RELIABILITY FIRST

2023 Transmission Outage Assessment

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REVIEWED BY: Transmission Performance Subcommittee

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Introduction

NERC has identified transmission system outages as a key finding to reliability of the Bulk Electric System (BES) in its State of Reliability Report[1]. Increased frequency and severity of facility outages can lay the groundwork for widespread system events. NERC has tracked and continues to track transmission line and transformer outage metrics on an annual basis. These are used to determine the relative system performance so NERC can identify trends, both positive and negative.

The ReliabilityFirst (RF) Transmission Performance Subcommittee (RF-TPS) initiated the development of this assessment to maintain focus on and perform an annual review of transmission outages. As part of this review, a thorough assessment of the outage cause categories within the RF footprint is included. The intent of the analysis is to develop key findings and recommendations within the RF footprint to improve reliability by reducing the frequency and severity of BES facility outages.

Purpose

The RF-TPS performs a review of the transmission line and transformer outage data reported to NERC under Section 1600 for registered entities in the ReliabilityFirst footprint. The RF-TPS performs a yearly analysis and multiyear trending to:

- Provide trend analysis of transmission outage data and possible root cause identification.
- Form conclusions/recommendations from the analysis to reduce the likelihood of future outages.
- Develop guidance and best practices for industry through technical documents and webinars pertaining to transmission outage trends, conclusions, and recommendations.
- Publish the results to RF's Reliability Committee (RF-RC) and the entities in the RF footprint.

The analysis focuses on the cause of facility outages to identify trends and reduce the number of future events.

Data and Analysis

The outage data used for this analysis was gathered in previous years and analyzed in 2023 with trending data from Jan. 1, 2019, to Dec. 31, 2022.

- The dataset was obtained by ReliabilityFirst from the NERC Transmission Availability Data Analysis System (TADS) 1600 reporting template with defined categories and causes.
- The 2022 TADS data is reviewed quarterly by Regional Coordinators and NERC staff. The 2022 data was compared to data collected since 2019 for trending and analysis.
- While American Transmission Company (ATC) participates in the RF TPS, the data related to ATC facility outages is submitted and evaluated within the MRO footprint.

[1] https://www.nerc.com/pa/RAPA/PA/Performance%20Analysis%20DL/NERC_SOR_2023_Technical_Assessment.pdf

Environmental Factors

Background

Climate change will cause temperatures to continue to rise, frost-free season and growing season will lengthen, precipitation patterns will change, droughts and heatwaves will become more intense, and the frequency, duration, and intensity of hurricanes will increase. Environmental factors are a broad risk category meant to include similar naturally occurring phenomena, such as extreme weather and vegetation related issues. Given its geographic location, the ReliabilityFirst footprint is susceptible to a wide variety of environmental factors.

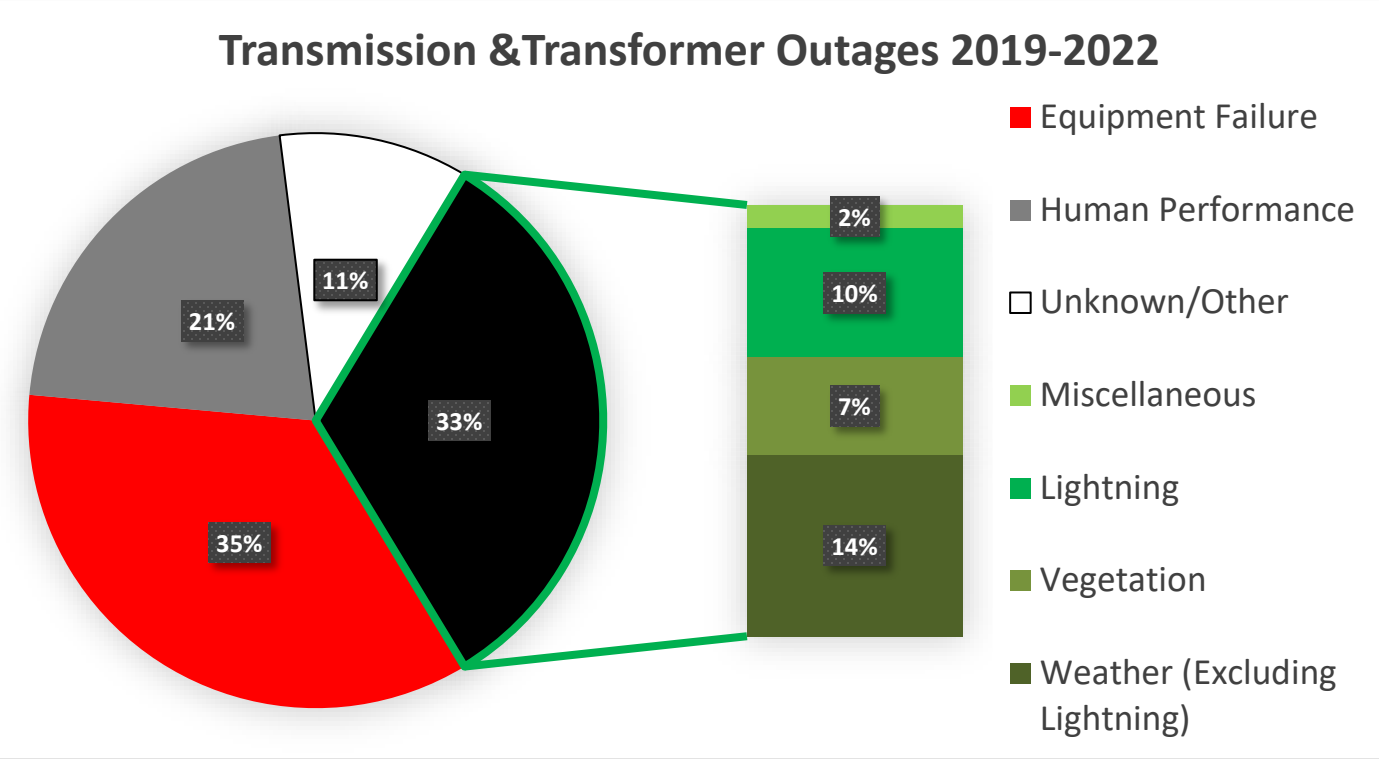


Figure 1: RF Transmission & Transformer Outages

The pie chart above breaks down transmission line and transformer outages into four major categories: equipment failure, human performance, environmental, and unknown/other. To provide more insight, the environmental category (shown in black) has been broken out into additional sub-categories: weather, lightning, vegetation, and miscellaneous. Environmental outages accounted for 33% of the transmission line outages within the RF footprint over the past five years. Note: RF generally has more influence and impact on mitigation activities related to reducing both human performance- and vegetation-caused outages, which comprise only 28% of the total outages experienced from 2019 to 2022.

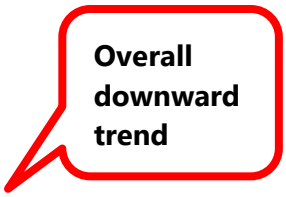
Proportional Impact of Environmental Factors

Year	Proportion of Total TADS-Reported Outages
2019	31%
2020	35%
2021	28%
2022	31%

Although the four-year average for environmental outages stands at 33%, the year-to-year comparison shows a significant decrease in the proportion of environmental-related outages in 2021 before increasing back to the average. This is mainly due to the drop in outages specifically associated with weather (excluding lightning) that year, which will be discussed in further detail later within this section of the report. Comparing this trend to the same data trend related to equipment failures (i.e., Failed AC Circuit Equipment, Failed AC Substation Equipment, and Failed Protection System Equipment) reveals that the proportion of equipment failure outages is higher than the proportion of outages caused by environmental factors, but is showing a decreasing trend.

Proportional Impact of Failed Equipment

Year	Proportion of Total TADS-Reported Outages
2019	38%
2020	32%
2021	36%
2022	35%



Although the four-year average for Equipment Failure outages stands at 35%, the year-to-year comparison shows an overall downward trend in the proportion of equipment failure-related outages. RF will continue to monitor this trend as it is expected to continue due to larger entities within the RF footprint implementing proactive equipment replacement programs.

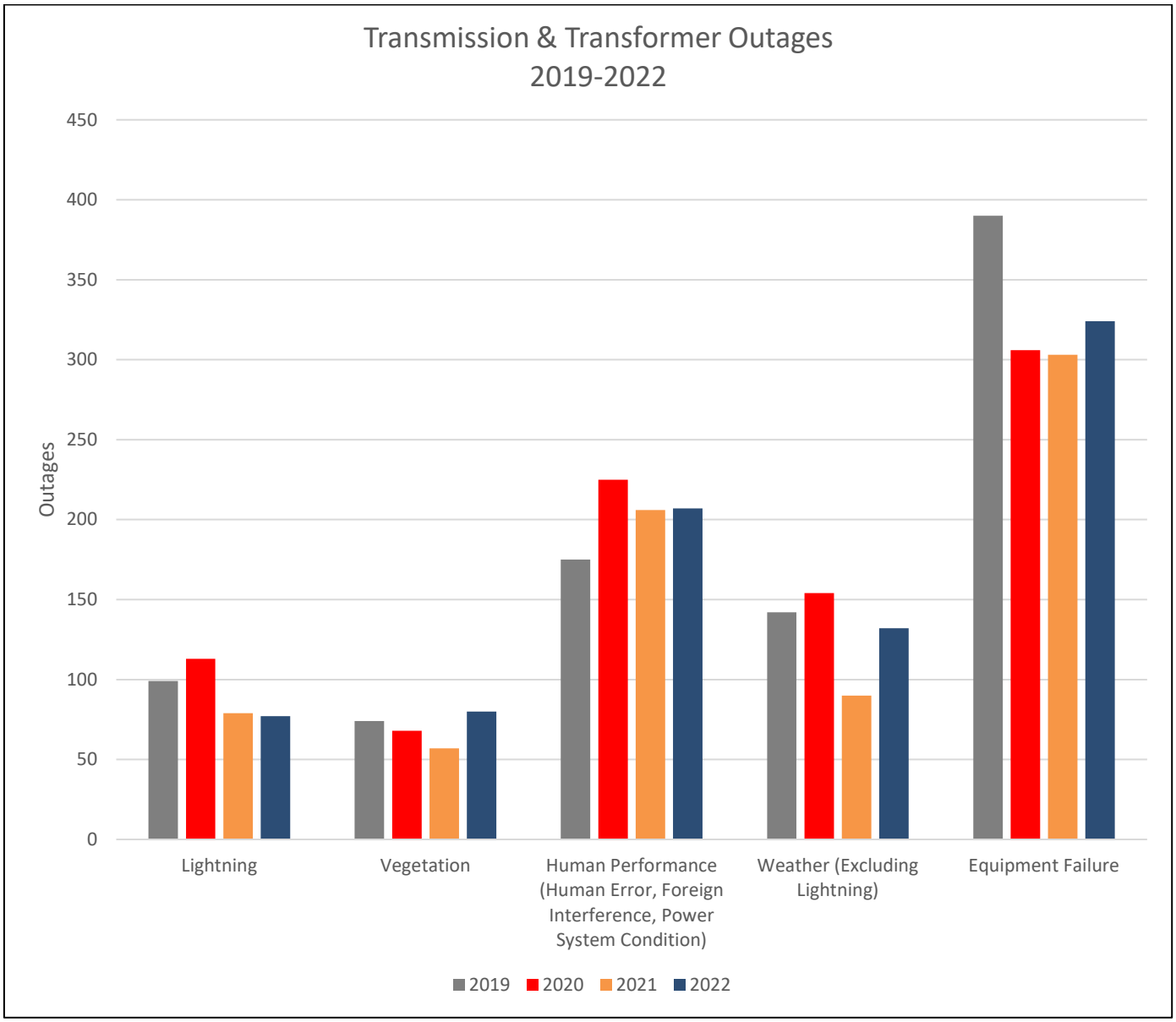


Figure 2: RF Transmission & Transformer Outages

The chart above compares human performance, equipment failures, and environmental induced transmission line outages in the RF footprint from 2019 to 2022. The main environmental-related causes of transmission outages reported in the TADS database include lightning, vegetation contacts, and weather (excluding lightning). As the figure above indicates, the trend for two of these categories shows a decreasing trend (i.e., lightning and weather), with a notable jump in the number of TADS-reported outages due to vegetation.

It should be noted that outages associated with both human error and vegetation contacts are on the rise. RF facilitates a Substation Maintenance/Human Performance Community of Practice and a Vegetation Management Community of Practice in an effort to reduce these types of outages. For equipment failures, RF is exploring methods to help entities proactively identify failure risks related to specific equipment types and manufacturer failure trends.

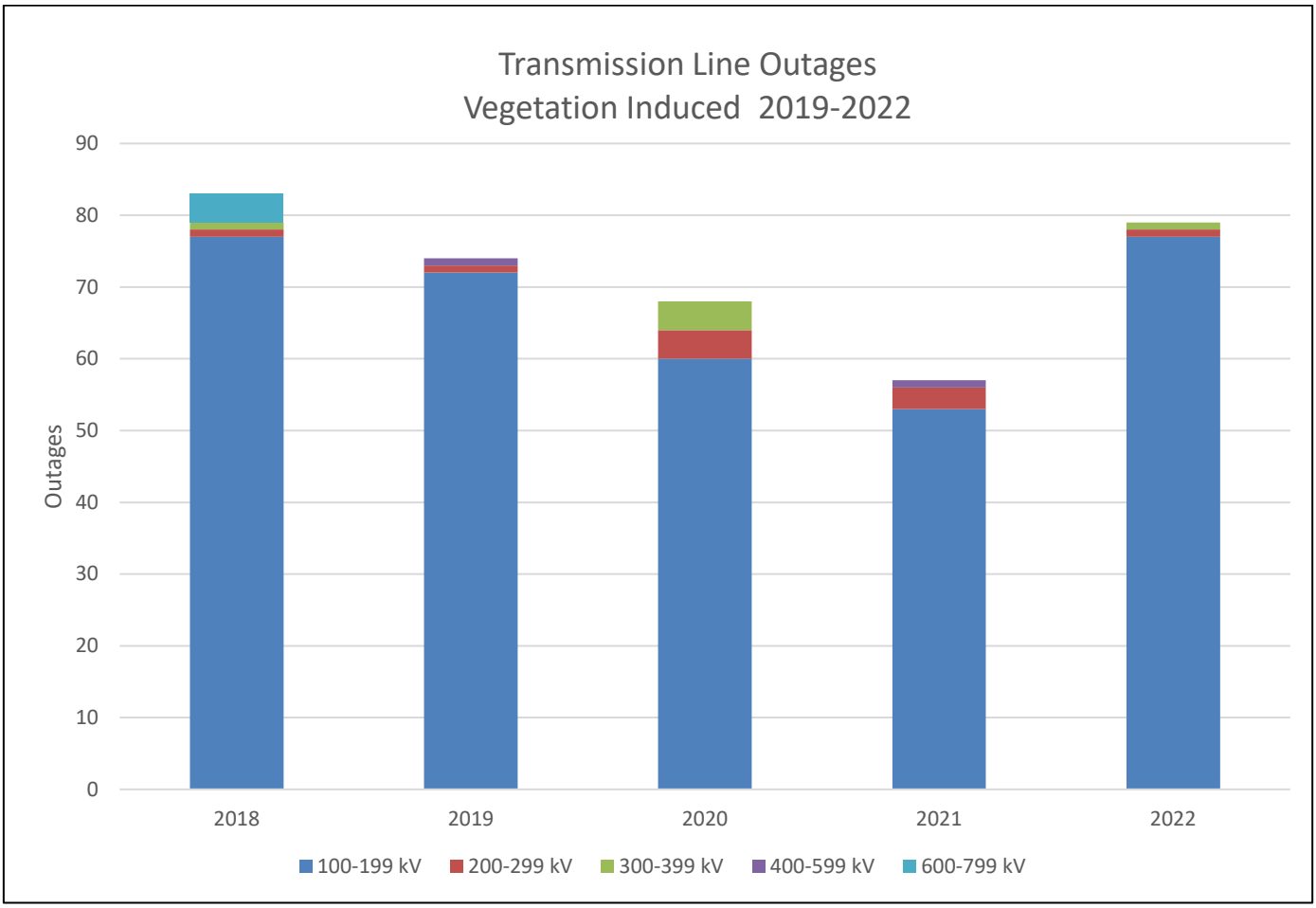


Figure 3: Transmission Outages 2019-2022, Vegetation Induced

There were 278 outages caused by vegetation from 2019 to 2022. Of these, 262 (94%) were outages of 100-199 kV lines, which is a voltage level where vegetation management is not covered by NERC Reliability Standard FAC-003-4. The average height of towers at these voltage levels is much lower, and rights-of-way tend to be narrower and therefore lower voltage transmission can be more susceptible to vegetation growth (or vegetation fall-ins from outside the rights-of-way). NERC and the Regions have raised awareness in various forums and publications during recent years as the vegetation related outages in this voltage class continued to rise. Industry responded and the trend started on a downward trajectory for several years before a sharp uptick in 2022.

Given the low number of vegetation related outages for 200 kV and higher lines, vegetation management covered by NERC Reliability Standard FAC-003-4 (transmission vegetation management) is performing well. However, there is still cause for concern surrounding vegetation management of the 100-199 kV lines even though the outage numbers have trended downward in recent years. Industry focus must be maintained on this segment of the system to ensure that these positive results continue.

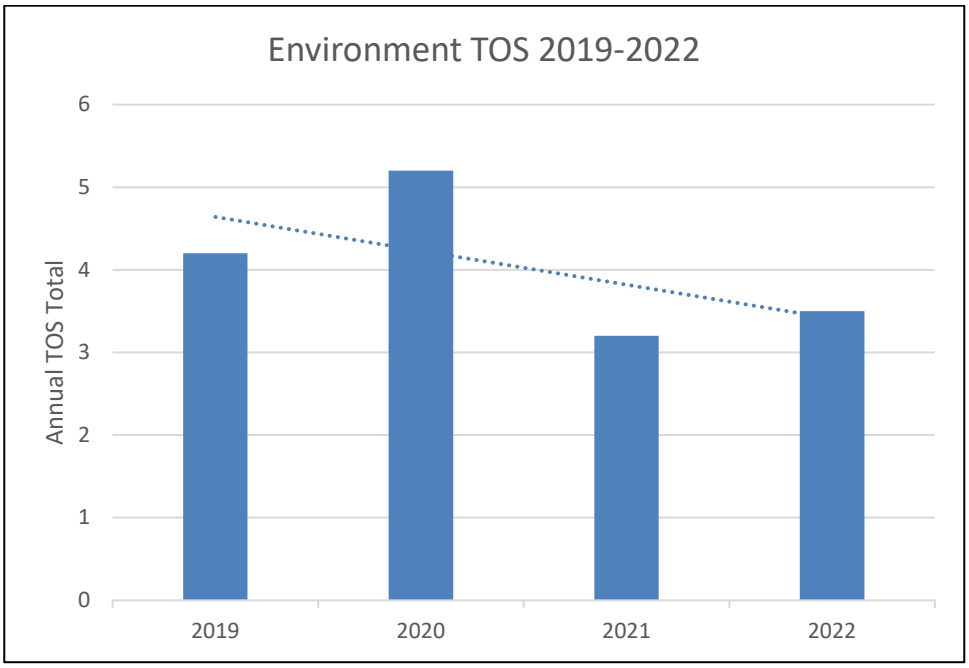


Figure 4: RF Environmental TOS 2019-2022

To measure the impact of transmission outages, a metric called Transmission Outage Severity (TOS) can be utilized. TOS is defined as the number of outages in an event and by the type and voltage class of transmission elements involved in the event. An analysis of the total TOS by year when considering outages caused by environmental factors indicates a decreasing trend for the past four years (see chart above). While environmental-related outages are typically less severe than outages associated with failed equipment, this is an indication that environmental caused outages are leading to less reliability impacts over time.

Event Response/Resilience

Background

ReliabilityFirst defines resilience as: The ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a resilient infrastructure or enterprise depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event. To assess system resilience, ReliabilityFirst examines (1) how frequently outages occur; (2) how long it takes to recover from those outages; and (3) overall system unavailability.

The ERO Enterprise utilizes three metrics to assess the resilience of the transmission system in its footprint. First, to determine how frequently outages occur, the metric, Sustained Outage Frequency ("SOF"), is utilized by dividing the number of sustained outages by the total number of system elements. Essentially, this metric indicates how likely it is that any given element will experience an outage. ReliabilityFirst uses a threshold of 0.10, or 10%, to determine if additional examination is needed for a particular transmission zone in its footprint. Second, to determine how long it takes to recover from outages, the metric Mean Time to Repair ("MTTR"), is utilized by dividing the total sustained outage hours by the number of sustained outages. This metric indicates how long, on average, it takes to recover from any given outage. ReliabilityFirst uses a threshold of 24 hours to determine if additional examination is needed for a particular transmission zone in its footprint. Third, to estimate overall system unavailability, the metric, Sustained Unplanned Outage Percentage ("SUOP"), is utilized by dividing the total sustained outage hours by the total number of possible in-service hours for all system elements. Essentially, this metric indicates the likelihood, at any given time, of a transmission system element being unavailable due to a sustained unplanned outage.

Notably, all these metrics are derived from the TADS database, which only includes data related to unplanned outages. Additionally, TADS categorizes outages into two types: momentary and sustained. Momentary outages last less than one minute as manual or automatic breaker action works to return the outaged facility to service. Sustained outages last longer than one minute, pose a greater threat to reliability, and therefore are used to calculate the various metrics in this report.

The three charts below trend these metrics over the last four years. To gain more insight, these metrics are then broken down further (by registered entity, lines, transformers, and causes).

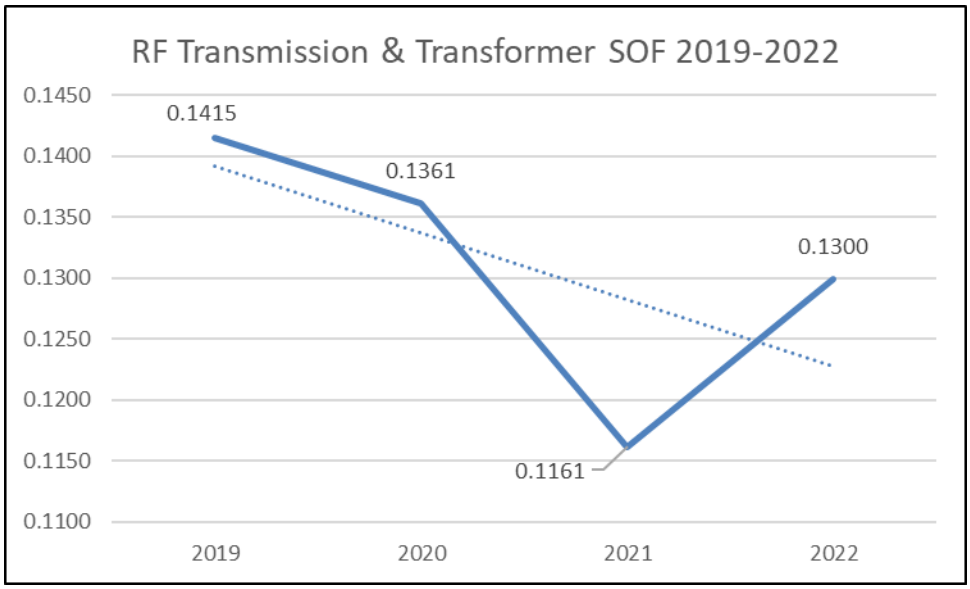


Figure 5: RF Transmission & Transformer SOF 2019-2022

When focusing on Sustained Outage Frequency ("SOF"), the RF footprint has maintained an average SOF of approximately 0.13 over the last four years. This indicates that within the RF footprint about 13% of the BES elements experience an outage every year. In other words, within RF, on average each BES element experiences an outage once every 7.6 years. While the RF SOF is above the 0.10 target, across the ERO Enterprise, RF has the lowest SOF when compared to its peer Regional Entities.

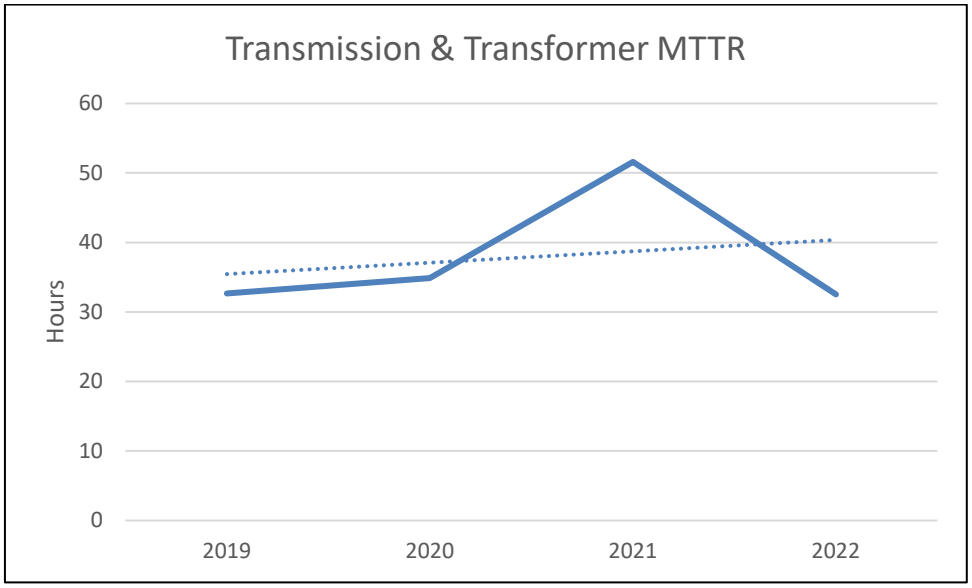


Figure 6: RF Transmission & Transformer MTTR 2019-2022

As shown in Figure 6 above, RF is experiencing a trend in Mean Time to Repair ("MTTR") that has slightly increased over the last four years. Taken together, these first two charts indicate that over the last four years, the RF transmission system is experiencing a decreasing number of outages but their outage time is increasing.

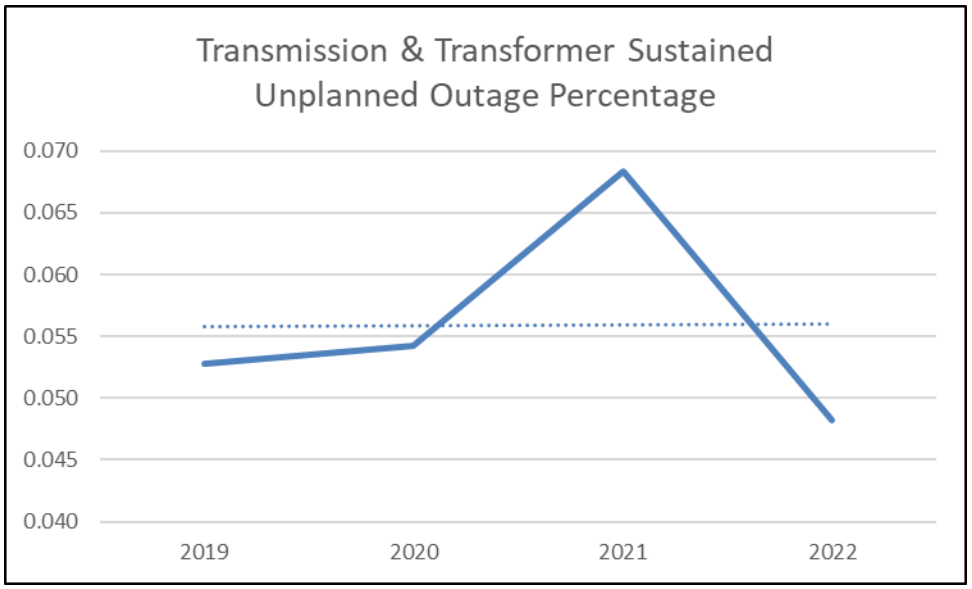


Figure 7: RF Transmission & Transformer SOUP 2019-2022

This conclusion is further supported by the Sustained Unplanned Outage Percentage (SUOP) over the past four years, which shows a flat trend line. This indicates the likelihood of a transmission system element being unavailable, at any given time, due to a sustained unplanned outage. In 2022, the RF SUOP was the lowest when compared to its peer Regional Entities.

We reviewed the SOF for each transmission zone within RF, as listed in the chart below, to see if the details provide some additional insight. Each reporting Transmission Owner is represented by a letter in Figure 8 below. More than half of the transmission zones within the ReliabilityFirst footprint (i.e., 59%) had transmission SOFs above the target level of 0.10. However, it is encouraging that the transmission zones that have the most elements have an average SOF of 0.14, which is lower than the RF 2022 average SOF of 0.19. These transmission zones account for 81% of the total transmission elements within RF. This indicates that the larger transmission zones are performing better than the entire RF footprint.

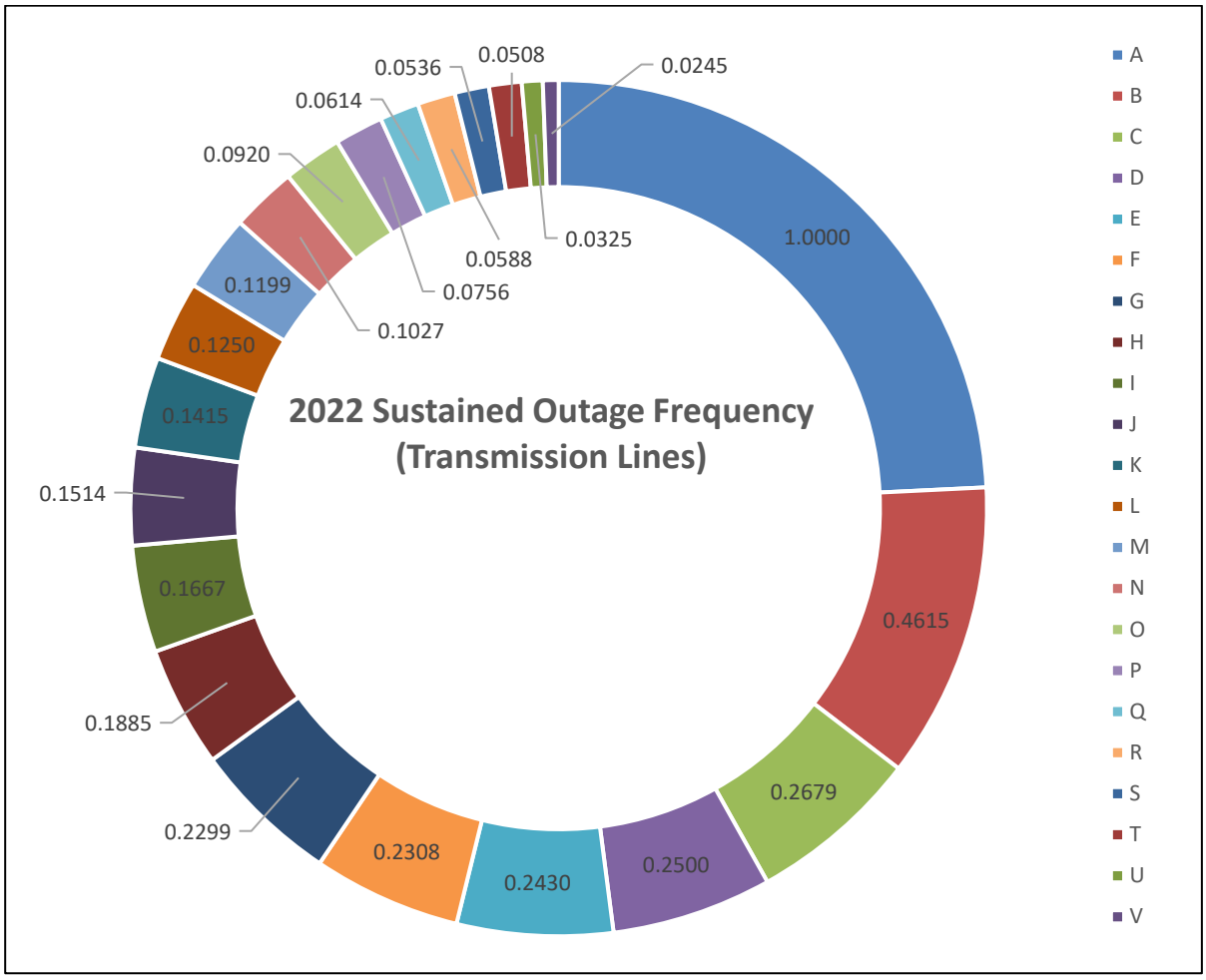


Figure 8: RF Transmission SOF 2022

Considering transmission line Mean Time To Repear (MTTR), the chart below indicates only half of the entities in the ReliabilityFirst footprint are managing the challenges with respect to MTTR well (with MTTRs below the 24-hour target level). Each reporting Transmission Owner is represented by a letter in Figure 9 below. However, the 50% of entities that are managing transmission line outages well accounted for 82% of total outages in 2022. In summary, while only half of the entities within RF are above the 24-hour target, these entities account for a majority of the assets within RF. Line MTTR is subsequently evaluated in more detail later in this section.

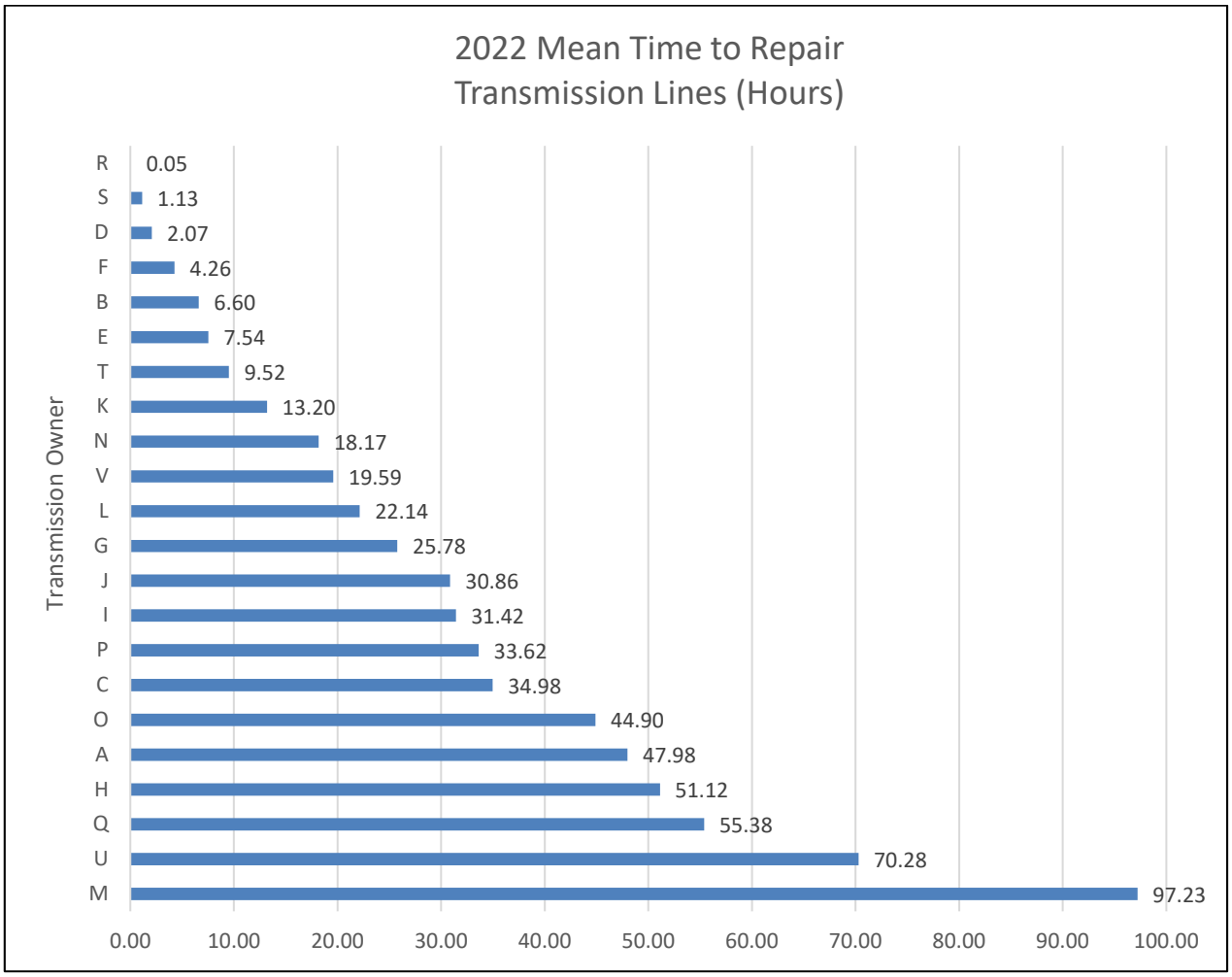


Figure 9: RF Transmission MTTR 2022

It is worth noting that the MTTR metric is susceptible to being skewed when an entity experiences a small number of outages that lasted an extremely long time. As an example, the table below displays all entities with a MTTR above the 24-hour target. When removing outages that exceeded 100 hours in duration, three more entities meet 24-hour target duration with two additional entities being just over the threshold. ReliabilityFirst plans to research these outages and perform outreach with entities as needed.

RF Transmission Owners Exceeding Line 24-Hour MTTR in 2022
Removal of Outages 100-Hours and Greater

Transmission Owner	MTTR - Existing	MTTR - Remove Long Duration
M	97.23	9.92
U	70.28	12.19
Q	55.38	16.30
H	51.12	24.13
A	47.98	47.98
O	44.90	27.37
C	34.98	4.26
P	33.62	9.30
I	31.42	31.42
J	30.86	18.52
G	25.78	11.15

In addition to analyzing metrics with respect to transmission lines, ReliabilityFirst also analyzes them with respect to transformers. Generally, transformers experience fewer outages, but tend to take longer to return to service, especially if the outage is the result of failed equipment.

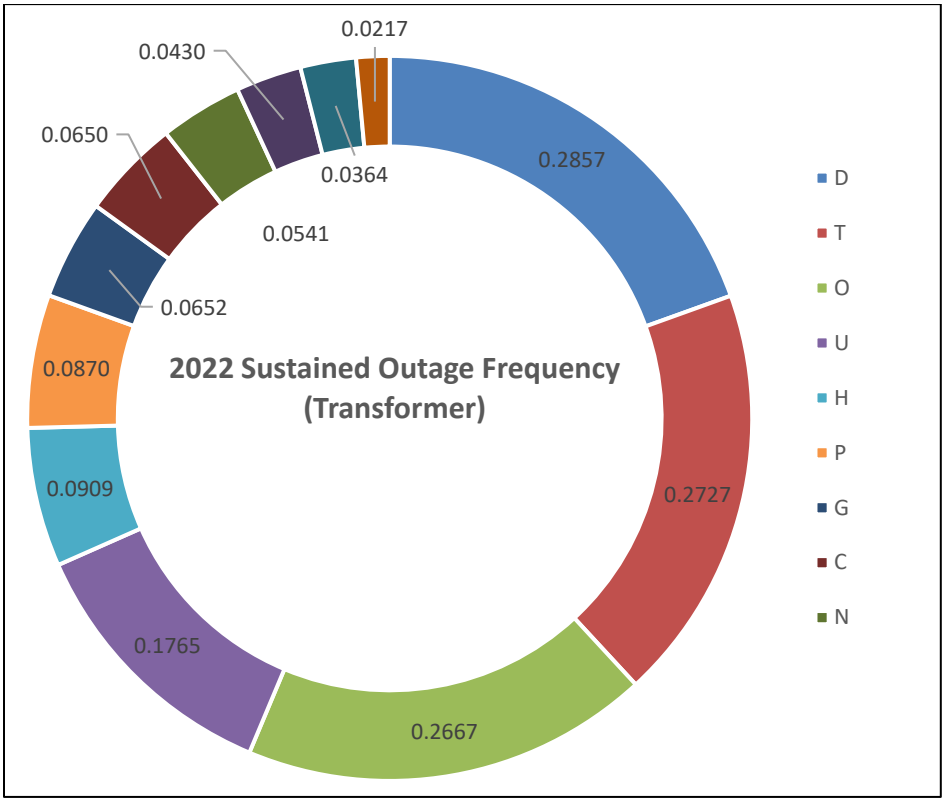


Figure 10: RF Transformer SOF 2022

In Figure 10 above, each reporting Transmission Owner is represented by a letter. The chart indicates that 33% of entities (four total) failed to meet the transformer SOF target level by having transformer SOFs above 0.10. Notably, however, many of those entities own a small number of transformers, which

significantly impacts their SOF. In fact, those entities only account for 5% of the total transformer inventory in the ReliabilityFirst footprint. Therefore, most transformers in the ReliabilityFirst footprint (i.e., 95%) are performing well based on SOF.

The chart below indicates that, of the 12 entities that experienced a transformer outage, seven of them (or 58%) were able to recover within 24 hours on average. However, the five entities that had a transformer MTTR over 24 hours consist of 32% of all transformers within the RF footprint. Again, while a lower number of entities within RF are above the 24-hour target, these entities account for a majority of the assets within RF. Transformer MTTR is subsequently evaluated in more detail later in this section.

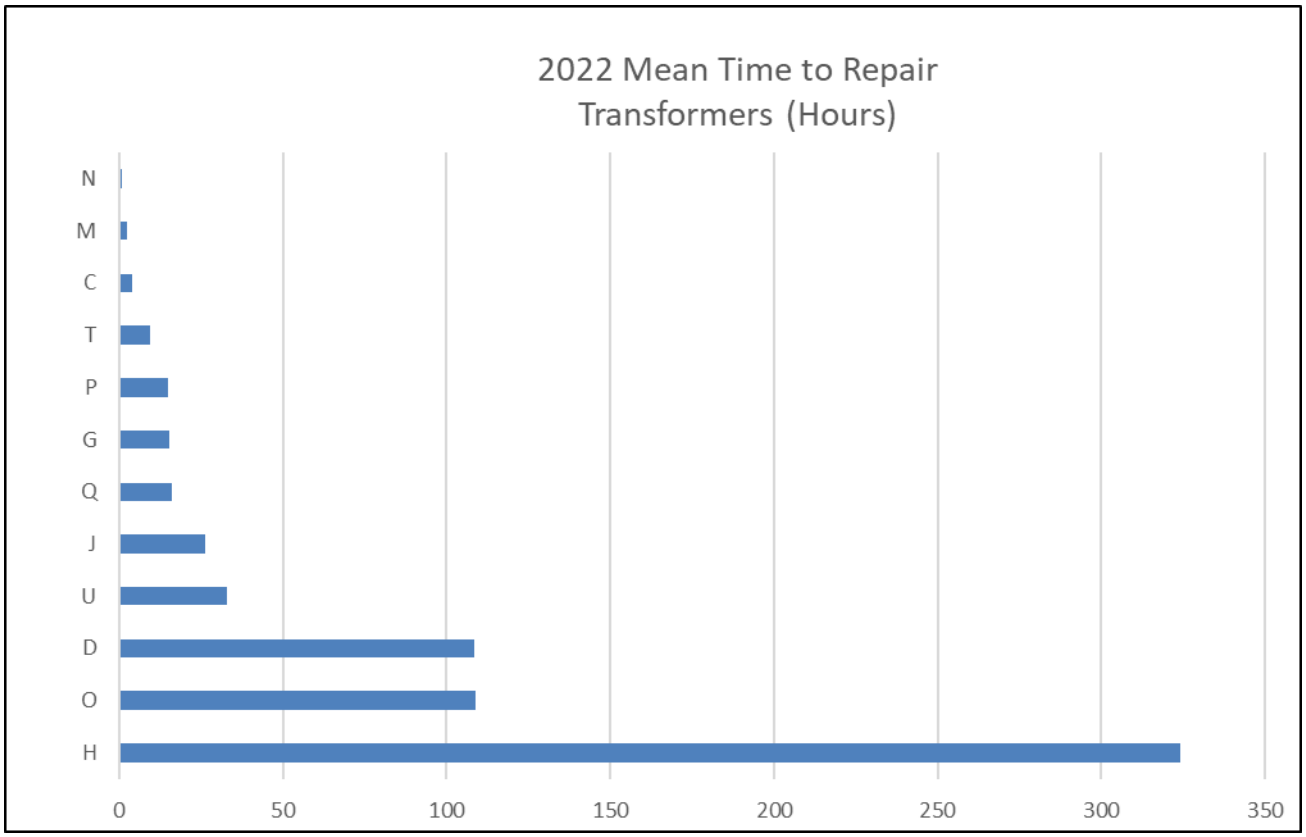


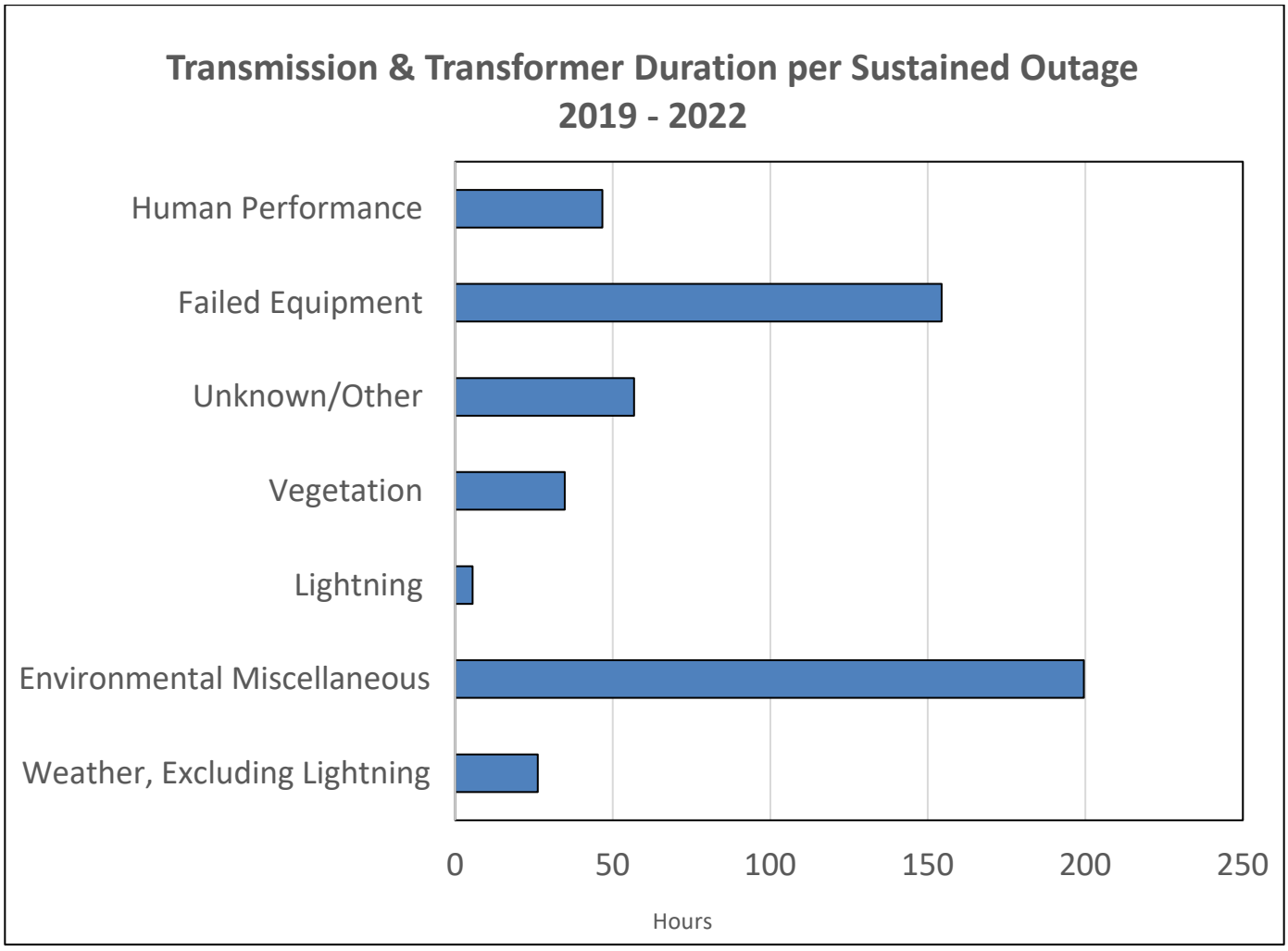
Figure 11: RF Transformer MTTR 2022

In general, since transformers are typically long lead-time equipment, transformer outages that ultimately result in failure of the transformer may have an extended duration. As a result, the MTTR metric for transformers is susceptible to being skewed when an entity experiences a transformer failure with an extremely long lead-time.

RF Transmission Owners Exceeding Transformer 24-Hour MTTR in 2020
Removal of Outages 100-Hours and Greater

Transmission Owner	MTTR - Existing	MTTR - Remove Long Duration
D	324.09	3.03
O	108.79	82.19
D	108.30	4.15
U	33.12	33.12
J	26.31	10.71

The table above displays all entities with a MTTR above the 24-hour target. When removing outages that exceeded 100-hours in duration, only two entities did not meet the 24-hour target duration.



Within RF, overall transmission line and transformer outage duration has remained steady from 2019 to 2022. The chart above breaks down each extended outage in the RF footprint by cause category. While the environmental miscellaneous category (i.e., Fire, Contamination, Earthquake, Avalanche, etc.) has an average of 200 hours per outage, this category only comprises 2% of the total outages between 2019 and 2020. From an outage duration perspective, human performance, failed equipment, and vegetation are the highest categories on average (exceeding the 24-hour target).

Human Performance

Background

Human Performance ("HP") is a topic that covers a broad stroke of risk exposure in the ReliabilityFirst footprint. Humans are involved in every aspect of the industry in one form or another. HP issues can cause significant safety issues or lead to reliability issues and disruptions. The power industry is putting significant effort into understanding the reasons behind why humans make the mistakes that they do. The majority of the current efforts are in understanding how to set people up for success in their jobs. The core theme is that people do not set out to make errors, so the effort is to change the conversation from one of blame to focus more on the real root causes of human failures. These efforts begin by examining the processes, policies, and culture in which humans operate.

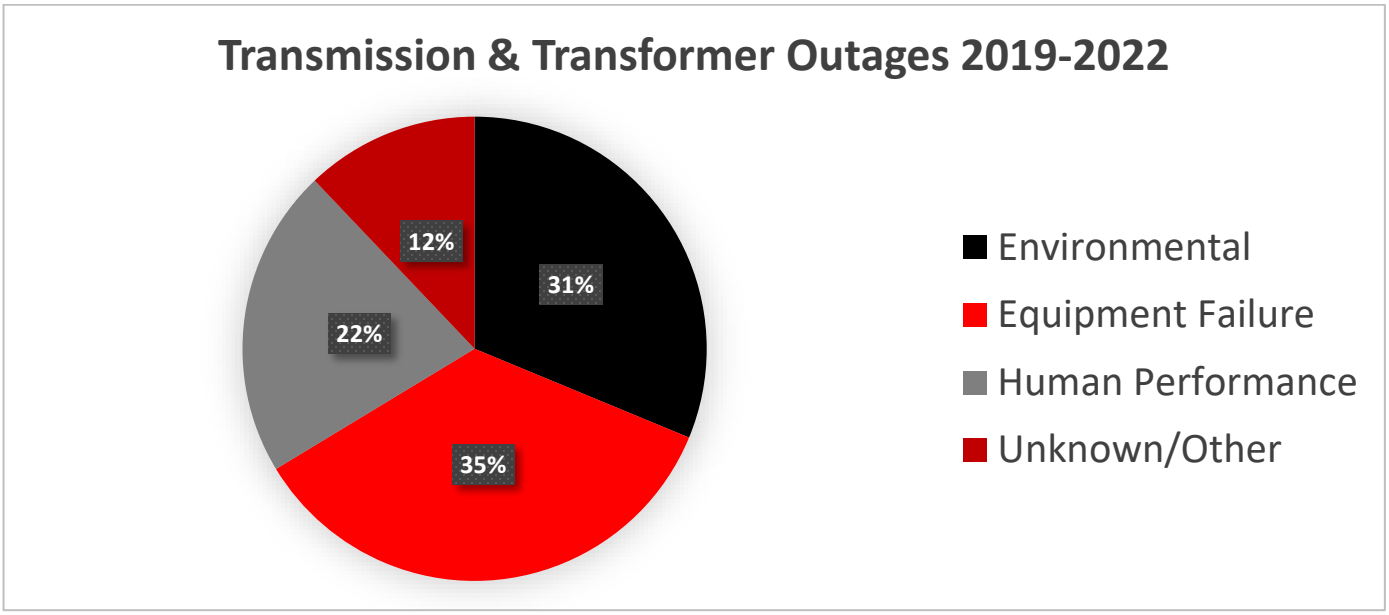


Figure 12: 2019-2022 Transmission HP Performance

The chart above breaks down transmission line outages into major cause categories: Environmental, Equipment Failure, Human Performance, and Unknown/Other. Human error accounted for almost a quarter of the transmission line and transformer outages within the ReliabilityFirst footprint over the past four years. This category includes outages caused by any incorrect action traceable to employees and/or contractors for companies operating, maintaining, and/or helping the Transmission Owner. This includes any human failure or interpretation of standard industry practices and guidelines that cause an outage.

Proportional Impact of Human Performance Factors

Year	Proportion of Total TADS-Reported Outages
2019	17%
2020	23%
2021	24%
2022	22%

Overall upward trend

Although the four-year average proportion for human performance related outages stands at 22%, the year-to-year comparison shows an overall upward trend. Within RF, the overall number of transmission line and transformer outages associated with human error has also shown an increasing trend since 2019. As stated in the NERC 2023 State of Reliability report, human performance related outages show no significant change during the same timeframe across the ERO. RF will continue to monitor these trends, analyze them, and collaborate with NERC.

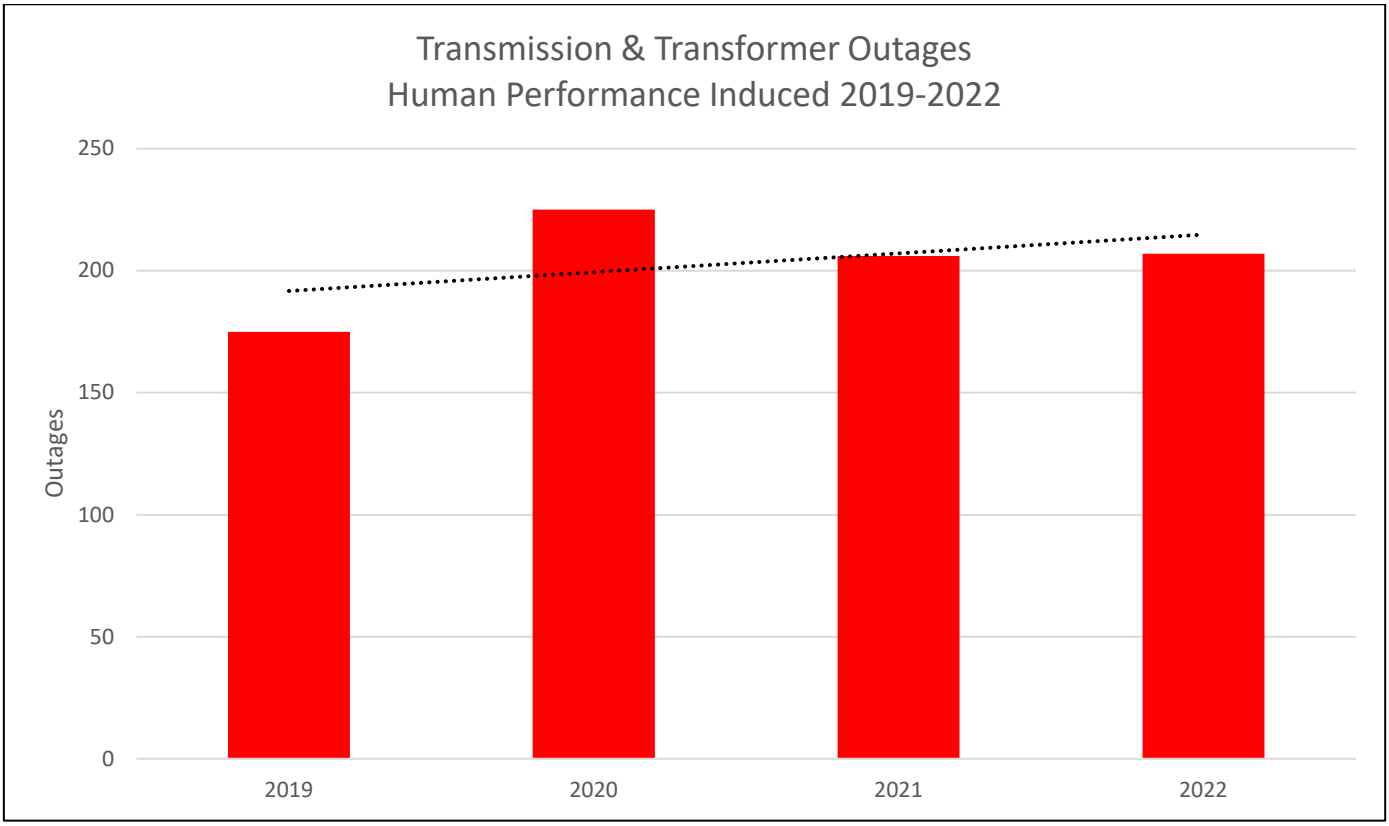


Figure 13: Transmission & Transformer Outages, Human Performance Induced

Conclusions

For transmission lines and transformers within the RF footprint, outages associated with lightning, weather (excluding lightning), and equipment failures have displayed a decreasing trend from 2019 to 2022.

However, outage categories like human performance and vegetation, where RF generally has more influence, are showing an increasing trend over the last four years.

For equipment failures, RF is exploring methods to help entities proactively identify failure risks related to specific equipment types and manufacturer failure trends.

While environmental-related outages are typically less severe than outages associated with failed equipment, environmental-caused outages are leading to more severe reliability impacts over time. This is something that RF plans to continue to monitor and analyze.

Between 2019 and 2022, the frequency of transmission and transformer unplanned outages in the RF footprint is on the decline. RF, on average, experiences a BES element outage (i.e., lines and transformers) once every 7.6 years. While the RF average transmission line Sustained Outage Frequency ("SOF") of 0.13 is above the 0.10 target, across the ERO Enterprise, RF has the lowest SOF when compared to its peer Regional Entities.

RF is experiencing a decreasing trend in Mean Time to Repair ("MTTR") that has held steady over the last four years. Half of the entities within the RF footprint are managing the challenges with respect to MTTR well (below the 24-hour target level) for line outages.

For transformer outages, most entities (67%) on average were able to recover within 24 hours. However, the four entities that had a transformer MTTR over 24 hours make up 32% of all transformers within the RF footprint.

From an outage duration perspective, human performance, failed equipment and vegetation are the highest categories on average (exceeding the 24-hour target).

When reviewing both SOF and MTTR over the last four years, the RF transmission system experienced on average a decreasing frequency of outages that are slightly increasing in duration over time.

Between 2019 and 2022, the Sustained Unplanned Outage Percentage ("SUOP") for RF has shown a decreasing trend as well. This trend indicates the likelihood of a transmission system element being unavailable, at any given time, due to a sustained unplanned outage. In 2022, the RF SUOP was lower than its peer Regional Entities.

For transmission line and transformer outages, human error related outages have been on a slight upward trend since 2019.