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An Intelligent Based DC Series Electric Springs in DC Micro Grids

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Abstract: The integration of intermittent energy sources into DC grids gains far-flung interest among researchers. However, it introduces issues with power quality like voltage stability and ripples in large power systems using intermittent renewable energy resources (IRES). The research analysis aims to utilise the concept of DC series electric springs (DCSES) to minimise the power delivered by the main grid during a generation shortage of IRES. This investigation briefs the emerging DC-DC converter-based DCSES technology with an artificial neural network (ANN)-based intelligent controller for mitigating issues of voltage regulation, harmonic reduction, and improving the battery's lifetime by reducing the storage capacity. ANN generates pulses for the DC-DC converter using the Levenberg-Marquardt-based back propagation algorithm (LMBP) for network training. The simulation is carried out in Mat lab/Simulink. Performance parameters like voltage regulation, DC harmonics, and voltage ripple are analysed and compared with conventional PI controllers. The results prove that the LMBP-based intelligent controller for DCSES, with its fast and accurate convergence speed, yields better performance compared with conventional PI controllers.

Keywords: *Artificial Neural Network (ANN), DCSES, PI control, DC Micro grid, LMBP*

1. Introduction

The steadily increasing interests about rising population and power requirements accelerate the pursuit among the researchers to broaden the centralized energy scheme. The realization of modern generation and distribution becomes a challenge with its constant increase in capital and running costs [1]–[2]. An environmental factor greatly affects the utilization of fossil fuels to fulfil the required energy demand. The generation and application of IRES such as wind and solar can be enhanced using distributed generation (DG) together with distributed energy storage (DES).

A micro grid is a collection of linked loads and dispersed resources for energy that operate as a single controlled entity in relation to the grid. A micro grid has the ability to connect and separate from the grid, allowing it to function in both power-connected and island-mode. A micro grid must have a power resource in order to satisfy the electrical demands of its customers.

DG and simulation performance in a 400-kVA micro grid [3]–[4]. Therefore, the future grids will have interconnected micro grids as a vital element that consumers have to effectively involve in the processes of generation, storage, and consumption. Each micro grid should have the capability to function in islanded mode and fix the energy issues so as to improve the quantity of iterations by 34%. [5]– [6]. To augment the increasing needs of electronic loads (ELs) and IRES, DC micro grids serve as a potential and promising contender grid system. [7]– [8]. It has a number of advantages, like involving limited power processing stages in a DC power system, simple RES integration, and easy power flow control with 32-bus radial [9]. The aforementioned advantages can improve the reliability, conversion efficiency, and profit margin of the grid [10].

Moreover, DC distribution enables easier storage element connection as it is in the form of DC, which in turn considerably increases supply continuity during faulty conditions on the AC grid and DG [11]. Additionally, its protection is tedious when compared to AC due to the absence of zero crossing [12]. It also needs a separate line for DC grid construction. The absence of the AC-DC rectification process and frequency synchronization greatly enhances the system efficiency of the choice for residential DC grids [13]. Like PV, fuel cells generate instantaneous DC output. The stability problems can be easily solved by proper control and energy management in IRES integration with the power system [14]. Yet, extensive penetration of IRES and ELs interfaced with converters leads to voltage regulation problems like voltage instability and harmonics at the point of common coupling (PCC) [15].

The major issue of reducing voltage variation can be solved by employing a battery energy storage system (BESS), which could supply uninterrupted power during a fault at IRES. However, it is expensive [16]. In addition, generation side management (GSM) and demand side management (DSM) serve to minimize the conditions of overvoltage, cost, and storage capacity [17]. Nevertheless, it deviates from clean energy harvesting and raises payback time [18]. The appropriate synchronization of new sources, IRES and BESS, into the grid requires the power electronic interface as a significant component [19]. In spite of several effective methods suggested for the mitigation of voltage regulation and harmonic issues, they have a sluggish response and are incompetent in solving power quality issues [20].

The emerging concept of the electric spring approach is suggested for both AC and DC systems, where AC electric springs provide reactive power and voltage regulation through

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effective voltage and frequency control [21]. Similarly, the DC electric spring regulates DC bus voltage, reduces harmonics, and decreases ripple content in the DC micro grid. In addition to filtering and mitigating harmonics, it has battery storage, which could afford a continuous DC supply [22, 27].

Non-linear loads that are known to cause harmonics in an electrical network's source current. For the purpose of solving this issue, instead of employing passive filters, active power filters (APF) have been devised to inject harmonic currents into the network with the same amplitude and reverse order as the phase current harmonic in the load [28]. A low-emittance collector is approximately 200% more sensitive to variations in the hot water demand scale than a high-emittance collector. Whereas the high-emittance collector generates more power than the low-emissivity collection agencies, it produces 38% less heat energy. Overall, the low efficiency collector generates more energy than the high emissivity collector, and this performance difference gets more evident as the need for thermal energy increases. As a result, low emissivity collectors are recommended for building applications where the objective is to satisfy electricity and a high volume of hot water demand [29].

Because AGM batteries have a limited ability to produce current, a higher current supply will diminish the battery's usable capacity. As a result, in order to react to high demand over a long period of time, this study recommended a distinct multi-level threshold to regulate the battery packs, having the control taking into account the form of current ratio applied to split the response time to load for every single battery type: Off-Peak in AGM: LFP at 0.5: 0.5, On-Peak in AGM: LFP at 0.7:0.3 [30].

Disturbances such as shifting wind speeds can decrease the power quality factor and robustness of the electrical grid if not properly controlled. The application of Active Disturbance Rejection Control with an extended state observation ESO for a PMSG Wind Energy Conversion System is examined to achieve an acceptable power quality factor, high performance, and grid stability against both internal and outside problems. The findings from simulations show that the controller delivers maximum power while maintaining constant DC voltage at the interface of the generator-side and grid-side conversion. Its findings also reveal that the system's performance is stable [31].

A method for increasing the output voltage of a piezoelectric as an energy harvesting device by using nonlinear magnetic forces derived from a phenomena known as vortex induced vibration (VIV). This harvesting gadget is built using two magnets located at the bottom of a circular cylinder and on the lower base. The mechanical conversion energy researched is the vibration that results from the movement of a circular cylinder via a phenomena known as Vortex Induced Resonance employing a piezoelectric transducer. A VIV-based energy harvested was built and tested in water circulation to determine the best output voltage that could be obtained [32].

In Micro grid application Artificial Neural Network (ANN) based approach to classify the errors that arise in hybrid power distribution networks. The hybrid system powered by solar and wind energy provides voltage to the grid at the point of common connection of the Common Coupling (PCC).This system uses a booster converter in conjunction with pulse-and-observe (P&O) algorithms to maintain a steady connection voltage. Whereas a proportional integral (PI) regulator helps to maintain a wind energy transformation technique's (WECS) link value. The help of D-Q theory taints the grid alignment. The ANN is used to evaluate faults such as islanding, line-ground, and line-line defects. The PCC observes the voltage signal, and the DWT (Discrete Wavelet Transform) is used to extract various characteristics and by applying the suggested methods, the Total Harmonic Displacement (THD) is reduced by 4.3%. [33].

Two series and parallel turbine configuration sets of experiments were created. Three different working challenges, such as 1.5, 3.2, and 5 bars, were applied in the examinations. It has been determined that the fluid rate of flow is the primary determinant of the turbine's performance, with an operating pressure of 5 bar (equivalent to 33 LPM and 6 W) allowing for a greater flow velocity. After completing the second turbine, the power output climbed to 12 W with a modest pressure reduction of 0.1 bar. But with the lower working pressure, it was found that the pressure loss was significantly greater [34].

Artificial Neural Network (ANN)-based Shunt Active Power Filters (SAPF) are a workable solution for reducing harmonic distortion and improving the reliability of power in electrical distribution networks. According to this examination, shunt active power filters (SAPF) are an effective way to improve power quality and reduce harmonic distortion in transmission networks. SAPFs employ the Artificial Bee Colony Improved Artificial Neural Network Controller (ABC-ANN). For SAPF, the ABC-ANN algorithms were developed with the intention of lowering grid harmonics at present and enhancing system efficiency [35].

The middle of every component in this layout is linked to a three-phase AC system, whereas the positive and negative ends of each leg are linked to the DC relationship. Each leg is essentially divided into the positive arm and the negative arm by these halfway points. A series-connected submodule and a current-limiting inductor make up each segment of the MMC [36].

The problem statement of previous study, DC bus voltage variation was not reduced, and there was a high converting stage from imbalanced hybrid AC-DC micro grids as Energy storage facilities have modest power charges, and energy management is minimal. Previous work has not provided backup power or balanced energy availability and responses.

In this work, the concept of intelligent controller-based DC series electric springs (DCSES) is proposed. The performance of the DCSES is investigated using the simulation model developed in Mat lab/Simulink. A LMBP-based ANN controller is employed to generate pulses for the DC-DC converter, and its performance is analyzed and compared with BESS in reducing the main-grid dependence of the DC micro-grid so that the NCL's completely follow the profile of the IRES. The voltage regulation, harmonics, and voltage ripple are observed with the PI controller and the ANN controller. The results are compared and discussed in the following sessions.

2. Modelling and Description DCSES connected Micro-grid

DC loads are expanding fast on the market at the moment, and DC micro grids powered by renewable energy are being created as a viable option to fulfil becoming demand for power. In general the DC micro grid is defined as a system which comprises of IRES, suitable control system, monitoring devices, critical load (CL) and Non-critical loads (NCL). Micro grids are basically a system of demand and distributed electrical power generation as well as energy storage technologies. A dc voltage drop in a dc micro grid is induced by a quick shift in micro-source power, load switching, and ac grid disturbances. DC micro grids are being extensively researched since they just demand voltage management and a large number of distributed renewables provide DC electricity. DCSES is modelled so as to enable them to minimize the power drawn from main grid during uncertainties in IRES. The system proposed is as shown if fig.1.It comprises intermittent supply system with CL and NCL, BESS which meets the power demand in times of generation intermittence.

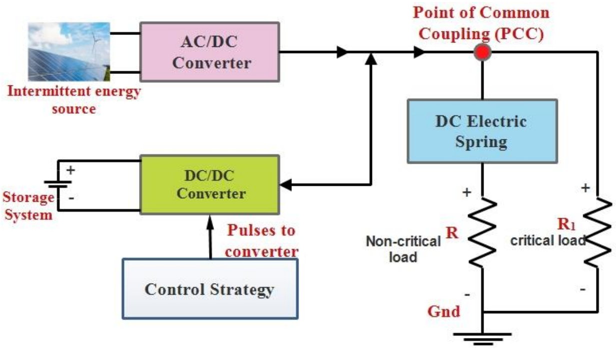

Fig.1 DCSES Circuit Diagram

Whenever there is uncertainties in generation during the operation of DCSES, the switch(S) is open and the switch (S1) is triggered by the pulses obtained using the Controlled PWM method such that the average voltage value applied to NCL is decreased to the certain allowable value lesser than the rated value. In case, if there is ample generation the switch(S) is closed which means the switch S1 is circumvented and rated voltage value is applied across NCL. The filter components L1 inductor and C capacitor illustrated. Filters the ripples present in the D.C supply across to the NCL and Diode (D) acts as a freewheeling diode. The correlation between power across the CL, NCL and total power delivered by the supply system is given by eqn (1).

$$P_T = P_{CL} + P_{NCL} \tag{1}$$

$$P_{NCL} = \frac{V}{R^2} \tag{2}$$

$$P_T = P_{sc} + P_{Ba} \tag{3}$$

Where PT is defined as total power across CL and NCL from the supply i.e. from source and battery. PCL is power across CL and PNCL is power across NCL. P_{sc} and P_{Ba} are power obtained from source and battery respectively. The equation (3) represents the total power delivered by the supply system. The power delivered by the supply and battery can be reduced by using objective function described in (4) and (5).

$$m^{n-1}\,[p(T) = P_{cl} + N_{cl} \tag{4}$$

Power drawn from BESS,

$$min_{p_{ba}} = P_{sc} - P_{cl} + P_{ncl} \tag{5}$$

3. Controller for DC-DC Converter Based DCSES

The control strategy to generate pulse to DC-DC converter shown in fig.2 is done by using both PI and ANN controller. Input intermittent energy source with Combination of PVM values are couples of inputs are calculated as data V_S, DCSES and battery starts operating. In fig 2 V_S is input the control signals for the DC-DC converter generated using LMBP based ANN controller which maintains the voltage supplied by the battery constant. Fig. 2 shows the control circuit for DC-DC Converter based DCSES.

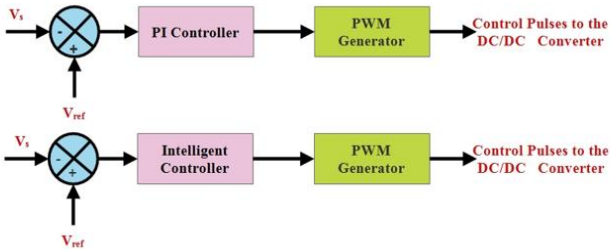

Fig.2 Control Circuit for DC-DC based DCSES

The Voltage Vs represents the voltage across IRES and Vref indicates the reference voltage which normally represented by the actual rated value of the micro grid. When the IRES generated value falls below the reference voltage, it produces the error signal. The PI controller processes the error signal and generates pulses with respect to PWM generator requirement. The generated pulses re fed to the DC/DC converter. The battery discharges which represent the battery supplies during abnormal grid conditions.

The values of KP and KI for the PI controller are deduced using the Ziegler and Nichols (ZN) technique. According the ZN experiments can be run to obtain the parameters for the approximate model if the system model cannot be physically derived. For example, if the step response of the plant model can be measured by an experiment, the output signal may be recorded and the ZN curve is obtained. The value of the KP and KI are calculated from the following equations. The values of T and L can be determined from the ZN curve [26]-[27].

$$K_P = {}^{T}/_{L} \tag{6}$$

$$K_I = {}^{K_P}/_{T_I} \tag{7}$$

$$T_I = {}^{L}/_{0.3} \tag{8}$$

The control signals for the DCSES are produced similar to battery. The voltage supplied by the IRES and the rated system voltage are compared and generate an error signal to open the S in the DCSES. It allows the power flow through S1. As and when the S is opened, the Chopper is triggered using PWM pulses and only 90% volt is set to appear across the non-critical load which ultimately reduces power drawn from the supply system during IRES abnormal generation. ANN with its ability in providing main suppleness, potent learning proficiency and ability to solve problems and generalize in pattern classification and matching, function optimization and approximation and associative memories make them suitable as an intelligent controller to generate pulses to the converter [23] – [25].It regulates the voltage and helps to support NCL during abnormal IRES and also minimizes the ripple content. The Levenberg Marquardt based back propagation algorithm (LMBP) is used for training the neural. Fig. 3 shows the two layer feed forward network used for training the network.

$$a^l = \sigma(\omega a^{l-1} + b) \tag{9}$$

Where a activations, weightsω, and bias, the procedure for neural network training is described in flowchart given

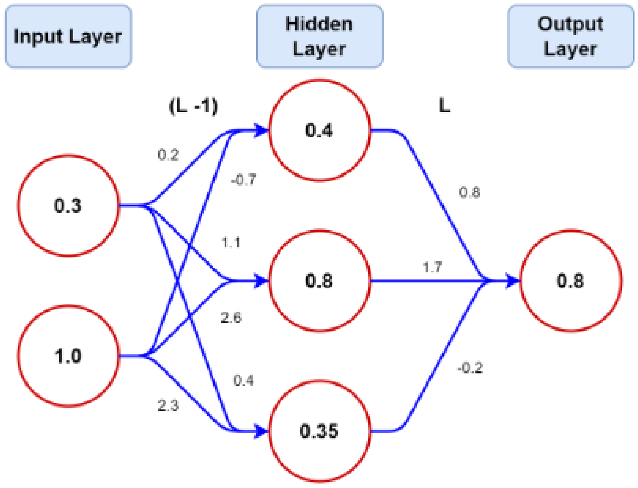

Fig.3 Two layer FFN

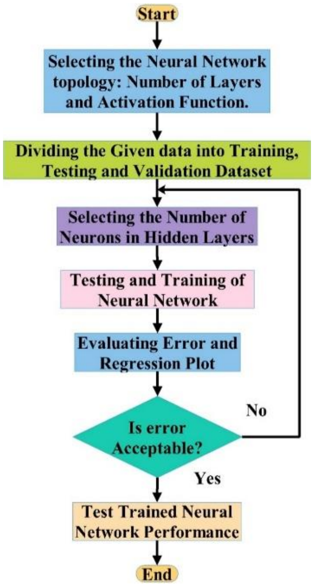

Fig.4 LMBP algorithm

Fig 4 shows the flow chart of MBP is standard back propagation algorithm consists of normalized pre-processed data which predicts and shows correlation pattern of input and output. This algorithm has more accuracy and high speed of convergence. This algorithm uses 100 values produced through MATLAB simulation where 70% of the data records were randomly assigned for training, 15% for testing, and the remaining 15% were relegated to validation. The ANN employed here 4 layers: an input layer, 2 hidden layers, and an output layer. The hidden layer has 10 neurons/layer. The feed forward neural network (FFNN) consists of three layers. The hidden layer consists of 10 neurons and here Tansig activation Function is used. The output layer uses the purelin linear transfer function.

4. Results and Discussion

The D.C micro grid structure utilized for analysis and the proposed system model is developed in Mat lab/Simulink. It comprises of IRES and AC to DC converter which converts the AC to DC power and supplies DC loads. The parameters used for investigation are referred from [17].The energy profile across the BESS and DCSES is depicted in fig.5. The operating curves of BESS with power, voltage and energy are illustrated in fig.6. Similarly the operating curves defining the performance parameter power, voltage and energy of DCSES are shown in fig.7

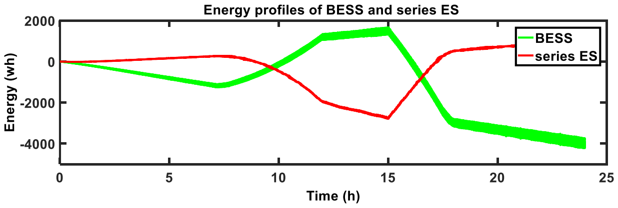

Fig.5 Energy profile of BESS and DCSES

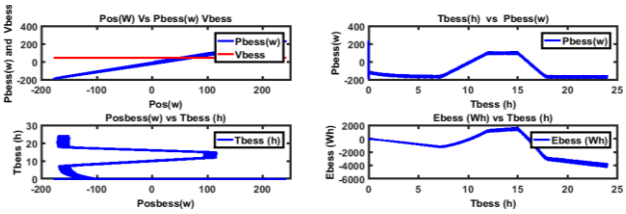

Fig.6 Power across supply and BESS

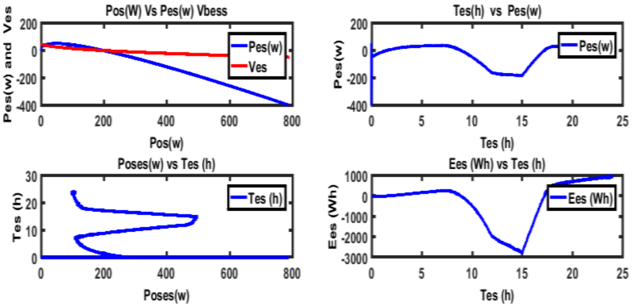

Fig.7 Power across supply and DCSES

The fig. 8 describes the power profile across BESS and DCSES. The power across non-critical load in BESS and DCSES is presented in fig. 9. It is observed that power supplied by battery is reduced by employing DCSES.

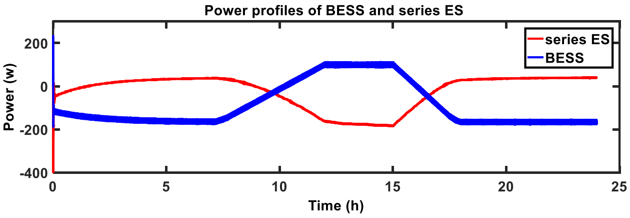

Fig.8 Power profile across BESS and DCSES

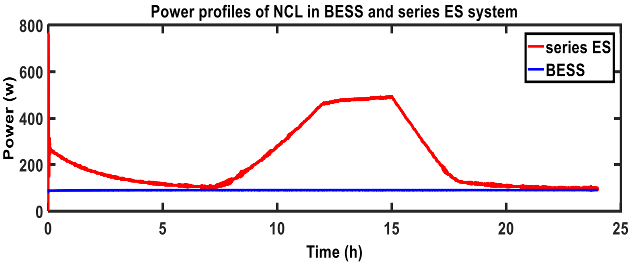

Fig.9 Power profile across NCL in BESS and DCSES

The power profile for 24 hours is observed across supply system, IRES and critical load are observed and presented in fig.10. It is observed that power across the critical load remains constant irrespective of variation of time, generation deficits.

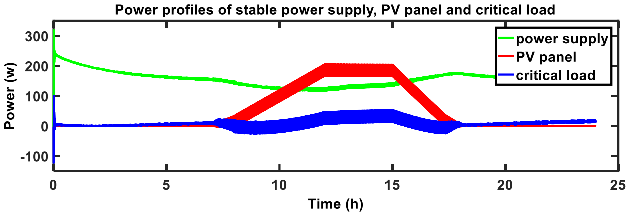

Fig.10 Power profile across power supply, PV panel and DCSES

The DC bus voltage (V_{dc}), battery voltage (V_{b1}), voltage across DCSES (V_{es}), Voltage across non-critical load (VNCL) and critical load (VCL) obtained using PI controller are observed and plotted. The results obtained are presented in fig.11. Here the time scale refers 24 hours (0.1= 1 hour) the sudden change load in applied at time t=1 sec.it is observed that voltage across CL remains constant and the remaining parameter settles well within .025 secs.

Table 1: Comparison of P&O, PI and ANN controller results during sudden change in non-critical load

Parameter (non-critical load)	**perturb and observe (P&O)**	**PI**	**ANN**
Voltage regulation	4.5V	3.9 %	2.8 %
Voltage Ripple	2.2V	1.6 V	0.956 V
THD [33]	4.3 %	4.10	3.05

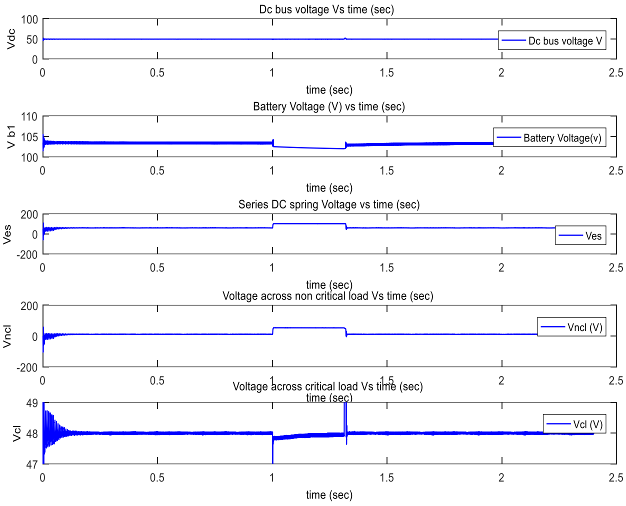

Fig.11 Performance characteristics of DCSES using PI controller

Similarly, the control strategy using LMBP is applied, the results are observed and compared with PI controller. The performance characteristics of Vdc, Vb1, Ves, VCL, and VNCL are presented in fig.12. It is clear that LMBP based ANN converges fast and accurate when compared to PI controller.

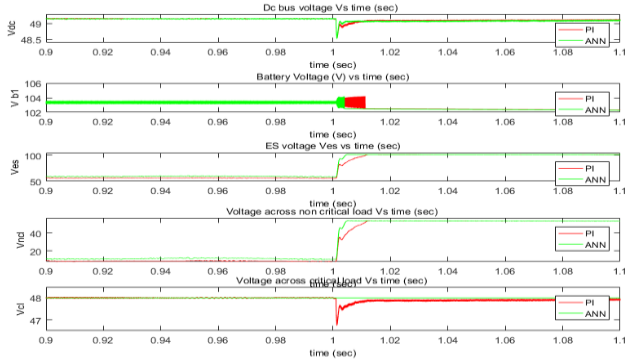

Fig.12 Comparative Analysis of DCSES using PI and ANN controller

The table.1 shows the comparison of PI controller and ANN controller when there is sudden change in non-critical load. The performance parameters voltage regulation, voltage ripple and harmonic percentage are noted when there is sudden change in load and plotted.it is observed that voltage regulation is improved greatly moreover voltage ripple is also reduced nearly 0.72V. The voltage regulation using ANN is improved by 28 % as compared to that of the PI controller. The ripple is reduced by around 40 % using the proposed method. The harmonics is also reduced around 1% which is around 25 % reduction than that of PI controller and hence proves that DCSES with ANN controller performs better compared to PI controller greatly reducing burden on battery thereby improving the battery life.

4. Conclusion

The DCSES technology incorporated DC micro grid concept which resolves several power quality issues is investigated in this paper. DCSES analogous to AC electric springs helps to obtain voltage stability, reduced harmonics and ripple content. The DCSES and NCL are connected in series. The attained results proves that the deployment of DCSES in DC micro grid structure improves the performance of the micro grids and extends the scope of micro grid greatly by reducing dependency on main grid. Making NCL follow the voltage profile of IRES demonstrates the capabilities of DCSES. To produce pulses for the DC-DC converter, the LMBP-based ANN and standard PI controllers are used. The outcomes are the Power profile across NCL in BESS and DCSES, the Power profile across the power supply, PV panel and DCSES, Performance characteristics of DCSES using PI controller and the Comparative Analysis of DCSES using PI and ANN controller examined are in the simulation, the suggested DC/DC converter is robust and suitable in any type of micro grid environment. Furthermore, it overcomes the fundamental grid diagonal aspects of the matrix to give an accurate classification of the data class in ANN Controller, while the additional values represent an inaccurate classification of the information being examined and employ less passive parts and switches to operate where the superiority of the suggested system is demonstrated.

4.1 Future scope

In future, Voltage Ripple, THD are improved when compare to previous research using feed forward neuro-controller's offline learning is often achieved by utilising a training dataset derived from either experimental data or the system modelling. Using online trained FNNs that adapt constantly to system uncertainties is more appropriate when the system being monitored is too complicated to predict or when experimental datasets are unavailable. The input of the subsequent layer in feedforward networks is the output of the cells in the previous layer. When the network is analysed layer by layer, it becomes clear that the input layer simply transfers data from the outside world to the cells in the intermediate (hidden) region.

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