Supervisory Controller for AC/DC Hybrid Microgrid Based on Solid-State Transformer

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Abstract - Power network reliability and safety are severely compromised by voltage fluctuations and power mismatches brought on by the dispersed, unpredictable, and intermittent nature of distributed energy resources as well as by variations in demand. In order to address this problem, this study presents the architecture of a Power Electronic Transformer-based AC/DC hybrid microgrid. Being capable of adequate control coordination ensures the system's steady and dependable functioning. To successfully reduce DC bus voltage fluctuations while scheduling power flow across energy storage, AC microgrid, DC microgrid, as well as solid-state transformers, an energy management technique is suggested. We provide a new adaptive droop control over energy storage that may maximize the economic value to customers while extending the life of supercapacitors. This droop coefficient can be determined using a fuzzy logic controller. It takes as input parameters the projected super capacitor charge state as well as unit-time electricity charge. The suggested energy management and control technique is validated via simulation.

Key Words: hybrid micro grid, SST, Fuzzy logic control, ANN, Energy management strategy

1. INTRODUCTION

Renewable distributed generation (DG) has become increasingly incorporated into power systems throughout the globe as a result of the rising global energy demand including the limitations imposed on production that utilize fossil fuels. Harmonic injection and voltage fluctuations are two examples of the poor power quality consequences that could result from connecting DGs straight to the power grids. Microgrids have grown more popular as a viable option for connecting distributed generation (DG) systems to distribution networks given they have high dependability and edibility. There are three main types of microgrids: direct current (DC), alternating current (AC), and hybrid AC/DC. There is a limitation on the types of power that DC and AC microgrids may deliver. The need for access to distributed renewable energy resources (DRERs) and the ever-increasing DC demands may be better met, however, by an AC/DC hybrid microgrid. At the same time, meeting the expectations of power customers requires a multiform and highly dependable power grid, something is challenging to do with conventional distribution networks. Energy routers (ERs) have been suggested in recent literatures as a means to achieve the aforementioned goals [6]_[8]. Power electronic transformers, as well as solid-state transformers, (PETs), can do all the same things as regular power transformers and more.

1. Some of the goals include better node autonomy within distribution networks,
2. More power interfaces.
3. More flexible operation for AC/DC hybrid systems.
4) As well as electrical isolation and transmission.

Here is a thorough introduction of SST. such as ideas, structures, categorization, power converters, material choice, and critical components of design standards and control systems. Residential energy routers using direct AC/AC power electronic transformers are suggested, together with their topology and management. Although this method may improve the device's power density and reliability upto a certain degree, it still requires extra converters with DC loads because it doesn't have a DC connection. We provide a general outline of methods for controlling and managing electricity in hybrid AC/DC microgrids. While [5] suggests a novel approach to controlling power and DC bus voltage, it does not address AC bus control. In [8], the authors provide a method for controlling DC bus voltage droop using SST with an energy storage unit. A common method for coordinating parallel inverters was conventional droop control, which regulates the frequency and amplitude between the voltage conventional a manner similar to a synchronous generator for power systems. This allows for the modulation of active and reactive powers.

In most cases, the rated power capacity, maximum allowable frequency variation, and voltage deviation for every DG are used to estimate the droop coefficients. This droop coefficient remains constant in traditional droop control. We provide an adaptive droop control approach that may dynamically adjust the droop coefficient according to changes within system operating circumstances like DG power production, battery storage SOC, or adaptive proportion-integral (PI) control parameter values. In spite of its importance, the suggested adaptive droop control architecture in the aforementioned literature fails to take energy price (EP) into account. It is recommended that EP be explored in order to meet the power consumption needs of ER-based low-voltage distribution networks as well as maximize economic advantages. To achieve power balance with independent power sharing, a new active power management technique is suggested for voltage converters that depends around the bidirectional droop feature. However, the suggested converter fails to include the SST's many features since it is a standard AC/DC bidirectional converter meant to link DC and AC microgrids. Suggest using fuzzy logic in achieving multi-control goals as part of the energy management plan for hybrid power systems. Future electric regenerative braking (ER) and

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flexible distribution power system architectures will revolve on SST. Previous discussions have demonstrated that the majority of current research has concentrated on creating new power devices other modulation schemes, as well as certain types of micro grids and SST topologies.

Nevertheless, energy management solutions for SST have received little attention. This research aims to change that:

1. This paper presents the architecture of an SST-based AC/DC hybrid microgrid and develops a mechanism for the control coordination between each component.
2. The second innovation involves an adaptive droop control method that goes against the grain of traditional droop control systems, which use a fixed droop coefficient.
3. To maximize the economic advantages for power users and extend the life of supercapacitors, an energy management method is provided.

2. Body of Paper

2. SST STRUCTURE AND CONTROL

Figure 1 shows the components within the SST, which include an AC/DC rectifier called a cascaded H-bridge (CHB), a DC/AC inverter, including a dual active bridge (DAB) converter incorporating a high frequency transformer.

CONTROL OF THE RECTIFIER STAGE

The 3 cascaded H-bridges that make up the rectifier phase have a DC bus reference voltage of 4kV. One way to express the rectifier's state equations is as:

$$\begin{cases} L_s \dfrac{di_s}{dt} = 3U_{hdc}d - U_s - R_s i_s \\ C_1 \dfrac{dU_{hdc}}{dt} = -di_s - \dfrac{U_{hdc}}{R_L} \end{cases} \quad (1)$$

here we have: d = Duty cycle of the rectifier's pulse width modulation (PWM) , *is* = input side current, *Us* = voltage applied at the input, *Rs* = input line resistance, *Ls* = input inductor, U_{hdc} = DC bus voltage, *C1* = rectifier DC bus capacitor. The load resistance of cascaded modules is represented as RL. When regulating the rectifier, a single-phase d-q vector is applied. Initially, we assume a theoretical phase that lags 90 degrees behind the real phase.

The imaginary phase can be determined using various techniques, such as:

- Delay method
- All-pass filter method (APF)
- Second-order generalized integrator (SOGI).

This study uses the APF approach to get the imaginary phase since it is quicker than SOGI along with the delaying method, according to a comparison of their performance.

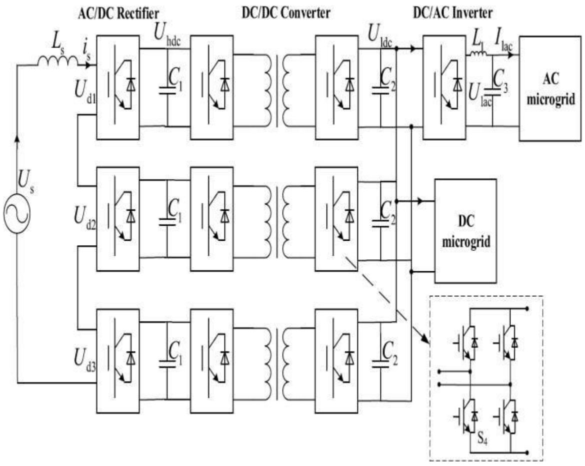

FIGURE 1. Topology of the SST.

The objective of the input-stage control was to achieve unity power factor operation and maintain a balanced DC-link voltage. Figure 2 illustrates the control mechanism for input-stage balancing, whereas Figure 3 depicts the single-phase decoupling current control for the input stage.

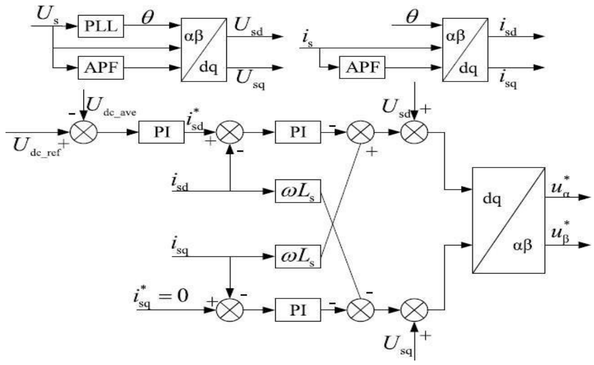

FIGURE 2. Single-phase decoupled current control.

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In Figure 2, the connection reactive current is set to zero to ensure a unity power factor. To compensate for voltage differences between the input-stage DC-link capacitor voltage reference () and the average values () of each input-stage DC-link capacitor, the voltage loop PI controller adjusts the active current reference (). A voltage balancing controller is implemented to maintain equilibrium in the DC-link voltage.

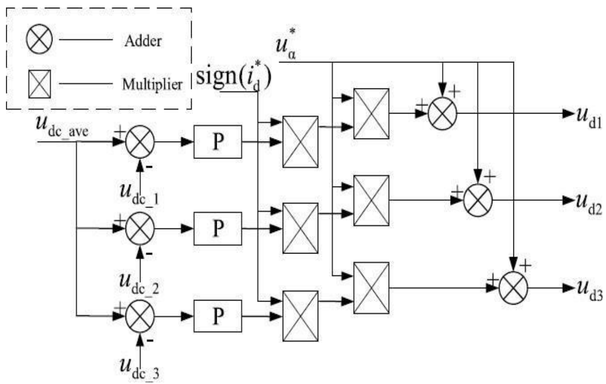

FIGURE 3. Input-stage voltage balancing control.

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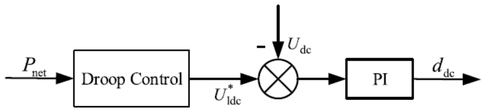
CONTROL OF THE DAB

A dual active bridge (DAB) consists of a low-voltage H-bridge, a high-frequency transformer (HFT), and a high-voltage H-bridge. The power transfer in the DAB (P) converter is regulated by adjusting the phase shift between the primary and secondary H-bridges.



When apparent from the block diagram of Figure 4, the DAB operates using a single-phase shift control. Here, Udc is managed by adjusting the PI controller depending on the voltage error among the low DC voltage. The regulation equation for power-voltage droop is employed to determine the reference voltage.

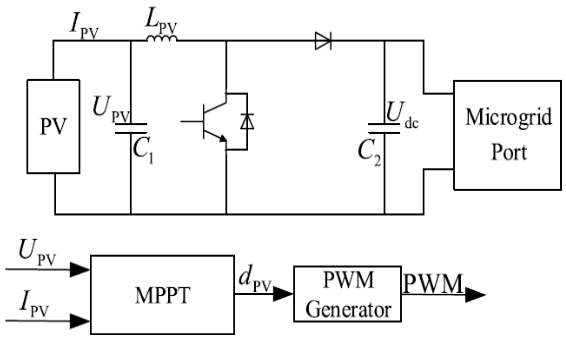


FIGURE 6. Topology and control of the PV DC/DC converter.

A control technique known as maximum power point tracking (MPPT) uses the P&O approach, which is an enhanced version of variable step perturbation, [20]. In a nutshell, everything works according to the Solar panel's P_V curve slope. whichever direction the slope, the operating voltage changes to follow the point of greatest power.

3. ENERGY STORAGE BIDIRECTIONAL DC/DC CONVERTER

During grid-connected mode, energy storage (ES) devices help maintain power balance, while in island mode, they can keep the AC/DC hybrid microgrid running smoothly. Microgrids that use distributed generation are now unable to function without ES since renewable energy sources are inherently intermittent. Both the ES device and the fast-charging/discharging supercapacitor are charged and discharged in this study using a bidirectional buck-boost converter [21]. In both grid-connected & island modes, an ES inductor voltage controls the two way directional power flow, which is one of the control goals underlying the system. Figure 7 shows the topology and regulation of the extrasensory system.

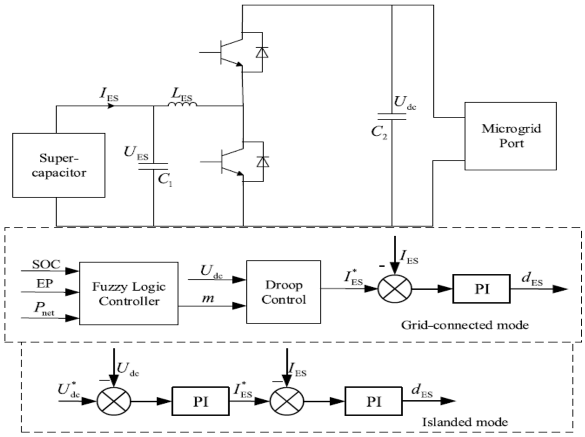


FIGURE 7. Topology and control of ES.

This work proposes an adaptive droop control for grid-connected mode. A approach for managing energy yields the droop coefficient. The electrostatic (ES) inductor current has a closed-loop, while the reference value for the ES charging/discharging current can be obtained via the droop control.

4. ENERGY MANAGEMENT STRATEGY

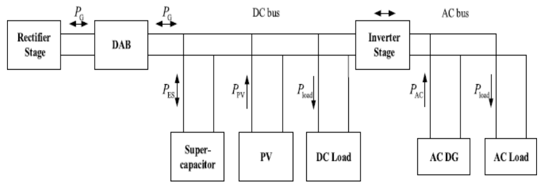


FIGURE 9. Power flows in grid-connected mode.

Here we'll go over the power flows under the grid-connected mode before we suggest a way to control that power. On grid-connected mode, potential power flows for SST are displayed in Figure 9. Therefore, while operating in grid-connected mode, the current electrical balance equation may be written as:

$$P_{DG}+P_{G}+P_{ES}-P_{load}=0$$

The distributed generation, which includes PPV and PAC, is represented by PDG, Pload denotes the DC and AC load power, and PG denotes the grid side power. If the total generated power generated by the hybrid AC/DC microgrid falls lower than zero, the electrical system and distribution network must make up the difference in power. However, the distribution network can charge the super capacitor and run smoothly if Pnet is greater than zero. Simplifying Equation (11) yields:

$$P_{net}+P_{G}+P_{ES}=0$$

The power balancing equation may be stated as long that the islanding mode has been set to PG D 0:

$$P_{net}+P_{ES}=0$$

According with the preceding power flow scenario, while the grid-connected mode remains in operation, electricity must travel among the power distribution network, energy storage, and hybrid AC/DC microgrid whenever Pnet 6D 0. Issues with power distribution might arise, and if they are not suitable, it can impact the life of supercapacitors and the economics of customers. Consequently, a trustworthy energy management plan is required for the reasonable distribution of power.

This article proposes an energy management approach that takes into account the effects of SOC capacity upon the lifespan of supercapacitors and the effects of power price on the financial consumers. Variations in renewable energy production power versus load demand may be mitigated using this approach. As we have seen, SOC, EP, and Pnet are the three variables that will choose the droop coefficient control. A technique for energy management which makes use of numerous, mutually limiting control goals is well-suited to fuzzy control. In the creation process for a controller's operation, fuzzy logic control (FLC) relies on faulty logic thinking. The primary objective of fuzzy logic aims to provide a middle ground between the binary numbers zero and one by including logic segments that allow for neither zero nor one. Hence, this paper's innovative adaptive droop control is implemented using an FLC. Unit-time electricity is a useful way to express EP and Pnet.

charge *EC*unit.

The suggested FLC takes mES as its output and uses SOC and ECunit as its inputs. Defuzzification generating fuzzy numbers is accomplished using the centroid approach. The SOC and ECunit ranges have been defined as:

$$\begin{cases} SOC \in [40\%, 80\%] \\ EC_{\text{unit}} \in [0, 1] \end{cases}$$

Importantly, while moving to isolated mode, the AC/DC hybrid microgrid must have sufficient residual capacity from the ES to keep running normally, and 40% is more above the minimum acceptable level of SOC. As seen in Figure 10, the FLC's output and input membership functions include _ve grades. The input and output variables will be explained using five grades: Classes: L for low, SL for slightly low, M for medium, SH for slightly high, and H for high.

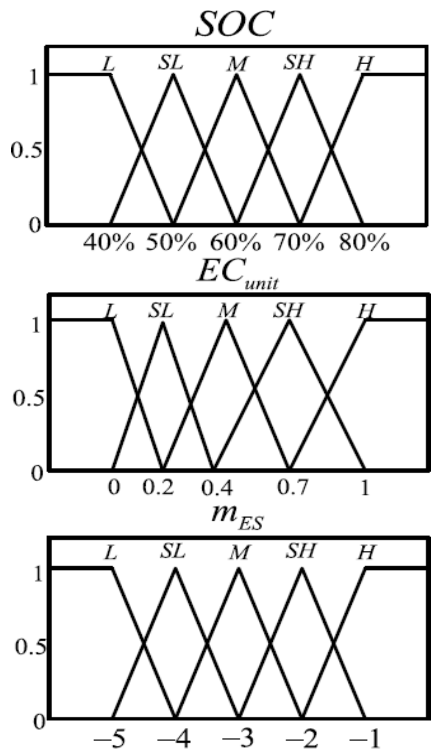


FIGURE 10. Membership functions of the input and output parameters.

1) Using a high state of charge (SOC), the supercapacitor charges using the lowest current possible. Discharging supercapacitor utilizing the minimum current is done when SOC was low.

2) The transfer of electricity via the SST to the transmission grid gets encouraged while ECunit is high. It is recommended that electricity be sent into the SST through the distribution grid whenever ECunit is low.

3) For economic reasons, sending excess electricity towards the distribution grid takes precedence whenever Pnet > 0.

4) In order to lower customers' energy expenses, ES prioritizes power delivery when Pnet isn't as than 0.

5. FUZZY LOGIC CONTROLLER

The quantity and diversity of uses for fuzzy reasoning have expanded recently at a dizzying pace. It is used by a wide variety of commonplace appliances and electronics, including video recorders, cameras, washing machines, microwaves, as well as certain medical devices. It is also used for industrial process control.

The sudden ascent to fame with fuzzy logic may be better understood if you are familiar with the concept.

The term "fuzzy logic" has two competing definitions. As a subset functional multivalve logic, fuzzy logic provides one kind of logic system. Ffuzzy logic (FL) while fuzzy set theory (FSST) have been, in a more general sense, interchangeable when discussing sets where membership appears relative and boundaries are not explicitly stated. Fuzzy logic, according to this school of thought, is nothing more than a subset about fuzzy logic featuring additional restrictions. even its reduced form, fuzzy logic differs conceptually and substantively with conventional multivalve logical systems.

The term "fuzzy logic" (FL) has its widest meaning when used in relation towards the fuzzy Logic Toolbox. A solid introduction to fuzzy logic may be obtained from the book Foundations for Fuzzy Logic. One other thing to think about: the linguistic variable in FL uses words instead of numbers for its parameters. A frequent misunderstanding about FL involves the belief that it may alone be used for computations using words. Words tend to be more in keeping with how humans see things, even if numbers are more precise. To reduce the solution cost while using words for calculation, we take use of the tolerance towards imprecision.

Tolerating imprecision, ambiguity, and partial truth are the foundation of soft computing, which aims to provide tractability, robustness, and cheap solution cost. Later systems having much higher Machine Intelligence quotients (MIQs) may prioritize soft computing over those constructed using more conventional methods.

Fuzzy logic instrument set has covered all bases. Development of successful artificial intelligence relies on this aspect of fuzzy logic. Learning how to use the fuzzy logic toolbox is an absolute breeze. Finally, it provides a contemporary, user-friendly introduction to fuzzy logic including all its capabilities.

The Fuzzy Logic Toolbox's software, when integrated alongside the technical application MATLAB, has the potential to be an effective tool for dealing with fuzzy logic issues.

The age-old human desire to maintain a balance between being exact and being significant is reflected in fuzzy logic, which makes studying it rather interesting.

Despite fuzzy logic's relative youth as a field of study, the fact that it relies on tried-and-true human reasoning skills makes it both fresh and old in certain ways.

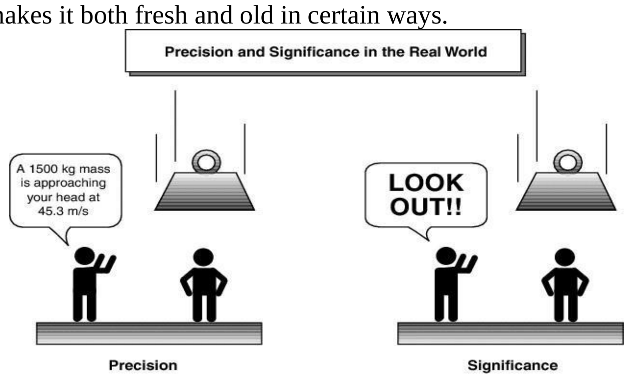


Fig. fuzzy description

It is possible to make good use of fuzzy logic to translate between two spaces, input and output. The first step is to convert inputs into outputs. Think about these instances: An acceptable tip may be calculated using your past experiences alongside the restaurant's service and a fuzzy logic algorithm. The water temperature may be fine-tuned to your exact requirements using a fuzzy logic algorithm. Automatic lens focus utilizing distance information regarding the photograph's topic is possible utilizing a fuzzy logic system. Automatic gear shifting is made possible by a fuzzy logic system which takes the vehicle's speed and engine RPM into account.

You may create systems that use fuzzy logic through the addition of the Fuzzy Logic Toolbox onto MATLAB's technical computing environment. Fuzzy inference systems may be more easily created with the aid of graphical user interfaces. Adaptive neurofuzzy learning and fuzzy clustering are two well-known methods in fuzzy logic, and they both have their place.

The collection of fundamental logic rules within the toolbox could be used to mimic the operation of complex systems when paired with a fuzzy inference system. Fuzzy inference might be powered by the toolbox if given free reign. By using simulink's fuzzy inference blocks, there is also feasible to include the fuzzy systems within a more comprehensive model for the entire dynamical system.

Pattern recognition and traditional fuzzy system design are both made much easier using the Fuzzy Logic Toolbox's graphical user interfaces (GUIs). The included toolkit offers a wide range of capabilities, including fuzzy clustering, adaptive neurofuzzy inference system construction and evaluation, and more.

The fuzzy controlling block from Simulink is another useful tool when modeling and simulating control systems that use fuzzy logic. C code can be generated using Simulink enabling embedded applications which incorporate fuzzy logic.

Fuzzy inference is the process of transforming an input vector into an output vector based on predefined rules. The Fuzzy Logic Toolbox provides graphical tools that simplify the creation of rule sets, the definition of membership functions, and the analysis of FIS operations. Various editors and viewers are available to assist in this process.

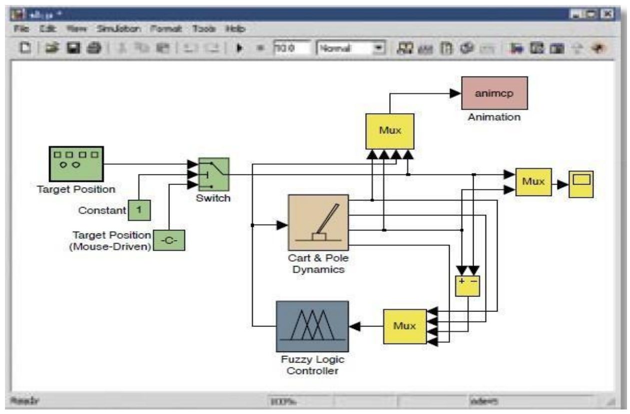
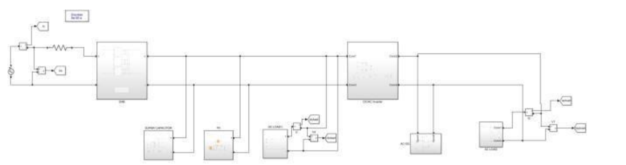
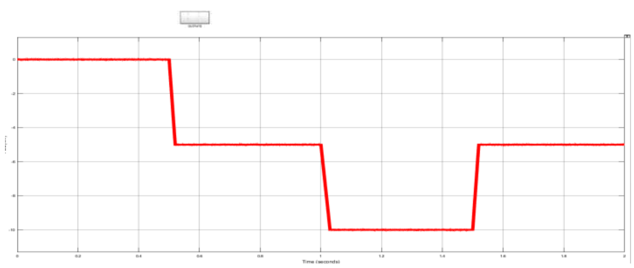


fig 5.2 fuzzy interference system





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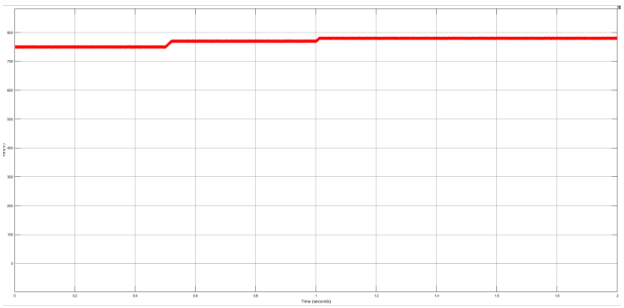
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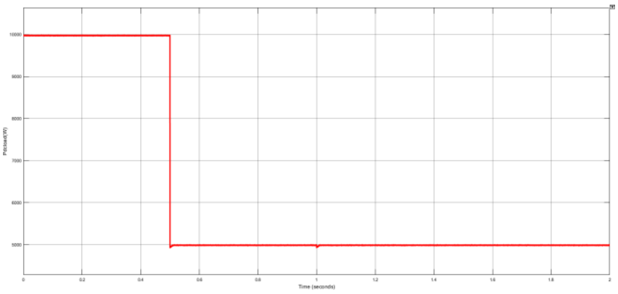
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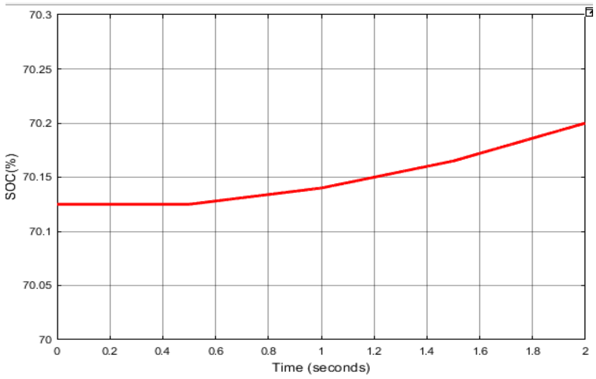

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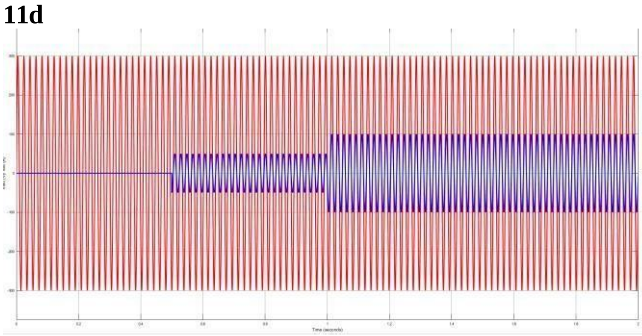
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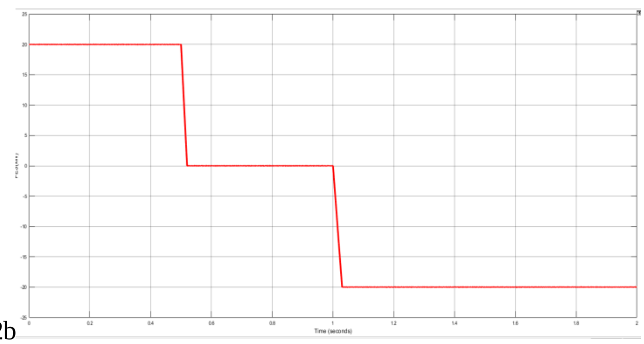
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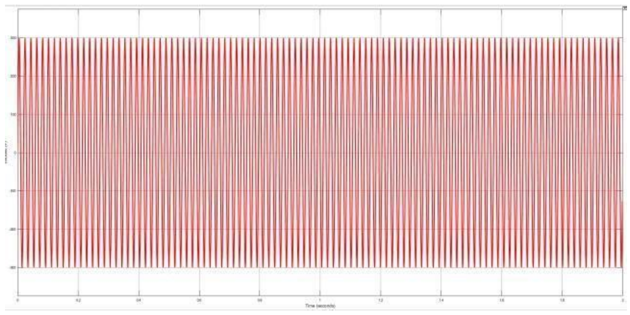
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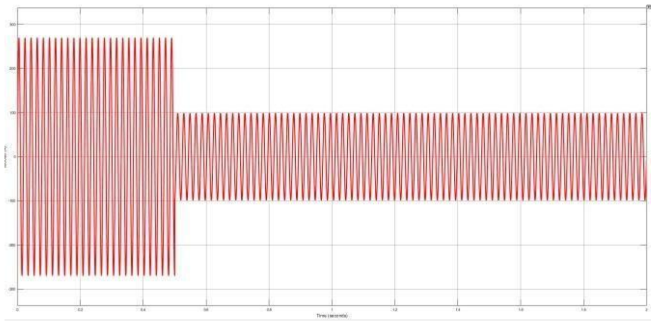
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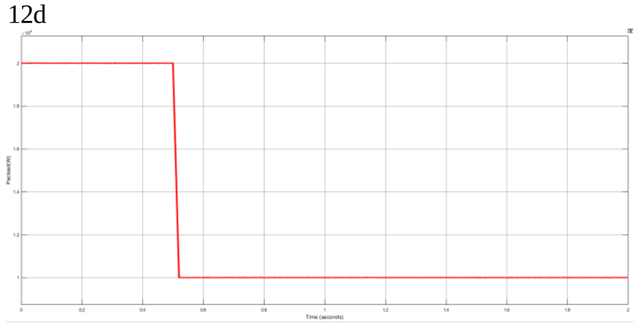
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6. Artificial Neural Network (ANN):

Artificial Neural Networks are inspired by the functioning of the human brain. They consist of interconnected nodes, known as neurons, that process information through multiple layers. By adjusting the weights of connections between these neurons, ANNs can learn and improve their performance over time the neurons, the network has the capacity to learn complex patterns from data, much like the human brain learns from experience. ANNs are capable of tasks such as image recognition, natural language processing, and prediction, as well as are particularly good at handling non-linear relationships throughout data.

The computer model known as an Artificial Neural Network (ANN) takes its cues from the intricate network architecture seen in the human brain. Machine learning and AI rely on it to identify patterns, categorize data, and tackle difficult issues. Artificial neurons, often known as nodes or perceptrons, are arranged in a multi-layer architecture in an ANN.

Input Layer: Receives the raw data input.

Hidden Layer(s): Utilizing weighted connections, intermediate processing units transform inputs.
Output Layer: Using the processed data, generates the end result.

A neuron takes in information from its environment, processes it utilizing an activation function, and then relays the results to other neurons throughout the network.

Working of ANN

a. Forward Propagation

Layer by layer, data is routed via the network.

Prior to being passed on through the subsequent layer, activation functions perform weighted summation and data transformation.

b. Backpropagation (Learning Process)

Error Calculation: Utilizing a loss function, one may quantify the disparity between anticipated and real output.

Weight Adjustment: Weights are updated via the gradient descent process to reduce mistakes.

Iterative Training: Iterative epochs are used to train the neural network until its performance was optimized.

Types of ANN

a. Feedforward Neural Network (FNN)

The flow of information is unidirectional, from input to output.

Nothing recursive.

Used for basic categorization and image recognition.

b. Convolutional Neural Network (CNN)

Expert in processing images and videos.

Makes use of convolutional layers for pattern detection.

Used for medical imaging or face recognition.

c. Recurrent Neural Network (RNN)

Enables data persistence via feedback loops.

Applications in voice recognition, time series analysis, including NLP.

d. Long Short-Term Memory (LSTM)

An RNN variant that is capable of recalling interdependencies over extended periods of time.

Used in stock market predictions, chatbots, and text prediction.

5. Training an ANN

a. Dataset Preparation

Preprocessing: Cleaning, normalizing, and converting stored information.

Splitting Data: Training set, validation set, and test set.

b. Training Process

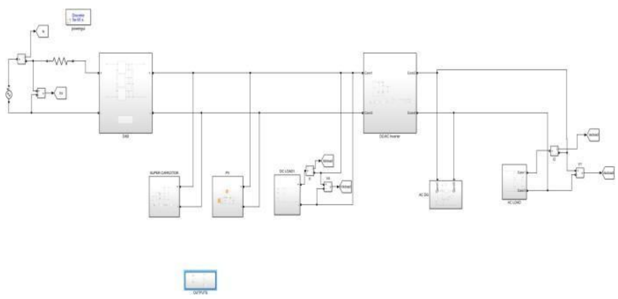
Put weights into the system at random.

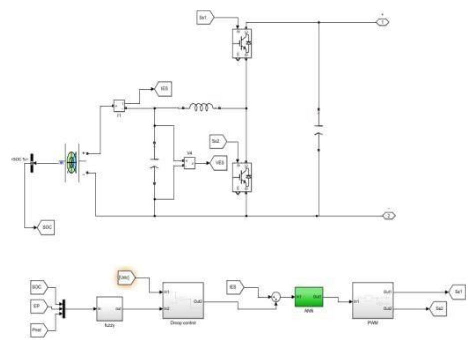
Put forward propagation into action.

Find the loss function, such as the Mean Squared Error using regression analysis.

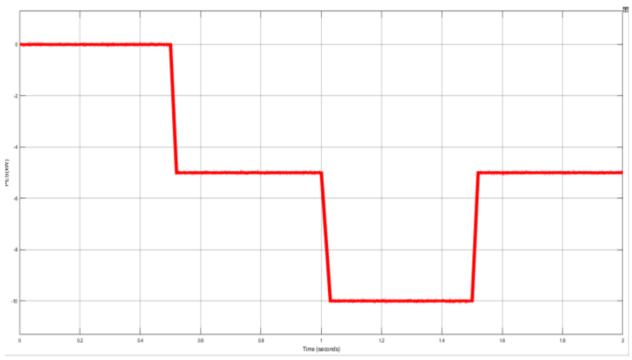
Get the weights exactly right through gradient descent and backpropagation.

Keep on till you reach a peak.





Simulation with ANN Controller



7. CONCLUSIONS

This study presents the construction of a miniature AC/DC hybrid microgrid that depends on SST. Traditional droop control systems use a fixed droop coefficient, which has its drawbacks. To fix these, an energy management approach is suggested. Power distribution can't be altered in response to changes within system operating circumstances, such as the unpredictable and variable availability of renewable energy sources, when the coefficient remains static. In order to increase the monetary advantages to power users and extend the operational life of supercapacitors, a new dynamic droop control mechanism is suggested to improve the ES system. Thorough simulation research confirms that the suggested energy management technique is feasible. The proposed mechanism surpasses the standard droop control system in optimizing power distribution, as indicated by the simulation results.

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