The Effect of Blocking Automatic Reclosing on Wildfire Risk and Outage Times

Carmen Haseltine and Line Roald
University of Wisconsin, Madison, United States,
{haseltine, roald}@wisc.edu

***Abstract*—In recent years, several catastrophic wildfires in North America have been attributed to electrical faults. As a result, there is now a spotlight on the role of electrical grids in these natural disasters. Attempts to mitigate the effects of power grid faults in drought regions include major changes to grid operational procedures, such as the removal of automatic reclosing. This paper examines the operational ramifications of these changes. A study is performed to analyze over a decade of outage data examining the impact of automatic reclosing on normal power grid operation and performance. We conclude that for a majority of faults, the initial reclosing attempt is successful. This implies that many power system faults could be cleared by one reclose attempt without incurring significant additional fire ignition risk. However, if the initial reclose attempt is unsuccessful, subsequent reclose attempts appear to have lower probability of success and could be avoided without significantly impacting reliability.**

***Keywords*—Wildfire risk, reliability, protection, 'automatic reclosing', outage duration**

I. INTRODUCTION

Recent years have seen many wildfires, due to drought conditions, high winds and high tree mortality [1]. Some of the most devastating and deadly fires were ignited by electric arcing faults, which are high releases of current associated with shorting the power transmission circuit. Following the 2018 wildfire season in California, utility Pacific Gas and Electric (PG&E) accepted responsibility, filed for bankruptcy protection, and accepted charges for manslaughter as a result of the fires [2], [3]. In efforts to reduce the risk of wildfire ignitions caused by electric faults, utilities in California have created detailed wildfire mitigation plans [1]. These mitigation plans include long term plans for more frequent circuit inspections, increased levels of maintenance, and improved vegetation management. In the short term, operational changes to the grid are implemented including de-energizing equipment (power shut-offs) and blocking an operational scheme known as *automatic reclosing*.

Equipment de-energization comes at great expense by long-duration power cuts to customers, which themselves have significant negative economic, societal, and health impacts [4]. As a result, a more frequently utilized operational mitigation to decrease wildfire risk is to block automatic reclosing. In normal operations, automatic reclosing is a mechanism which attempts to reconnect the faulted line after a breaker interrupts a fault. If the cause of the fault was a momentary event, such as a tree branch falling onto a conductor and then to the ground, the reclosing attempt is successful and the line is back in operation. If the cause of the fault is more permanent, such as a tree that has fallen onto a line, the reclosing attempt will lead to another rush of fault current before the breaker again opens the line.

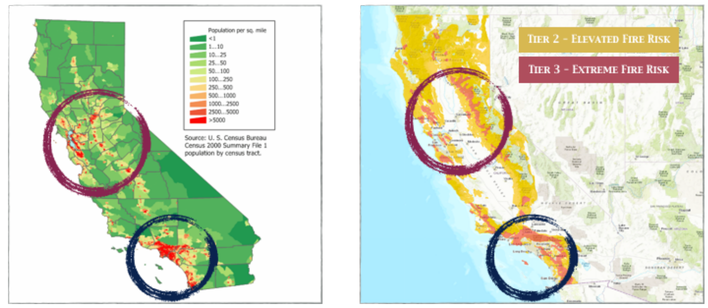


Fig. 1: Comparison of areas with high population density [8] and high wildfire risk [9] in California.

The arcing and heat associated with each fault occurrence is a potential source of ignition. Therefore, when operators block automatic reclosing the result is minimal system faults capable of wildfire ignitions. However, blocking automatic reclosing also prevents all the successful reclosing attempts, thus prolonging the average time components remain out of service (outaged) after a fault. The common recourse used by California utilities to reduce the heightened risk of fire ignitions that comes from a series of arcs (as opposed from a single arc due to an initial fault) is to remove automatic reclosing [5] [6] [7]. In the plans created by Southern California Edison, San Diego Gas and Electric, and Pacific Gas and Electric the automatic reclosing schemes are disabled in all areas with extreme wildfire risk. These steps are modifications to the fundamental protection schemes of the power system.

Fig. 1 compares the areas with extreme wildfire risk (left) with the population density in the state (right). It can be seen that several of the areas with very high wildfire risk are surrounding the areas with the highest population density, indicating that the plans to block automatic reclosing would affect grid operation in very large population centers.

To the best of our knowledge, there currently exists no publicly available study on how partial or full removal of automatic reclosing affects the balance between wildfire ignition risk and power system operation and performance. This paper is a first attempt at improving our understanding of these relationships. Specifically, the contribution of this paper is to quantify the impact of inhibiting automatic reclosing on both power grid performance and wildfire risk by investigating the correlations between automatic reclosing schemes, number of arcing events and outage duration. This analysis is performed on publicly available data from a Bonneville Power Authority

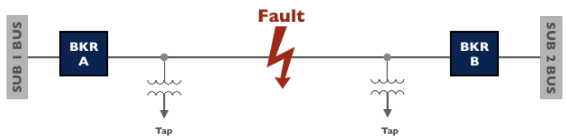


Fig. 2: Faulted Line Configuration.

(BPA), located north of the geographical regions impacted by wildfires.

II. Power System Faults and Automatic Reclosing

Automatic reclosing is a key part of power system protection schemes. Power system protection has two primary goals, namely security and reliability. Security is protecting the equipment that makes up the bulk electric system against damage from electric faults. Protection systems provide security by ensuring that faults are cleared as quickly as possible, thereby limiting physical damage and maintaining system stability. Reliability is achieved by ensuring proper day-to-day operation of the power system [10]. Protection systems contribute to reliability by preventing over-tripping and by allowing timely re-energization for undamaged elements of the bulk electric system. When faults occur on the grid, transmission protection schemes detect the fault and de-energize the affected line by tripping (i.e., opening) the appropriate breakers to stop the flow of fault current. However, there are different types of faults. Some faults are more permanent, like a downed conductor, while others are more temporary in nature.

One example of a temporary fault would be a flashover initiated by a branch falling on a transmission line, which would be resolved once the branch falls off the line. As temporary faults are common, *automatic reclosing schemes* attempt to reconnect the line after the fault has had the chance to clear. By greatly shortening the outage time of such temporary faults, automatic reclosing schemes balance the security of the grid components with reliability of supplying energy to end users [11]. The fault clearing and automatic reclosing processes are described in more detail below.

A. An Overview of Automatic Reclosing

1) Fault Clearing: Fig. 2 shows the basic transmission line configuration. Consider the common scenario of a branch falling onto the transmission line. The substation breakers at each end of the line should open within 30 cycles (0.5 seconds) of fault/arc detection to de-energize the faulted line. The resulting system topology is denoted as the loss of the one transmission line (i.e. N-1 condition). Restoring the system to normal conditions as quickly as possible for temporary faults ensures system stability during contingency, reduces switching over-voltages, and improves grid reliability [11]. The automatic reclosing sequence is not initiated until the line-end breakers are opened for the initial fault.

2) Automatic Reclosing Sequence: In this process, the breakers are closed in an attempt to re-energize the line. If the fault was resolved after the initial trip of the breakers, the line remains closed. If the fault condition persists, the breaker will trip once again. In such situations, several reclosing attempts can be made for a given fault. Fig. 3 gives an example of a full reclosing sequence. The IEEE Guide for automatic reclosing (C37.104) [12] states there are up to *three re-energizing attempts* allowed on a power line, before the fault is declared permanent. We note that each reclosing attempt involves connecting a de-energized line to an energized bus, which is referred to as a hot bus to dead line or H/D shot. Each reclosing attempt, if unsuccessful, leads to a subsequent trip initiating a new release of fault current, which can lead to high-temperature arcing or sparks [13].

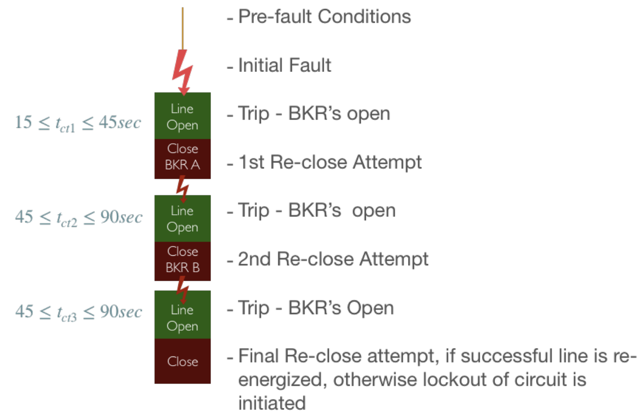


Fig. 3: Automatic reclosing sequence to re-energize a transmission line with voltage $>$ 100kV. In this example, each reclosing attempt fails until the successful third attempt.

3) Manual and Remote Closing : When a fault is declared permanent the line-end breakers enter a lockout condition. In this case, the line can only be cleared after a physical examination of the line and *manually closing* the line-end breakers at the respective substations [14], [15]. The duration of time required for a manual closing varies widely[1].

There are situations where the line is not in a lockout condition and remains de-energized following an initial fault, due to e.g. misoperation of a reclosing scheme. In these rare instances transmission operators can *remotely close* the breakers (termed RTO Remote) [10].

B. Automatic Reclosing Logic

The complete logic for implementation of an automatic reclosing scheme is quite involved, and is covered extensively in the context of on power system protection [11], [14], [15]. For the purposes of this study a high-level overview of the reclosing logic is provided in Fig. 4. The logic shows that there are multiple conditions which need to be met prior to the breaker closing. There are two primary conditions, 1) there needs to be a 3-phase trip of a breaker in good condition [2] 2) the breaker cannot be in a lockout condition. The dead time interval t_{ct} is the time between a trip condition and the subsequent reclose attempt. Table I shows the differing intervals for various transmission voltages [15], [16].

Automatic reclosing schemes vary for each transmission utility, nevertheless there are commonalities determined by

[1]Manual inspection does not have a maximum time limit as the time complete repair differs for each fault cause and line type.

[2]There is single pole operation however it is not as common for most transmission grids.

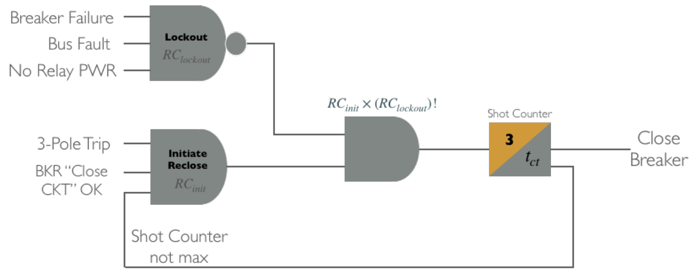


Fig. 4: Simplified Reclosing Logic

TABLE I: Dead time intervals t_{ct} between each reclosing attempt, for different voltage levels.

Label	Voltage Range	t_{ct1}	t_{ct2}	t_{ct3}
HVDC	900kV +	15-30 sec	60 sec	60 sec
EHV	200-900kV	30-60 sec	60 sec	60 sec
HV	100-200kV	60 sec	60-120 sec	60-120 sec
MV	50-100kV	60 sec	60-120 sec	60-120 sec

both the IEEE standard and common used relays. The IEEE standard does provide a minimum time for a breaker to operate following a fault by the de-ionization time for air surrounding the arcing fault[12]. A sizeable number of relays on the North American grid have logic based on electromechanical relay schemes which curtail the operation of reclosing to 1 minute approximately[14].[3]

C. Benefits and Concerns related to Automatic Reclosing

1) Benefits of Automatic Reclosing: Most North American transmission systems are designed to be secure and retain reliability for the loss of one transmission element (N-1), however it is quite possible for secondary outages to occur if elements are not restored following a transient fault. The system is not designed to optimally control for (N-1 -1) events. It is for this reason automatic reclosing is essential to normal transmission grid operations to restore outage of transmission lines as quickly as possible.

2) Concerns about Automatic Reclosing: Although there exist many benefits to the automatic reclosing schemes there are several concerns worth mention. While automatic reclosing schemes has the potential to quickly remove the impact of temporary faults, if the reclosing scheme is unsuccessful, the result may be multiple subsequent faults with corresponding arcing hazards. Specifically, each unsuccessful reclosing attempt may create a high magnitude of short circuit/fault current, i^2t, which can damage power system physical elements such as substation equipment and transmission cables.

Furthermore, each reclose attempt causes additional arcing and sparks, which increases the risk of igniting a fire at the fault location. Recall, California utilities removed automatic reclosing as part of wildfire mitigation plans (see Section I). When automatic reclosing is removed the lines will enter a lockout condition after the initial fault. The result becomes faults which are normally resolved through automatic reclosing instead require manual reclosing, leading substantially longer outage times for the line.

[3]Microprocessor relays have larger time range options; nevertheless, when retrofitting grids it common practice for new schemes follow a similar applications.

III. An Analysis of Automatic Reclosing Impact to BPA Outage Data

In this section, we use publicly available data from Bonneville Power Authority (BPA) [17] as a study case to qualitatively examine the impact of removing automatic reclosing on the duration of system faults. The outage data from 2009 to 2019, inclusive, was included using R-GUI. While we would ideally like to analyze outage data from California before and after automatic reclosing was removed, there are multiple reasons why we instead use BPA data. First, outage data from California data is not openly available, making it hard for others to replicate our results. Second, the BPA data includes outage data across more than a decade, which allows us to investigate trends across years. This is important, as we found significant differences in the data between years. Third, the outage data from BPA is (to the best of our knowledge) currently unaffected by blocking of automatic reclosing due to wildfire risk, and thus provides a better starting point to assess the impact of automatic reclosing on outage times.

A. Connecting Outage Duration and Automatic Reclosing Attempts

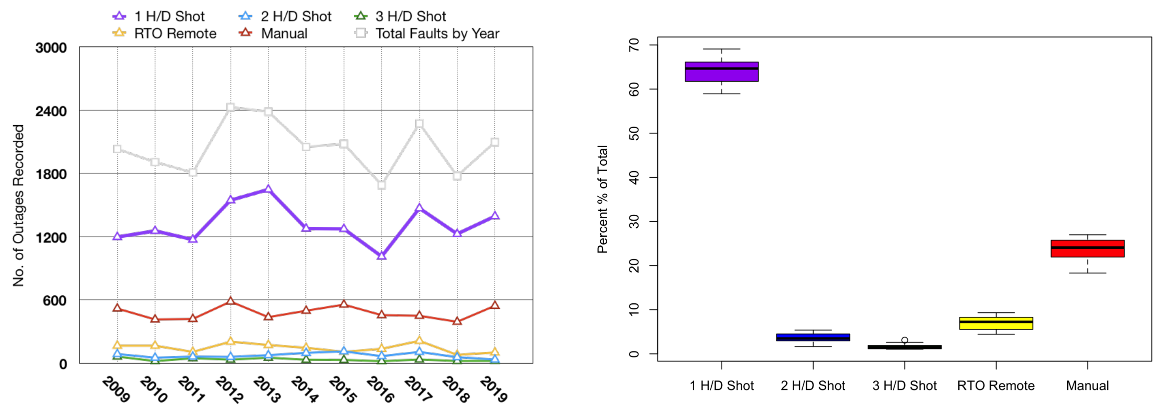
We analyze BPA outage data from 2009 to 2019, inclusive. While BPA reports different outage types, including transmission line outages, customer outages and transformer outages, we only include the transmission line outages in our analysis. There are 22,679 unplanned outages at transmission level voltages which occurred within this time span. While BPA records outage duration as a separate field in the data, we assumed that it is more accurate to calculate the outage duration from the SCADA time stamps (the two types of data are similar, but not identical).

For each outage, we use duration to estimate the approximate number of reclosing attempts. These timings were chosen by considering the dead time intervals, t_{ct}, for each voltage range shown in Table I. One concern was data granularity. Automatic reclosing shots are set by seconds and the outage data provided only has minute by minute recordings. Additionally, a fault can occur anywhere within the one minute scan. For this reason, zero minutes is denoted as a unit of time, since the outage can occur and be cleared within the 60 second time between SCADA records. The mapping between outage duration in minutes and estimated number of reclosing attempts is provided in Table II.

The remote reclosing attempts (RTO Remote) is limited to 15 minutes, as Remedial Action Schemes/Plans performed by transmission operators must occur within the emergency rating, i.e. Rate C or 15-minute rate, of the transmission line [10]. Manual re-energization of the line can be as short as 16 minutes, however it can range greatly depending on the fault scenario.

B. Analysis of Outage Categories in BPA Data

In the following, we analyse how the outages reported in the BPA outage data is distributed across the different re-energization categories. Data is analyzed per year, by voltage level and by season.



(a) Total number of outages in each category for each year.

(b) Percentage of outages in each category.

Fig. 5: Outage Data from 2009 to 2019, Grouped by Year.

TABLE II: Dead Time Link to Outage Duration & Voltage Level

Label	Voltage Range	1 shot	2 shot	3 shot	RTO Remote	Manual
HVDC	900kV +	0 min	1 min	2 min	3-15	16+
EHV	200-900kV	0 min	1 min	2 min	3-15	16+
HV	100-200kV	0-1 min	2-3 min	4 min	5-15	16+
MV	50-100kV	0-1 min	2-3 min	4 min	5-15	16+

1) Outage Categories by Year: We first investigate the number of outages in each re-energization category by year. Fig. 5a shows the absolute number of outages per year, both in total and for each re-energization category, across the decade from 2009 to 2019. Fig. 5b show the percentage of outages in each category for each year from 2009 to 2019. We observe that there is a large variation in the number of outages per year, and there are no clear trends towards more or less outages across the considered periods. We further observe that the percentage of outages in each category remain more similar across the different years. Furthermore, our analysis estimates that approximately two thirds of all outages are so short that they must have been cleared within just one reclosing attempt (i.e., within one minute). However, if the first reclose attempt is ineffective, it is likely that the subsequent reclosing shots will also not be effective. We estimate that between 20 and 30% of all outages require manual inspection (i.e., take more than 15 min to resolve).

2) Outage Categories by Voltage Levels: We next investigate the difference in outage types as a function of the voltage levels. Fig. 6 (a) show the break down of the outages across voltage levels. We observe that the reported outages are all at the transmission level, with 91% of the reported outages occuring at the high-voltage (HV) or extra high voltage (EHV) levels. A smaller fraction of the voltages occur on the Pacific DC Intertie, a high-voltage DC (HVDC) connection from the Pacific Northwest to California, and on medium voltage (MV) level. This highlights that the BPA data we used is representative of high-voltage transmission grids rather than sub-transmission or distribution.

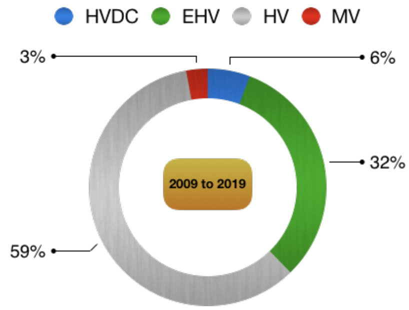
The bar chart in Fig. 6 (b) breaks down the frequency of each re-energization type by voltage level. It shows that the vast majority of the outages are resolved within a single reclosing attempt regardless of the voltage level.

3) Outage categories by season: We next investigate the difference in outage types for different seasons. This is important to analyze because wildfire risk is particularly prevalent during the drier, hotter and windier parts of the year. The results of the analysis in Fig. 7 (a) show that there is not one particular season with more outages than any other, although the percentages of faults is slightly higher in spring and summer. The bar chart in Fig. 7 (b) breaks down the frequency of each re-energization category for each season averaged over the ten years. We observe that the majority of the outages are resolved within a single reclosing attempt regardless of season. However, the first reclose attempt is more likely to be effective during spring and summer, while more outages require manual inspection and repair during fall and winter.

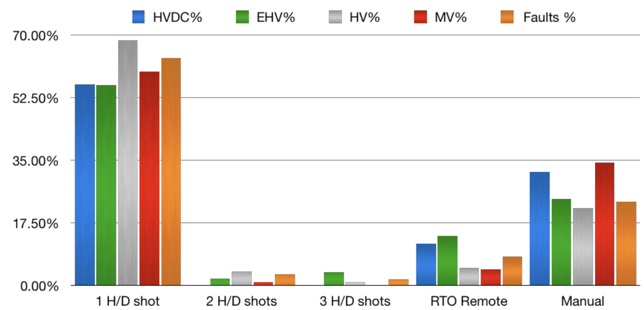
C. Illustrative Example: The Effect of Removing Automatic Reclosing

Fig. 8a is a temporal snapshot view of publicly available outage data from Bonneville Power Authority (BPA), obtained from [17]. It shows outages recorded between 18:10 and 21:10 on the evening of June 21, 2018, with time along the x-axis and each blue box corresponding to the starting point and duration of the fault. Simultaneous outages are listed on top of each other at the same snap shot in time. Fig. 8a illustrates that there are numerous outages on the system at a given time, and that the outages vary in length between less than a minute and several hours. Many of these outages are cleared within less than a minute, which is faster than an operator can perform switching actions. These micro-outages are a result of automatic reclosing. Nevertheless, the system sometimes experience multiple simultaneous outages with a worst-case (N-K) of $K = 9$.

We then consider how the temporal outage data could look if automatic reclosing is removed. For each outage that was originally resolved through automatic or remote reclosing, we increase the outage duration to illustrate an outage with manual reclosing. To find representative outage duration for system

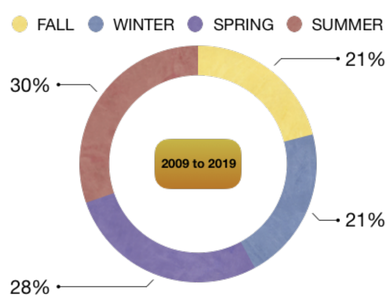


(a) Percentage of outages occurring at each voltage level.

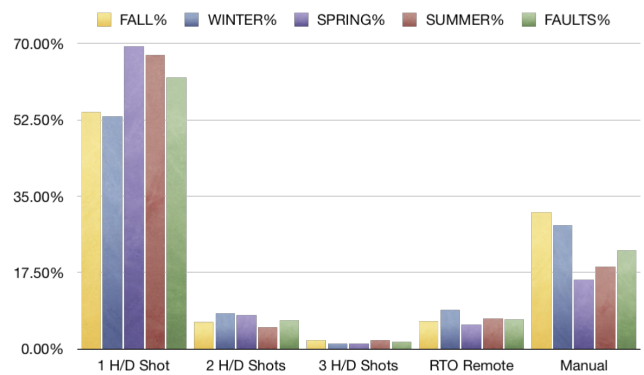


(b) Distribution of different re-energization types within each voltage level, and as an average across all voltage levels.

Fig. 6: Outage data grouped by voltage level, with high-voltage DC (HVDC), extra high voltage (EHV), high voltage (HV) and medium voltage (MV) labels assigned as in Table II. The label "Faults" represent the average across all voltage levels.



(a) Percentage of outages occuring in each voltage season.



(b) Distribution of different re-energization types within each season, and as an average across all seasons.

Fig. 7: Outage data grouped by seasons. The label "Faults" represent the average across all seasons.

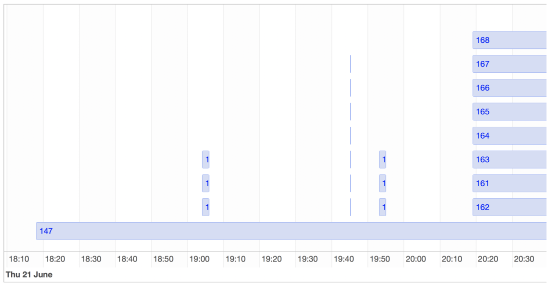
faults without automatic reclosing, we analyze the outage duration of manually resolved outages (5433 outages). We find that the distribution is extremely heavy tailed, with a median outage time of 158 min, mean equal to 1256 min and the standard deviation equal to 10,733 min.

To generate illustrative (though not statistically representative)[4] outage duration, we generate random outage duration from a uniform distribution with minimum of 16 minutes (manual minimum) and a maximum of 316 minutes (2 times the median outage time of the manually resolved outages). The temporal outage data for the hypothetical case without automatic relocsing is shown in Fig. 8b. When comparing the number of simultaneous outages between a situation with automatic reclosing in Fig. 8a and without automatic reclosing in Fig. 8b, we observe that removing automatic reclosing results in an increase of the worst case (N-K) from $K = 9$ to $K = 22$ for the same two hour time span. This large increase in simultaneous outages illustrates how automatic reclosing aids in system stability and reliability.

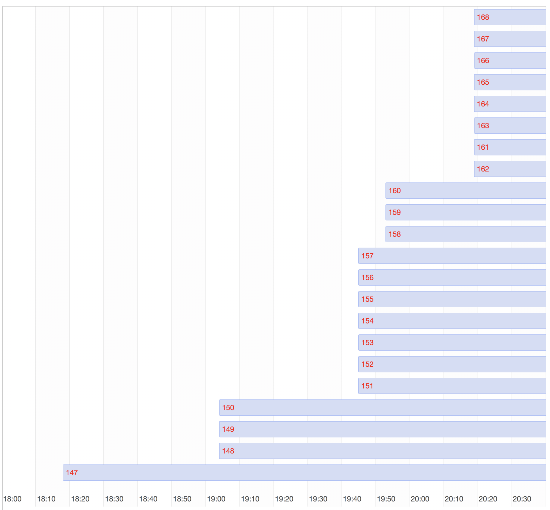
[4]Currently, there is ongoing research into the appropriate statistical model for transmission outages.

D. Discussion

The results above show that automatic reclosing is effective across all years, for all voltage levels available in the data, and at any time of the year. Since the vast majority of the reclosing attempts on the line are successful after the first re-energization shot, the system is normally not in a post contingency state for more than one minute. Therefore it can be concluded that removal of all reclosing shots will assuredly impact the reliability of the power grid. Furthermore, the fact that a single reclosing shot is sufficient in most cases is important because a successful initial reclosing attempt means that *there is no additional arc* meaning that the outage was resolved both very quickly, and with no additional risk of wildfire ignitions. Allowing for a single reclosing shots would resolve



(a) Temporal View of BPA Outage Data with Automatic Reclosing (June 21, 2018 from 18:10 to 21:10)



(b) Temporal View of BPA Outage Data with Automatic Reclosing Removed (June 21, 2018 from 18:10 to 21:10)

approximately 65% of all outages within one minute, which would greatly decrease the number of simultaneous outages on the system. For the remaining 35% of the outages, there would still be two initial arcing events.

For outages where the fault was resolved through automatic reclosing with 2 or 3 reclosing shots or through remote reclosing by the RTO, the outage duration was shortened, but at the expense of an increased risk of incurring additional fault currents. For those outages, automatic reclosing seems less effective, with less than a third of remaining outages resolved by the second or third reclose attempt.

Thus, one potential solution to achieve a better balance between power system reliability and wildfire risk would be limiting transmission reclosing to a single hot to dead shot for a faulted line[5]. In Fig. 4, which shows the reclosing logic, the max shot counter would be changed from “3” to “1”, meaning that after a single reclose attempt the line would be driven to lockout. The lockout condition would only be resolved by manual inspection of the line. This solution, allowing one reclosing shot, balances system reliability of maintaining power to end users with security of reducing wildfire risk (i.e., limiting the number of arcs) on the grid.

[5]Note, these changes would require settings changes for all substation reclosing relays. This could be an extensive process.

IV. Conclusion

Due to increasing frequency of wildfires globally it is important to determine the impact of wildfire mitigation plans. A commonly used mitigation is the blocking of automatic reclosing. Automatic reclosing schemes directly support both system stability and reliability, yet they also increase wildfire vulnerabilities in drought prone regions.

The analysis of BPA data shows direct impact on system outage duration by removing automatic reclosing with similar performance across voltages and seasons. Moreover, clearing faults within a single shot automatic reclose would resolve the majority of system faults.

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