with the clients so remedial action can be taken according to the up normality [10]. However, for the smooth running of the smart grid, it requires accurate demand-side management.

Globally, electrical energy demand has been raised every year. Two ways to manage the required demand: one is to construct the new power generation unit and thereby implement the energy conservation policy, and another is Demand-side Management (DSM). It focuses on reducing waste and energy-efficient equipment, respectively [11]. The primary objective of DSM is to reduce the peak level of energy consumption on a particular day. It can operate the system more efficiently by controlling the consumer loads. Also, it recommends incentives to consumers for keeping the demand within a certain limit for a particular duration, maybe an hour of the day, week of the month, or month of the year. It can be achieved by smart meters [12].

The meters can fix the tariffs according to energy consumption and time. A consumer consuming high power during peak hours produces a very high tariff. An accurate DSM has the following significance: reduction in the number of blackouts and so period, rate of fault occurrence, and excellent energy service with optimum cost [13-14]. Due to rapid technology growth, much research has been carried out on the DSM. This article elaborates on the analysis carried out on Demand Side Management and Grid Connected Energy Storage Systems using ANN. The article has been organized in the following ways as section (1) highlights about Introduction, section (2) proposes the model, section (3) discusses the Results and Analysis, and section (4) concludes the research findings.

2. Proposed Model with and without DSM

Fig. 1 shows the block diagram representation of the proposed system without battery management. The generation unit is here to act as a grid with a rating of 154MW to 34.5kV. It feeds the supply to the transformer. The primary and secondary winding configurations are star connected. It steps down the voltage from 34.5 kV to 400 V and feeds the supply to the grid through a three-phase transmission line. The loads are connected in parallel with the transmission line. A total of five loads are connected for analysis purposes. The loads considered are residential loads and industrial loads. In the proposed model, loads 1 and 2 are residential, and the remaining loads are a combination of industrial and residential loads, respectively.

The loads are connected between the grid and the grid-connected battery, and the total number of loads is eight. Initially, data set for loads are collected and fed to the simulation using repeating sequence and interpolation block. The load profile of every load varies over time. The peak line-to-line voltage of each load is 400 V. The instantaneous power is measured using a power measurement unit, as shown in Figure 2, i.e., with Battery Management System (BMS). It requires two inputs, time and state of charge, which act as inputs to the neural network, and the battery control command is the output. When the battery control command is positive, the battery supplies power to the grid. When the neural network command is negative, the battery is charging from the grid at that moment.

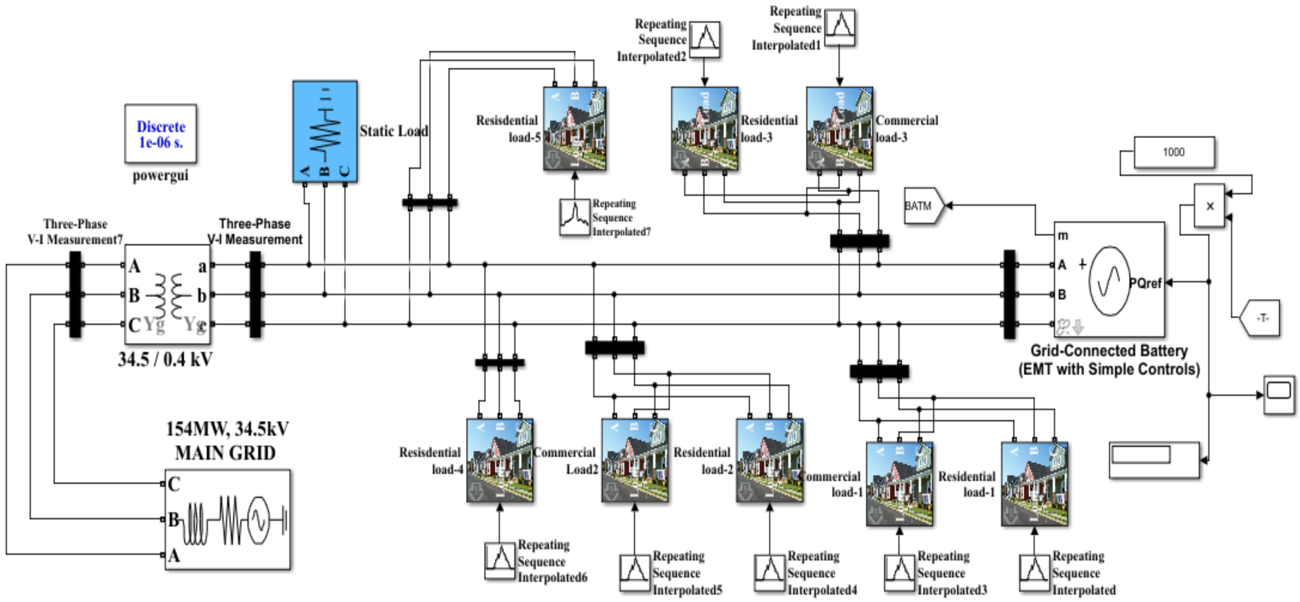

Fig. 1 Schematic representation of the proposed system without a battery management system

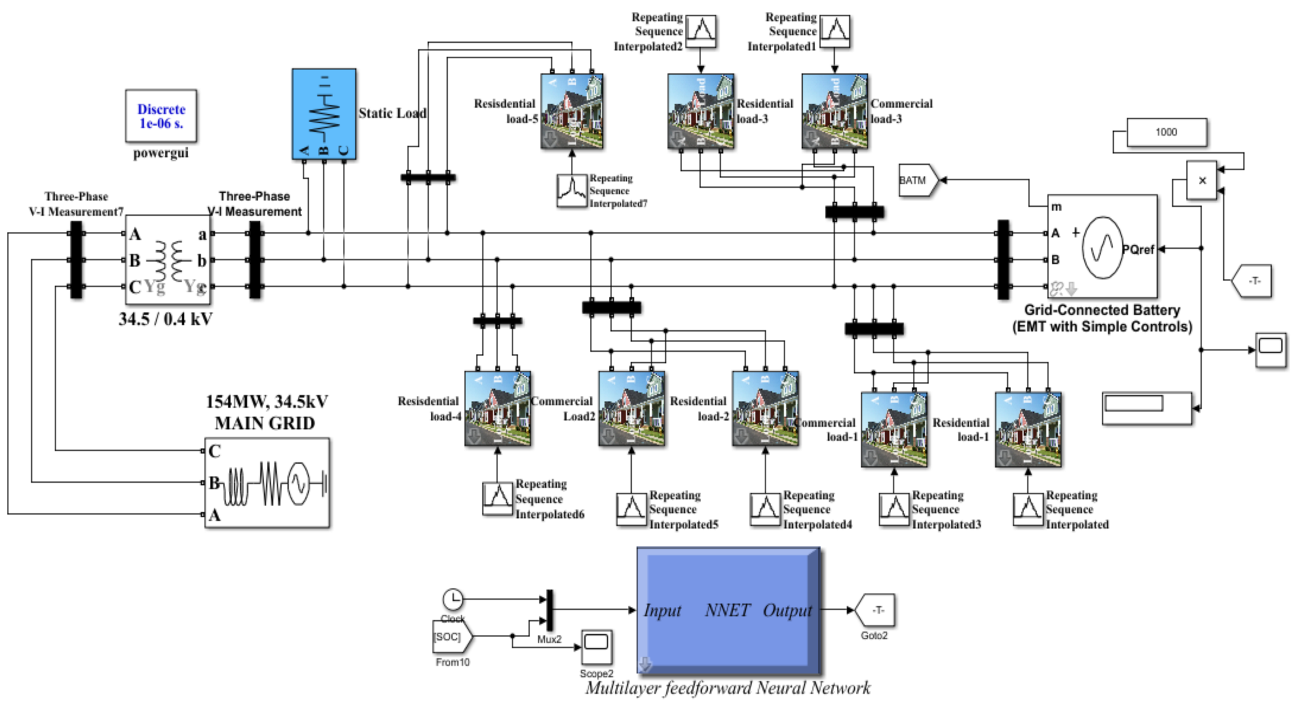

Fig. 2 Block diagram representation of the proposed system with the effective battery management system

3. Design and performance analysis of Neural Network

Neural Networks are highly interconnected multiple layers, represented in the form of algorithms [20] to recognize the interrelation between the data through a specific process. This network is in the same manner as the human brain. In another form, the ANN is nothing but the representation of human thinking power. Computational artificial neural networks are applied in different areas where the complexity of the problem is very high. The applications of ANN systems are classification, dimension optimizing, machine translation, structure prediction, decision finalizing, and abnormality detection. Moreover, these networks are helpful for satellite communication systems and atomic research. The block diagram of the proposed multilayer neural network is given in Fig 3.

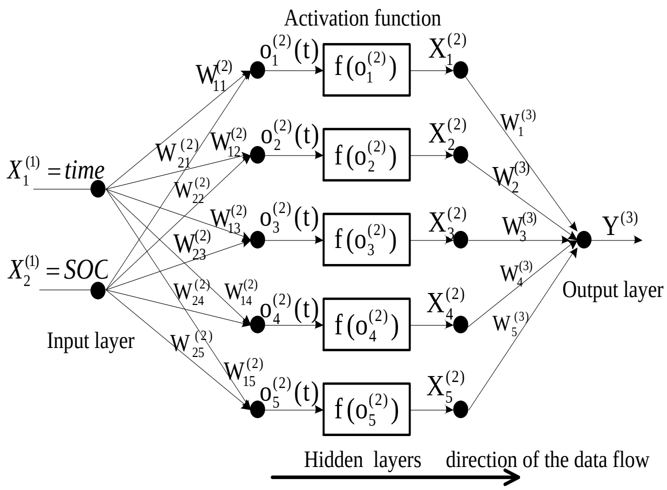

Fig. 3 Schematic picture of neural network configured multilayer system

From Figure 3, it is identified that the input layer has two different neurons that receive the signals of time-varying values and state of charge. The hidden layers receive signals from input neurons, and their weights are updated based on the target value. The network's learning has been done by utilizing supervised and unsupervised methodologies.

4. Results and Discussion

The simulation results found that all loads vary over time, but there is no energy in the battery because the battery is not connected to the grid. It was noticed that the grid delivers power and the total load consumed power is the same.

The time duration between 10 am to 6 pm is considered peak hours. The remaining time duration is considered off-peak power hours. Therefore, loads only draw high power from the grid during peak hours. Thus, running the generating unit with peak power is necessary to satisfy the demands. The obtained simulation results of the proposed system without considering the battery management system are given in Fig. 4.

To satisfy the loads, it is required to suddenly enhance the power generation rate of the generator suddenly and subsequently reduce the generation capacity to a certain level. Consequently, the battery is incorporated with the existing power system to satisfy the energy demands during peak hours, which reduces the unwanted burden on generating station. During off-peak power hours, it will store the electrical energy in the battery. The ANN has controlled the battery energy storage system. It has two inputs: the state of the battery (SOC) and the time of the day. Hence, ten thousand samples were generated in MATLAB editor to train he neural network, followed by a time of the day, and SOC was generated using the rand function.

Subsequently, set the condition based on the requirements. Initially, check the condition of the battery level, such as SOC being lesser than 50% of its rating for the duration between 0 to 10 am. If the condition is true, the neural network generates the negative command, which results in battery charging. Next, check the SOC of the battery between 10 am to 12 pm. Suppose SOC is greater than 50% of its capacity. In that case, the neural network generates the positive command, which causes the battery to supply the stored energy to the grid to satisfy the sudden raising demand. Then, the state of SOC is checked between off-peak periods between 18hrs to 24hrs. During this duration, if the battery state of SOC is less than 50% and subsequently feeds the supply to the grid.

As shown in Figure 5, the grid peak power has been significantly reduced. But all loads consume the required electrical power. It indicates that the end users are unaffected by the inclusion of demand-side management in the existing system. An accurate demand-side management system has achieved it. During peak hours, the power delivered by the generation unit, such as grid power, is marginally reduced compared to Figure 4. Because during peak hours, excess power can be delivered by the energy storage system, as shown in Figure 5. During the peak hours, power supplied by the battery is increased; hence, during the off-peak period, it consumes electrical power from the grid. It was ensured that battery availability full fills the future demand.

5. Conclusion

An accurate DSM based on the neural network has been developed by using MATLAB/Simulink environment. The results show that the ANN-based battery energy management system is working in a very efficient manner when compared to the others. Whenever a peak period occurred, the proposed model was able to supply sudden rising demand at that instant. Therefore, the burden on the main grid is getting reduced. Furthermore, ANN maintains battery energy above its 50% charge, so it can always be available. The proposed model supplies a sudden rise in excess energy and optimizes the generation unit cost.

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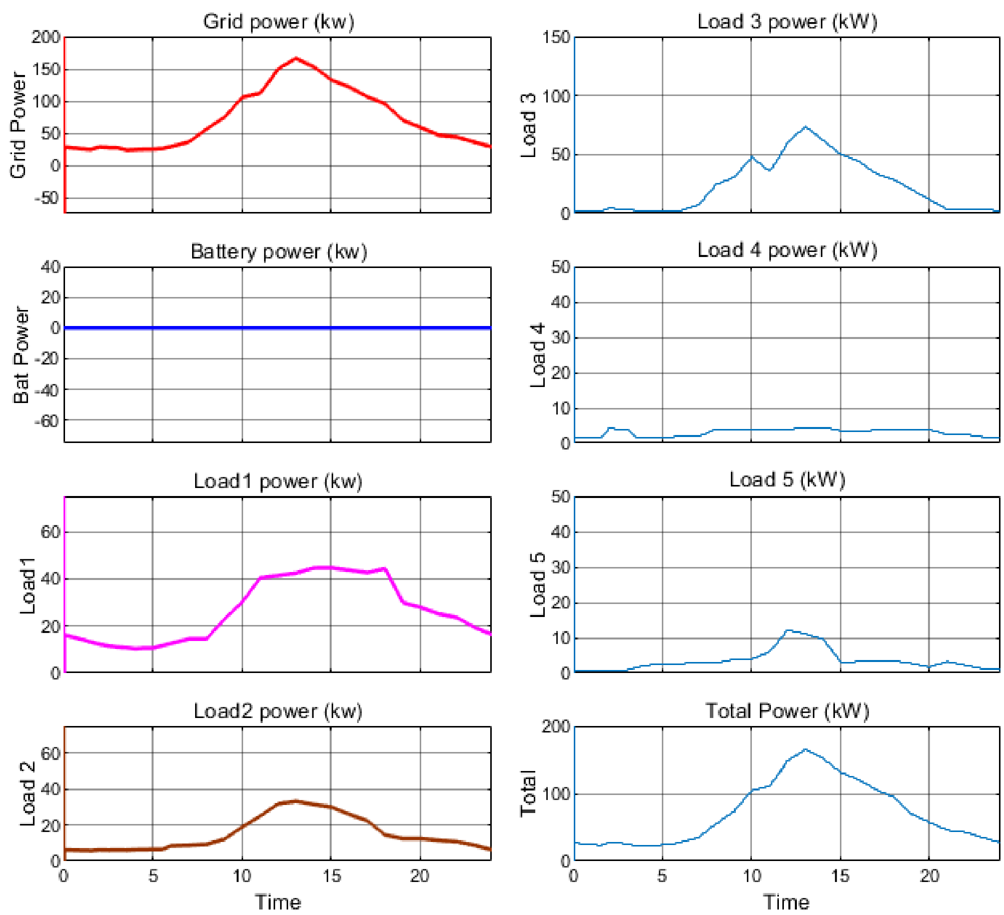

Fig. 4 Simulation results of an introduced system without considering battery management

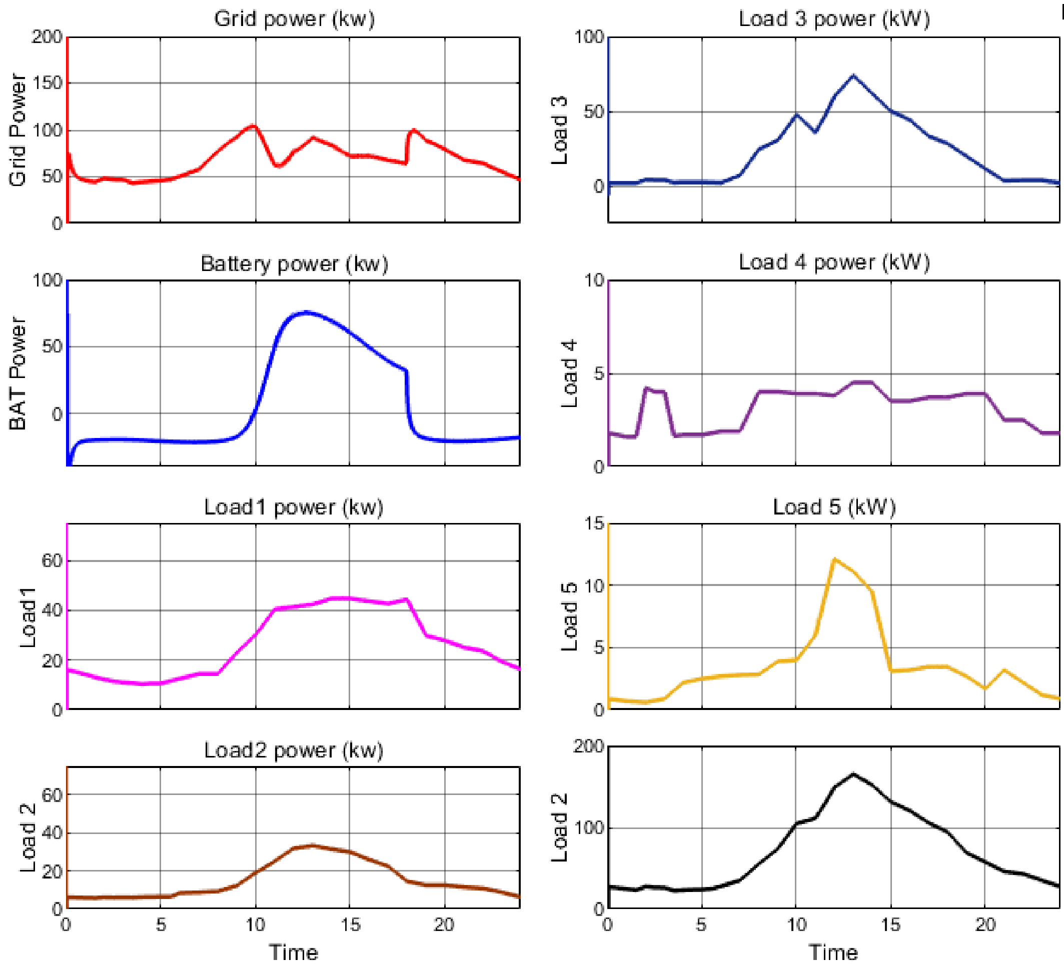

Fig. 5 Simulation results of the introduced DSM system with battery energy management system