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A Portable Educational Model for an Energy Management System of Duke Energy

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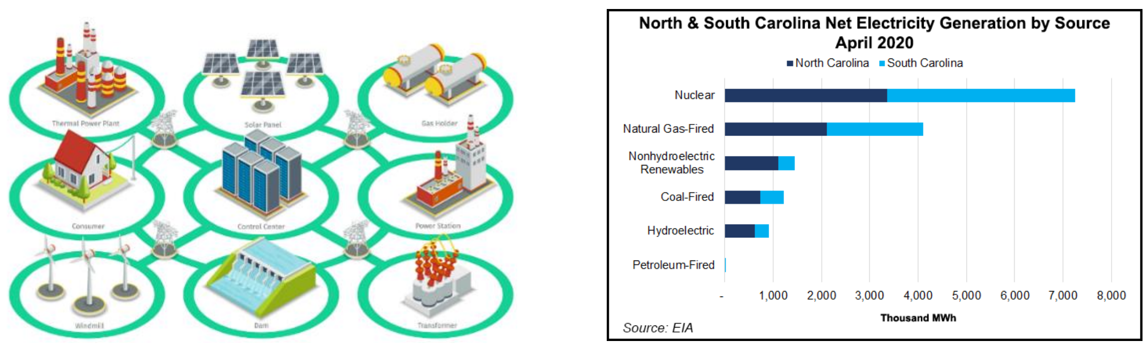
Introduction

Duke Energy, the largest energy company in North Carolina (NC), is a publicly listed firm specializing in energy holdings. The company's electric utilities provide services to 8.4 million consumers across North Carolina, South Carolina, Florida, Indiana, Ohio, and Kentucky. In addition, they collectively own an energy capacity of around 54,800 megawatts [1-4]. The corporation offers energy generating, transmission, and distribution services to its industrial, commercial, and residential clients. Duke Energy operates different types of power generation facilities, consisting of 27 hydroelectric plants, 11 coal-fired plants, 6 nuclear power plants, 32 natural gas facilities, 31 solar farms, 2 pumped storage facilities, 8 battery sites, 1 microgrid, and 2 fuel oil facilities [5], as shown in Figure 1a,b [6]. Each generation facility plays a vital role in Duke Energy's objectives and goals to deliver environmentally friendly, dependable, and cost-effective energy within its' designated service area.



(a) (b)

Figure 1 (a) Illustration of Duke Energy's electricity generation methods. (b) North and South Carolina net energy generation by source

In a recently released report, Duke Energy has indicated that numerous significant changes to the energy landscape will have an impact on its future expansion plan over the next ten years [3-4], including:

- Anticipated large increase in demand and reserve capacity, as NC is undergoing rapid expansion, they are attracting not only residential consumers but also major industrial and commercial enterprises, which necessitates a more environmentally friendly generation mix for them to relocate or remain in NC.
- Cleaner energy sources than coal power plants have to be used due to the policy of regulatory environment.
- The incentives offered by the Inflation Reduction Act (IRA) of 2022 and the Infrastructure Investment and Jobs Act (IIJA) for customers to use solar energy and electric vehicles, require

more energy to be generated and follow a different load curve behavior than the traditional ones.

Therefore, the retiring coal capacity must be substituted with equally reliable resources to preserve and improve reliability before baseload generation ceases operation [7]. Among these resources are renewable energy resources (RES), which are mostly solar, wind, and hydro, which will help reduce the dependence on fossil fuels, lower the carbon footprint, and diversify the energy mix.

Further, one significant challenge that Duke Energy faces is ensuring a dependable power supply. This is because solar power, which is only generated during the daytime and is heavily influenced by weather conditions and shading, does not align with the continuous and reliable power supply needed to meet electricity demand. Duke Energy might address this problem by implementing a pumped storage approach, which involves pumping water from a lower reservoir to an upper reservoir throughout the day using excess energy from the grid. Then, during times of energy shortage from the grid, the stored water in the reservoirs can be used to spin turbines and generate electricity. These facilities are highly valuable to a system operator since they offer flexibility to an otherwise inflexible system.

Given the challenges confronting Duke Energy, it is critical to gain public support and prioritize efforts to educate the public about the operation of the power system. By educating the public, the grid will have customers who have a better grasp of the system and are more likely to offer vital help to Duke Energy when it is needed. Furthermore, Duke Energy seeks to motivate and encourage talented young people to pursue careers with the company, recognizing that enthusiastic young professionals will play an important role in meeting the growing demand for energy utilities, particularly as ambitious clean energy initiatives are implemented.

Therefore, as part of their effort to educate the public about the electric grid, Duke Energy partnered with the College of Engineering and Technology at Western Carolina University (WCU) to develop an educational tool. This tool is a portable model that visually represents the daily Winter load curves for seven distinct sources of power delivered by Duke Energy, together with the functioning of the pumped storage system (PSS). A total of eighteen synchronized videos were produced to demonstrate how the producing station efficiently fulfills the daily energy requirements of a certain metropolis area, taking into account the fluctuating weather conditions.

The subsequent sections of the article are structured in the following manner: Section 2 provides a systematic approach for creating models of the daily load curves representing Duke Energy's overall power generation; Section 3 explores the sequential process of designing digital displays for daily load curves; the paper is concluded in Section 4, which also provides suggestions for future directions.

Modeling of the Daily Load Curves for Duke Energy's total power production

One of the project's objectives is to aid the public in comprehending how the generation responds to changes in load and the difficulties involved in aligning demand with generation. Therefore, Duke Energy needed a graphical depiction of each component of their system to facilitate the conversation and presentation of how their power-producing facilities respond to changes in demand. Consequently, it was necessary to employ an Area Control Error (ACE) curve to accurately depict the whole electrical demand and supply at any given moment within a twenty-four-hour timeframe. ACE is a quantitative measure that calculates the discrepancy between power generation and power consumption, and it is required by every system operator to uphold a minimum ACE to prevent excessive strain on adjacent system operators. In addition to these graphs, a graph was required to illustrate the generation of all six types of generation as well as the Bad Creek Pumped Hydro facility. The Bad Creek graph was unique due to its inclusion of both positive and negative load generation. Another stipulation for these graphs was to display data continually throughout the entire day. One of the panels featured a digital clock that displayed the time in a twenty-four-hour format. The graphs required to be synchronized with this clock. By displaying these graphs, a presenter can effectively direct the audience's focus on the system's fluctuations throughout the day in response to changes in demand. The graph generated for this project was to replicate the actual load demand and generation statistics provided by Duke Energy. To accomplish this objective, it is necessary to create a daily load curve that includes the generation reaction to load fluctuations. This curve should then be visually displayed in a slow-motion animation lasting 5 minutes. As a result, the decision was made to use MATLAB to implement random generation with real load data. The selection of MATLAB was based on its outstanding matrix capabilities and the superior quality and user-friendly nature of its plotting tool. Matrices were utilized to store the data for the graphs, and a dynamic plotting function was necessary to exhibit the graphs. A MATLAB code was created to produce the daily power generation response to load changes, as shown in Figure 3.

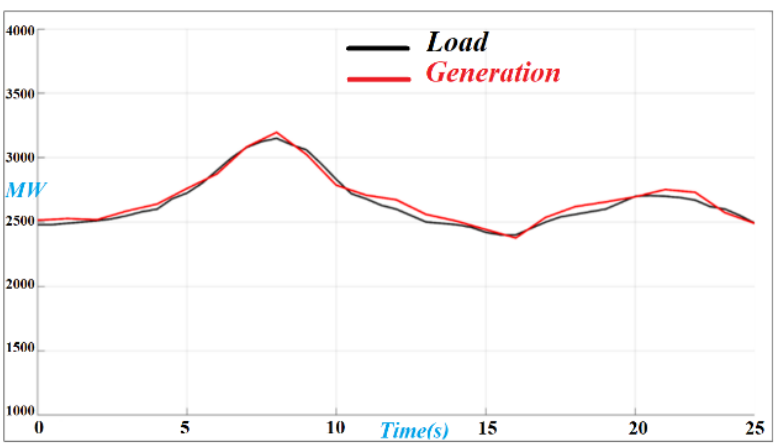
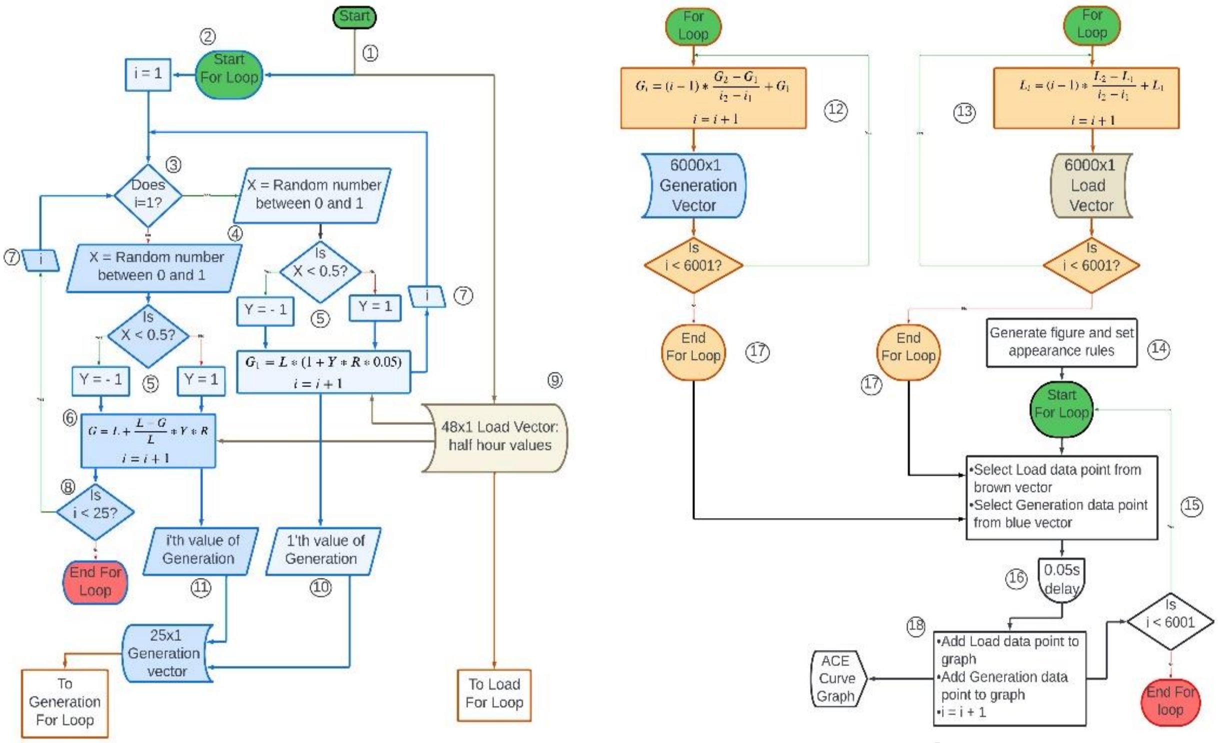


Figure 3. Load curve for the Duke Energy Grid Model.

To do this, two matrices of size 1x48 were created to contain load and generation values for each half-hour interval. The load figures were preselected to correspond with a typical load profile for a winter day. A stochastic number generator, with customizable parameters for allowable variance, was used to generate data points that correlated with the load values but did not exactly match, as this accurately reflects the operational characteristics of an actual power system. The matrices were organized to accommodate 6000 values, with a gap of 124 points between each data point. The intermediate values were constructed by using an algorithm that generates points along a line segment, using the original data points as the starting and ending values. When 6000 points are utilized, the graphs exhibit a seamless plot. A comprehensive explanation of it can be found in the flowcharts seen in figures 4a,b.



(a) (b)

Figure 4. ACE curve flow diagram part (a) data creating script (b) graph creating script.

Design of Digital Displays for Daily Load Curves

An Energy Management System (EMS) is necessary to aid the network operator in monitoring, controlling, and optimizing energy networks and it is a key element of the network control room. The primary functions of EMS include monitoring network power flows and voltages, forecasting demand and generation, and dispatching and controlling generation. Additionally, EMS is responsible for coordinating network protective systems, network restoration following fault incidents, enhancing network efficiency, and maximizing the use of network resources.

As one of the main goals of the paper is to provide a portable demonstration of EMS to visually demonstrate how Duke Energy's facilities adapt to the fluctuations in the city's energy daily demand. Eighteen synchronized videos were produced to capture the daily load fluctuations of various power-producing facilities and demonstrate the functioning of the PSS utilized by the Bad Creek hydroelectric power plant. The videos were created with a 5-minute time lapse. The time lapses were designed to act as a focal point for the presenters, enabling them to highlight slight variations in the city's electricity demand that would necessitate the activation or deactivation of power-producing facilities or employing the PSS. The subsections below cover the video gathering, editing, and combining procedure.

The Selection of Recording Tools and Software

- **GoPro Camera:** the system was initialized by generating an onboard time-lapse by compiling a series of pictures captured over a specific duration. The chosen camera should possess portability and lightness, waterproof capabilities, and image stabilization that provides exceptional digital stabilization which was done using the GoPro camera [11].
- **Davinci Resolve 18.1:** Once the camera was selected and the footage was captured, it became essential to edit the recorded content. The decision was made to designate Davinci Resolve 18.1 as the primary program for video editing. Davinci is a free software that offers a wide range of online tutorials and is relatively user-friendly. [12].
- **Open Broadcaster Software (OBS):** After completing the video editing, it was necessary to generate load curves using MATLAB that would align with the timelapse video and incorporate data from Duke Energy. Once the task was finished, a total of eight distinct load curves were generated and subsequently documented for the purpose of being superimposed into the final videos. Open Broadcaster Software (OBS) is a freely downloadable software [13].
- **HTML Script and Intel Graphics Command Center:** Upon completion of the video editing process, multiple instances of the software were launched using VLC media player and synchronized into a single instance. This allowed for a single pause/play button and scrubbing bar. Nevertheless, this approach proved ineffective in achieving synchronization for all the videos, prompting the implementation of an HTML script as a solution to this issue. The script was utilized to develop a webpage that operates independently without depending on Wi-Fi network connection or any external connections. Nevertheless, an additional obstacle arose during the project's implementation, as the sponsor requested the use of three distinct rows of videos to provide clear explanations of different aspects of the project to the audience. The problem was rectified by utilizing the Intel Graphics Command Center (IGCC), which enables the computer to configure its GPU to recognize the three monitors as a cohesive and expansive display [14,15].

Process of Video Capturing

The flowchart depicted in Figure 5a provides a thorough explanation of the process of video editing capturing. During the video editing process, it was determined that the original Bad Creek video would require 10 minutes, rather than 5 minutes, to generate a 24-hour video. Initially perceived as a significant problem, it was promptly discovered that the playing speed in Davinci can be increased, resulting in a reduction of a 10-minute video to a 5-minute duration. Consequently, the GoPro settings were modified to address this problem. Once all the time lapses and video editing had been completed, the process of capturing load curves commenced. An issue occurred in MATLAB when attempting to capture all load curves due to discrepancies between them. Attempts to troubleshoot the code were not fruitful. To minimize the effects of corrupted content, the playback speed of the recorded recordings in various portions can be modified.

Once all the videos were assembled into the three main ones, VLC media player was used to play them. However, VLC was unable to play multiple instances of the software in synchronization, with only one pause/play button and a video scrubbing bar. Consequently, an HTML script was programmed to create a simulated website that can access files stored on the user's computer and play them in specific locations on the screen as designated by the user. To ensure that the HTML script can be created to display all three videos separately when in full-screen mode, all three displays must be recognized as a single entity. The Intel Graphics Command Center was then installed on the PC to treat the three individual displays as a unified singular display. By using an HTML script, all the videos could be synchronized and displayed in full-screen mode.

HTML Script

The primary HTML script for video editing capturing is explained in the flowchart depicted in Figure 6. The HTML script exhibited the three videos and facilitated their synchronization with a single pause/play button and scrubbing bar. The script imports three files located in the same directory as the script. The script invokes the execution of three videos in a Microsoft Edge browser and then presents them at a location provided by the user. Subsequently, it was ultimately fine-tuned and performed in its entirety. Most of the script involves assigning identical play/pause and scrubbing bar functionalities to the three videos and positioning them at the top of the screen. Figure 7 displays a graphic depiction of the completed functional model, highlighting its compact size, mobility, and user-friendly design. The model has three screen that emphasize the following:

- The top screen displays the current weather conditions in the city together with a graph showing the variation in electricity use due to weather fluctuations.
- The middle screen displays the Bad Creek Hydro power plant's response to the city's weather conditions, including power generation and the operation of the pumped storage system.
- The bottom screen displays the response of the six power producing facilities to fulfill the requirements of the base load, peak load, and daily fluctuations.

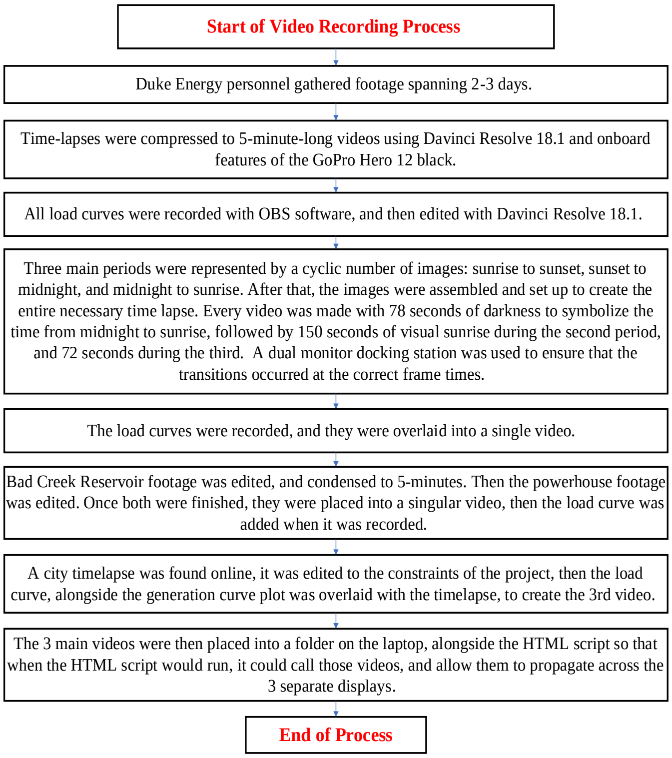


Figure 5. Flowchart describing the process for recording the videos.

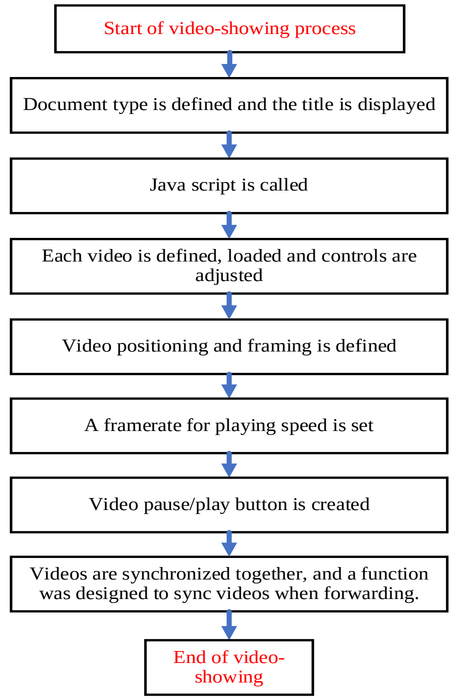


Figure 6. Flowchart describing the process for the HTML script

Figure 7. The portable energy management system

Conclusion

The biggest energy company in North Carolina, Duke Energy, is facing several challenges because of the major changes in the energy landscape resulting from the retiring coal capacity that must be replaced with equally dependable resources to preserve or increase dependability before baseload generation stops operation. Consequently, it is imperative to gain public support and give top priority to educating the people about the operation of the electricity system. Public education will allow the grid to have consumers who understand the system better and are more inclined to provide Duke Energy with necessary crucial assistance when it is needed. Moreover, Duke Energy aims to inspire and support talented young people to work for the company since it understands that driven young professionals will be crucial in fulfilling the increasing demand for energy utilities, especially in view of ambitious clean energy projects.

Therefore, to inform the public about the electric grid, Duke Energy collaborate with the College of Engineering and Technology at Western Carolina University to create a portable educational tool to visually present the response of its different power generation facilities to fulfill the daily energy requirements of a certain metropolis area, considering the changing weather conditions. The model is used to play and synchronize eighteen videos made from real-time data and MATLAB code, which are played for five minutes using an HTML script. All the videos can be played with a single plug-and-play button. Comprehensive flowcharts outlining each design process are available, along with a visual representation of the finished functional model. The model includes case studies and simulations that engineers may use to assure reliable grid integration of conventional and renewable energy sources while also providing an accessible presentation to the public.

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