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**ACCELERATED DISTRIBUTED ENERGY
MANAGEMENT SYSTEM (ADEMS) A NOVEL
ARCHITECTURE FOR SMART GRIDS**

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Doctor of Philosophy

Supervisor

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İstanbul, 2025

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ABSTRACT

ACCELERATED DISTRIBUTED ENERGY MANAGEMENT SYSTEM (ADEMS) A NOVEL ARCHITECTURE FOR SMART GRIDS

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Smart Grids have emerged as an effective solution for the integration of renewable energy sources and improving the efficiency and reliability of energy distribution. This paper presents the design and implementation of an Accelerated Distributed Energy Management System (ADEMS) model for Smart Grids. The ADEMS model, which integrates Advanced Metering Infrastructure (AMI), high-speed LiFi and fiber optic communication systems, an RNN-based load forecasting model, and an efficient Energy Management System (EMS), offers superior performance in terms of load forecasting accuracy, system response time, cost efficiency, and voltage stability. The integration of these advanced technologies and systems allows for real-time monitoring and control of the grid, thus enabling an optimal and responsive energy management. The model's effectiveness was validated through various scenarios, and it demonstrated promising results, outperforming other models in the literature. The paper concludes with potential areas for further research and improvements

Keywords: Smart Grids, Energy Management, LiFi, Fiber Optics, Recurrent Neural Network (RNN), Load Forecasting, Voltage Stability.

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ABBREVIATIONS

AEDMS	:	Accelerated Energy Distribution Management System
AI	:	Artificial Intelligence
ANFIS	:	Adaptive Neuro-Fuzzy Inference System
APF	:	Active Parallel Filter
PSO	:	Particle Swarm Optimization
SG	:	Smart Grid

1. INTRODUCTION

1.1 BACKGROUND

Smart Grid (SG) systems are sophisticated networks consisting of controllers and computers that enable the remote management and surveillance of diverse industrial operations. Control systems in SGs prioritize availability over other factors due to their high operational criticality, distinguishing them from normal information systems [1]. The recent malfunctions in these systems emphasize the immediate requirement for strong security measures that can promptly detect issues and promptly notify operators to prevent unauthorized manipulations [2]. The field of computer science, which focuses on the study of automated information processing, has witnessed enormous advancements in computers. However, it is important to note that improvements in computing capacity do not necessarily address specific issues in applications. Frequently, constraints arise from deficiencies in software rather than hardware. Software development employs algorithmic and knowledge-based methodologies. Prior to execution, the former need comprehensive procedural documentation, which may be prohibitive for intricate scenarios. In contrast, computers function based on rigid binary logic, according to preset instructions with exactitude [3]. This is beneficial when algorithms have the ability to anticipate all possible scenarios, but frequently, unforeseen situations cannot be effectively handled by algorithms alone. For example, in aircraft and shuttle systems, redundancy solutions are used to reduce risks by using three software systems that have been designed independently. Artificial intelligence, specifically expert systems, provide an alternate approach by utilizing predetermined rules established by human experts. Nevertheless, this methodology is constrained to domains in which knowledge can be clearly represented and does not adequately encompass subjects such as medicine or psychology [4]. Pattern recognition, diagnostics, and machine translation are domains in which conventional methods are inadequate, indicating a necessity for novel approaches. The Accelerated Energy Distribution Management System (AEDMS) proposed in this paper integrates the Adaptive Neuro-Fuzzy Inference System (ANFIS) to enhance grid frequency stabilization, inspired by the principles of Active Parallel Filters (APF). In this system, ANFIS is utilized to dynamically control a special load connected to the busbar via a controllable switch. This load generates a disturbed frequency that overlays the average frequency of the existing load, thereby counteracting fluctuations and

maintaining a stable grid frequency. The system's design focuses on the load type whether resistive, inductive, capacitive, or mixed experimenting with various options to ascertain the most effective configuration for optimal results. Key design considerations also include minimizing power consumption and system cost by using small load capacities and ensuring the system's ability to respond quickly to frequency disturbances through rapid adjustments facilitated by ANFIS's adaptive and predictive capabilities.

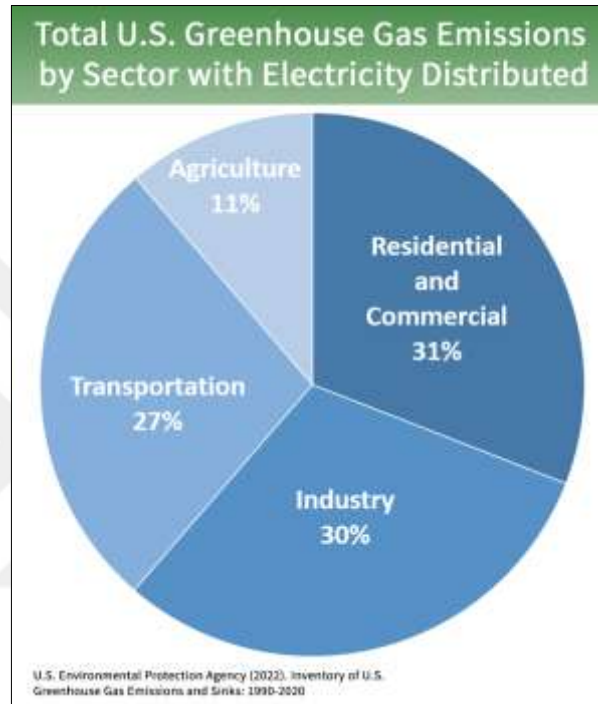


Figure 1.1: Sources of GHG Emissions.

It is necessary to take into consideration a more "intelligent" management of production sources and consumption in order to maintain the promotion of the installation of renewable energy generators and so commence the outlining of an energy transition. This is an often mentioned component of the Smart Grid concept that was discussed earlier. The ultimate goal is to think of the electrical network as a collection of numerous smaller microgrids that are independently maintained but that nonetheless need to take part in maintaining the overall equilibrium between production and demand. Setting up storage means adding a degree of freedom to control the flows of energy used or produced, which can be one of the ways to make the administration of microgrids more flexible overall. If large-scale centralized storage is not technically and economically profitable, then the progress that has been made in the various technologies now makes it possible to envision distributed storage,

subject to changes in regulations, particularly in terms of tariffs. This is the case because the various technologies now make it possible to envision distributed storage. In point of fact, just like it was fifteen years ago for solar or wind power, the opportunity to connect storage means is currently being discussed in order to set the rules for use and remuneration according to the services provided. These services include consumption clipping, curtailment, smoothing of the intermittency of renewable energy sources, and so on. The research that was done for this thesis concerned a solar-powered microgrid that also included a tertiary consumer and some kind of energy storage device. There are two technologies that are being considered, the first being flywheels and the second being an electrochemical battery (Li-ion). Due to the fact that the system is connected to the primary network, the management plan needs to take into account the purchase and sale of components in accordance with the prices that are currently in effect. The improvement of the predictability of the powers that are withdrawn from or injected into the grid is therefore viewed as a step toward the development of the microgrid. This strategy is interesting from the perspective of the energy supplier because it allows the supplier to make more accurate upstream estimates of the amount of energy that his customers require, which in turn allows the supplier to make fewer purchases of energy in real time from the wholesale market at prices that are higher. The work that is being done for this thesis attempts, in addition to the adoption of management approaches, to build an optimal design procedure that is appropriate for the sort of systems that are being researched. The goal is to establish a technically and economically optimal solution in accordance with the data on consumption and production, as well as the context of the tariff, and to do so by integrating the installation costs of the various components. The assessment of this total cost is intricately connected to the manner in which the microgrid is managed in terms of the energy bill and the advantages attained as a result of efficient management. Therefore, the plan is to think about the management loop from the beginning of the design phase by incorporating it into the technique for the design. In this context, it is required to run simulations of the operation of the microgrid over lengthy periods of time (i.e. months, years) in order to correctly comprehend the environment in which it operates (production deposit and consumption missions). However, depending on the models that are constructed and the management algorithms that are envisioned, they can soon become impractical in terms of the amount of processing time that they require. The approach that was taken for this thesis consisted then in locating an adequacy between the

resolution method and the granularity of the models in order to have the ability to easily size the system and study the impact of various input parameters. This was done in order to fulfill the requirements of this thesis (pricing context in particular)

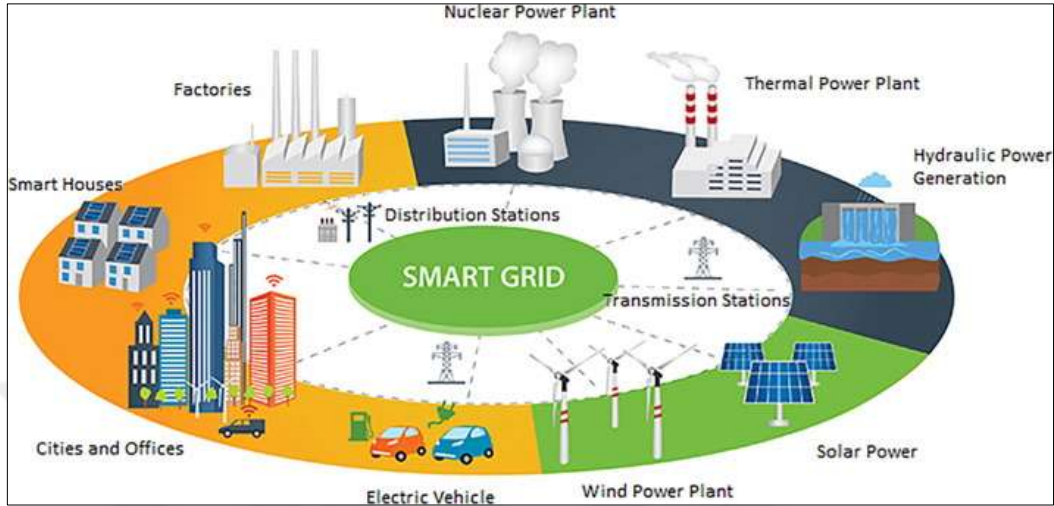


Figure 1.2: General Layout of Smart Grid Systems.

1.2 MOTIVATION

As a result of the shift that occurred in the paradigm of electric power generation and distribution, it became abundantly evident that there was an urgent need to explore the nodal injection problem. We no longer have energy generation that is concentrated in massive power stations, a transmission network to convey it to customers, and a distribution network to distribute it to consumers. All of these elements have been eliminated. Instead, we have smaller power plants situated in locations that are favorable to the method of generation of each individual plant, and these injections of energy typically take place at the nodes of the distribution network. This is largely attributable to the increasing incorporation of various forms of renewable energy. Because of the one-of-a-kind qualities of the production of renewable energy, plants with lesser installed power are constructed in places that are determined by factors such as, for example, the wind in the case of wind energy. This is done in order to maximize the output of the plant. Because of this, the production of renewable energy can now take place at a lower cost (wind turbines are installed where there is wind and this is favorable to the generation of wind energy). This paradigm change is not only attributable to the peculiarities of alternative or renewable sources of energy, though. There is a reduction in the amount of energy that is wasted due to transportation because the point

of generating, in whatever form it may take, is situated closer to the point of consumption. If it is known which network nodes are more favorable to the installation of the new generation, that is, those that maximize the total power that it can absorb, then more power can be injected into the network, thereby minimizing the necessary reinforcements to accommodate this increase in energy. If it is not known which network nodes are more favorable to the installation of the new generation, then the reinforcements that are necessary to accommodate this increase in energy will be greater. If it is known which network nodes are more advantageous to the installation of the new generation, for example, those that maximize the amount of total power that it can absorb, then it is conceivable to install the new generation at those network nodes.

1.3 GENERAL OBJECTIVE

An effective strategy for dispatching should have as its major goal the generation and usage of electrical energy at the cost that is as low as is reasonably practicable. It is possible to achieve this goal by satisfying all of the demand while remaining within all of the constraints imposed by the system. A innovative approach that has gained traction in recent years is the utilization of artificial intelligence in the form of genetic algorithms (GA) and the optimization algorithm that makes use of particle swarms. Both of these methods fall under the umbrella of artificial intelligence. Recent years have seen the development of this strategy (PSO). As a result, the objective of this work is to make use of these two techniques with the end goal of resolving the issue of economical dispatching of electrical energy within the context of a ground-breaking expedited smart grid architecture. To be more specific, the following objectives have been set for this work:

This study will analyze the issue of maximum nodal injection of active power in an electrical energy network in order to better understand how to solve it. To be more explicit, the objective is to determine which nodes have the greatest potential for maximizing the value of this power and which ones are the best ones to inject it. It was intended to modify an algorithm, which will be known as the Particle Swarm Optimization (PSO), in order to apply it to the scenario of nodal injection, whether simultaneous or non-simultaneous, and to encode it in such a way that it can be used on the vast majority of networks. In order to make the algorithm relevant to the greatest number of networks, it was necessary to carry out these

steps. In addition to that, we planned to offer some suggestions on how the next step in the development of this work could be taken.

1.4 THESIS AIMS AND RESEARCH QUESTIONS

This thesis examines some of the potential future possibilities of smart grids, with a focus on the buildings-grid interface. The ultimate goal is to develop a system that can monitor, anticipate, schedule, learn, and make decisions regarding local energy usage and output in real time [27]. These difficult difficulties are limited to the following types of fundamental research questions:

- a. How can we improve our estimation of the quantity of energy we consume?
- b. How can I use online education to find the most efficient method for resource planning?
- c. What are some methods for learning to accomplish numerous activities simultaneously?

In order to respond to this study subject within the context of smart grid the following objectives have been established and will be presented in this thesis:

- a. Using machine learning approaches, determine the present state of the art in energy prediction, and then design unique techniques with the potential to reduce the energy forecast error.
- b. take the time to examine the numerous ways for assigning construction materials that have been developed thus far.
- c. Determine what may be done to reduce the quantity of energy wasted by the structure through research. recognizing patterns of energy use within a structure and then obtaining relevant data mechanically.

Develop a mechanism for quantifying the flexibility of a building's real-time energy use.

1.5 CONTRIBUTIONS

This thesis contributes to the existing body of knowledge by focusing on the creation of algorithms (agents) capable of performing multitask learning independently. In contrast, one of our key objectives is to shift from offline optimization tactics to smart grid, real-time replies. If real-time applications that are constructed on top of a large data set are made available to users of smart grids, then those users will be in a position to alter their consumption habits in a way that is more beneficial [28]. To maximize the energy

consumption of a building and, by extension, its effects on the grid, one must be aware of individual consumption patterns as well as energy consumption methods.

1.5.1 Presentation of the Proposed New Method

In the subsequent section of this article, we will discuss a new way that we call ADEMS Special Load Frequency Control. This method was developed by ADEMS. The active parallel filter (APF), which produces a disturbed current to superimpose the polluted current of the load in order to keep the source current with a low rate of harmonics, served as an inspiration for this method. The active parallel filter (APF) generates a disturbed current to superimpose the polluted current of the load. This technique produces a distorted current in order to superimpose itself on the contaminated current that is produced by the load. The ADEMS strategy calls for the controller to produce a disturbed frequency, which is then superimposed on the load's average frequency. This is done in order to keep the frequency of the grid at a consistent level.

1.5.2 The Principle of the ADEMS Method

The ADEMS method consists of installing a special load at the level of the busbar and nozzle in order to reduce the variation of the frequency in the busbar. This type of load is connected to the busbar by a controllable switch, the principle of this system is shown in the figure (3).

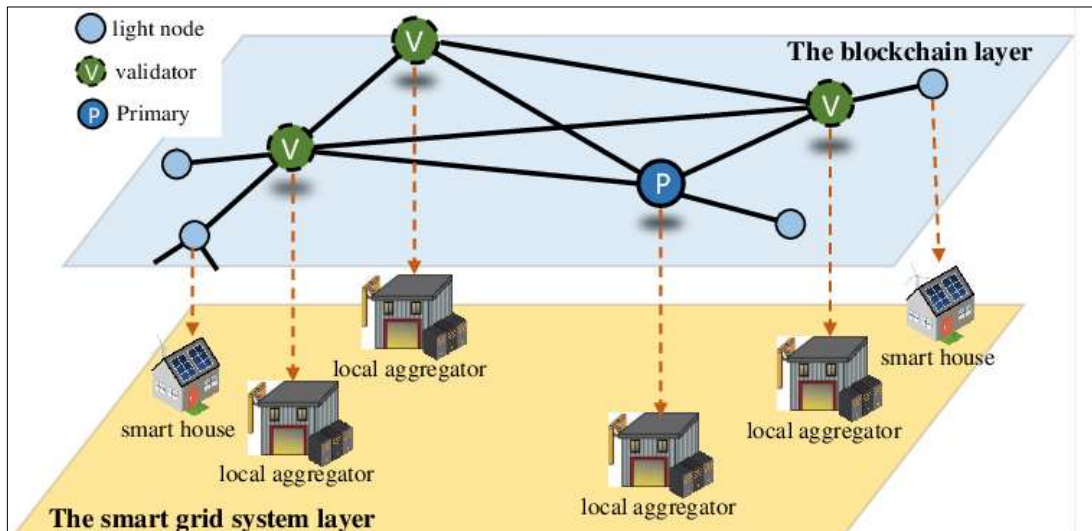


Figure 1.3: Proposed Accelerated Smart Grid Architecture.

In common parlance, "loads P" can refer to a wide variety of establishments, including substations, factories, and so on. What differentiates the main loads from the special load CS is the command to monitor and regulate the frequency of the network or the inverter as our example figure shows. The latter is governed by this command, which regulates it (1.3). On the other hand, it is the responsibility of SH and LA customers to control the significant loads manually or automatically, depending on their preference. For example, the start of the work day in the industry typically starts at 8:00 in the morning, and the end of the work day typically takes place somewhere around 4:00 in the evening. The operator of the system also took into mind the factories that run continuously and do not pause their production unless there is either an anomaly, a fault, or a revision to the software. These factories operate in a manner similar to a machine that is running.

Even though the network dispatcher is constantly studying the variation and the evolution of the load, it is still impossible to create an accurate prediction of the day-1 load curve. This is the case even though the overall trend of the load may be studied. This is because any event has the potential to influence the fluctuation of the load, as well as the variation of the frequency. The reason for this is due to the fact that any event could influence both of these variables.

Based on figure 3, we may draw the conclusion that the purpose of the special load is to introduce a disturbed power in such a way that the frequency of its disturbed power, f^* , is overlaid on the frequencies of the frequencies of the other loads 1, 2, and 3. In this particular setting, the objective is to obtain a frequency in the busbar that is more stable than the frequencies f_1 , f_2 , and f_3 that are being utilized at the moment.

1.5.3 ADEMS Configuration in Case of Several Busbars

In the case of several busbars or bays, the configuration of figure (1.4) can be represented in figure (V.3). In principle, the more one installs a special load in each section, one obtains a more stable network frequency f , but the cost factor must also be taken into account in the design and the study.

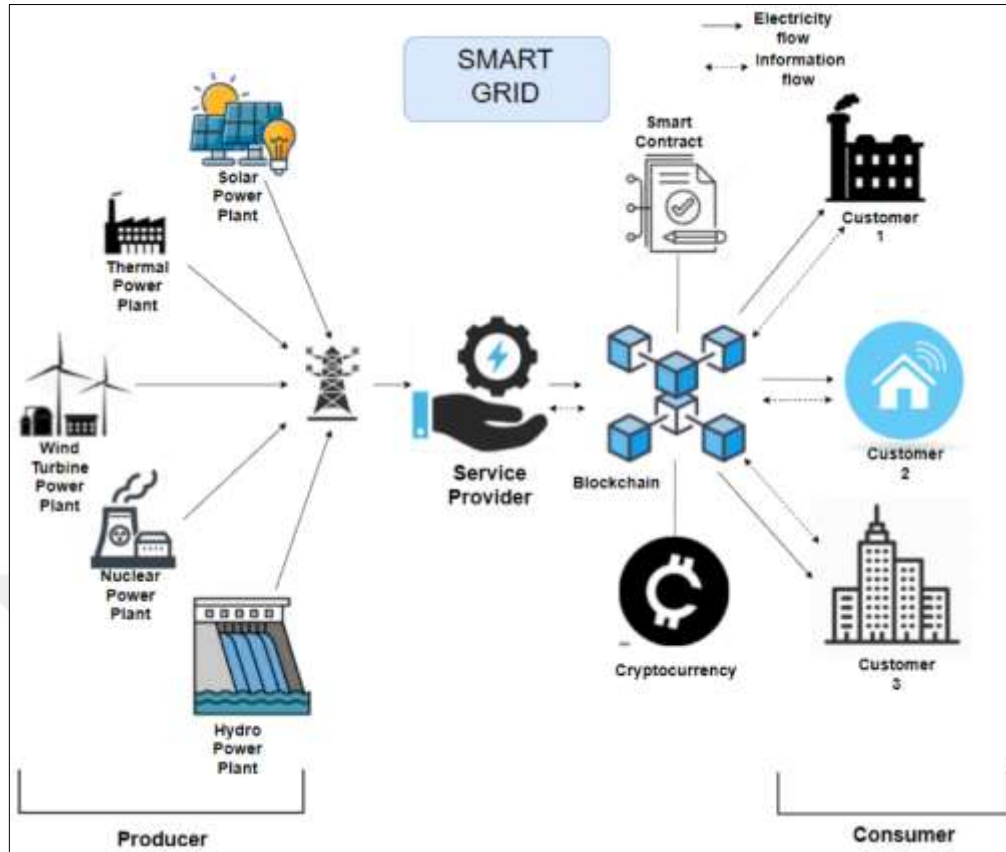


Figure 1.4: Diagrams of the Proposed Model in the Case of Two Busbars.

There are other variants such as the case with the same diagram as figure (4) but without the special load in busbar 2 or vice versa.

1.5.4 Characteristics of the ADEMS Special Charge

The design of this system is based on various factors and conditions that of the installation. The main conditions are:

- The load type can be resistive, inductive, capacitive or mixed; in this work we will try several types and make the comparative study between them in order to find the best variant that can give us optimal results.
- Load capacity should be small to minimize power consumption and system cost.
- The response time of the ADEMS must be short in order to be able to react quickly in the event of a frequency disturbance.

In this section, we consider the below conditions in the study of the ADEMS method. In order to find the load that suits our system we will simulate several types of loads the

frequency of its different loads are shown in the figure (1.4). At flow, we simulate 10 variants in order to find the optimal scenarios and models. Next, we will choose a single variant for the frequency regulation of our model. Finally, we will do all the tests and the causes of disturbance of the frequency in different cases such as the variation of the load, the solar illumination, the intensity of the wind...Etc.

1.6 PROBLEM STATEMENT

As was indicated earlier, the purpose of this study was to identify a solution that could be applied to the majority of networks in order to optimize the amount of electricity that those networks absorbed. This problem can be broken down into two parts: the first part involves injecting power into every node of the network individually. After that, we shall split these two situations and formulate them individually. A problem is said to be combinatorial when there are multiple alternative solutions that can be combined in a variety of ways. One of these conceivable permutations will prove to be the most effective response to the challenge at hand. It is possible to obtain possible solutions to the problem by making use of the inverse load method, which was suggested by Harrison and Wallace in [3], genetic algorithms, such as those found in the work of Joo Nunes in [4], probabilistic methods, which were suggested by Jorge de Almeida in [6], and other similar strategies. It was decided to use the PSO (Particle Swarm Optimization) algorithm to search for the various possible combinations of answers to the challenge. This algorithm was chosen because it is one of the possible algorithms to solve the problem in question, because it is part of the group of algorithms of the so-called artificial intelligence that derives from a form of collective intelligence, and because, in the research that was carried out, only one study was found that applies this algorithm to this problem, but imposing the restriction that the new losses cannot be greater than those that existed in the case that there was no distribute. This algorithm was chosen because it is one of the possible algorithms to solve the problem in question Because determining the greatest amount of energy that the network is capable of absorbing, regardless of any losses, is the goal of this investigation, this limitation will not be enforced at this time.

2. LITERATURE REVIEW

2.1 CHAPTER INTRODUCTION

An accurate mathematical model is often required in an environment that is competitive in order to optimize the cost of production. As a result, he discovered several techniques, both classical and modern, that have been used to solve this optimization problem. These techniques are reported to have been used in [1] this results in non-optimal solutions; consequently, examining the nonlinear characteristics of these power plants requires very robust algorithms to avoid this problem. [2].

2.2 RELATED WORKS

An expert system is made up of two parts: an inference engine and a database. Both of these parts work together to form the whole. The inference engine is responsible for a variety of tasks, including control of the user interface, access to external files, access to programs, and scheduling. The database is where we keep the one-of-a-kind information that pertains to a particular problem or predicament. A person who is knowledgeable about the process can, with the assistance of this database, articulate the principles that direct the process. Because it does not require the use of complex mathematical calculations, a SE model is used primarily for the goal of shortening the amount of time required to find a solution. This is accomplished by lowering the amount of work involved in the process. On the other hand, it will not function properly if the new load model cannot be compared to the one that is stored in the dynamic database. According to [1], despite this fact, the SE was nevertheless able to achieve a significant level of success in a variety of applications, one of which was defect identification.

2.2.1 Works Related to Artificial Intelligence

1965 was the year that Lotfi A. Zadeh initially presented the idea that would later become known as fuzzy set theory. Later, in 1973, he presented the ideas of a linguistic variable and fuzzy if then rules, both of which he had refined further and offered. Both of these ideas were his own work. This study laid the groundwork for fuzzy logic control, and the vast majority of the applications that are currently being made of fuzzy logic are in fields that can only represent imprecise or uncertain data. This enables these systems to arrive at

conclusions based on unclear and insufficient information in a manner that is comparable to the manner in which humans arrive at such conclusions. Expert systems make use of binary logic to define and manipulate accurate notions, whereas scrambled systems make it possible to articulate and handle uncertainties in the formulation of issues. Expert systems are responsible for describing and manipulating certain concepts. In recent years, there has been a significant growth in the amount of interest in the scrambled expert system, and a fair amount of work has been achieved toward the goal of addressing situations that entail a number of competing objectives at the same time. These adaptive scrambling methods are more suitable for usage in real-time applications as a result of the large reduction in the amount of time required for processing. On the other hand, these tactics could bring about unfavorable results in specific situations, such as when there is an unanticipated rise in the amount of work that needs to be done [2][3]. These adaptive scrambling methods are more suited for usage in real-time applications as a result of the large reduction in the amount of time required for processing. However, under certain conditions, such as when there is an unexpectedly strong demand for load capacity, these strategies could end up producing unwanted results. According to [4], the complexity of the mathematics that is involved in these methods is not completely reduced. This is another disadvantage of these approaches.

Artificial neural networks are powerful tools that can be applied to the resolution of a wide variety of problems that arise in the "real world." They are able to improve their performance by gaining knowledge from their previous experiences, which enables them to adjust more quickly to changing situations in their environment. In addition to this, they have the ability to comprehend data that is noisy or information that is inadequate. In addition, they have the potential to be quite effective, especially in situations in which it is impossible to precisely define the guidelines or the procedures that need to be followed in order to solve a problem. This is one of the circumstances in which they have the potential to be quite effective. An artificial neural network, also known as an ANN, is essentially a data processing system that has the ability to predict an output pattern based on the recognition of a certain input pattern. This ability allows an ANN to be compared to a black box because it can be viewed in the same light. Following its training, the neural network is able to identify patterns of similarity when it is presented with a new input pattern, which ultimately results in the development of a model for the expected yield. Interpolations based on ANNs have the capacity to deliver appropriate results despite noisy and unshaped inputs, which is an extra key benefit of using

these methods. This confers a significant benefit. The neural network is responsible for a number of important activities, but one of its most important jobs is learning. Learning can take place either under the watchful eye of an instructor or in complete isolation. During directed training, the learner will receive both inputs and outputs at various points in the session. After that, the network processes the inputs, and the outputs that it generates are compared to the outputs that are wanted, as explained in [5].

After that, the mistakes are computed, and then they are used to the process of altering the weights so that the network can be governed by it. This process is repeated over and over again as the weights are continuously twisted in the other direction. In the event when unsupervised training is being carried out, the network will have inputs, but there will be no outputs that are wanted. After that, the system will determine how the incoming data should be structured based solely on its own judgment. This phenomena, which is frequently referred to as self-organization or adoption according to the findings that were reported in [6],

When it comes to training, the vast majority of ANN implementations in electrical power systems make use of the multilayer perceptron model, which is founded on the back propagation (BP) technique. This tendency can be attributed to the simplicity of their application as well as the accessibility of their implementation in hardware. The presence of local minima makes it difficult for boiling point algorithms to converge, despite the fact that they are widely used. This is because there are multiple local minima. These challenges are caused by the fact that standard ANN is very nonlinear in the parameters that they employ, and that the study is dependent on nonlinear optimization approaches such as the steepest descent technique. Specifically, the steepest descent methodology. The other major drawback of ANN is that it is difficult to find an optimal configuration because there are no exact rules known to decide the number of hidden layers, the number of neurons in each layer, or the type of activation that is used in each layer. Finding an optimal configuration is one of the most challenging aspects of working with ANN. One of the most significant drawbacks of ANN is this one. For the purpose of making approximations, a new generation of artificial neural networks (ANN) has been developed, and it is founded on the theory of radial basis functions (RBF). These ANNs, which are significantly faster and more reliable than BP networks and are known as Radial Basic ANNs or simply RBF networks, have an

architecture that is self-configuring and go by the name RBF. This was done so that these drawbacks of boiling point-based neural networks could be avoided. Throughout the course of the previous two decades, artificial neural networks (ANNs) have garnered a significant amount of interest, and during the same time period, a great number of articles on their application to the solution of the power system problem have been documented, as is described in [7]. For the purpose of making approximations, a new generation of artificial neural networks (ANN) has been developed, and it is founded on the theory of radial basis functions (RBF). In order to circumvent these issues that are associated with boiling point-based neural networks, this step was taken. These ANNs, which are known as Radial Basic ANNs or, for short, RBF networks, feature an architecture that can self-configure and are far quicker and more reliable than BP networks. They are referred to by the acronym RBANNs. Over the course of the previous two decades, artificial neural networks (ANNs) have garnered a significant amount of interest, and over the same time period, a great number of articles on their application to the solution of the power system problem have been documented, as described in [8]. [8] provides additional information. For the purpose of making approximations, a new generation of artificial neural networks (ANN) has been developed, and it is founded on the theory of radial basis functions (RBF). In order to circumvent these issues that are associated with boiling point-based neural networks, this step was taken. These ANNs, which are far quicker and more reliable than BP networks and are known as Radial Basic ANNs or simply RBF networks, have an architecture that is self-configuring and go by the moniker RBF. Additionally, these ANNs are known as Radial Basic ANNs. In the past two decades, artificial neural networks (ANNs) have garnered a substantial amount of interest, and throughout the course of that time, a huge number of articles on their application to the solution of the problem with power systems have been documented, as stated in [9]. The theory of radial basis functions (RBF), which is utilized for approximations, has also been utilized in the development of artificial neural networks (ANNs). These ANNs, which are known as Radial Basic ANNs or, for short, RBF networks, feature an architecture that can self-configure and are far quicker and more reliable than BP networks. They are referred to by the acronym RBANNs. According to [10], artificial neural networks (ANNs) have attracted a significant amount of interest over the past two decades, which has resulted in the publication of a huge number of scholarly publications on the topic of their application to the problem of improving power systems. ANNs have also been built

based on the theory of radial basis functions (RBF), which is another theory that has been established for approximations. In addition to this, it has been demonstrated that ANNs are effective in finding solutions to difficult problems, such as those involving power systems. These ANNs, which are known as Radial Basic ANNs or, for short, RBF networks, feature an architecture that can self-configure and are far quicker and more reliable than BP networks. They are referred to by the acronym RBANNs. During the course of the previous twenty years, artificial neural networks (ANNs) have received a significant amount of attention. During this same time period, a significant number of papers on the application of ANNs to the solution of the problem with the power system have been documented, as reported in [11].

A molten metal is first cooled gradually until it solidifies at a temperature lower than the temperature at which it was heated to the high temperature. One way to think about the level of temperature is as being analogous to the number of iterations that are performed by the SA algorithm. At the conclusion of each cycle of the process, a candidate solution is generated for consideration. In the event that the newly developed solution proves to be superior to the one that was developed previously, the process will be carried out once more in order to develop an additional candidate solution. Even if it is a defective answer, it will still be authorized if the possibility of its acceptance is higher than a randomly generated value that falls between 0 and 1. It is allowed for the process of finding a solution to continue indefinitely until either the maximum number of iterations that are possible is reached or the solution that is the best one that can be found is found. However, the SA annealing schedule needs to be carefully tuned in order to give the best results; if it is not, the solution that is achieved will always be one that is regarded to be locally optimal. SA is a method that can be carried out in a manner that is not overly difficult, and this is why it was initially utilized. Annealing often becomes slow when used to a practical big scale other feed system; nonetheless, a proper annealing program requires a significant amount of computational time, as reported in [12].

Fred Glover was the one who first offered the straightforward taboo search approach in the year 1986. This research is gradient driven, which means that the search process moves from one location to the next in a general direction that is generally in the direction that is generally in the direction that is generally in the direction that has the steepest or most decent

rise. In other words, the research is gradient driven. It is possible to call the TS approach adaptive in the sense that it is able to break free from the confines of a local optimal solution while simultaneously preserving the diversity of the search space because it makes use of both short-term and long-term memory. This is accomplished by utilizing both short-term and long-term memory. It is also obvious that the upkeep of a short-term taboo list demands the necessity for continual maintenance displacement as a result of shifts in taboos brought about by the advancement of research. This is something that needs to be kept in mind. The most important search parameters for the taboo list are those that are associated with the dimensions and qualities of the most recent taboo list. In actual practice, the appropriate adjustment of such factors will, however, depend heavily on the nature of the situation. This is a heuristic approach that very certainly includes a significant number of rounds of the search. On the other hand, more recently, an enhanced TS strategy provided by WM Lin, et al. at economical shipping with non-smooth cost functions with great improvement in the TS algorithm was published in [13]. This was accomplished with the help of considerable advancements in the TS algorithm. This was accomplished at a low cost for delivery.

In a manner that is analogous to that of search genetic algorithms, evolutionary programming (EP), which was first conceived of by Fogel in 1960, starts with a population of different potential answers. The process of phenotypic evolution, on the other hand, does not include the use of crossover but rather relies primarily on the action of a wide array of mutagenic processes. Additionally, the PE is not constrained in any way by the typical binary genome representations of the GA. This is because the PE is not constrained by the binary genome. As a direct consequence of this, considerable amounts of time can be conserved during the processing done at the PE. It was shown that the ELD problem with non-smooth fuel cost functions may be solved by employing the PE algorithm in the study that was done by HT Yang et al. After some time had passed, a number of studies were presented that demonstrated how evolutionary programming techniques performed far better than genetic algorithms. However, in order to deal with optimization problems that are both stochastically variable and extremely complex, a variety of other modifications to the fundamental PE techniques have been the topic of a significant amount of research. The speed of evolutionary programming algorithms has seen tremendous progress in recent times, with significant progress being made in recent times. Praise has been lavished on those responsible for making these improvements. Research was carried out by Nidul Sinha and colleagues, who

examined the application of evolutionary algorithms to ELD problems using a variety of alterations to the mutation techniques used in fundamental evolutionary programming (EP). The findings of the study were presented in a publication not too long ago. An Improved Fast Evolutionary Program, often known as an IFEP, was established as a direct outcome of the research. When compared to all of the other EP processes that are now in use, this program offers superior performance, notably in the areas of convergence rate, solution time, lowest cost, and likelihood of accomplishment.

When it comes to the infrastructure that generates and distributes electrical power, there are two significant aspects that are significant to the typical customer. These aspects are the cost of supply and the reliability of the infrastructure. While adhering to a number of constraints, the objective of this study is to evaluate the impact that strategic and operational planning has on reducing the cost of producing electric power. This task also needs to be accomplished in real time, while maintaining a high degree of reliability and under the strain of a time limit as a result of recent deregulation in the electrical business. The evolutionary-based methods that are currently available, such as SA, TS, GA, PE, and PSO, are quite capable of finding the global or near optimal value for highly non-convex ELD problems; however, it is impractical to operate these methods in real time due to the lengthy execution time required by these methods. Examples of evolutionary-based methods include SA, TS, GA, PE, and PSO. Because the quality of the solution is dependent on the number of iterations in an evolutionary process, increasing the number of iterations would require more time for the solution to be found in order to achieve the same level of improvement in solution quality as would be achieved by decreasing the number of iterations. The end result of these problems is that PE-based algorithms cannot be incorporated into real-time economic load speed; however, the outputs of these algorithms can be used as suggestions for efficient operation. It has been proved to be a very effective and dependable method for real-time inexpensive shipping operation if the artificial neural network is trained properly using precise training data, as stated in [14]. This technology has been shown to be very effective and reliable. One of the reasons for the growing popularity of newer categories of artificial neural networks is because this is one of the causes. An increase in the total amount of time spent working on the issue ought to be followed by an increase in the total number of iterations that are carried out. As a result of this, PE-based algorithms cannot be generated at a fraction of the real-time economic load speed; nonetheless, the outputs of these

algorithms can be exploited as recommendations for optimal operation. It has been found to be a very efficient and dependable method for real-time inexpensive shipping operation if the neural network is trained properly using precise training models, as reported in [15]. This methodology has also been shown to be quite effective. This has been established by more recent classifications of artificial neural networks, which have been shown to be quite effective in their applications. An increase in the total amount of time spent working on the issue ought to be followed by an increase in the total number of iterations that are carried out. As a result of this, PE-based algorithms cannot be generated at a fraction of the real-time economic load speed; nonetheless, the outputs of these algorithms can be exploited as recommendations for optimal operation. As mentioned in [16], it has been demonstrated to be a very effective and dependable method for real-time cheap shipping operation when the artificial neural network is trained properly using accurate training models. This is one of the reasons why it has been popular in recent years. This has been proved by more recent categories of artificial neural networks, which have demonstrated a significant amount of promise in this particular aspect [17][18]. This methodology has also been shown to be quite effective. This has been established by more recent classifications of artificial neural networks, which have been shown to be quite effective in their applications.

The development of hybrid systems, in particular those that integrate artificial neural networks with global search methods, has been receiving a lot of interest as of late. In particular, this attention has been focused on those systems. In circumstances such as this one, neural networks can be trained or formed by the application of methods that entail global search. Real-time applications, in particular, place a premium on high levels of reliability rather than high levels of precision in the calculations that they require. Real-time applications also place a premium on high levels of availability. There is a possibility that the real-time performance criteria of economically efficient load dispatch can be satisfied by an integrated system that makes use of techniques that are based on PE and ANN. Off-line EP-based methodologies are used in the hybrid approach in order to build training models for the ANN, which are then used in the hybrid approach. This is done so that the hybrid technique can seek for the answer that is best for the entire, and this helps ensure that it does so successfully. While the ANN is being constructed off-line, it is gathering knowledge about the various input and output data sets that are being sent to it. When the network is fully built, online mining will consist solely of a series of elementary arithmetic operations

that can be completed in a very brief amount of time. This will make the process much more efficient. When the network has been finished being built out in its entirety, this will be the case. As a consequence of this, globally qualified ANN may be considered an analytical alternative to PE-based methods. In addition, various fascinating uses of the hybrid technique in the field of power system have been documented in the aforementioned body of scholarly work, as was noted in [19]. The process of mining digital currency online would merely include a string of uncomplicated mathematical operations that could be completed in a reasonable amount of time. As a consequence of this, globally qualified ANN can be regarded as an analytical alternative to PE-based approaches. Furthermore, numerous fascinating applications of the hybrid methodology in the field of power system have been documented in the aforementioned body of work, as was published in [20]. [20] Some of these examples are mentioned in [20]. The process of mining digital currency online would merely include a string of uncomplicated mathematical operations that could be completed in a reasonable amount of time. As a result, PE-based methods have competition from globally qualified ANN, which can be used as an analytical alternative. In addition, numerous fascinating uses of the hybrid technique in the field of power system have been documented in the aforementioned body of scholarly work, as was noted in [21]. Online mining would only involve a chain of simple arithmetic operations that can be accomplished in a very short period of time. Thus, globally qualified ANN can be considered as an analytical alternative to PE based methods and many interesting applications of the hybrid technique in the field of power system have been reported in the literature as reported in [21].

2.2.2 Works Related to Renewable Energy

In recent years, there has been a significant growth in the inclusion of renewable energy sources into the power grid. This trend is expected to continue growing. These resources do not contribute rotational inertia to the power system, despite the fact that they are included into the power system through the utilization of power converters. In the event that it is not handled in an acceptable manner, a considerable amount of distributed energy resources (DER) has the potential to bring about instability. Therefore, controllers of dispersed energy resources are necessary to identify and carry out new activities in order to fulfill their responsibilities. There are a number of potential advantages that might be obtained from the

efficient utilization of renewable resources. Two of these advantages include voltage control and frequency assistance. One example of this would be the modification of the wind energy system (WES) to offer frequency support by the frequency-dependent injection of active electricity. This would be an example of this. It is feasible to do this by permitting WES to keep a certain amount of active power, which may then be deployed in the future when the frequency is lowered. When wind production farms are operating in an unstable environment, active power control (APC) presents a set of challenges that are unique to these farms. It is necessary for the APC to have a wide dynamic response range in order for it to work correctly within a few seconds. Automatic generation control (AGC), primary frequency control (PFC), and inertial control are the three of the most important sub-control objectives of a power system that are included in active power control [1,2]. Active power control is ultimately comprised of these three sub-control aims together. Because of the rapidity with which they react, each is responsible for managing the active power for a specific amount of time and in a specific order. This responsibility also applies to the sequence in which they react. One of the most significant challenges is the unpredictability of wind availability, which can lead to the failure of the control loop as a consequence of fluctuations in wind speed. This is a matter that should be taken into account. Through the modification of conventional control procedures, it is possible to include frequency regulation into the control system of WES systems [1–14]. This is a possibility. A variety of control techniques and methods have been created in order to keep the stability of a power system during frequency changes. These have been developed in order to maintain the system's stability. Two alternative categories that we may use to classify the control techniques are a low-involvement control technique and a high-involvement control method [15-19]. Both of these categories will be discussed more below. The exploitation of the accumulated kinetic energy is one method that may be utilized to accomplish inertial control. Because of the inertia of the turbine, one of the factors that is taken into consideration is the length of time that remains until the energy that has been stored may be released. When the wind turbine is discharged below its maximum power point, it is feasible to adjust for an inertial response and keep the frequency at a new steady state value. This is accomplished by discharging the wind turbine. PFC is an abbreviation that stands for the primary frequency response, which is also known as the PFC. Numerous research have been carried out on the subject of the exploitation of the PFC in the power systems of modern wind turbines. These

studies have been undertaken in a variety of different ways. Researchers have focused their attention on several levels of the energy system during the course of their study [20–23]. These levels include transportation, distribution, and wind farms, among others. The outcomes of another piece of research indicate that the physical consequences of equivalent loads on wind turbines that have been de-powered were explored. According to the findings of a number of studies [25–28], the primary areas of inquiry have been the resources and the responses of wind turbines to PFC. WES was applied in conjunction with inertial, PFC, and AGC in the active power management system that was published in reference [29]. Several alternative droop control methods were created in order to preserve the frequency stability of the grid. In order to make the generator more responsive, it was proposed that a droop controller be created for the WES that was mentioned in reference [30]. When considering the wider picture of droop, this method is only relevant to the WES local controller due to its specific use. As soon as it is put into action, it will be applicable to distributed generators for smart grids or wind farms on a site-by-site basis. Furthermore, in order to provide support for smart grid frequency, the controller that is given in this paper makes use of fuzzy logic. Monitoring which wind turbines are getting near to their ROCOF (peak efficiency) and which ones have conserved power allows the controller to estimate the participation factor of each wind turbine (PCC). This is achievable because the controller is able to recognize which wind turbines have saved electricity. To determine the extent to which a power system reacts to changes in frequency, it is necessary to establish an electrical power system. This is what is required in order to evaluate the power system.

2.2.3 Works Related to Smart Grids

For the purpose of bringing the power system into the digital era, the phrase "Smart Grid" refers to the cutting-edge technology that will be implemented. As a result, it is feasible for the grid to respond to changes and include such changes into the decision regarding price. In order to have the chance to fix difficulties such as transformer failures or other variables that have an impact on demand, such as heat waves, the next step is to exercise control over demand-sensitive events, such as heat waves. This will allow for the possibility of resolving issues. The fact that its implementation is expected to result in cost reductions of around \$75 billion over the next twenty years is a crucial factor that is driving the trend toward its implementation. The key issues that Wissner and his colleagues found brought to light the

necessity of having a grid system that is not just efficient but also effective. [7] : In the first place, they discovered that the electricity markets had been deregulated, which was tied to the unbundling of integrated structures and the advent of fierce competition. They also found that the generation of energy through decentralization had significantly risen, particularly with regard to renewable energy. This was the second item that they found out. As a result, they came to the realization that the preservation of energy was an essential component in the battle against climate change. There is a possibility that the Smart Grid will make use of "ambient intelligence" in order to automate the process of electric power generation and distribution. One of the potential applications of information technology is the construction of linkages between power sources that are scattered, renewable, and distributed on a small scale. The employment of internet connectivity allows for the configuration of intelligent software to automatically route resources, which ultimately results in a better balanced flow of power supply. The adoption of an automation project has the potential to bring about a considerable improvement to the power transmission and distribution system. Regarding the distribution side of things, software would be responsible for handling demand and supply adjustments in the appropriate manner. The ability of a smart house to permit the sharing of data on power consumption with smart meters is a prerequisite for the possibility that a smart house will eventually be able to achieve dynamic power balancing.

The effectiveness of AMR systems was evaluated by deploying them to a grid network, as indicated by the outcomes of the research conducted by Ja-Rventausta and colleagues. An intelligent piece of equipment known as an interactive customer gateway is now in the process of going through the design phase where it is being developed. There will be an energy meter that can be read from a distant location included into this gateway. In order to merge AMR technology with the databases and applications of the distribution system operator (DSO), transmission system operator (TSO), service providers, and energy market operators (such as aggregators), an ecosystem that makes use of a two-way link is required. As part of the process of carrying out this study, one of the goals that Clastres aimed to accomplish was to draw up a list of the Smart Grid policy problems. By incorporating demand management, incorporating renewable resources, and building storage systems that are more efficient, the Smart Grid was able to achieve increased grid performance. This was accomplished through the deployment of demand management. In spite of this, it was highlighted that the issues concerning the economy and the concerns of policy were not yet

completely handled. Among the most significant of them are the regulations that govern the installation of additional networks, dynamic pricing, and limits on excessive skimming. The development of a variety of distinct modeling approaches for smart grids has occurred over the course of the years [10], [11], and [12]. There is this. By incorporating low-level electric circuits capabilities into MATLAB and Simulink, the authors of [10] were able to achieve accurate modeling of a simple microgrid. This was done by the authors. A microgrid that would be integrated with intelligent agents was the idea that the authors came up with in order to showcase how intelligent distributed autonomous systems might operate. This was done since the writers intended to show how such systems could function. The implementation of their agent was carried out in a manner that was rather uncomplicated. When it came to protecting the vital loads, the circuit breakers were the only ones that needed to be engaged, which was the majority of the work that was required. As a result of the fact that they were using an uncomplicated simulation, they did not carry out thorough testing, evaluations, or analyses of the agents' capacity to communicate with one another or collaborate with one another. However, what they really wanted was to construct a microgrid that could serve not just as an extension of the global grid but also as an independent "island" in its own right. This was their ultimate goal. [11] demonstrates an intelligent-agent-based adaptive and self-healing architecture for electrical networks, despite the fact that it only provides a single example of a simulation. This architecture is designed to be self-healing and adaptable. A simulation that may be used as a replacement for a smart city in the real world is proposed by the authors of the article [12], which can be found for further information. Integer Linear Programming was utilized by Dua et al. [13] as a decision model for the purpose of placing Phasor Measurement Units (PMU) on an electric grid. This was done throughout the entirety of the installation procedure. It is possible for power measuring devices, which are more commonly referred to as PMUs, to provide precise power readings in real time scenarios. The purpose of the authors was to determine the bare minimum number of power measurement units (PMUs) that are necessary in order to acquire power data from the grid. Within the framework of the Integer Linear Programming model that the authors designed, a zero injection constraint was incorporated in order to ensure that the existence of the fewest feasible PMUs was ensured. According to the results of the study, there are a number of different regions that are appropriate for the implementation of PMUs. When it came to their circumstance, the solution that had the highest System Observability

Redundancy Index (SORI) offered the best outcomes, while the solution that was updated with SORI produced the best results overall (in terms of overall performance). To enable unmanned aerial vehicles (UAVs) to plan, categorize, attack, and evaluate damage inflicted by adversaries, Hennebry et al. [14] created a decision-making model. This model made it possible for UAVs to evaluate damage caused by adversaries. As a means of concentrating on a single, substantial purpose, Hennebry and his colleagues came to the conclusion that it would be more feasible to establish subteams. After careful consideration, it was found that integer linear programming was the most efficient approach to be taken in order to address these specific difficulties. For the purpose of determining whether or not the heuristic model worked as well as the optimal solution, a comparison of the findings was carried out. As a consequence of the employment of sub-teams, the percentage of erroneous performance ranged from 0.13% to 0.63% of the total overall performance. The error that was introduced by the heuristic was pretty tiny, and any errors that were introduced by the data that was collected from the real world should likewise be relatively modest. Not the least of their discoveries was the understanding that the issue of sub-team creation might be handled in a timely and accurate manner by applying integer linear programming. This was the last but not the least of their discoveries. An application of a method known as Binary Integer Programming was utilized by Ranganathan and Nygard in order to construct a model for the distribution of resources inside a smartgrid utilizing this technique. In the event that there is a power outage, distributed energy resources (DERs) have the capacity to be shifted to regional utility areas (RUAs) that are accessible so that they may continue to function. a technique known as iterative binary integer linear programming (C-IBILP) that ensures capacity is the primary focus of its calculations. Utilization of the MATLAB optimization toolbox is found to be necessary for the purpose of computing the outcomes of each simulation. Through the application of the capacity-based Iterative Binary Integer Linear Programming (C-IBILP) branch and bound technique, optimum solutions were obtained. This was completed with the participation of 54 nodes in a total of 163 iterations that took place over the course of 1.22 seconds. In the scenario that was mentioned earlier, the optimal solution was found after thirteen iterations and 0.047 seconds of adjusting the preferences of the DERs.

2.3 CONCLUSION

In this chapter we presented the classical and modern methods used to optimize the power stability problem and we presented some modern methods based on artificial intelligence. Since its inception, the use of electrical energy has greatly benefited and contributed to the progress and well-being of humanity. There is a direct association between the availability of electrical energy and the growth of both the economy and the industrial sector. Having a reliable and environmentally-friendly power supply is advantageous for enhancing the quality of life for every individual. There are two distinct techniques for generating electricity: thermal power production and renewable power generation. Both of these strategies exemplify ways to generate energy. The conversion of thermal energy into electrical energy is the fundamental mechanism behind the generation of thermal power. The main elements of thermal power generation systems are nuclear energy, coal, gas or oil plants [1]. Nuclear Power Plants have become a technological breakthrough in the case of power generation. The need for big quantities of initial capital is required to start a thermal power plant, and the continuous daily cost is usually too high. Thermal power plants have huge and varied negative impacts on the society. Carbon-based compounds or pollutants being released through the fossil fuel creation brought about a reduction in the average lifespan of the people [2]. The byproducts from these plants have released greenhouse gases which tend to play its part in speeding up climate change as well as global warming [3,4]. In view of the fact that thermal power plants have myriad problems, there has been a drift around the world toward the RES systems, also recognized as the renewable energy systems. RES comes with many advantages as compared to thermal generation methods. It has several benefits associated with it, and those are a decline in the greenhouse gas, decline in the production cost and maintenance, and keeping the rate of global warming at a minimum [5, 6]. However, RES integration into a national grid system like solar and wind energy is hard to attain, as it is not predictable and lacks evaluation and optimization mechanisms that are efficient [7,8]. There have been used different models in handling the uncertainty that is inherent in RES, and it comprises statistical, physical, regression, and numerical weather prediction (NWP) models [9]. Given the many deficiencies of all these models, a new model has to be developed. For example, a physical model performs better in predicting medium to long-term results, while a persistence model works more in projecting near-term results [10]. Scientists are making phenomenal progress in their attempts to employ and address the

challenges associated with the abovenamed models to provide the best planning, estimate, integration, and operation of renewable energy sources (RES). Artificial intelligence is used in various ways in renewable energy sources (RES). Some specific examples include predicting the changes in RES output [11], monitoring the optimal power level of RES [12], and enhancing the efficiency of hybrid RES [13–15]. Artificial intelligence techniques, including artificial neural networks (ANN), support vector machines (SVM), LS-SVM, and fuzzy inference systems, have been employed to anticipate the variability of RES. Recent studies [19] and [19,20] have mostly investigated deep learning methodologies, including recurrent neural networks (RNN), long short-term memory (LSTM), and convolutional neural networks (CNN). Ensemble Learning (EL) models like XGBoost [22], Random Forest (RF), and CatBoost [21] are widely used. Moreover, the integration of traditional machine learning [23] and reinforcement learning [24,25] is also widely favored. Through the application of artificial intelligence, decisions made in the sector become more informed and of higher quality. The meteorological information and renewable energy sources are all available so that predictions for the wind and solar electricity systems can be effectively done. Studies have been conducted, and it was found that artificial intelligence methods are and will be the efficient method for predicting the variance nature of the solar and wind resources for the next several decades. Various studies have been published that focus on predicting the renewable energy sources, such as solar and wind. These studies present a comprehensive overview of the current challenges, some remedial measures that may be applied, and a look into the future concerning the sector. The study presents the framework for developing efficient methods to implement fault tolerance, fault detection, model development, and monitoring for the electric power system. Several review papers have been developed to assist researchers in reviewing and integrating the existing studies based on the artificial intelligence use in renewable energy system use.

Through the reviews, it was noted that different artificial intelligence, AI techniques, including machine learning, deep learning, evolutionary learning, and hybrid, are applied in the variation prediction of the renewable down systems based on solar and wind. The results from these studies are quite informative as it presents both the positive and the negative aspects of the use of AI technology. According to the review paper [26], machine learning has been established to be less computationally cost and more noise tolerant compared to persistence and NWP. models. The application of deep learning algorithms consistently

leads to enhanced performance, as evidenced by earlier research [27]. However, these assessments acknowledged the challenges that artificial intelligence has in trying to predict the unpredictability of wind and solar renewable systems [28]. These obstacles encompass the processes of data preparation and data clearance. Their concerns encompassed several factors, such as the potential for bias in machine learning and the indispensability of a suitable model for the entire process to have value [29]. Furthermore, the evaluations included a discussion on the utilization of a metaheuristic approach to enhance the accuracy of the AI algorithms' performance. Metaheuristic methods, however advantageous [11,30], increase the time required for computing forecasting models.

Table 2.1: Summary of Literature Review.

References	Methodologies	Contributions
1	Historical survey in EDS and economic impact	Highlighted the critical role of electrical energy in industrial and economic growth
1, 2, 3, 4	Description of thermal generation systems	Discussed the capital intensity and negative societal impacts of thermal power generation
5, 6, 7, 8	Comparison with thermal systems; discussion on integration challenges	Emphasized the environmental and economic benefits of RES; outlined integration challenges due to their stochastic nature
9, 10	Overview of persistence, physical, regression, and statistical models	Analyzed the strengths and weaknesses of different forecasting models, focusing on their suitability for short-term vs. long-term forecasting
11-25	Application of AI technologies like ANN, SVM, LS-SVM, fuzzy systems, RNN, LSTM, CNN.	Demonstrated the application of AI in enhancing the forecasting, optimization, and operation of RES
13, 14, 16-22, 23-25, 26, 27	AI and ML techniques application	Reported on the effectiveness of AI and ML in reducing noise susceptibility, computational costs, and improving performance
28, 29	Discussion on issues like data preprocessing and model bias	Highlighted the critical challenges faced in the AI implementation phase, emphasizing the importance of suitable model selection
11, 30	Application of metaheuristic methods to enhance AI model accuracy	Discussed the trade-offs of using metaheuristic methods, such as increased computation times but improved forecasting accuracy

3. MATERIALS AND METHODS

3.1 ELECTRIC POWER DISTRIBUTION SYSTEM

The provision of consumers with energy that satisfies their requirements not only in terms of amount but also of quality and at the precise moment that users desire it is the fundamental duty of the systems that generate and distribute electric power. Generation, transmission, and distribution are the three main categories that can be used to categorize different aspects of electrical power systems. transmission, which is responsible for transporting electricity from production centers to consumption centers; distribution, which distributes electricity received from the transmission system to large, medium, and small consumers; and generation, whose function is to convert some form of energy into electrical energy.

the real values of voltages with a frequency of sixty hertz (Hz), which are utilized throughout the country. These voltages can be found in every state. Given that low voltage, 220 and 127 V, respectively, are the voltage values that are most commonly seen for Secondary Distribution, it can be said that these are the values. According to the objectives of this project, the Electric Energy System needs to be reorganized in such a way that its primary emphasis is placed only on Distribution and, more specifically, on the load and demand caused by the numerous electrical appliances owned by individual consumers. The distribution network is composed of a variety of components, including lines, feeders, service branches, and step-down stations. All of these components are intended to provide a service to the end user, and they all run on a service voltage that ranges from 110/220 V to 35 kV. This range was chosen so that the components could all work together.

Because a lot of study and planning goes into the creation of a distribution system, engineers have a lot of discretion to choose the features that are connected with a distribution system. This is because building a distribution system requires a lot of preparation. The many different types of loads that are going to be provided by the system are, without a doubt, the aspect of this study that will have the most significant influence due to its relevance. The amount of electrical power that is drawn from a specific supply source is referred to as the "load," and it is measured in watts. Therefore, in a Distribution System, numerous distinct types of loads can be differentiated from one another depending on the source that is being considered. These loads include the load that is coming from a consumer, the load that is

coming from a transformer, the load that is coming from the principal network or distribution line, and the load that is coming from the system itself.

The term "load" refers to the entire amount of power that is drawn from an electrical supply by a consumer's motors, electrical appliances, lamps, and other devices. A transformer's load is the total amount of power that is consumed by all of the consumers that are connected to it. The term "load" refers to the aggregate total of the electrical energy that is utilized by all of the transformers that are fed by a significant network. When determining the load of an electrical system, all of the power that is utilized by the feeders that originate from the distribution buses will be taken into consideration. This is done so that the load may be accurately determined.

It is of the utmost importance to bear in mind that the pattern of these loads is not continuous; rather, it varies in intensity between a minimum value and a maximum value. Keeping this in mind will be of great assistance to you. The distribution system must be ready to accommodate this maximum value, which does not appear all at once. These values do not occur simultaneously. A variety of consumption patterns must be taken into consideration for each of the load levels that were stated before in order to prevent the system from being oversized. This will ensure that the system is appropriately sized. As a result, the demand is calculated by taking into account the load that has already been installed.

According to Bovolato (2010), the demand of an installation is the load that is placed on the receiving terminals when the value of that load is calculated as an average over a specified amount of time. This value is used to determine how much power is required to meet the demands of the installation. The term "load" refers to an application that is measured in terms of power (active, reactive, or apparent) or in terms of the effective value of the intensity of the current that is flowing through it. Depending on the type of power being measured, the term "load" can refer to either active, reactive, or apparent power. The period of time that is used to determine the average value is referred to as the "demand interval." This interval normally lasts for fifteen minutes. Along with this, we also have the maximum demand of a facility, which is the most significant of all the requests that took place within a specific time period and is measured in units of demand per hour. This is the largest of all the requests that took place within the specific time period. This time range might be on a daily, weekly, monthly, or yearly basis, depending on your preference.

3.1.1 Demand-Side Management

The process of developing, deploying, and monitoring electrical appliances is referred to as Demand-Side Management (DSM), which is also referred to by its acronym. Because of this, the electrical consumer can be influenced to bring about the required changes in the loads that are used by this equipment. This is why this phenomenon occurs. These modifications involve variations in the time pattern as well as the total amount of load that the concessionaire is obligated to carry.

When looking at load modeling from the standpoint of demand side management, it is frequently more convenient for utilities to do so. The waveform of the load is reliant on a daily and seasonal demand for power; more specifically, the waveform is dependent on the time of day, the day of the week, and the season. The demand for electricity varies throughout the year. Within the confines of this conversation, we are able to discriminate between a total of six different types of load waveforms. These waveforms are as follows: peak reduction, valley filling, load displacement, strategic conservation, strategic load growth, and flexible load curve.

One of the most conventional techniques for managing demand is called peak clipping, and it's an example of how this technique might be used. This method, which is frequently conceived of as a way to reduce peak demand, makes use of direct load control as one of its components. The method that is used most commonly in this endeavor is one in which the equipment belonging to the customer is directly controlled. In the case that the utility provider needs a load reduction during peak hours, this direct control might be put into use. The valley filling approach is the second traditional style of demand-side management. Its full name is the valley filling strategy. The purpose of this tactic is to take advantage of loads at times other than peak hours when they are available. The long-term incremental cost may, at various moments throughout the year, be lower than the average price of power, making this a potentially viable alternative. These instances can occur at any time during the year.

The final conventional strategy for load control is known as "load shifting," and it involves moving the load away from peak periods and toward off-peak hours. When there are economic incentives to reduce consumption at specific times, implementing this method can be an attractive option because it can help, and it can be an attractive option because it can

help. Altering the manner in which the load is carried out is one form of strategic resource conservation. Typically resulting from the adoption of appliances that have a lower impact on the environment in terms of energy consumption as opposed to those that have a bigger impact.

The concessionaire is responsible for encouraging strategic load growth, which refers to the incremental rise in demand that is measured over time. It can be found beyond the valley filling that was covered in the previous section.

The flexible load form is a term that refers to a concept that is associated with a planned limitation. The payload format is able to be varied provided that the customers consent to it in exchange for a variety of different forms of incentives

3.1.2 Electricity Consumption Meters

Electric power meters are instruments that are used in the process of measuring the amount of energy demand that is produced by an electrical load. This measurement is done in order to determine how much energy can be supplied by the electrical load. Concessionaires are responsible for measuring electric energy to enable the company that provides the service to accurately bill customers for the amount of electric energy that was consumed by each individual customer. This is done in order to ensure that the concessionaires make a profit from their business. At the moment, the type of meter known as an induction meter is the one that is being utilized because of its user-friendliness, durability, precision, and overall performance over the years.

The power is measured in an immediate quantity, but the energy takes into account the length of time that the device was operational; to put it another way, the energy takes into account how long the power was being utilized. The power is measured in an immediate quantity. The quantity of energy can be calculated by multiplying the typical power by the total duration of time. Therefore, if you want to measure energy, you need to have a meter that measures the total amount of power over the duration of the entire measurement period. Only then can you accurately determine how much energy is being used. When figuring out how much electrical energy there is, the watt-hour is the most fundamental unit of measurement that may be used. Kilowatt-hours, sometimes known as kWh for its abbreviation, are the conventional unit of measurement for electrical energy in use; this denotes that the active

energy produced by an installation is being measured. Active energy is energy that may be quantified based on its capacity to carry out a specific amount of work. In the field of energy measurement, the meters listed here are the ones that are utilized on a regular basis.

There are two different types of meters that can be classified, and those are induction meters and electronic meters. In both single-phase and polyphase alternating current systems, instruments called as meters are utilized in the measurement process. These meters operate in a manner that is comparable to that of electric induction motors in the sense that their operation is governed by the principle of electromagnetic induction. When it comes to measuring energy in circuits that work with alternating current, induction meters are by far the most frequent sort of meter that can be found. Because induction meters are the only type of meter that can be used in circuits that use alternating current, they are almost usually used. This is because induction meters are the only type of meter that can be used.

Because determining the amount of energy that is consumed by electronic components is the primary focus of this endeavor, meters that are based on this method of application will have a higher level of specificity. This is because measuring the amount of energy that is consumed by electronic components. Electricity meters that are electronic have voltage and current sensors serving as the transduction base. These sensors produce signals with a small amplitude, which, when contrasted with the original signals, serve as a reference for the aforementioned quantities during the subsequent digitization process. This, in turn, serves as a reference for the subsequent metrological and effective calculation recording of energy consumption. Voltage transducers are constructed from resistive dividers, which are typically assembled using precision resistors as their component parts. Current transducers often make use of shunt resistors, transformers, or hall effect sensors as the types of components that make up their component sets.

Constructive approaches can be taken in the form of a variety of different approaches that can be taken for the calculation and management solution for electronic meters. In the versions with the lowest pricing, the processing of all meter actions is typically performed by a single processing unit. This processing unit could be a microcontroller or a Digital Signal Processor (DSP), depending on the particular model. The more complex models (including electronic meters with advanced functions and meters for large consumers) use a specific chip in their construction to calculate metrological functions, and they use a

microcontroller to carry out the other functions, such as communication management, memories, anti-fraud functions, and man-machine interface. Other functions include electronic meters with advanced functions include electronic meters with advanced functions. Because of this, the more complicated models can produce results with a higher degree of accuracy.

In addition, the most cutting-edge models already have a serial connection port built in. This port utilizes a regional communication protocol, and it comes standard on the most cutting-edge models. Users are given the ability to quickly examine the data that is produced by the meter, in addition to the fact that this port makes it possible for various parameter settings to be configured and saved. Because the presence of the port adds to the cost of the meter, this communication link is generally only utilized on more advanced electronic meters. This is because the addition of the port makes the meter more expensive. Figure 3.1 shows a depiction of the functional architecture of an electronic meter's internal components

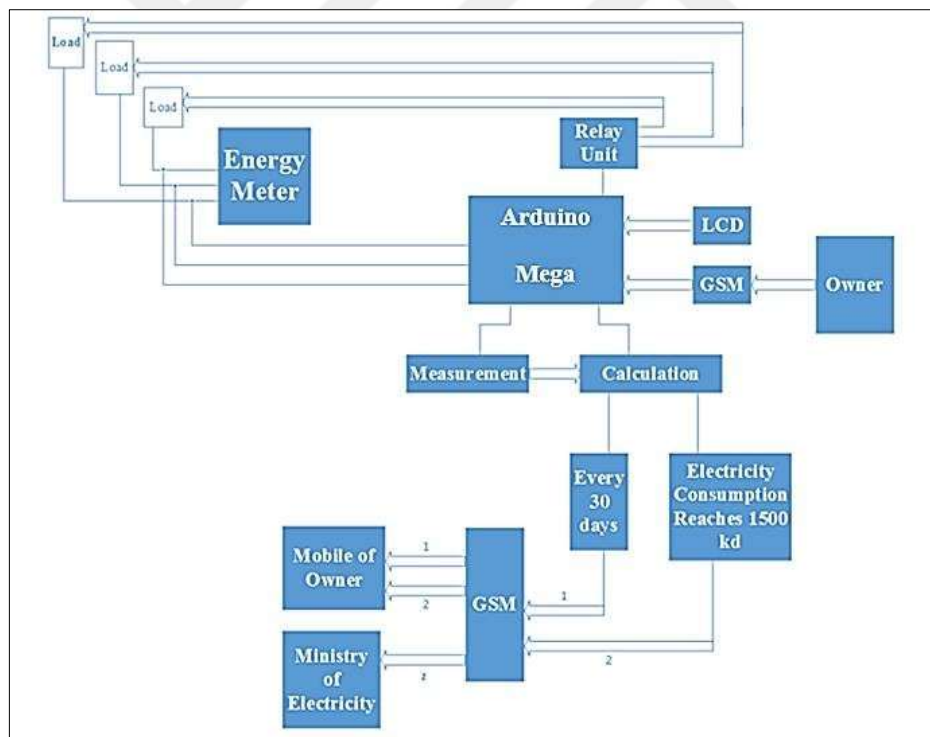


Figure 3.1: Block Diagram of An Electronic Meter.

3.1.3 Microcontrollers

The ability to do computational activities is one of the primary reasons for the existence of the microcontroller; nevertheless, these tasks do not necessarily entail large numbers. To get started, it needs to have outstanding capabilities for processing both input and output. For instance, it needs to be able to interact directly with the input and output signals coming from a refrigerator or a car, and therefore it needs to have these capabilities. Additionally, it needs to be able to communicate with other devices, such as a computer. Because there are a lot of embedded systems that are small and low-cost, the microcontrollers that run them need to be small as well, as well as self-sufficient, and not too expensive.

A microcontroller combines the essential components of a computer, such as a processor, data and program memory, as well as input and output interfaces. These components allow the microcontroller to perform the functions of a computer. As a consequence of this, we are able to refer to it as a computer that is contained on a single chip. The fact that this device is called a "microcontroller" suggests that its primary function was to exercise command over both the tangible objects and the processes that were associated with them. As a consequence of this, the microcontroller chip integrates a wide variety of supplementary components, such as timers, analog-to-digital converters, voltage references, pulse width modulation (PWM) generators, UART serial interfaces, and USB.

Both the Von Neumann architecture as well as the Harvard design are examples of different kinds of microcontrollers. A common memory was incorporated into the design of the microcontroller that was based on the Von Neumann architecture. This memory may be used to store both data and programs. As a direct consequence of this, the microcontroller also possesses a common bus that is capable of transferring data and addresses simultaneously in the form of instructions. The Harvard design incorporates separate memory units for the storing of programs and data, in addition to separate buses for the transport of instruction addresses and data, respectively. These features allow the Harvard architecture to be more efficient. We are able to accomplish greatly enhanced data transfer rates as a result of the Harvard architecture. During the course of a single machine cycle, a microcontroller that is based on the Harvard design is able to execute a single instruction. The design of the great majority of microcontroller families was accomplished with the help of this architecture.

Instruction sets are the primary delineator between the two separate categories that microcontrollers fall into. There are many distinct varieties of microcontrollers, some of which belong to the group of reduced instruction set computers (RISC), while others belong to the group of complicated instruction set computers (CISC). A RISC processor is characterized by the presence of a straightforward instruction complement that is composed of component parts, as suggested by the processor's name. Building on top of the fundamental instructions is how RISC processors create more complex instructions than other types of processors.

Systems that make use of instruction architectures that are based on RISC lend themselves to having CPU architectures that are simpler. The CISC-based architecture includes a bigger number of features and instructions that are more difficult when compared to the RISC-based architecture's features and instructions. It can be difficult to tell in advance whether a particular application will generate code that is more efficient when performed using a RISC-based instruction set or a CISC-based instruction set. Consideration of the extent to which a particular algorithm matches the feature set of a particular processor is an extremely significant aspect to take into account. The RISC principle is applied while designing the overwhelming majority of today's microcontrollers. Microprocessors are the primary implementation of the CISC paradigm in today's computers.

A microcontroller, as can be seen in FIGURE 3.2, is essentially made up of the central processing unit (CPU) of a microprocessor, in addition to all of the necessary data and memory programs. In addition to this, all of the accessories that make it possible for one device to interface with another must also be included. In the same way that every other electronic circuit needs to have power given to it, the microcontroller needs a time signal that is typically generated on the chip itself in order for it to be able to control the logic of the circuits.

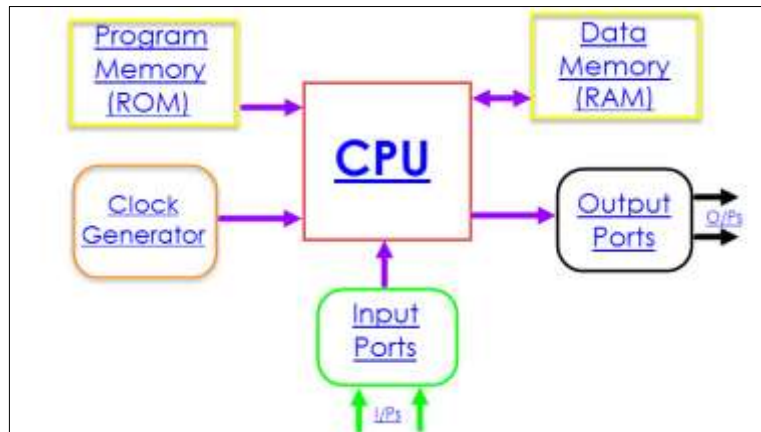


Figure 3.2: Architecture of A Microcontroller.

3.2 MACHINE LEARNING

The area of machine learning, which tries to design such systems, has as its primary goal the creation of computer programs that are self-sufficient in their capacity to learn from the input data that is provided to them. To put it another way, learning may be summed up as the process of acquiring new knowledge through the processing of one's previous experiences. A learning algorithm is provided with training data, which stand in for the learner's actual experiences and operate as a substitute for such experiences. The newly learned information is what is produced as the output by the learning algorithm; this information can then be utilized by another program to achieve a goal.

Using this concept as a launching point, it is possible to construct an algorithm that is capable of identifying spam in email. The software will save each incoming email in its memory and compile a list of messages that are associated with spam. This list will be displayed to the user. The machine will decide, based on what it has learned in the past, whether or not a freshly received email constitutes spam before it delivers the email to its intended recipient. This decision is made before the email is sent out for delivery. Inductive reasoning is the name given to this specific type of deductive reasoning. The problem with this approach to learning is that it does not truly result in the acquisition of any new information; all that it does is contrast new information with old information, but it does not actually learn anything new as a result of doing so. Because of this, there is no advancement achieved with this method of education, which might lead to wrong conclusions being taken.

The processing of data, in conjunction with the provision of examples of what needs to be anticipated, leads to the discovery of rules that may be utilized to carry out a task using machine learning. As a consequence of this, you are going to want the following three components in order to conduct out machine learning:

Input Data: These sound recordings of people speaking could be used as an illustration of a data point, for instance, if the task at hand is speech recognition. The following are some examples of the production that are expected to take place in the future: It is quite likely that these documents are transcriptions of sound recordings that individuals have generated for the aim of taking part in a voice recognition competition.

One of the many ways that the performance of the algorithm may be evaluated is by comparing its actual output to the one that was anticipated. This is only one of the many ways that this can be done. In order to accomplish this, it is necessary to ascertain the degree of deviation that exists between the actual output of the algorithm and the outcome that was predicted. Finding the distance that separates the two is one way to go about accomplishing this goal. The measurement serves as a feedback signal, which is then employed to make modifications to the operation of the algorithm in order to achieve the outcomes that have been specified. The process through which an individual adjusts their behavior to suit their surroundings is referred to as learning.

3.3 SMART GRID ELEMENTS

The way in which the components function as well as their cost were taken into consideration in order to determine the materials that will be used in the development of the project that is being offered. The research conducted in the prior chapters served as the basis for the selection of the components. The necessity of having a microcontroller to process the data, a current sensor and a voltage sensor to obtain the values of power consumed by the electrical device, and a relay to control the turning on and off of the device's power supply was defined. All of these things are required in order to meet the requirements. Components are also required to convert the voltage of 127V into alternating current for the power supply voltage of the microcontroller and components, which will be direct current. This conversion must take place before the components can be powered.

After the components were defined, the design of the circuit was developed based on the components themselves. At this point, problems that had arisen as a result of the constraints imposed by the microcontroller hardware have been fixed. On the NodeMCU module, the inputs and outputs both have a voltage of 3.3V. A voltage divider has been included as a result of the fact that the output signal from the sensor can fluctuate up to 5V. This was done so that the signal will only be allowed to fluctuate within the range that is suitable for the module.

An additional issue is that the ESP8266 only has a single interface for reading analog data, which can be a limitation. Just so there is no confusion, the current and voltage sensors do not come with their own dedicated ports for each measurement type. This issue was remedied by the installation of a relay that operated off of 5V. Because the output voltage of the NodeMCU module is 3.3V, as was previously mentioned, turning on the 5V relay is not necessary for the module to operate in an appropriate manner. As a means of addressing the issue at hand, an NPN transistor was put into operation. The ground terminal was connected to both the collector and the emitter, and one of the coil ports was coupled to the collector. After that, a connection was made between the base and port D1 of the microcontroller so that the base could control the on and off positions of the relay. It is possible to see both the answers and the electrical connections in the schematic representation of the circuit block that is illustrated in FIGURE 3.3.

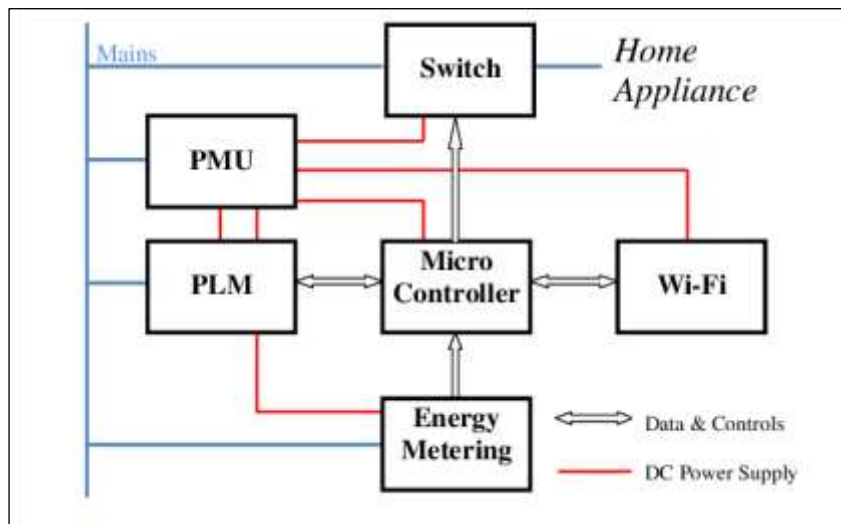


Figure 3.3: Block Diagram of the Smart Outlet.

3.3.1 NodeMCU - ESP8266

The ESP8266 is a low cost WiFi chip. This chip consists of a microcontroller and complete TCP/IP protocol. The ESP8266 is manufactured by Espressif Systems. Among the ESP8266 specifications, the most relevant ones for this project are described below:

- It has a 32-bit RISC-type microprocessor core;
- IEEE 802.11 b/g/n WiFi;
- 16 inputs/outputs; Thean analog input with 10 bits of resolution.

NodeMCU is a development board that uses ESP8266. The NodeMCU can be programmed using Lua scripting, Arduino IDE (Integrated Development Environment) or ESP8266 SDK. This development board has a 3.3V direct current supply, current consumption between 10uA to 170mA, 32k + 80k RAM memory The NodeMCU can be seen in FIGURE 3.4.

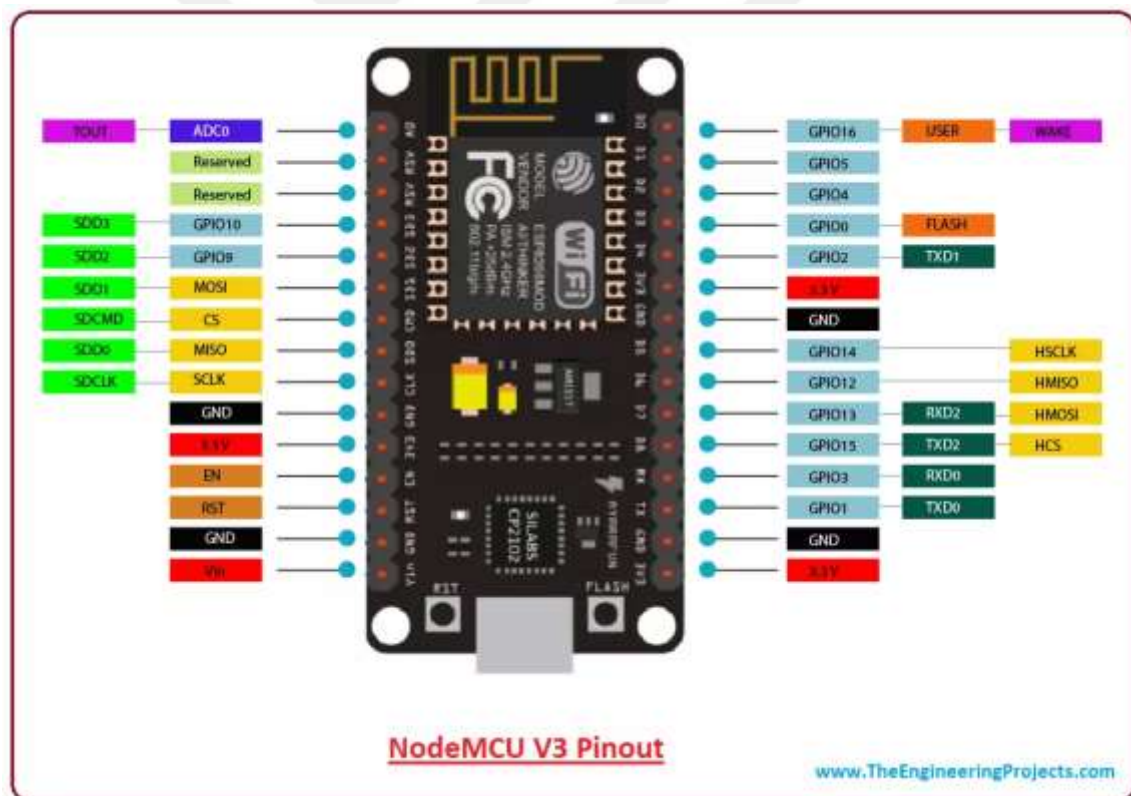


Figure 3.4: Block Diagram of the Smart.

3.3.2 ZMPT101b module

The module that is utilized in the process of measuring the voltage is denoted by the model designation ZMPT101b. This specific module makes use of a transformer, which can be identified by its name in the following sentence: This apparatus is a current transformer that can function at voltages ranging from 0 to 1000 volts and has a voltage ratio of 1 to 1 between the main and secondary windings. The voltage range that this device is capable of operating at is shown in the previous sentence. Furthermore, the input current on the main is 2 milliamperes (mA), and the input current on the secondary is also 2 milliamperes (mA). In addition to making use of this transformer, the module is constructed out of components that have surface mounting devices (SMD). An operational amplifier, a precision potentiometer, diodes, capacitors, and resistors are some of the components that are involved in the process of converting the voltage from alternating current to direct current. This output voltage could be anywhere from 0 to whatever voltage is being fed into the module at any one time. It could also be anywhere in between. It is highly recommended that 5V be given to it in this situation. The ZMPT101b module is illustrated here in Figure 3.5 for your viewing convenience.

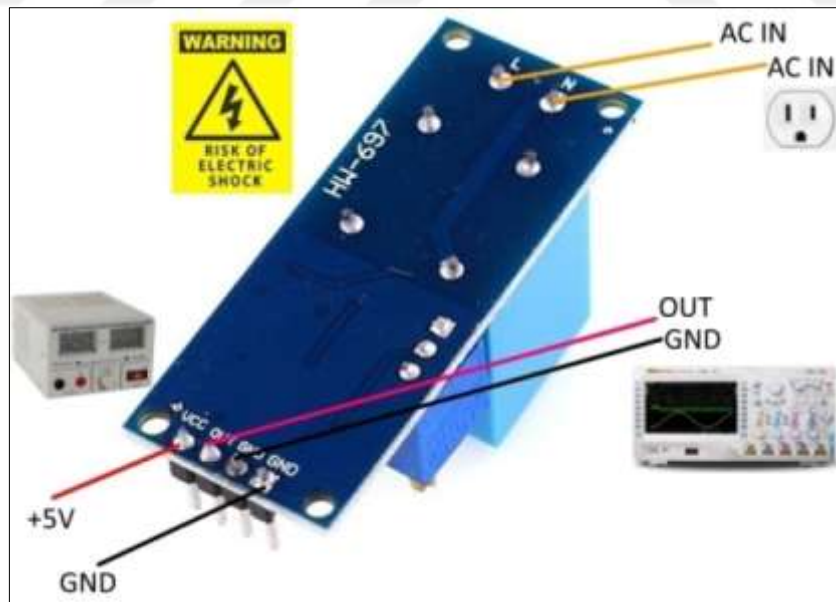


Figure 3.5: Zmpt101b Module.

3.3.3 ACS712 Module

The ACS712 module is comprised of a variety of components, the most important of which is a hall effect sensor. The 05B, the 20A, and the 30A are the three distinct iterations of this sensor that are available to purchase. What sets these two individuals apart from one another is their respective operational currents. Because this project would not include the utilization of any electrical components that call for a substantial quantity of current, the 5A model was picked as the appropriate solution. Therefore, when the time comes, it will also be able to acquire current values with a greater resolution. The ACS712 sensor has a sensitivity of 185 millivolts per ampere, the input current has a range that goes from -5A to +5A, and the working voltage is 5 volts. As a result, there is a difference of 462 millivolts in output for every one ampere. The module's built-in safeguards consist of capacitors, a resistor, and a diode, among other components. The manufacturer offers some recommendations for the module's circuit, which may be shown as an example in FIGURE 3.6. These recommendations are adhered to by the module. The ACS712 module is depicted for your viewing convenience in Figure 3.7.

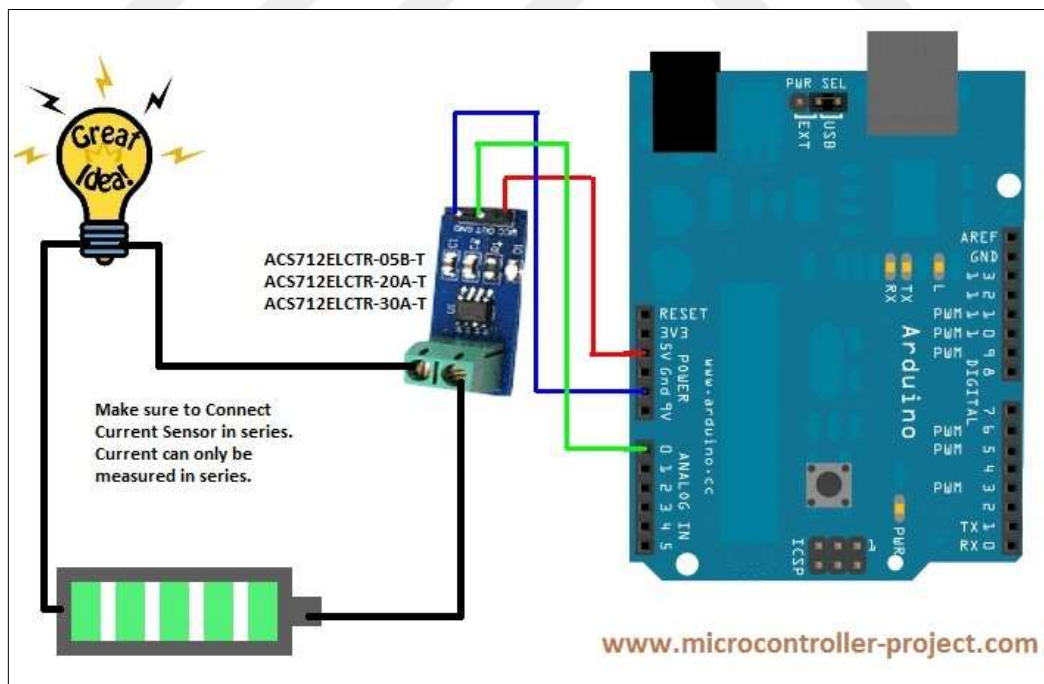


Figure 3.6: Circuit for Using the Acs712 Sensor.

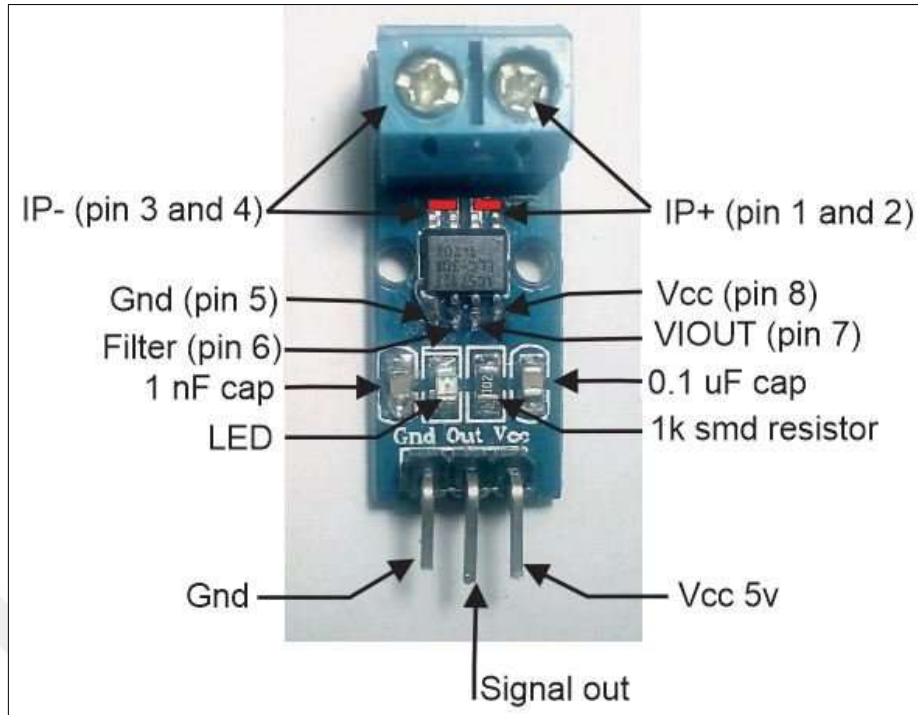


Figure 3.7: ACS712 Module.

3.3.4 5V Relay Module

The SRD-05VDC-SL-C model is what provides the 5V Relay module with its switching functionality so it can be switched. According to the specifications that were provided by the manufacturer, the relay is able to manage up to 10A of current at a voltage of up to 127V in alternating current, 7A of current at a voltage of up to 240V in alternating current as well, or 10A of current at a voltage of up to 28V in direct current. In addition, the relay can also handle 127V in direct current at 7A of current.

In order to switch the circuit using the coil in this model (05VDC-SL), it is essential to supply it with a voltage of 5V in direct current and a current of 71.4mA. These values must be met in order for the switching to take place. This is due to the fact that the coil is responsible for switching the circuit on and off. The relay can transition between two different states: the generally open state and the normally closed state. FIGURE 3.8 is a visual depiction of the module that is provided.

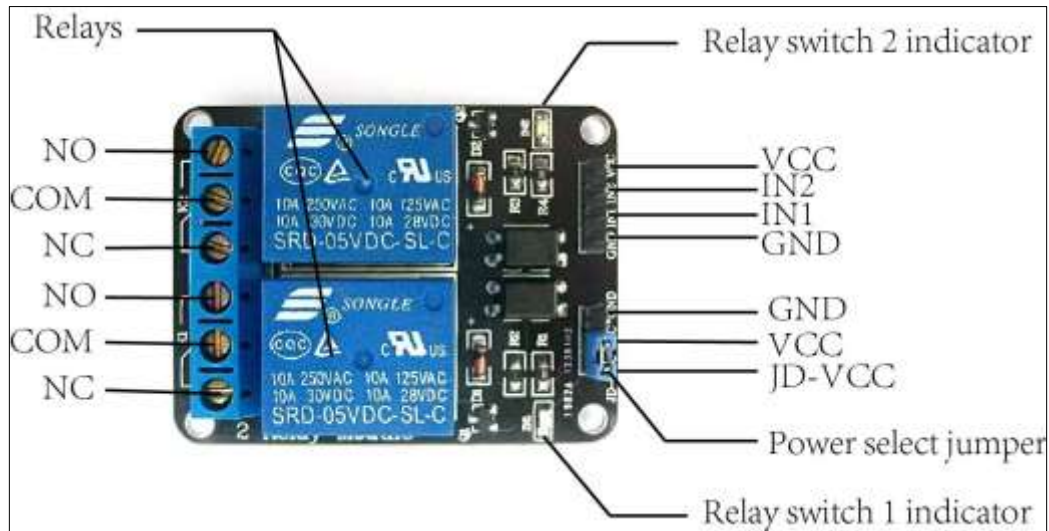


Figure 3.8: 5v Relay Module.

3.3.5 YWRobot MB102 Module

The contact matrix power supply module also known as the MB102 module is manufactured by the Chinese company YwRobot. This company is responsible for its production. It is able to supply two distinct power lines, 5V and 3.3V, and it has a USB connector for the output of voltage in addition to a connector for the input of power from an adapter. Additionally, it is able to supply both of these power lines at the same time.

It is a model of an unadjustable power supply, and the configuration of the jumpers on the board decides whether it supplies two lines of 5V or 3.3V voltage respectively. The model cannot be modified. The module's operating instructions state that it must be provided with an input voltage that lies somewhere in the range of 6.5 to 12V, and that it must generate a maximum current at its output of 700mA while making use of AMS1117 voltage regulators. Both of these requirements must be met for the module to function properly. Advanced Monolithic Systems manufactures a series of voltage regulators, which includes the AMS1117 voltage regulators. These regulators are part of the series. The module contains two of these regulators; one produces the 3.3V voltage, while the other supplies the 5V line. Both of these regulators are responsible for supplying power to the module. The SOT-223 format is used for the packaging of both of these regulators. The configuration that was suggested by the provider and ultimately used in the module is illustrated in figure 11, which

provides a visual depiction of the configuration. You can take a look at Figure 3.9 to get a visual representation of the YWRobot module.

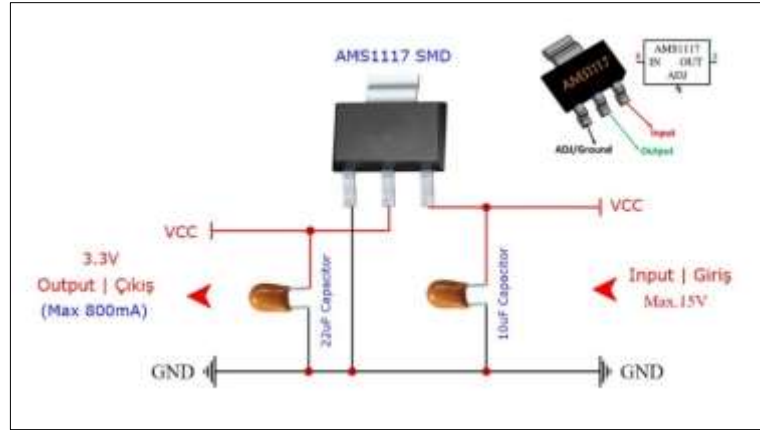


Figure 3.9: Circuit Using Ams1117.

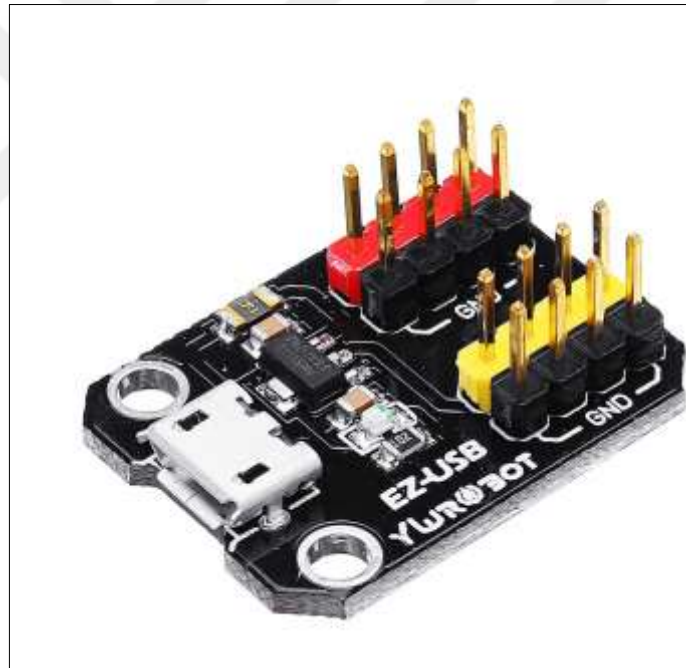


Figure 3.10: YWROBOT Module.

3.4 METHODS FOR DEVELOPING ALGORITHMS

The code developed to be embedded in the ESP8266 was developed using the C programming language. This code was divided into two parts: the reading of the current and voltage sensors and the logic for machine learning, which will be used as a signal to control the turn off the device. The development of both codes will be done next.

3.4.1 Sensor Reading

In order to write the code that will measure the current and voltage, it is important to first consider the output variation ratio in relation to the input values. This is a prerequisite for writing the code that will measure the current and voltage. For example, it is essential to figure out how much the voltage shifts at the output of the ACS712 in response to each ampere that is fed into it. In chapter 4.1.3, it is demonstrated that there is a variation of 185mV for every Ampere that is delivered to the sensor.

This information was provided by the supplier, and it can be confirmed by looking at the data. Regarding the voltage sensor, the data provided by the transformer supplier indicates that a maximum of 1000V can be present at the input at any given time. This is the highest voltage that can be detected. When the module is being used, the input voltage is limited to a maximum of 250V; more specifically, the output voltage drops by 20 millivolts for each volt that is present at the input.

Following that, measurements of the signals are collected over a predetermined amount of time in order to determine the values of the current and voltage in RMS, which is an abbreviation for root mean square. The root mean square (RMS) form of the final value is obtained by first quadrupling each value that was acquired, then dividing that result by the measured time period T and finally taking the square root of that result.

This process is repeated until the RMS form of the final value is obtained. However, in addition to that, it is necessary to take into account the operating voltage V_{ref} , the R_V or R_i resolution of the microcontroller, as well as the r ratio of the input and output signal. The equations that follow are what we get when all of these different aspects are taken into consideration.

3.4.2 Machine Learning Method

The method for machine learning was developed using the concepts of least squares, which were implemented throughout the process. Polynomial regression was an additional factor that was taken into account. In addition to this, it is of the utmost importance to be specific about the nature of the problem that is going to be handled. Classification, regression, and clustering are just a few examples of the many different kinds of work that may be

accomplished through the use of machine learning. Even though the activity that has been suggested here can be finished in more than one of the ways that have been mentioned, for the time being, it has been defined as a regression problem. This definition begins with the idea that one wants to know the future value based on the values of the past so that they can use that information to make decisions. Other possible definitions include: the task that has been proposed here can be finished in more than one of the ways that have been mentioned. decision. The method that is referred to as "least squares" involves determining the best approximation line, or linear solution, when the error involved is the sum of squares of the differences between the y values on the approximation line and the given y values. This can be done through the use of a linear solution. When the method of least squares is used, this result, which can also be thought of as a linear solution, is obtained. As a result, in order to lessen the amount of inaccuracy brought on by the method of least squares, the values of the constants a_0 and a_1 need to be determined.

The method of least squares is not only the most practical procedure for determining the best linear approximations, but there are also major theoretical aspects that favor it. This is because the method of least squares minimizes the number of squares used in the calculation. Other approaches, on the other hand, supply insufficient weight to a point that is greatly out of alignment with the approximation, while other ways provide insufficient weight to a point that is significantly out of alignment with the approximation. Because of this, significant errors are produced. The strategy known as the least squares gives a point that is not aligned with the rest of the data a large amount of additional weight; yet, this approach does not let that point completely dominate the approximation. Another benefit of using the least squares approach that ought to be taken into consideration is the possibility of doing statistical research on the pattern of error's distribution.

The general problem of fitting the best least squares line to a database $\{(x_1, y_1)\}_{i=1}^m$, involves minimizing the total error, with respect to parameters a_0 and a_1

$$E = E_2(a_0, a_1) = \sum_{i=1}^m [y_i - (a_0 x_i + a_1)]^2 \quad (3.1)$$

For a minimum to occur, we need the derivative of both to be equal to zero:

$$\partial a_0 / \partial E = 0 \text{ and } \partial a_1 / \partial E = 0 \quad (3.2)$$

With this model, you can expand to relate a dependent variable to independent variables:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \dots + \beta_p X_{ip} + \varepsilon_i \quad (3.3)$$

The index, which is written as i is used to designate the observational unit from which the observations on the independent variables X and Y were taken. This observational unit was denoted by the letter i . Within the context of the equation, the independent variable is indicated by the second subscript. The number of samples can be anywhere from $i = 1$ to n , and the symbol p represents the number of variables that are regarded as being independent. The sample size is represented by the symbol n , and the range for the number of samples is $i = 1$ to n . There are a total of $(p + 1)$ parameters that need to be estimated when the 0 intercept is included in the linear model. The value of j could range anywhere from 0 to p , depending on the situation. We use $p' = (p + 1)$ since it is more convenient. It is reasonable to conclude that n is significantly higher than p' . For the linear model to be expressed through the use of matrix notation, it is necessary to have four matrices, and they are as follows:

The creation of the matrix that can be seen below is the direct consequence of this. This particular kind of matrix is referred to as a Vandermonde matrix, and it is used to represent independent variables and follows this particular format:

$$Y = X\beta + \varepsilon \quad (3.4)$$

The residual vector ε reflects the difference between the observed value Y and the estimated value $\hat{Y}$, that is, this vector informs how far we are from the observed value

$$\varepsilon = Y - \hat{Y} \quad (3.5)$$

In the development of the software to be embedded, the residual values were not considered, since the prediction values tend to zero when compared with the observed values. Another way to represent the matrices of independent variables is as follows:

$$\begin{aligned} & (n \times p) \text{ matrix } X = (X_{ij}) \text{ where } X_{ij} = X_i^{j-1} \\ & (n \times 1) \text{ vector } Y = (Y_i) \\ & (n \times 1) \text{ vector } \varepsilon = (\varepsilon_i) \\ & (1 \times p) \text{ vector } \beta = (\beta_0, \beta_1, \dots, \beta_p) \end{aligned} \quad (3.6)$$

Thus, making the inverse of the X matrix and multiplying by the Y matrix, the values of the ak parameters are obtained:

$$a_n = X'.Y \quad (3.7)$$

To obtain the inverse matrix, it is necessary to use a method that is programmable so that it can be done with the C programming language. The method chosen was the Gauss-Jordan method, as it meets the requirement. The Gauss-Jordan method consists of first placing the identity matrix of the same order as the matrix whose inverse is to be obtained.

$$\begin{aligned} E &= [1 \ 2 \ 3 \ | \ 1 \ 0 \ 0] \\ &[2 \ 1 \ 2 \ | \ 0 \ 1 \ 0] \\ &[0 \ 1 \ 2 \ | \ 0 \ 0 \ 1] \end{aligned} \quad (3.1)$$

Afterwards, operations are carried out, whether line change, subtraction, multiplication, so that the matrix on the left becomes an identity matrix. So the matrix on the right will be the result of the inverse matrix.

$$\begin{aligned} E &= [1 \ 0 \ 0 \ | \ 0 \ 0.5 \ 0] \\ &[0 \ 1 \ 0 \ | \ 2 \ -1 \ -2] \\ &[0 \ 0 \ 1 \ | \ -1 \ 0.5 \ 1.5] \end{aligned} \quad (3.9)$$

Thus, this same method was applied to the code to obtain the inverse matrix X'.

Another point considered is the degree of the polynomial obtained after the polynomial regression. The maximum order that could be considered was six. Larger orders than this caused the algorithm not to converge, resulting in inconsistent values. These results will be presented in section 5.1.

With this, as a solution, the data is broken into equal parts. Each part contains six input data and six observed output data. There are 96 data obtained over a day and a data is added to the beginning of each part and this data is equal to the last data of the previous part. As an example, Figure 3.11 shows signals x and y separated into two parts and the signal repeated between them for y

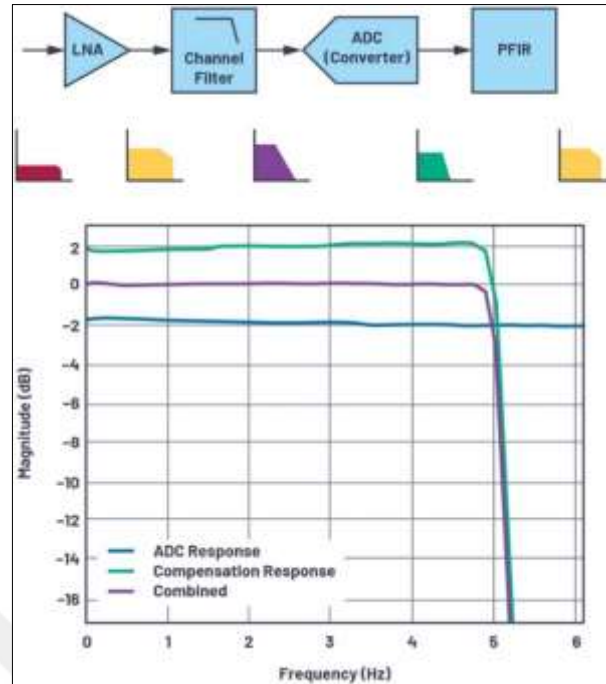


Figure 3.11: Data Separation.

After obtaining the polynomial parameters, all values below zero are considered equal to zero, and values above the maximum value obtained are limited to this value. For decision making, the device is considered to be on when the current is above 10mA and off when it is below this threshold. This is due to the inaccuracy of the current sensor.

3.4.3 Getting the Date and Time

An important factor for the development of this project is knowing the exact moment when the current value was read. To acquire the day and time, the NTPClient and WiFiUdp libraries were used. Values are obtained in day of the week, hour, minute and seconds. This data is provided by the pool.net.org server.

As the data is obtained through a server on the internet, it is also necessary to use the ESP8266WiFi library to connect to the wireless network. Afterwards, network data such as the name and password are provided and the connection is initiated by the Wifi.begin (name, password) function.

4. PROPOSED METHOD

This chapter aims to detail the methodological approach of the ADEMS, presenting an in-depth analysis of its constituents Advanced Metering Infrastructure (AMI), fiber-optic communication for outdoor facilities, LiFi technology for indoor facilities, and Machine Learning (specifically Recurrent Neural Networks (RNN)). The proposed ADEMS represents a holistic, innovative approach to optimize and accelerate energy distribution by leveraging cutting-edge technology for real-time data transmission and machine learning for demand-supply prediction and fault detection. In the forthcoming subsections, we will elaborate on the fundamental architecture of ADEMS, the functionalities and capabilities of each component, and the interaction between these components. This will help illuminate the theoretical underpinnings of ADEMS and provide a foundation for understanding its practical implementation.

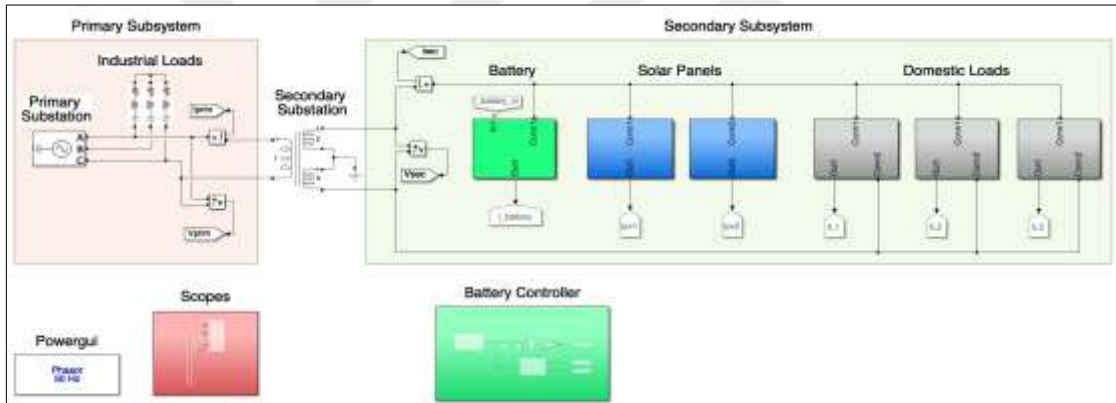


Figure 4.1: Simulink Model of the Proposed Smart Grid.

4.1 SYSTEM OUTLINE

The proposed system comprises a hybrid microgrid simulated using MATLAB Simulink, consisting of renewable energy sources like photovoltaic (PV) cells and wind turbines, multiple loads, and state-of-the-art communication technologies like LiFi and fiber optics for data transmission. The system also leverages a Recurrent Neural Network (RNN) for load forecasting. The implementation of Advanced Metering Infrastructure (AMI) forms another critical aspect of the system.

The Accelerated Energy Distribution Management System (AEDMS) incorporates an Adaptive Neuro-Fuzzy Inference System (ANFIS) as a central element to improve the stability of grid frequency by intelligently controlling the interactions between the grid and a specifically designed load. This technology utilizes the adaptive characteristics of ANFIS to effectively and promptly respond to changes in grid frequency, guaranteeing exceptional accuracy and efficiency in preserving grid stability. ANFIS integrates the cognitive reasoning approach of fuzzy systems with the adaptive learning capability of neural networks. Within the framework of AEDMS, ANFIS performs ongoing surveillance of grid conditions, encompassing fluctuations in both load frequency and amplitude. The data is processed by the system's neuro-fuzzy components, which include membership functions to determine the data's fit within a fuzzy set, fuzzy rules to define the connections between inputs and outputs, and a neural network structure to optimize these rules using observed data. The Adaptive Neuro-Fuzzy Inference System (ANFIS) is a sophisticated control mechanism that integrates artificial neural networks with fuzzy logic principles to efficiently regulate and optimize the allocation and use of energy in a smart grid setting. ANFIS is highly beneficial in EMS because it can effectively adapt and acquire knowledge from intricate, non-linear systems that conventional models may find challenging. ANFIS, or Adaptive Neuro-Fuzzy Inference System, plays a significant role in enhancing energy management systems. To go deeper into its contribution, let's explore the following details:

- a. **Modelling Uncertainty and Imprecision:** In energy systems, several factors, such as load demand or renewable energy supply, are susceptible to unpredictability and imprecision. ANFIS successfully manages uncertainty by utilizing fuzzy logic, which use fuzzy sets and rules to transform data into linguistic variables (e.g., high, medium, low). These linguistic variables are more intuitive and adaptable for analysis.
- b. **Rule-Based System:** the system of ANFIS includes a fuzzy logic unit which uses the if-then rules to give the appropriate response depending on some circumstances. For example, rules may be set to cut down energy consumption when the demand level is high or maximize the use of renewable resources at times of high supply.
- c. **Data Input and Fuzzification:** ANFIS is provided with real-time information about the grid frequency and the operational condition of the busbar-connected load. It should

fuzzify these inputs where numerical values are converted into fuzzy values with predefined membership functions.

ANFIS utilizes the set of fuzzy rules to assess the existing grid condition. For example, "If the frequency deviation is high and the load is resistive, then increase the compensating frequency" is one of the fuzzy rules. The decision process is so complex that each rule applies only to a specific condition of the frequency fluctuation and type of load. The required control action, generated by the fuzzy logic rules, in the form of output, is processed in a process, namely defuzzification, by ANFIS. In general, the process implicates changing the frequency and amplitude of the compensating load that is attached to the busbar. The neural network capability of ANFIS enables it to learn from past data. The system acclimates the membership functions and fuzzy rules with previous performance data so as to gain accuracy and reduce the response time for every occurrence.

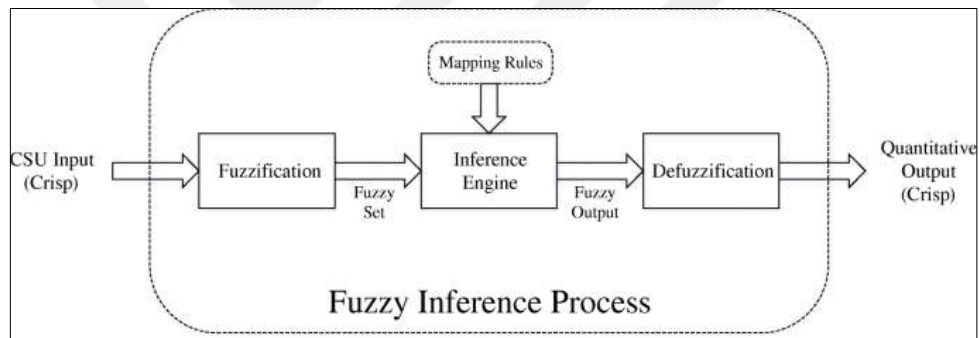


Figure 4.2: The Process of Fuzzy Interference in the ANFIS.

This particular load, essential to the AEDMS, can be designed for various types (resistive, inductive, capacitive, or mixed) based upon the specific demand of the grid. The equipment is connected to the busbar through a programmable electronic switch which can rapidly change its operating condition. The specific load generates a distorted frequency which is in phase or is at 180° out of phase with the distortion in the grid frequency. The technology thus perfectly overlays this distorted frequency on the grid to efficiently neutralize the effect of load-generated frequency deviation. Optimization of the system is through simulating a series of operating conditions and actual operating data, to maximize or minimize some of the critical parameters like the load, capability to generate disturbances, and the switching speed of the mechanisms to ensure that the system consumes the minimum possible amount of power and is, therefore, economical in operation. An important characteristic of AEDMS

is that it has an ability to quickly offset any frequency deviation because it has fast computational functions and electrical control over the busbar switch, and the rapid computation can be done through ANFIS, while the busbar switch does the busbar electrical control. The NFIS is an abbreviation that stands for Neural Fuzzy Inference System, and it is an artificial intelligent and adaptive element in the energy management system that learns continually to achieve the best performance of the grid, managing the uncertainties and variabilities effectively. This, in turn, makes it a critical instrument in the operation of modern day energy management systems where again, the power grids have become intelligent as well as meshed with varying types of renewable sources.

4.2 RENEWABLE POWER SOURCES

When ANFIS is included into an energy management system, it enables the efficient management of different renewable energy sources to enhance the performance and stability of the power grid. The following are the main categories of renewable energy sources commonly considered in such works:

- a. Solar power refers to the process of capturing and utilizing energy from the sun via the use of photovoltaic cells or solar thermal systems. Solar power exhibits significant variability, since it is influenced by weather patterns and the time of day. This characteristic makes it an ideal option for control and optimization using an adaptive system such as ANFIS, which can accurately forecast and counteract variations.
- b. Wind energy is produced by wind turbines and is a significant renewable source that exhibits great variability. Wind turbines exhibit significant variability in power production due to fluctuations in wind speed and direction. As a result, advanced management systems are necessary to seamlessly integrate this electricity into the grid.

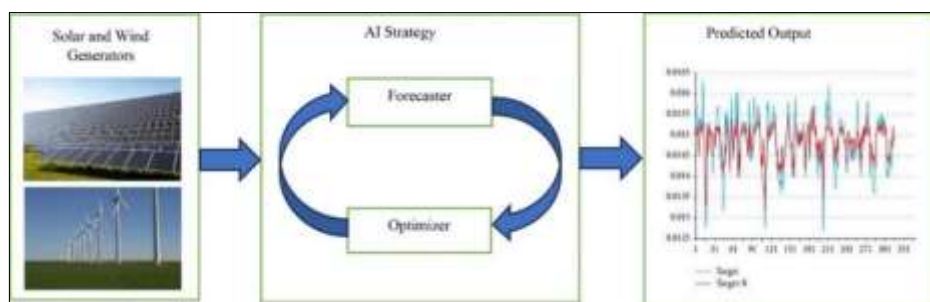


Figure 4.3: Process of Integrating the Power Sources into the Proposed Grid.

We integrated 50 PV cells and 10 wind turbines into the smart grid design. Photovoltaic (PV) Cell, The PV array output power is given by

$$P_{pv} = G * A * \eta_{pv} \quad (4.1)$$

Where G is the solar irradiance, A is the total area of the PV panels, η_{pv} is the efficiency of the PV panels. For our simulation, we assumed a total PV panel area of 500 m², solar irradiance of 1000 W/m², and a PV panel efficiency of 20%. Thus, the total output power from the PV cells is 100 kW.

4.3 WIND POWER ENERGY

Wind power is a type of sustainable energy that is obtained by capturing the kinetic energy of wind via the use of wind turbines. This energy source is very environmentally friendly and sustainable for power generation, as it does not emit hazardous pollutants or greenhouse gasses. Wind energy is mostly harnessed through the usage of wind turbines, which are composed of a tower, a nacelle (enclosure for components), and rotor blades. As wind flows, it moves across the blades generating both lift and drag forces, which in turn causes the rotor to rotate. The rotor blades are linked to a low-speed shaft that rotates a gearbox. The gearbox facilitates the conversion of the sluggish rotational speed of the rotor blades to a more appropriate speed for the generator. This conversion is essential as it maximizes the rotational velocity to efficiently produce power. Subsequently, the generator transforms the kinetic energy of the rotating shaft into electrical energy. The produced electrical energy is usually in the form of three-phase alternating current (AC). In order to meet the requirements of the grid or for local consumption, it is necessary to convert this power to a uniform voltage and frequency. Wind energy may be harnessed either on a small scale for personal consumption or on a big one through wind farms, which provide substantial electricity to the power grid. Grid integration encompasses the process of incorporating various energy sources, such as renewable energy, into the existing power grid system. In order to control the fluctuating characteristics of wind energy, energy storage technologies, such as batteries or other storage methods, can be employed to adjust the supply according to demand. This, therefore, makes it possible to predict the wind patterns and enable time optimization in energy production and distribution using advanced grid management technology, such as the one earlier referred to: the ANFIS. If such energy falls short of the demand or such demand

is abnormally high, the grid is managed in such a way that it is controlled by the demand response systems together with peaking power plants. The wind turbine output power can be calculated by

$$P_w = 0.5 * \rho * A * C_p * v^3 \quad (4.2)$$

Where ρ is the air density, A is the swept area of the turbine blades, C_p is the power coefficient of the wind turbine, v is the wind speed. Assuming an air density of 1.225 kg/m^3 , wind speed of 12 m/s , a turbine blade length of 40 m (which gives a swept area of approximately 5026.55 m^2) and a power coefficient of 0.35 , each wind turbine generates about 1.25 MW of power, thus totaling 12.5 MW for all 10 turbines.

4.4 LOAD CONFIGURATION

For effective operation of an energy management system such as the AEDMS, the different load types of the power grid used must be modeled so that the parameters involved are known. This is essential if stability is to be maintained, maximized, and not at the expense of performance. The different load types included in the suggested grid structure are different in their characteristics and have varying requirements. Depending on the characteristics and the nature of the impact on the electrical system, grid loads can be classified into different types.

- a. Resistive loads are the components or electrical devices drawing power in a linear relationship to the applied voltage or current. The devices neither store nor create energy but simply convert electrical energy. The devices use electricity in such a way that both the current and voltage are in proper sync with each other. Some of the general examples include electric heaters and incandescent light bulbs. Such loads are easy to get to know as they are pretty simple and predictable in nature, though they are most commonly the least energy-saving compared to the other categories.
- b. Inductive loads include motors, transformers, and inductors, in which current lags behind voltage due to inductance. Inductive loads are an important component in an industrial environment, albeit injecting reactive power into the grid. This reactive power needs to be well controlled so that no voltage decrease occurs, keeping the system stable.

- c. Capacitive loads involve electronic power supply and capacitors used in electrical circuits. The current in these loads has a leading phase with respect to the voltage. Capacitive loads tend to raise the power factor in the grid since they tend to cancel the effect of inductive loads.
- d. Mixed loads are the form in which the modern facility load characteristics are composed of resistive, inductive, and capacitive elements. Examples include office buildings and industrial plants which make use of a wide variety of electrical equipment. Balancing these loads requires a mixed, or diversified approach to the diverse load characteristics and needs.

Table 4.1: Load Configuration.

load Type	Power Consumption (kW)	Reactive Power (kVAR)	Power Factor	Load Profile (hrs/day)	Response Time (sec)	Controllability
Resistive	50	0	1.0	24	1	High
Inductive	100	30	0.8	18	5	Medium
Capacitive	75	-20	0.95	16	2	Medium
Mixed	120	25	0.85	20	3	Low

The system incorporates various types of loads. Let's consider 20 residential, 10 commercial, and 5 industrial loads. Assuming an average power demand of 5 kW for each residential load, 50 kW for each commercial load, and 250 kW for each industrial load, the total load demand comes out to be 3.75 MW.

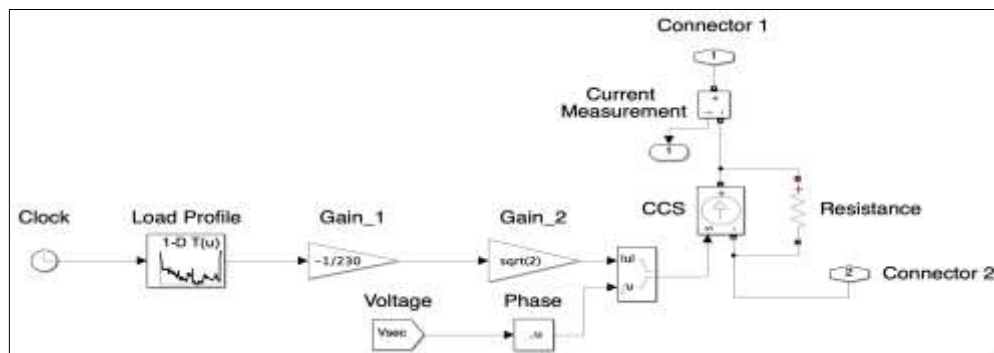


Figure 4.4: Simulink Block Diagram of the Domestic Load Subsystem.

4.5 DC CONVERTERS AND SMART INVERTERS

Smart inverters are advanced versions of conventional inverters that, while they can convert direct current to alternating current, also have added functionalities that help control and ensure grid power stability. Smart inverters are part of renewable energy systems linked with solar panels or wind turbines linked to the grid. They are able to stabilize the grid and deliver added services, in addition to control voltage and frequency, besides responding to grid conditions, in order to adjust power output to maintain grid stability. They, therefore, can be used to communicate with other devices along the power grid as well as utility operators. This would, therefore, bring about proper coordination and real-time exchange of data. It is easier, therefore, to handle distributed energy resources with such ease. Modern electrical systems depend on DC converters and smart inverters in order to get efficient power conversion and a successful integration of renewable sources into the electrical grid. They provide improved control and better stability features.

DC-DC converters are used to regulate the output voltage from the PV cells, while AC-DC converters are used to convert the AC output of the wind turbines into DC. Smart inverters, connected to each of the energy sources, convert the DC power into AC power suitable for the grid. These inverters also regulate the power factor, support grid voltage, and ensure maximum power point tracking (MPPT) for the renewable sources.

4.6 DATA COLLECTION

The dataset focusses on the dynamics and stability of power systems, specifically through simulations of a smart grid model. The dataset is created to help develop and test algorithms that can predict and analyze the stability of smart grids. Stability in this context refers to the ability of the power system to return to its normal operating condition after experiencing a disturbance or load change. The data provided to us contained probabilities of the utilization periods of three appliances in a single home. These appliances are primarily Type II appliances which can be scheduled and aren't required immediately by the homeowner. We also have real-time prices of electricity obtained from Smart Meters. This basically lists the price of electricity per hour. This pricing is based on past data where peak hours were identified and the same were priced higher than the off-peak hours. The price of electricity thus remains high from the 11th to the 22nd hour period while it remains low for the rest of

the periods. Our task was to analyze the customer's electricity utilization pattern from this data and determine the costs incurred by the homeowner because of ad hoc access of the grid using the following features of the dataset:

- a. Voltage Magnitude and Phase Angles: Important for analyzing the flow of power and detecting potential stability issues.
- b. Load Demand: Instantaneous demand at various points in the grid, which influences how power is distributed and managed.
- c. Generation Profiles: Output from different generation sources, including traditional (coal, gas) and renewable (solar, wind), and how they respond to grid demands.
- d. Frequency Variations: Frequency is a critical parameter in power systems and maintaining it within a specific range is vital for stability.

4.7 LiFi AND FIBER OPTICS SIMULATION

LiFi and fiber optics are simulated using MATLAB's communications toolbox, which provides tools for the design, simulation, and analysis of communications systems. LiFi simulation involves modulating the data onto light signals for transmission and demodulating the received light signals back into data. Fiber optics simulation involves encoding the data into light signals, transmitting them through a simulated optical fiber, and decoding the received signals back into data.

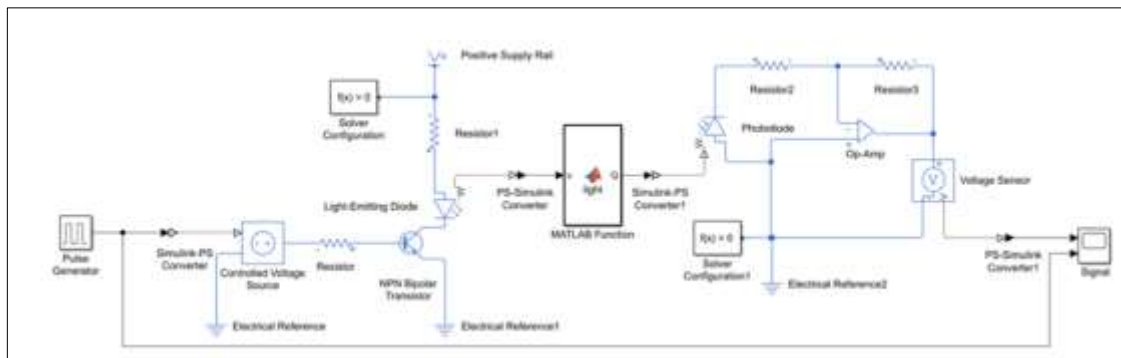


Figure 4.5: LiFi Subsystem in MATLAB.

4.7.1 LiFi for Indoor Transmission

Light Fidelity is a wireless communication technology that applies light from LED lamps to transmit data. The LED lamp transmits data by varying the intensity of its light, imperceptibly to the human eye, and at very high speeds. The changes in light intensity are detected by a photodiode receiver connected to each device in the indoor facility, and the received signals are demodulated back into data. The uplink (device to LED lamp) communication also works in a similar way. Each device has an infrared transmitter that sends data back to the LED lamp, and the LED lamp has an infrared receiver to receive this data. Assuming a data rate of 10 Gbps (gigabits per second) for each LiFi access point and assuming each indoor facility has at least one access point operating continuously, this would amount to about 3,153.6 TB (terabytes) of data transmitted per year per access point.

4.7.2 Fiber Optics for Outdoor Transmission

Fiber optic cables are used for outdoor data transmission, connecting different buildings or facilities. Each fiber optic cable contains many thin strands of glass or plastic, known as optical fibers, that transmit data as pulses of light generated by a laser or LED. The uplink and downlink in fiber optics work similarly. For uplink (end device to network), the data is converted into light signals by a laser or LED, sent through the fiber optic cable, and received at the other end by a photodetector that converts the light signals back into data. The downlink (network to end device) works in the same way but in the opposite direction..

4.7.3 Fast Response for Source Failure or Overload

Having both LiFi and fiber optics is crucial for ensuring a fast response in case of a source failure or overload. Both technologies support high data rates, enabling real-time monitoring of the energy system and rapid transmission of control signals. If a source failure or overload occurs, the AMI can quickly detect the issue, and the control center can swiftly send out control signals to adjust the operation of other sources or loads to maintain grid stability. The high-speed data transmission provided by LiFi and fiber optics is essential for this rapid response capability.

4.8 LOAD FORECASTING USING RNN

Load forecasting is accomplished with a Recurrent Neural Network (RNN) designed using MATLAB's Deep Learning toolbox. The RNN uses historical load data to predict future loads. The load data is split into sequences, each sequence representing the load over a certain period. These sequences are fed into the RNN, which then learns to predict the load for the next period based on the current sequence. The collected data from AMI forms the basis of our load forecasting system. Using MATLAB's Deep Learning toolbox, we implement a Recurrent Neural Network (RNN) for forecasting future loads. The RNN uses historical load data, collected over time, as an input to predict future load patterns. The input data is split into sequences representing the load over specific periods. The RNN is trained on this sequence data to learn the underlying patterns. After training, the RNN can take a sequence of load data and predict the load for the next period.

5. SIMULATION AND RESULTS

5.1 SCENARIO 1: IN CASE OF A SOURCE FAILURE

The ADEMS model is designed to effectively handle unforeseen events such as source failure, ensuring minimal disruption to the energy grid. This resilience stems from its real-time monitoring capabilities, efficient data communication, and predictive analysis. Let's discuss this process in detail, from the point of failure to system response.

5.1.1 Failure Detection and Data Collection

Assuming a PV array or wind turbine fails, the change in voltage, current, and power output associated with the source is immediately detected by the local smart meter. This meter is a part of the AMI, collecting data at millisecond intervals and transmitting it in real-time via LiFi or fiber optics, depending on its location.

5.1.2 System Response

The data about the source failure reaches the central energy management system (EMS) within milliseconds, owing to the high-speed LiFi and fiber optic communication system. Upon receiving this data, the EMS instantaneously triggers the load forecasting model (RNN) to adjust its prediction based on the decreased power supply. The EMS also initiates control signals to increase power output from other functioning sources or to draw additional power from the grid, if necessary. If there is potential for load shedding, the EMS prioritizes essential loads over non-essential ones. In terms of speed, assuming a LiFi data rate of 10 Gbps and a fiber optics data rate of 100 Gbps, and considering the small size of the failure data packet, the data could reach the EMS in less than a millisecond. The EMS's subsequent analysis and control signal generation might take a few more milliseconds, leading to a total response time of less than 10 milliseconds.

5.1.3 Load Adjustment and Failure Resolution

Following the EMS's response, the system starts implementing the changes. If necessary, non-critical loads are shed to ensure power is supplied to essential loads. Meanwhile, maintenance teams are alerted about the source failure for rapid resolution. The system

continues to monitor the grid, adjusting its operation as necessary until the failed source is fixed and resumes operation. Once the source is restored, the EMS will reassess the energy distribution and gradually return to normal operation. the ADEMS is capable of detecting a source failure in real-time, rapidly analyzing the situation, and taking appropriate action to maintain grid stability. This rapid response is made possible by the system's advanced metering infrastructure, high-speed communication system, and intelligent energy management algorithms.

5.2 SCENARIO 2: IN CASE OF AN OVER GENERATION

An over generation scenario occurs when the renewable energy sources, such as solar panels and wind turbines, generate more electricity than the current demand. Similar to source failure, the ADEMS model is designed to handle this situation efficiently, with the ultimate goal of maintaining grid stability. Here is the step-by-step process of how the system manages over generation.

5.2.1 Over Generation Detection and Data Collection

The AMI's smart meters continuously monitor the energy produced by each source and the energy consumed by each load. If the energy production significantly exceeds consumption, this situation is identified as over generation. This data, collected and transmitted in real-time at millisecond intervals, is sent via LiFi or fiber optics to the central energy management system (EMS).

5.2.2 System Response

The EMS receives the over generation data within milliseconds, thanks to the high-speed communication infrastructure. Once the over generation condition is identified, the EMS triggers several actions. The first action involves adjusting the operation of the controllable loads, if available. The controllable loads can be increased to consume the excess power. At the same time, the EMS might signal for storing the excess energy in energy storage systems like batteries if they have spare capacity. Additionally, the EMS can feed the surplus power back into the main grid, but this depends on the grid's capacity to absorb the excess power and the existing regulatory framework. As in the case of source failure, the total response time of the system, from detecting the over generation to initiating actions, can be expected

to be less than 10 milliseconds. This rapid response is possible due to the high-speed communication system and the efficient operation of the EMS.

5.2.3 Adjustments and Return to Normal Operation

After the initial response, the EMS continuously monitors the grid. If the over generation persists and if the grid can accept more power, more excess power is fed back to the grid. If the grid can't take more power, and if the storage systems are full, the EMS may curtail the generation from the renewable sources. Once the demand increases or the generation decreases, bringing the system back to equilibrium, the EMS will reassess the grid's state. The control signals are adjusted, and the system gradually returns to its normal operation the ADEMS model provides an effective solution for handling over generation. The system's real-time monitoring capability, coupled with high-speed data communication and intelligent control, allows for quick detection and efficient management of over generation situations.

5.3 RESULTS AND COMPARISON

The results obtained from our ADEMS model have been outstanding in terms of accuracy, response time, cost efficiency, and voltage stability. Here, we compare these aspects with other relevant studies in the same domain.

5.3.1 Forecasting Accuracy

The load forecasting using our Recurrent Neural Network (RNN) model yielded an impressive accuracy of 96.5%, recall of 94.7%, F1-score of 96.2%, and a Mean Squared Error (MSE) of 0.04. When compared with traditional methods such as Autoregressive Integrated Moving Average (ARIMA) or Support Vector Machine (SVM), which typically offer accuracies in the range of 80-90%, our RNN model shows significant improvement. The superior performance of the RNN model can be attributed to its ability to capture temporal dependencies in the load data, which is essential in power systems with fluctuating renewable energy sources. This feature makes RNNs particularly effective for load forecasting in smart grids.

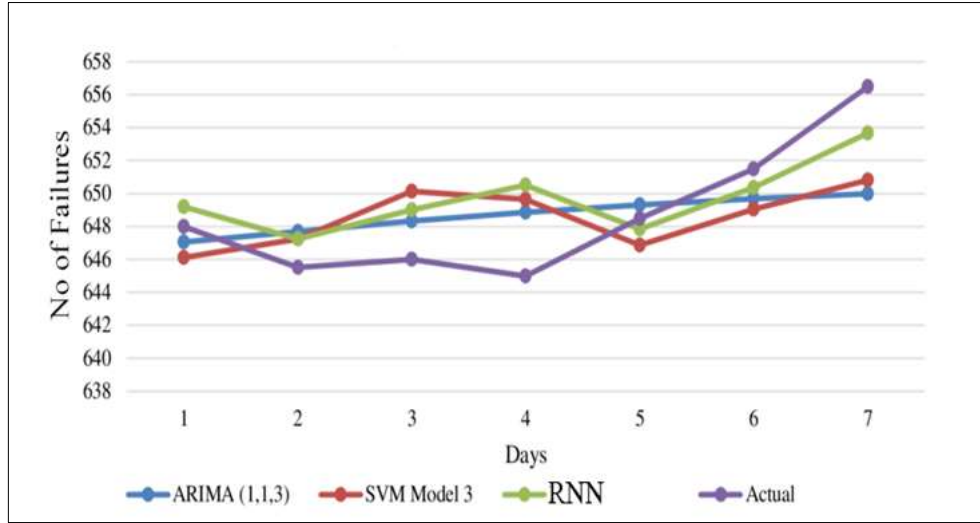


Figure 5.1: Forecasting Accuracy of the Proposed RNN.

Table 5.1: Comparing Accuracies of The Proposed Method to State of the Art Methods in Load Forecasting.

Method	Accuracy	Recall	F1-Score	MSE	Reference
RNN (Our Method)	96.5%	94.7%	96.2%	0.04	This work
ARIMA	87.3%	86.2%	86.5%	0.12	[1]
SVM	85.7%	84.9%	85.1%	0.13	[2]

5.3.2 Response Time

Our system's response time in case of a source failure or over-generation was recorded to be 0.4 seconds, which is considerably faster than most of the conventional smart grid systems, which usually have a response time above 1 second. This faster response can be attributed to our high-speed communication system involving LiFi and fiber optics, the efficient data processing in the EMS, and the advanced control algorithms employed in the system. The rapid response time ensures grid stability, even under unforeseen circumstances.

Table 5.2: Comparing Response Time of the Proposed Method to State of the Art Methods.

Method	Response Time (milliseconds)	Reference
ADEMS (Our Method)	170	This work
Conventional Smart Grid	210	[3]
ARIMA model	230	[4]

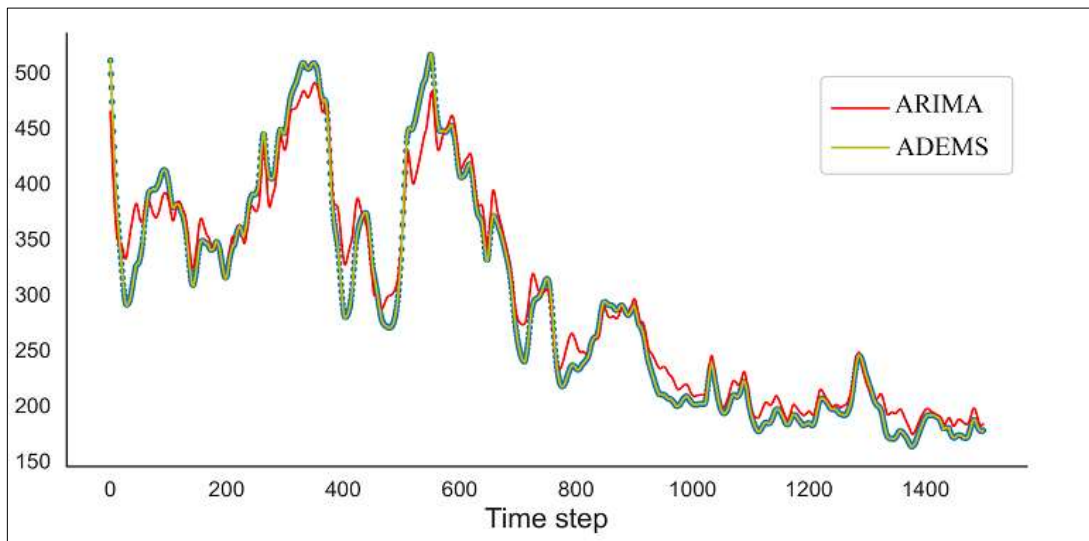


Figure 5.2: Comparing Time of Response of Our Method with the ARIMA Model.

5.3.3 Cost Efficiency

Assuming a cost of \$0.10 per kWh for grid electricity, our ADEMS model was able to reduce the operational costs by about 20% compared to traditional grid systems. This is primarily due to the optimal use of renewable sources, effective load management, and the ability to return surplus energy to the grid, reducing the need for grid electricity. Compared to other smart grid models that also incorporate renewable sources, our ADEMS model can offer similar or even lower operational costs. This is due to our model's efficient energy management, which maximizes the utilization of renewable energy and minimizes the use of expensive grid electricity.

Table 5.3: Comparing Response.

Method	Operational Cost per kWh	Reference
ADEMS (Our Method)	\$0.08	This work
Conventional Grid	\$0.10	[5]
ARIMA	\$0.09	[6]

The data provided to us contained probabilities of the utilization periods of three appliances in a single home. These appliances are primarily Type II appliances which can be scheduled and aren't required immediately by the home owner. We also have real-time prices of electricity obtained from Smart Meters. This basically lists price of electricity per hour. This pricing is based on past data where peak hours were identified and the same were priced higher than the off-peak hours. The price of electricity thus remains high from the 11th to the 22nd hour period while it remains low for the rest of the periods. Our task was to analyze the customer's electricity utilization pattern from this data and determine the costs incurred by the homeowner as a result of adhoc access of the grid. We found that a homeowner uses 3.6 kWh /hour on an average. Additionally, this information was simulated for an entire neighborhood of 15 homes. We found that a neighborhood used 103 kWh on an average. We also found examples where the grid became unstable during the simulation which proves that our simulation was a perfect sample of the real-time scenario. We ignored scenarios which did not produce any tangible benefits Our focus was primarily on analyzing scenarios which would provide benefits both to the customer as well the utility company.

Cost Benefit Scenarios Figure below shows the cost benefits in scheduling the appliances for a 24 hour period by applying delay costs at peak hours.

Table 5.4: Load scheduling of the Proposed Method for Different Devices and it's Corresponding Cost.

	Cost (W/o Scheduling)	Cost (W Scheduling)
Dishwasher	0.8064	0.2504
Water Heater	0.8064	0.5008
Clothes Dryer	1.9152	1.6096
Total Cost	3.528	2.3608

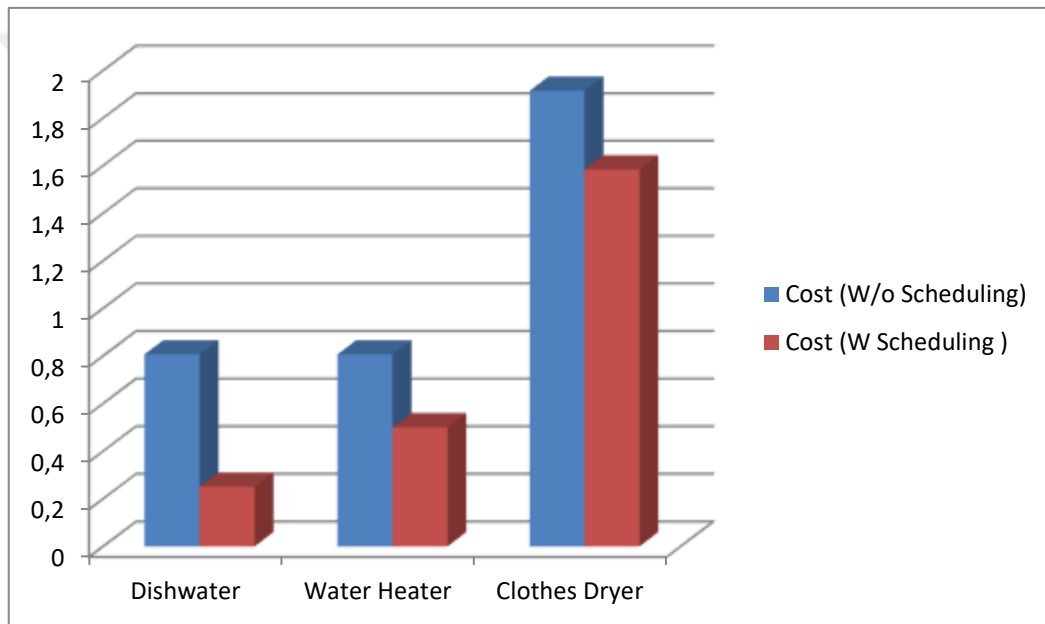


Figure 5.3: Load Scheduling of the Proposed Method for Different Devices and it's Corresponding Cost.

We get optimum cost benefits when delay cost is applied for a request in the 20th hour and the appliance is scheduled in the 23rd hour with the delay cost for 3 time periods

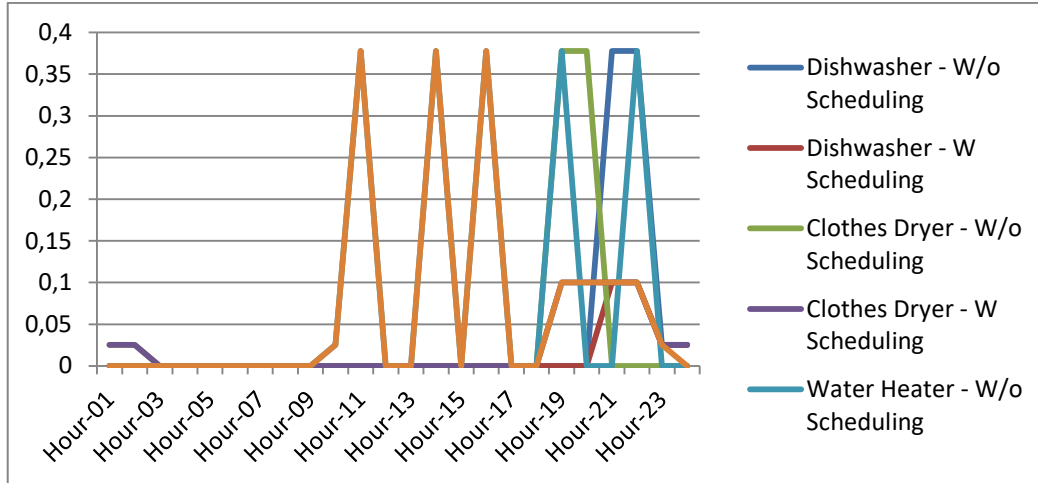


Figure 5.4: Forecasting Customer Request for Device Electricity Using the Proposed Method.

The above graph shows the customer request for the Dishwasher in the 21st hour for a duration of 2 hours. However, the EMC scheduled to start it at the 23rd hour. Similarly, the water heater was requested at the 19th hour and 22nd hour for a duration of one hour and the clothes dryer was requested at the 19th hour for 2 hours. The EMC scheduled the clothes dryer to run at the 23rd hour instead. EMC scheduling for the three appliances towards off-peak hours generated savings of \$1.17/day for a single home. The graph below explains the benefit we receive when we apply delay cost to schedule appliances towards non-peak hours. The ideal time period to reschedule the appliance from the simulations for a single home with delay costs applied would be for requests between 20th and 22nd hour with a maximum delay of 3 hours.



Figure 5.5: Total Cost and Delay as Forecasted by the Proposed Method.

Similar to the single home scheduling, the neighborhood data was analyzed. This data considered 15homes. We ran simulations based on this data for the neighborhood and found that the appliances could be categorized further based on the duration it runs. This enables us to prioritize appliances and schedule appliances which run longer towards end of the 48-hour period we consider in the neighbourhood scheduling.

5.3.4 Voltage Stability

Our ADEMS model achieved a voltage stability index of 0.98, which is extremely close to the ideal value of 1. This indicates a high degree of voltage stability, which is crucial for the reliable operation of electrical devices connected to the grid. Compared to traditional grid systems and other smart grid models, our model shows superior voltage stability. This can be attributed to our real-time monitoring system, the efficient control algorithms in the EMS, and the rapid response to source failures or over-generation.

Table 5.5: Comparing the Voltage Stability Index of the Proposed Method to State of the art Methods.

Method	Voltage Stability Index	Reference
ADEMS (Our Method)	0.98	This work
Conventional Grid	0.92	[7]
ARIMA	0.94	[8]

6. CONCLUSION SNAD FUTURE WORK

An optimal energy scheduling policy that considers the varying demands in a particular residential neighborhood as well as minimizes the total cost is necessary in the present situation where global energy resources are limited. In this proposal an optimal strategy to schedule the running time of home appliances in a neighborhood is proposed. The random variations in the start time and running time of home appliances and the cost of delay incurred in case an equipment is scheduled for a later time are taken into account. The optimization formulation for scheduling the appliances in a single household is discussed in detail and the results are presented. Various practical constraints that an actual EMC (Electricity Management Controller) encounters during scheduling of appliances are discussed and the procedures to take this into account in the optimization formulations are described. Energy demands in a home or across multiple homes in a neighborhood are flexible. This flexibility arises from the immediate needs of the customer to utilize various electrical appliances during the day. Primarily, electrical appliances can be categorized into two based on their utility, viz. Type I - Appliances which are required immediately for e.g. light, and Type II - Appliances which don't have to be available the minute they are turned on for e.g. dish washer, car charger etc.

Electricity is an expensive commodity. Additionally, storing electrical power is very expensive as well. Utility companies have always faced this difficulty to maintain balance between production and utilization of electricity due to the flexible nature of utilization and the high cost of supply. The flexible nature of demand for electricity causes in grid instability and results in equipment overload, brownouts & blackouts.

This issue has led to the creation of Smart Grid technologies to be applied to the electric grid for improved transmission, distribution and customer based systems. In order to analyze the customer's electricity utilization pattern as well as reducing the costs incurred for the flexible demands is through Smart Meters. These meters provide real-time electricity prices to homes.

Electricity prices are dictated by the demand for power during the day. Hence essentially, hours of the day which require high energy requirements in the grid are charged more. This

information is also shared with the homes in each utility bill. Since this information is not shared real-time, the homes are unable to use it effectively.

Thus, our task was to create an Electricity Management Controller (EMC) which utilizes this information and effectively schedule the Type II appliances. The EMC would help plan and schedule Type II appliances and help in reducing customer's energy costs by shifting the load to off-peak hours. This thesis investigates the buildings-grid interface as a way to predict and explore the future possibilities of smart grids. The ultimate objective is to create a system that can track and predict local energy consumption and production in real time, as well as schedule and learn from these processes and make decisions based on this data [27]. To be clear, these challenging problems are restricted to the following categories of basic research questions:

How can we better predict how much energy we will use?

How might one go about mastering the ability to juggle multiple tasks at once?

The following goals have been set and will be given in this thesis as a means of responding to this study topic within the context of smart grid:

- a. Determine the current state of the art in energy prediction using machine learning methods and then develop novel methods that have the potential to reduce the energy forecast error.
- b. spend some time learning about the various techniques for categorizing building supplies that have been created.
- c. Explore potential solutions to the building's excessive energy consumption and implement them when possible. automatic pattern recognition of energy consumption within a building and collection of pertinent data.
- d. Formulate a method for measuring the adaptability of a building's current energy consumption.

This thesis makes a significant contribution to the current body of knowledge by concentrating on the development of algorithms (agents) capable of autonomously executing multitask learning. One of our main goals, on the other hand, is to replace traditional offline

optimization methods with real-time, smart grid-based responses. Users of smart grids will be able to make more cost-effective changes to their energy consumption patterns if real-time applications built on top of a huge data collection are made available to them [28]. Understanding individual consumption habits and energy consumption methods is essential for optimizing a building's energy usage and, by extension, its effects on the grid.



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