Impact Study Of Thunderstorms On The US Power Grid Using Publicly Available Dataset

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***Abstract*—This work analyzes the impact of thunderstorms on the US power grid based on publicly available data. Since thunderstorms can bring lightning, heavy precipitation, and wind storm, analyzing their impact on the power system provides a combined correlation of lightning strikes, floods, and wind storms on power outages. This paper leverages publicly available thunderstorm datasets from the National Weather Service (NWS) and power outage datasets from Oak Ridge National Laboratory's Environment for Analysis of Geo-Located Energy Information (EAGLE-I) to study the correlation between thunderstorms and power outages. This work is analyzing the patterns of thunderstorms from 2007-2022 which shows that the thunderstorms are not slowing down and seem to continue their impact on human life in the future. This work is also analyzing the monthly and yearly pattern of the impact of thunderstorms on power systems at the country, state, and county level.**

***Index Terms*—EAGLE-I, NWS, power outage, thunderstorm**

I. Introduction

Impacts of weather events on the US power grid have been increasing in the last decade, resulting in human suffering and detrimental economic impacts. Adverse weather is the cause of roughly half of all power outage events and of more than 80% of all customer outages [1]. Among several severe weather event types (e.g. tropical cyclone, winter storm, thunderstorm, heat waves, cold waves, etc.), thunderstorms alone are responsible for 47% of weather related events, and are attributed to more than 35% of weather related customer outages. Thunderstorm can bring lightning, heavy precipitation, and wind storm. Lightning can ignite lightning strike on several power system equipment ranging from electrical home appliance to larger distribution and transmission system equipment. Heavy precipitation can cause flooding, impacting power plant, distribution system, power generation plants, and transmission system. Similarly, windstorm may causes trees to fall on the power line resulting damage of the power system infrastructure and disrupting the power supply. The impacts are exacerbating as the number of thunderstorm and resulting lightning strike, flooding, and wind storm are increasing over years due to climate change. Therefore, the detail impact analysis of thunderstorm on power system is crucial.

The major power outage events are causing billions of dollar of monetary loss every year (18 to 33 billion dollar loss [2]; 25 to 70 billions dollar loss [3]) to the US economy, their analysis and developing mitigating measure is important. To analyze the impact of the major events, the US Department of Energy (DOE) collect power outage data for major power system events [4]. DOE mandates the utility companies in the United States to submit major major power outage information which DOE publishes on OE-417 report. The major events have been defined as events that cause power outage to more than 50,00 customers or more than 300 MW power demand disruption.

Using DOE's major power outage information several analysis have been documented in the literature to study the impact of the weather events on power system. For example, authors in [1] studied the impact of these events in the power delivery of the United States. The impact of major events in terms of number of customer affected , duration of outages, and cost of outage has been studied by combining the OE-417 data with 35 electric utilities dataset in [1]. Seasonal patter of power outages has been analyzed in [5] in which seasonal pattern in frequency of blackout was observed to correlate with the frequency of the storms. For example, more storms frequencies in the summer and mid-winter months were seeing more frequency of the outages during these months. Although, these events analysis are provide great information in bigger picture, they are missing several granular analysis that are important and significant in the local level. In the country level, the major power outage event-based outage filtering threshold makes sense, however, it overlooks many important events that are less than the threshold. These events may not be of significant when we analyze them individually as compare to national scale (above threshold) event, however, many such events in the county level add upto significant number. Additionally, impact of each individual event is of big significant in the county and the state level demography.

Recent work [6] have leveraged the publicly available EAGLE-I power outage dataset to study the impact of the weather events on the power system. However, work presented in [6] does not explicitly performs analysis on the cause of the specific event types (e.g. hurricane, windstorm, thunderstorm, etc.). Information about the weather events type helps for better power system planning as different planning strategies may be required to tackle with different event types. Authors in [7] use the power outage dataset from poweroutage.us which are not freely available. Also, authors in [7] do not perform the specific impact analysis of thunderstorm in the county and state level.

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To address these challenges, this work analyze the impact of one of the major power outage causing weather event:thunderstorm in the country, county, and state level. In this work, we leveraged the publicly available thunderstorm dataset obtained from the National Weather Service (NWS) and power outage dataset obtained from Oak Ridge National Laboratory (ORNL)'s Environment for Geo-Located Energy Information (EAGLE-I) to study the correlation of the thunderstorm and the power outages. We have also perform the yearly and seasonal pattern analysis of the frequency of the thunderstorm events and the power outages due to the thunderstorm events. Furthermore, this work also analyzes the power outages that last more than 1 hour and outages that last more than 8 hours (medically significant power outages events [7]).

Rest of the paper is organized as follows. Section II explain and preprocess the thunderstorm detest obtained from the NWS, explains and preprocess the historical power outage dataset obtained from EAGLE-I, and observes the trends in the dataset. Section III provides the results of impact of thunderstorm on power outages. Finally concluding remarks are provided in Section IV.

II. Data Processing and Trend

A. Thunderstorm Data

1) Thunderstorm Data Source: Thunderstorm datasets are obtained from National Weather Service (NWS). NWS, a part of National Oceanic and Atmospheric Administration (NOAA), is a federal agency of the United States [1]. NWS is responsible for providing information about weather, water, climate data, warning, advisory, historic, forecast, and impact-based decision support system to protect the human life and enhance the US economy. To be more specific on the data source, we used NWS Valid Extend Code (VTEC) archieves dataset processed by Iowa State University Iowa Environmental Mesonet (IEM). This dataset contains information about the geography and life cycle of weather events that occur in the United States, which include watches, warnings, advisories, and others. VTEC's metadata are publicly available in the Shapefile and Keyhole Markup Language (KML) formats. VTEC datasets are updated daily at 2:00 a.m. Central time. The severe thunderstorm dataset in VTEC achieve are denoted by two-character phenomena code "SV". Please refer to IEM VTEC achieve website for further details on the data [2].

Table I provides a sample of preprocessed Thunderstorm dataset. We preprocessed the dataset by filtering in only the thunderstorm dataset leaving behind other type of phenomenon, as shown in column "PHENOM" with two letter code "SV". We have also converted polygon to county which is useful to perform the analysis at the county level. We also combined ISSUED, EXPIRED, PHENOM, SIG, County, and STATE to create identical events ID for each events at county level. Since we are looking into the county level granularity, same thunderstorm event occurring at the same time in multiple county will be counted as multiple thunderstorm events. Note that "W" and "Y", in the SIG column denote warning and advisory, respectively. Since "W" and "Y" are the most impactful events, we are filtering only the "W" and "Y" type SV events for our analysis.

2) Thunderstorm Trend: To analyze the number of thunderstorms change over year, we have plotted the thunderstorm data from 2007 to 2022 in the country level as shown in Fig. 1. This figure shows the number of thunderstorm cases are changing over time and they are not decreasing. This trend shows that thunderstorms events will keep impacting the human life (including the power system) in the future. Fig. 2 shows the number of thunderstorm case by state. This figure shows that Texas sees most thunderstorm events followed by Oklahoma, and Kansas. Overall, United State south seems to be more prone to thunderstorm events.

Month wise trend of the thunderstorm are as shown in Fig. 3. This figure shows that the most number of thunderstorm

[1]https://www.weather.gov/

[2]https://mesonet.agron.iastate.edu/info/datasets

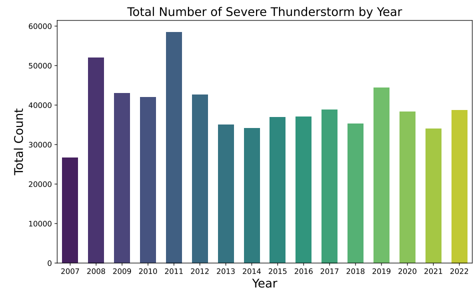

Fig. 1. Number of Severe Thunderstorm change per year in USA from 2007-2022.

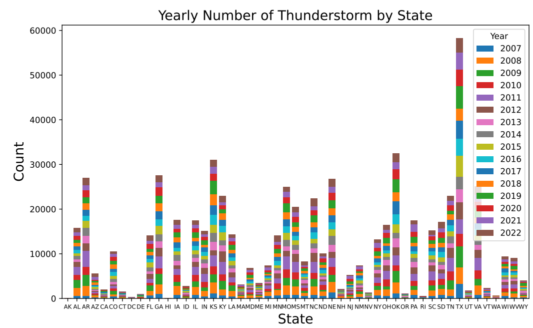

Fig. 2. Number of Severe Thunderstorm change per year in various USA states from 2007-2022.

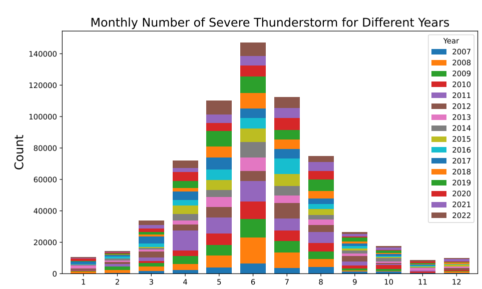

Fig. 3. Number of Severe Thunderstorm change by months in USA from 2007-2022.

TABLE I
SAMPLES OF THE PREPROCESSED NWS VTEC THUNDERSTORM DATASET

EVENT_ID	ISSUED	EXPIRED	FIPS	SIG	PHENOM	COUNTY	STATE	YEAR	DURATION
201801080347-201801080405-SV-W-Waller-TX	1/8/2018 3:47	1/8/2018 4:05	48473	W	SV	Waller,TX	TX	2018	0 days 00:18:00
201801122029-201801122100-SV-W-Appomattox-VA	1/12/2018 20:29	1/12/2018 21:00	51011	W	SV	Appomattox,VA	VA	2018	0 days 00:31:00
201801122029-201801122100-SV-W-Buckingham-VA	1/12/2018 20:29	1/12/2018 21:00	51029	W	SV	Buckingham,VA	VA	2018	0 days 00:31:00
201801122029-201801122100-SV-W-Campbell-VA	1/12/2018 20:29	1/12/2018 21:00	51031	W	SV	Campbell,VA	VA	2018	0 days 00:31:00
201801122249-201801122345-SV-W-Jefferson-WV	1/12/2018 22:49	1/12/2018 23:45	54037	W	SV	Jefferson,WV	WV	2018	0 days 00:56:00
201801122249-201801122345-SV-W-Washington-MD	1/12/2018 22:49	1/12/2018 23:45	24043	W	SV	Washington,MD	MD	2018	0 days 00:56:00

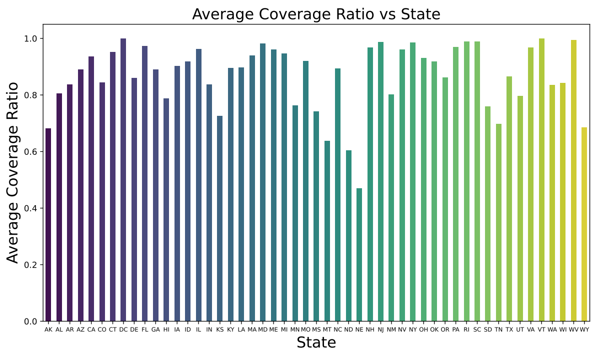

Fig. 4. Average Coverage Ratio (of coverage ratio between 2018-2022) for Different States

cases are seen in June followed by May, July, and August. The least number of thunderstorm cases are in February followed by January, and November. Overall summer months are seeing significantly more thunderstorm cases than winter months, seeking for more attention in summer to safeguard human life and infrastructures. Note that the higher power demand and higher number of thunderstorms in summer months may exacerbate the human suffering.

B. Power Outage Data

1) Data Source (EAGLE-I Data): In this work, we leveraged the publicly available power outage data for the US obtained from ORNL's EAGLE-I platform [3]. EAGLE-I is an interactive geographic information system that allows the user to view and map the nation's energy infrastructure and obtain near real-time information updates concerning the electric, petroleum and natural gas sectors withiin one visualization platform. EAGLE-I platform has been collecting the county level power outage datasets of the US power grid from 2014. EAGLE-I dataset are available for academic research.

EAGLE-I datasets are collected based on the voluntary participation of the utilities companies in the United States. The participation of electric utilities has been increasing over years, making it more reliable and useful power outage dataset. Fig. 4 shows the state wide average (of coverage ratio from 2018-2022) coverage ratio. Coverage ratio is the ratio between the total number of electrical customer that share data (through resprective utility) to total number of electrical customers.

2) Power Outage Trend: These outages trend discussed in this section includes all the outages cased by any kind of cause (weather, operation, cyber, etc.), they are mapped with the thunderstorms data in the section below. Fig. 5 shows the

[3]https://eagle-i.doe.gov/

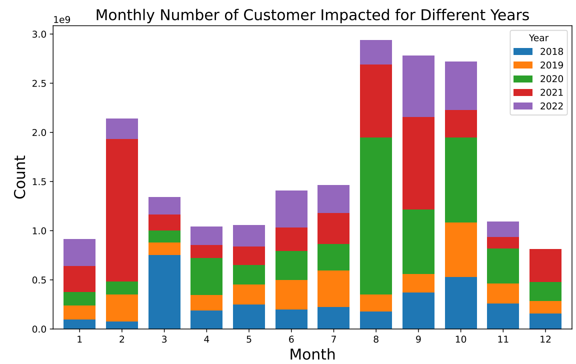

Fig. 5. Number of Customers Impacted Due to Power Outages by months in USA from 2018-2022.

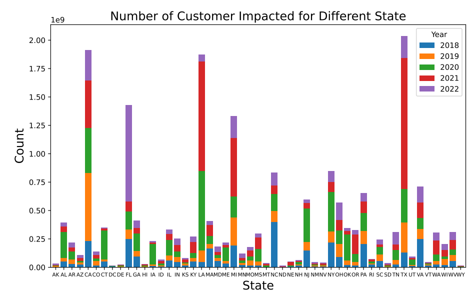

Fig. 6. Number of Customers Impacted Due to Power Outages by State from 2018-2022.

monthly number of customers impacted due to power outages in the US from 2018-2022 (although EAGLE-I started the data collection from 2014, data for some state are not available until 2017, therefore, we are analyzing only 2018-2022 EAGLE-I dataset). This figure shows that maximum number of cumulative power outages occur in the month of August followed by September, and October. The possible reason for this trend of power outage could be due to their coincide with the tropical storms, thunderstorms, heat waves and resulting more demand, and more industry demand due to businesses ramp of after summer breaks (pushing the infrastructure capacity limits towards or above the limit boundary).

Fig. 6 shows the yearly number of customers impacted due to power outages by states in the US from 2018-2022. This figure shows that maximum number of cumulative power outages occur in Texas followed by California and Louisiana. The possible explanation for the maximum number of outages in Texas and California could be due to significant number of weather events, power grid running near to or above its capacity, and being significantly more populous states (more

population means more customers could be impacted).

Although the number of customers impacted by the power outages are changing over year, however, drawing conclusion with these limited data will be premature. Therefore, more data will be required to draw a concrete conclusion.

C. Mapping Thunderstorm and Eagle-I Data

To analyze the impact of thunderstorm on power outages, we mapped the thunderstorm datasets obtained from NWS and EAGLE-I datasets from ORNL using the geographical and temporal information from both sources.

It is common for multiple related weather events to occur simultaneously or in close succession within a region, so instead of analyzing each weather event's impact to power systems, we have first identify groups of weather events that are highly relevant and then assigned the longest weather event in the group as the type for the entire event weather event group. Figure 7 illustrates four weather events from the NWS dataset spanning the timeline in Kent County, Delaware (DE) (FIP 10001), from 2018-05-12 23:25:00 to 2018-05-13 1:30:00.

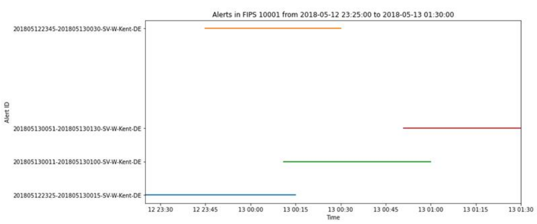

Fig. 7. Visualization of a weather event group composed of four different weather events.

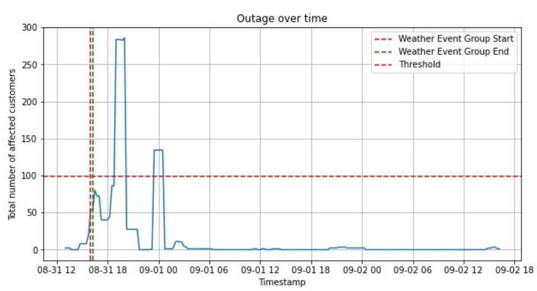

Fig. 8. Power outage pattern from 3 hours before to 48 hours after a weather event group (FIPS=1001 from 2018-05-12 23:25:00 to 2018-05-13 1:30:00).

Figure 8 displays a power outage pattern corresponding to a weather event group consisting of events depicted in Fig. 7. The red vertical line signifies the beginning of the weather event group, while the green vertical line indicates its end. The horizontal dotted line is a threshold to account the outages of more than 0.1% (90th percentile of customer out per hour) of the total customers in a county similar to [7].

Power is restored to the majority of customers within 48 hours after an extreme weather event [8]. Thus, we considered any outages that occurred within the time frame of 3 hours before (to accommodate the uncertainty with NWS data recording, NWS starts to record the data after the alter which could result some uncertainty) to 48 hours after the expiration time of the weather event group to be correlated with the weather event group.

III. Results

In this work, we have performed several case studies to observe the the impact of the thunderstorm on the power outages. We are studying the correlation (if there is a thunderstorm what is a chance of experiencing the power outage) of power outage to the thunderstorm in the country level, state level, and county level. We are also studying the number of outages longer than 1 hours and longer than 8 hours (medically significant) in country, state, and county level.

The analysis of the impact of the power outages due to thunderstorms using the proposed framework are presented as follows.

A. Correlation of Thunderstorm and Power Outage

For this case, we analyzed how many times the power outage occurs when there are thunderstorm. The thunderstorms count is based on the thunderstorm grouping presented in the previous section. In the US, if there is a thunderstorm it is likely to result power outage events 69 percent of the time.

Figure 9 shows the percentage a thunderstorm results power outage events in different state of the US. Figure 10 shows the percentage a thunderstorm results power outage in a county (which has maximum number of thunderstorms) of a state.

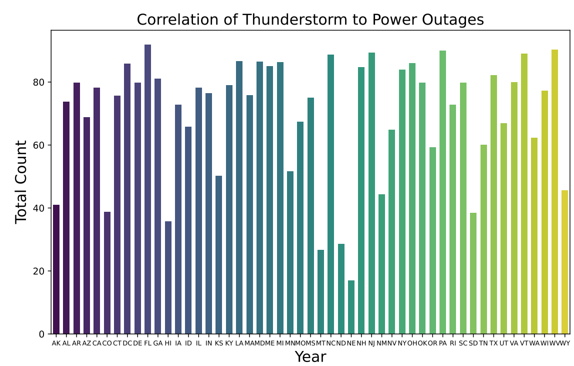

Fig. 9. Thunderstorm and its probability of causing the power outage by each state

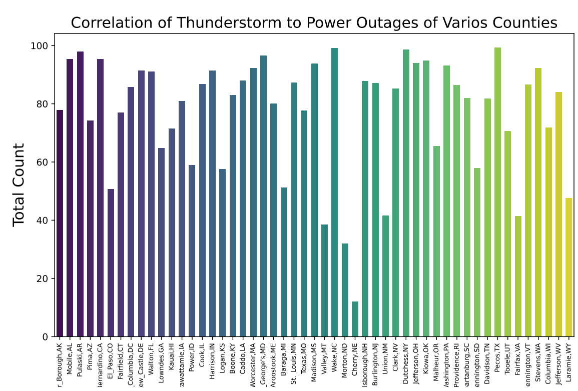

Fig. 10. Thunderstorm and its probability of causing the power outage of Counties

B. Thunderstorms and Outage Duration

Looking into specifics of the thunderstorm and the power outage, there are 226,168 power outage events that are caused by the thunderstorm event groups at county level. There are 169,680 power outage events that are longer than 1 hours which is 75% of the total power outage events. In other words, if thunderstorm event groups that causes power outages its last more than 1 hours 3/4th of the time. There are 34,630 events which are longer than 8 hours (medically significant) which is 15% of the total power outage events due to thunderstorm event groups. In other word, one out of every 7 thunderstorm event groups cause power outages longer than 8 hours (needing medical attention).

State level event analysis are as shown in Fig. 11, and Fig. 12 for power outage events that are longer than 1 hours and longer than 8 hours, respectively. These figures show that power outage in Hawaii are longer than one hour if they are caused by the thunderstorm (Hawaii has experienced a very small number of thunderstorm between 2007-2022 as shown in Fig. 2). The power outage in Michigan are about one third of the time longer than 8 hours while power outage in Rhode Island are more than 8 hours in less than 5 percentage of the time.

The percentage of power outages longer than 8 hours by various counties are as shown in Fig. 13. The county level analysis shows that there are some county in the United state which experience longer than 8 hours if power outage occur due to thunderstorms. Special attention need to be provided in these counties to reduce the impact of thunderstorms on power system.

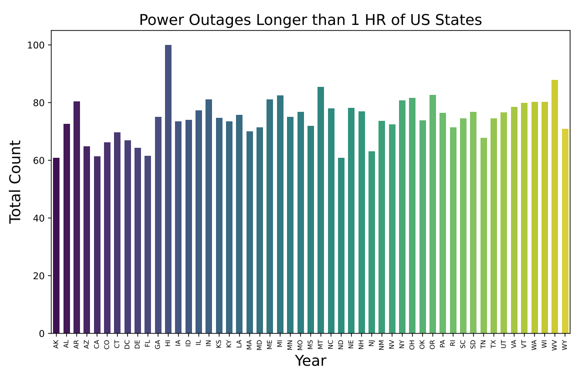

Fig. 11. The percentage of the power outage events which are more than 1 hours at state level

IV. Conclusion

This paper studied the impact of the thunderstorm on the US Power Grid. This work leveraged the publicly available power outage dataset obtained from ORNL's EAGLE-I platform and thunderstorm dataset obtained from NWS's VTEC dataset. We mapped the thunderstorm dataset with the power outage to study the correlation of the power outage to thunderstorm at state and county level. We also studied the thunderstorm and power outage trend by state and season. We also analyzed the number of power outage events that exceed 1 hours and 8 hours at country, state, and county level.

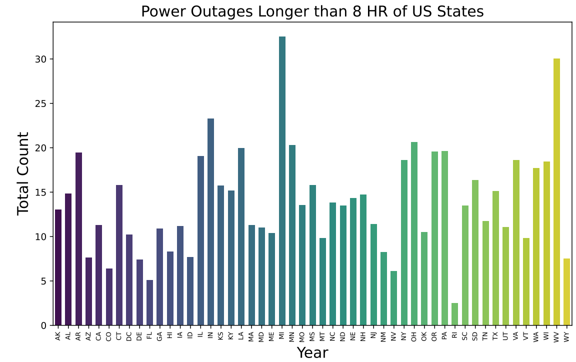

Fig. 12. The percentage of the power outage events which are more than 8 hours at State level

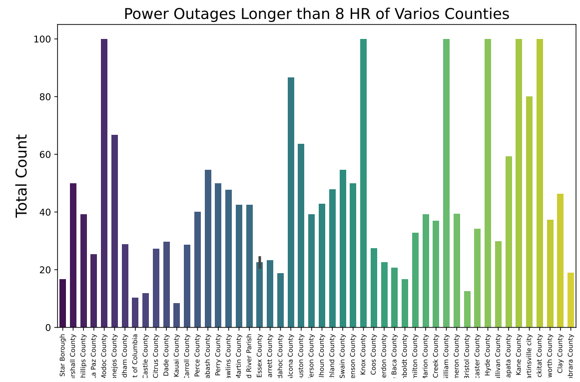

Fig. 13. The percentage of the power outage events which are more than 8 hours for various counties.

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