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Review of Advanced Optimization Approaches in Smart Grid Technology

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Abstract: *In order to create a power grid that is durable, efficient, resilient, and sustainable, smart grid technology advances the conventional grid via the use of computational intelligence and networking capabilities of different communication networks. It is thought to be the grid of the future because it uses a bidirectional electrical stream via a communication module, which creates an environment that allows consumers to become prosumers individuals who may autonomously produce and control the import and export of electrical energy in their local community. A smart grid offers a safe, self-healing, adaptable, and efficient power infrastructure that enables power exchange amongst several stakeholders. An efficient and safe communication network between the smart grid's electronic devices and those in users' homes is essential for the system to function properly. To improve the power system, data interchange across communication modules need effective communication and optimization systems. Our contribution consists of a comparative study of several optimization strategies that might be used to energy management in smart grids. We have identified the main obstacles that might prevent the smart grid from operating and controlling effectively in order to solve the issues facing its successful adoption. We think that early-career academics involved in smart grid energy optimization will find this research paper beneficial.*

Keywords: Smart grid, Optimization Algorithms, Energy Management.

I. INTRODUCTION

The traditional grid was not intended to sustain high-tech civilization or be integrated with the newest communication technology when it was built more than a century ago [1]. The conventional grid handles and uses energy inefficiently. Blackouts and power outages are common because of outdated infrastructure and an unstable power system. A blackout in the Northeast occurred in 2003, affecting almost 50 million people in the United States. Around six million people were impacted by another blackout that occurred in 2012 when superstorm Hurricane Sandy struck the Atlantic, affecting 15 states in the US as well as the District of Colombia [2]. In order to address the frequent blackouts and upgrade the conventional power grid with the newest technology, the current power system is transitioning from a conventional to a next-generation grid. Renewable energy sources take the place of conventional energy sources. The emergence of renewable energy sources highlights the need of creating a power system that is reliable, efficient, and secure. As new loads are added to the smart grid,

Bus bar voltages have had a significant impact on infrastructure [3]. We must forecast and optimize the load demand of the customer in order to replace the additional voltages. Two approaches to managing consumer load are load forecasting and energy management. Many techniques and strategies are used in the literature for energy management and load forecasting.

Smart Grid Optimization

Maintaining the ideal balance between availability, cost, reliability, and efficiency is part of grid optimization. Grid optimization may be accomplished by monitoring load behavior [4], converting peak energy demand into off-peak hours, and quickly resolving any power outages [5]. In addition, it facilitates the building of energy reservoirs to meet increased demand [6], the inclusion of plug-in electrical cars [7], and the collection and sharing of real-time user data with utility providers [8]. Furthermore, it creates an effective communication network between utilities and inactive

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users. Additionally, it promotes the development of microgrids to convert the centralized power grid into a distributed generation interface, the integration of renewable energy resources to produce green energy, and intelligent price management to entice the greatest number of users to adopt the smart power system [9].

Optimizing the grid has many advantages, including decreased power transmission, distribution, and usage losses; increased grid dependability; and decreased emissions of harmful and polluting gases. Moreover, it assists in reducing energy expenses [10]. Furthermore, it is possible to reduce power uncertainty and voltage fluctuation, as well as minimize the time between device protection failures.

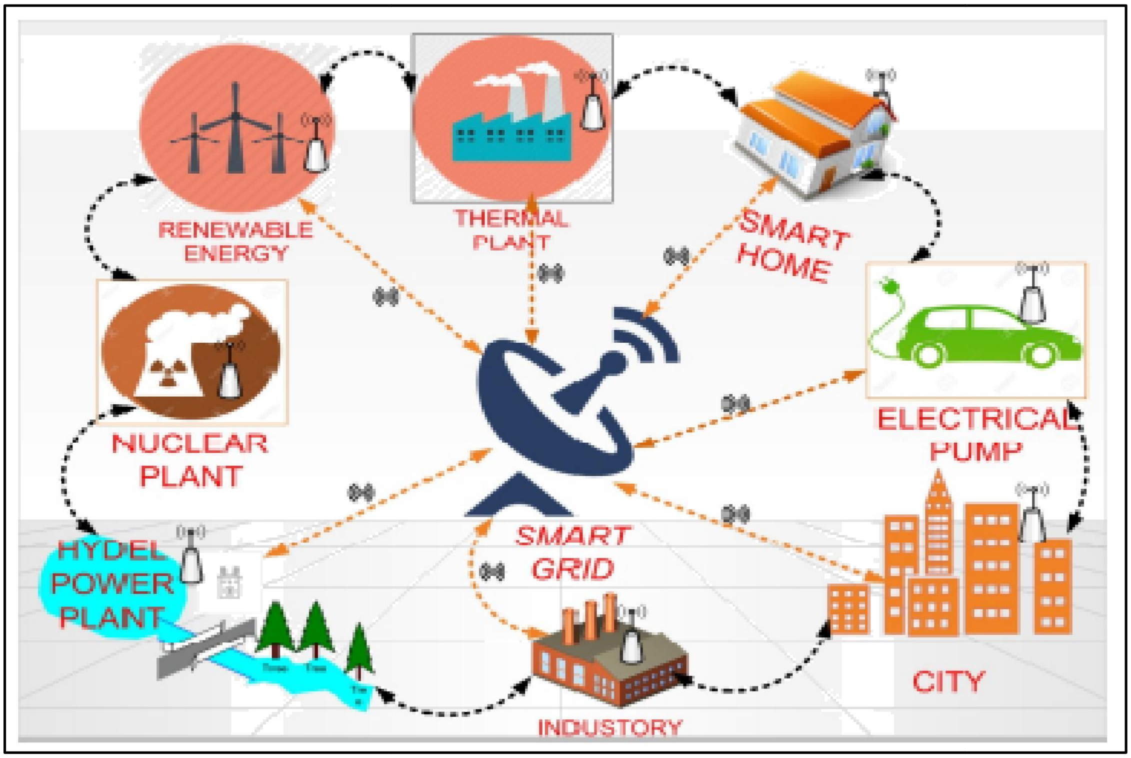

Fig. 1. Structural model of Smart Grid

Advanced optimization systems based on learning algorithms provide a challenge to the current power grid with the integration of renewable energy supplies. The present power system must be in line with the communication and optimization trends of the times. The demand for energy has increased dramatically due to the inclusion of new loads, such as plug-in electric vehicles (PEVs), charging stations, and E-busses, among others. In light of the increasing load, managing electricity use has become critically important. The power system may be impacted by the peak in the requested load caused by this increased load. Peak demand must be controlled in order to maintain a stable power system.

The smart grid's use of advance metering infrastructure (AMI) helps estimate demand and boosts domestic energy efficiency [11]. By assisting power plants in meeting the required energy demand, AMI helps them avoid operating their units unnecessarily, which reduces the amount of harmful gasses like CO_2 and greenhouse gases released into the atmosphere. The effectiveness of smart meters used in the consumer market determines how well the smart grid performs. Every smart metre has an energy consumption controlling unit (ECCu) installed. Smart meters are supplied data via home area networks (HANs). By LAN, every ECCu in the region is linked. Information on power use must be shared by ECCu. A distributed algorithm (DA) may move certain loads from peak to off-peak hours with the use of the ECCu data. AMI may be used to schedule equipment operation in order to manage power consumption restrictions. In order to shift peak hours, appliances must be run at predetermined intervals of time. Achieving optimization in a smart grid, which is a complex network of several networks, is a difficult undertaking. Various algorithms are suggested in order to maximize optimization. A lot of effort has been done in the last 10 years to improve the energy graph using

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load forecasting and demand side management (DSM) [12]. The assessment examination of many optimization techniques, including the genetic, firefly, and particle swarm optimization algorithms, was carried out by the authors in reference [13]. To improve energy demand forecasting, they suggested a hybrid, clever fusion of many techniques, including wavelet transform and fuzzy ARTMAP, using firefly optimization technology. Recent years have seen the addition of demand response and appliance scheduling as additional viable energy management strategies [14]. Depending on the cost and energy requirements of the consumer, various appliances are scheduled for different timeslots [15]. Appliance scheduling helps to improve grid stability, lower the peak to average ratio, and preserve customer comfort [16]. The two energy management methods, residential energy management (REM) and home energy management (HEM), are proposed and compared by the authors in [17]. Appliance scheduling in REM is done by linear programming. This optimization model aims to lower the cost of power. HEM is utilized to reduce energy costs without sacrificing consumer comfort. Automatically operated appliances (AOAs) and manually operated appliances (MOAs) are the two types into which in-home appliances are divided in the HEM model [18], [19]. Washing machines, dishwashers, and air conditioners (ACs) are examples of AOAs. We further divide the automated appliances into interruptible and non-interruptible categories in order to persuade users. Non-interruptible appliances cannot be rescheduled, while appliances that are capable of being stopped at any moment and restarted later may. MOAs, such as televisions, PCs, and vacuum cleaners, need human contact to function, in contrast to AOAs (VC).

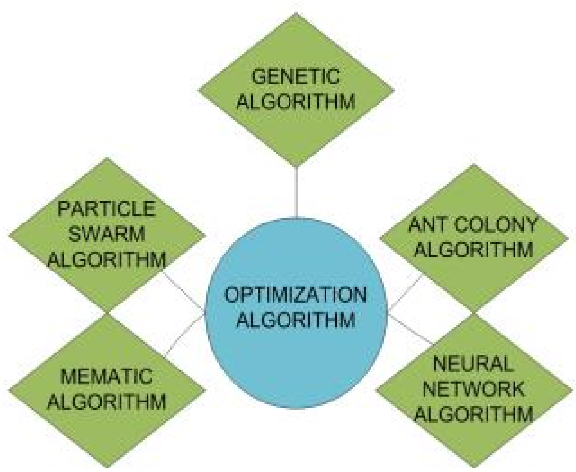

Fig. 2. Optimization Algorithms

Genetic Algorithm

An evolutionary algorithm inspired by nature is called a genetic algorithm (GA). The non-linear function is optimized with the aid of GA [20]. Climate affects user energy consumption in smart grids. GA thus has a potential role to play in optimizing this non-linear data. In order for GA to function, solutions must be searched from one population of solutions to another until the optimal solution is found [21]. Like chromosomes, GA functions. A collection of chromosomes represents the solution to any issue. Chromosome-containing genes include Athe values of the optimization variable. The best chromosomes communicate information when they mutate and crossover in order to create offspring (solution). The week companion is used to test Off-Spring (solution). Until the optimal fitness is achieved, the procedure is repeated.

GA is essential to the smart grid's effective operation. In order to prevent energy theft, decrease the cost of distributing power, and control substation voltages, the use of GA in smart grid technology entails fault detection in the transmission and distribution lines.

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Memetic Algorithm

Memetic is an evolutionary algorithm that emulates the metaphors of biological evolution. The non-linear function in a smart grid is addressed by the memetic algorithm (MA). Another important aspect of smart grids that requires attention is energy optimization. In a smart building, MA is utilized to optimize energy loss [22]. When it comes to how they approach a particular issue, MA and GA are comparable. Unlike genes in GA, elements holding the optimization variable in MA are called memes. Unlike GA, memes in MA get some local experience before engaging in any evolutionary processes.

In MA, the initial population is created at random. To get some experience, a random variable is used for the first local search. As a result, the local optimal solution is found. After going through the crossover and mutation phases, randomly produced variables provide offspring (solution). The generated solution undergoes local search in order to preserve local optimization. MA is also used to feed the grid with renewable energy.

Particle Swarm Optimization

Another evolutionary technique with some similarities to GA is particle swarm optimization (PSO). A swarm of soaring birds traveling to an unidentified destination served as the inspiration for PSO. In PSO, each bird in the flock represents a solution, while the flock itself represents a particle. Particles in GA behave in the same way as chromosomes. Particles do not go through the crossover or mutation phase, with the exception of PSO. They only change in relation to society. Birds in flight converse with one another to determine which bird is in the optimal position. Every bird moves in the direction of the bird that is in the best position. Once they've found the ideal spot, they search for an even better bird to approach. Until the birds arrive at their goal, this procedure keeps on.

The PSO plays a critical role in optimizing the smart grid's efficiency. In the near future, cities will be equipped with PHEV charging stations. The installation of PHEVs will cause a significant power burden on the power systems. By effectively assigning electricity to PHEV charging stations, PSO manages all PHEVs in the city [23]. Another difficult job in the smart grid context is the efficient placement of sensors. PSO is also used to determine where sensors should be deployed to provide the optimum coverage range [24]. Phaser measuring devices are used in conjunction with PSO to optimize the substation.

Ant-Colony Optimization Algorithm

Like PSO, the ant-colony optimization algorithm (ACOA) evolves socially rather than genetically. The idea behind this algorithm is that ants choose the quickest path to food. In order to do this, phermone concentration is deposited, which encourages the other ants to follow the trail. The concentration of phermones directly correlates with the effectiveness of the solution. The more phermones, the better the solution optimization. Phermones are updated after the first iteration, and in the next iteration, ants adjust their route (related variable values) in relation to the concentration of phermones. When compared to PSO, ACOA is less effective in terms of processing time and success rate. However, it may be optimized for usage in smart grid systems.

Bus bar voltages are negatively impacted by the introduction of additional loads, such as PHEVs, into the electrical system. ACOA is used to detect voltage collapse conditions in power networks in order to maintain loads below safe limits [3]. ACO is used in the smart grid's virtual deployment. In order to improve communication inside power plants, many methods are suggested with the assistance of ACO in [35].

Artificial Neural Network

An artificial neural network (ANN) is a prototype method for information processing that draws inspiration from biology. It functions similarly to the human brain. Similar like the human brain, ANNs learn from their experiences. It is beneficial to tackle optimization issues because of self-learning and self-organization. Data may be extracted from intricate patterns that are invisible to computers or humans thanks to neural networks (NNs) [37]. Computers using ANN architecture are designed to resemble human brains. In ANN, elaborate communication networks are created by connecting hundreds of processing units (PUs) via wire. Every PU is designed to resemble a genuine neutron, which is in charge of transferring data between various networked nodes. An ANN is a cluster of layers that are placed in a network so that some levels interface with the outside world and receive information as input, while other layers process the information and output it to the outside world [38]. The cornerstones of the future smart grid will be prosumer dominance and autonomous power production. Prices and loads for electricity are crucial considerations when distributing and using energy. ANN is a useful tool for handling the stochastic behavior of pricing and load. A characteristic in NNs that is input based on data collected from historical climate, pricing, and calendar records. Based on the information given, the output feature collected the estimated outcomes [28]. In the smart grid, ANN is also used for load forecasting applications. For price forecasting, pricing information gathered from the consumer domain using an ANN model is used. An ANN model may also be used to identify cyber security assaults.

Smart Grid Cost:

The needs of traditional users were taken into account while designing the current electricity system, however the next generation grid represents a transition of the traditional grid. Energy in the current electricity system is measured using a conventional metering method. Power moves through the stages of production, transmission, distribution, and use in a standard grid, but in the future, the whole grid image will be altered. We have the phases of smart generation, distribution, transit, and usage. Only when we replace the antiquated infrastructure with one outfitted with the newest technologies—such as AMI, sensors, actuators, and hybrid electrical vehicles, among others—will this dream come true. This transition requires a significant amount of cash, which presents a significant barrier to the smart grid.

Energy Management:

One of the major challenges faced by utility companies is energy demand fluctuation. With the addition of new load i.e., Energy variations related to electric vehicles are anticipated to increase in the near future [39]. Traditional methods to energy concerns may be used to include new renewable sources or peak demand energy can be considered.

II. CONCLUSION AND FUTURE PROSPECTS

We covered the various smart grid optimization strategies in this research. We have provided an extensive review of the literature on heuristic algorithms and shown their great potential in this field. It is difficult to bridge the gap between the hostile power system and the communication infrastructure. The integration of communication technologies with the old power system has been deliberated. Additionally included are the fixes for the main issues. The existing grid is not able to satisfy the demands of the global globe, hence the world is going through a phase transition from conventional grid to smart grid. When creating the optimization plans for smart energy controllers, this document might be consulted. Energy management is an excellent fit for heuristic algorithms. Significant challenges in smart systems that investigate new study fields have been identified by the report.

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