GENETIC ALGORITHM-BASED OPTIMIZATION OF MICROGRIDS

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WHAT IS A MICROGRID?

As society continues moving into the twenty-first century, the growing power demands of a booming global population mixed with a horribly inefficient grid has become a daunting task to tackle. In the United States alone, 1MW of power consumed costs 2.2MW of generation and transmission capacity, or in other words, the power system is operating at a 50% efficiency rate [1]. And with such an immense challenge comes an abundance of ways to begin chipping away at the energy problem. However, one solution has been discussed over the course of the last decade and is now receiving more credibility as a viable solution to resolving the energy dilemma. With the advent of more affordable renewable energy technology, microgrids have received recognition for potentially being an effective and efficient alternative to the current grid system as is known across the United States today.

Essentially, microgrids act as miniature grids with defined electrical boundaries that can connect and disconnect from the larger grid. These microgrids can also be solely powered through renewable energy sources or can be supplemented with fossil fuel generators [1]. Although one difficulty with the microgrid has been creating sufficient dependence from both the larger grid and fossil fuels, progress is being made to create clean and dependable systems. And one of the primary movers in this advancement is genetic algorithm-based optimization of these fledgling microgrids.

Genetic algorithms are programs that model nature’s method of natural selection and genetic mutation to solve problems with seemingly random or stochastic data sets. So in the same manner that breeding can result in a virtually infinite number of genetically different offspring due to the complexity of an organism’s genetic makeup, genetic algorithms solve problems whose inputs are complex and stochastic. And, as is common for most parts of the world, the weather is rather unpredictable and unreliable. Due to the volatile nature of weather patterns, systems that rely on the weather to operate, such as photovoltaic or wind-powered generators, are often discounted as practical means of power generation and distribution because they can’t be relied on to consistently meet energy demands. With the use of genetic algorithm-based optimization, “smoothing out” these periods of high demand and low demand is made realistic when used in conjunction with battery storage systems. As renewable energy power generation becomes cheaper and more widely used by the general public on small scales, the implementation of this technology by effectual means will become critical for the use of these renewable resources on a macroscopic level. The creation, maintenance, and optimization of microgrids will establish a lasting and expandable solution to the developing energy crisis around the globe.

STRUCTURE OF MICROGRID SYSTEMS

General Structure

In the realm of power grid infrastructure, a microgrid can have a relatively loose definition and different systems can operate differently yet still fall in the domain of a microgrid. Generally speaking, all microgrids fall under the aforementioned definition. All microgrids are viewed as a single entity by the larger grid and can connect and disconnect from the larger grid. While there are many remote microgrids that function almost entirely independently of a larger grid due to the unreliability of the larger grid or the isolated nature of the microgrid, most systems in the United States are those that have the capability of connecting to a relatively stable power grid and can choose to switch between an isolated “island mode” and a grid-connected mode. In grid-connected mode, the renewable energy power sources produce whatever the circumstances will provide and is either supplemented by power from the larger macrogrid or feeds excess power generated back into the system [2]. However, the major impact of genetic algorithm-based optimization is applied to the other state of microgrids. In island mode, a microgrid is isolated from the larger grid and powers the system through power generation, such as through photovoltaic or wind-powered generators, and by balancing out energy demand through the use of battery storage systems.

FIGURE 1 [3]

This illustration shows a simple component breakdown of a microgrid.

This isolated state of the microgrid is most critical to the overall resolution of growing energy demands. If the power grid can be divided into smaller, self-sufficient microgrids, greater power independence and efficiency can be achieved. And not only does it provide greater power independence, but critical failures can be more easily avoided. For example, a
power outage that lasts just one sixtieth of second can crash critical systems in a hospital [1]. Therefore, a system that can be independent is crucial for a society so connected and tethered to the power grid.

**Battery Storage Systems**

A major component of microgrids, and ultimately their optimization, is battery storage systems. Known as hybrid generation systems, microgrids with the inclusion of both renewable energy power generation sources and battery storage are “inherently uncertain” [4]. Since daily and seasonal weather variations exist, powering a microgrid on an on-demand model is virtually impossible. Because the typical clean sources of power generation cannot continuously operate, as the sun is not always shining and the wind is not always blowing, there has to be a system in place to draw from during periods of high energy demand and a place to store energy during periods of low energy demand. In order to accomplish this, microgrids integrate battery storage systems. This process of storing and drawing from the battery storage system is known as “wind and solar energy smoothing” [5] and essentially provides a means of renewable energy reliance.

Many battery storage solutions are becoming available as the technology becomes more widely available and widely studied. However, engineers are still investigating technologies for better large scale storage, such as on the scale of a large wind farm or solar power plant [5]. While this may mitigate the advancement of large scale renewable power production, the cheapening cost of photovoltaic power generators coupled with small scale battery storage systems are making microgrids on a community or household basis a realistic possibility today. The optimization of smoothing out periods of low and high energy demand with battery storage technology is also the point of research for many individuals and organizations at the present moment. For example, according to Muhamad Zalani Daud, Azah Mohamed, and M.A. Hannan, a project in Japan showed that “for a large scale PV generation, the fluctuation becomes more pronounced after 11 AM which might adversely impact smaller or weaker power systems. Therefore, a more suitable control algorithm with high efficient batteries needs to be introduced to further smooth out the power fluctuations” [6]. As made evident by their research, controlling power beyond the point of production is critical in taking steps towards seriously implementing microgrids.

**OPTIMIZATION OF MICROGRIDS**

While no system can perfectly predict something as vacillating as weather systems, genetic algorithms make steps towards creating a system that takes changing weather into account. Genetic algorithm-based optimization does this by drawing from ten years of hourly weather data, primarily wind speed and solar irradiance, and power load data [4]. The data, modeled by different functions, is formed into clusters to model what can be considered average seasonal variations in the weather. With this information, the genetic algorithm manipulates the data sets through different mutations and combinations to determine an optimized component sizing or the hybrid system. In order to come to an optimization with practical applicability, constraints are put on the algorithm over a given period of time. The two common restraints are that the energy generated through photovoltaic or wind-driven systems are enough to meet the load and that at any instant, the sum of photovoltaic, wind, and stored energy meet the load demand at any moment. In the case of the work conducted by University of Nevada researchers A. Arabali, M. Ghofrani, M. Etezadi-Amoli, M. S Fadali, and Y. Baghzouz, constraints similar to these were put in place to meet the energy demand of heating, ventilation, and air conditioning, or HVAC, loads in residential and commercial homes [4].

![Figure 2](image)

**FIGURE 2 [7]**

Breakdown of genetic algorithm logic. “Initial population” is given by weather and load data sets. Data is manipulated through selection, crossover, and mutation until best battery storage configuration is achieved. Manipulations of the data are repeated until the established termination criterion are met, such as the ones established by the University of Nevada researchers.

**IMPACT OF GENETIC ALGORITHM-BASED OPTIMIZATION**

**Microgrid Self-Sufficiency**

Genetic algorithm-based optimization opens the door for future microgrid self-sufficiency. As it stands with the falling price of photovoltaic power generation, a microgrid infrastructure is slowly becoming more realistic as a macrogrid-independent means of operation. With this general...
independence from the macrogrid, power outages can more often be localized and resolved without having widespread outages due to a linear and interconnected centralized power grid. The end result of this microgrid self-sufficiency is a move towards more efficient and stable energy practices that will have a lasting impact on how society views energy consumption and production for decades to come.

Renewable Energy Focused Systems

By optimizing microgrid systems, particularly through the use of genetic algorithms, a move can be made away from dirty and scarce sources of fuel and towards clean and renewable energy resources. Presently, the generation of electricity accounts for 41% of all carbon dioxide emissions [8]. Microgrids functioning on renewable energy cannot only aid in reducing this number significantly by moving away from fossil fuels and other fuels responsible for carbon dioxide emissions, but it can also aid in reducing power lost in large centralized power grids where power can be lost between the power plant and the end-user. By taking on more of the local energy demand through the use of distributed energy resources such as solar or wind energy, dependency on inefficient infrastructure can be reduced [1].

Genetic Algorithm and Microgrids Over Classical Optimization

Although the energy crisis confronting modern society does not have one solution that perfectly resolves the situation, microgrids optimized to their fullest extent are a serious consideration that can have a lasting impact into the future. While others may focus on producing more energy, it can clearly be seen that how energy is carried, where it is carried to and from, and how we produce energy are far more important questions that need to be addressed. In this particular case, microgrids provide an efficient answer to these questions because it reduces the distance energy is transported, stores and draws power close to where it is used, and creates power through renewable resources that not only have minimal environmental impact, but also are relatively stable over the long term [1]. And even though microgrids to have their downsides, in that they can be relatively unpredictable when powered exclusively by photovoltaic and wind-powered generators, by implementing battery storage systems and using genetic algorithm-based optimization of these systems, microgrids can be a major component in the answer to resolving energy inefficiency and availability issues today and in the future.

POWERING THE FUTURE

As society moves further into the twenty-first century, how it consumes, produces, and stores energy is constantly under evaluation. And in this evaluation, the need for localized, efficient, and green power grids is becoming a larger problem that needs to be addressed. Through the use of microgrid systems and battery storage technology, all three of those criteria can be met. And by continuing to improve on that system with genetic algorithm-based optimization that would account for variations across the globe, microgrids can become a viable power grid infrastructure solution in the near future. As a future engineer, and even as an ordinary person, how society moves forward addressing cleaner and more efficient power systems is of critical importance. The sooner that the restructuring of the old and outdated power grid can be done, the smoother the transition into a more sustainable power grid that can provide a sustainable and stable future. Since almost every facet of everyday life is dependent on a stable, secure, and steady source of power generation and distribution, the power grid needs to be up to date. Each generation is faced with opportunities to reform the technological landscape and implement new and innovate systems to better the world and break down the barriers impeding advancement into the future. One of the most fundamental tools for any advancement is having a power grid capable of sustaining those connected to it. And with microgrid technology, implemented in an efficient manner with the help of genetic algorithms, this can be achieved.

REFERENCES


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