IEEE 1366- Reliability Indices

IEEE Boston Section- February 19, 2019
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Some Important Definitions

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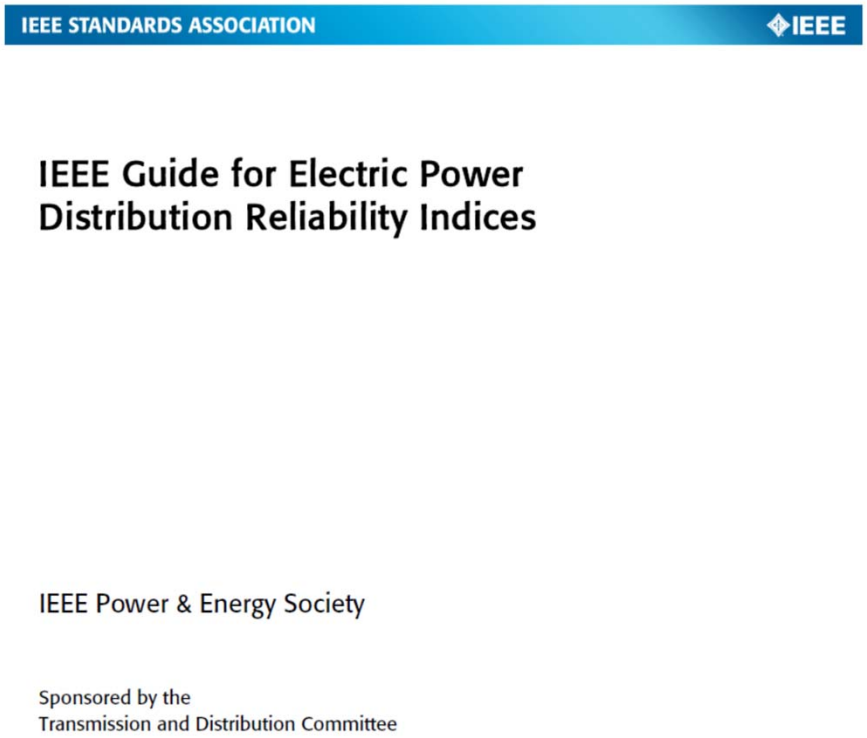
Purpose of IEEE-1366

1. **To foster uniformity in the development of distribution service reliability indices and to aid in consistent reporting practices among utilities.**

2. **To provide guidance for new personnel in the reliability area and to provide tools for internal as well as external comparisons.**



What's a customer

Customer:

"A metered electrical service point for which an active bill account is established at a specific location."

Sounds like common sense.

Just remember:

A Three-decker is three customers.

An apartment building may be 100 customers.

Load doesn't matter.

Population doesn't matter.

Interruption vs. Outage

Interruption:

"The total loss of electric power on one or more normally energized conductors to one or more customers connected to the distribution portion of the system."

Does not include "Power Quality" issues (sags, swells, etc.)

Part power?

Loss of "power" not "voltage"?

Distinction:

Interruption refers to CUSTOMERS

Outage refers to EQUIPMENT

Outage:

"The loss of ability of a component to deliver power."

Momentary vs. Sustained Interruption

Momentary Interruption:

"The brief loss of power delivery to one or more customers caused by the opening and closing operation of an interrupting device."

Each recloser operation is a separate momentary interruption

Sustained Interruption:

"Any interruption not classified as a part of a momentary event. That is, any interruption that lasts more than five minutes."

Some companies and/or jurisdictions may use one minute or some other interval.

The original intent was probably to exclude interruptions restored by automatic operation

Duration and Step Restoration

Interruption Duration:

“The time period from the initiation of an interruption until service has been restored to the affected customers.”

Step Restoration:

“The process of restoring all interrupted customers in stages over time.”

Fundamental Factors

CI = Customers Interrupted

CMI = Customer Minutes Interrupted

CS = Customers Served (IEEE 1366 call this N_T)

$$\text{SAIDI} = \frac{\sum r_i N_i}{N_T} = \frac{\text{CMI}}{N_T}$$

CAIDI and Her Sisters

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The Big Three- SAIFI, SAIDI, CAIDI

SAIFI (System Average Interruption Frequency Index):

How often the average customer experiences an interruption

SAIDI (System Average Interruption Duration Index)

The total number of minutes (or hours) of interruption the average customer experiences

CAIDI (Customer Average Interruption Duration Index)

The average time required to restore service

→ **Be careful with this one. The numbers can be deceiving.**

Comments on the Big Three

Sustained interruptions only (no momentary)

Usually applied over a specified time period (typically one year)

Usually applied over a specified customer base (typically an entire system, state, town, feeder, etc.)

Averages can be deceiving.

If the average system SAIFI is 0.5. That's pretty good.

But if 90% of customers had no interruptions and 10% had 5, is that good?

The Building Blocks- Calculating CI and CMI

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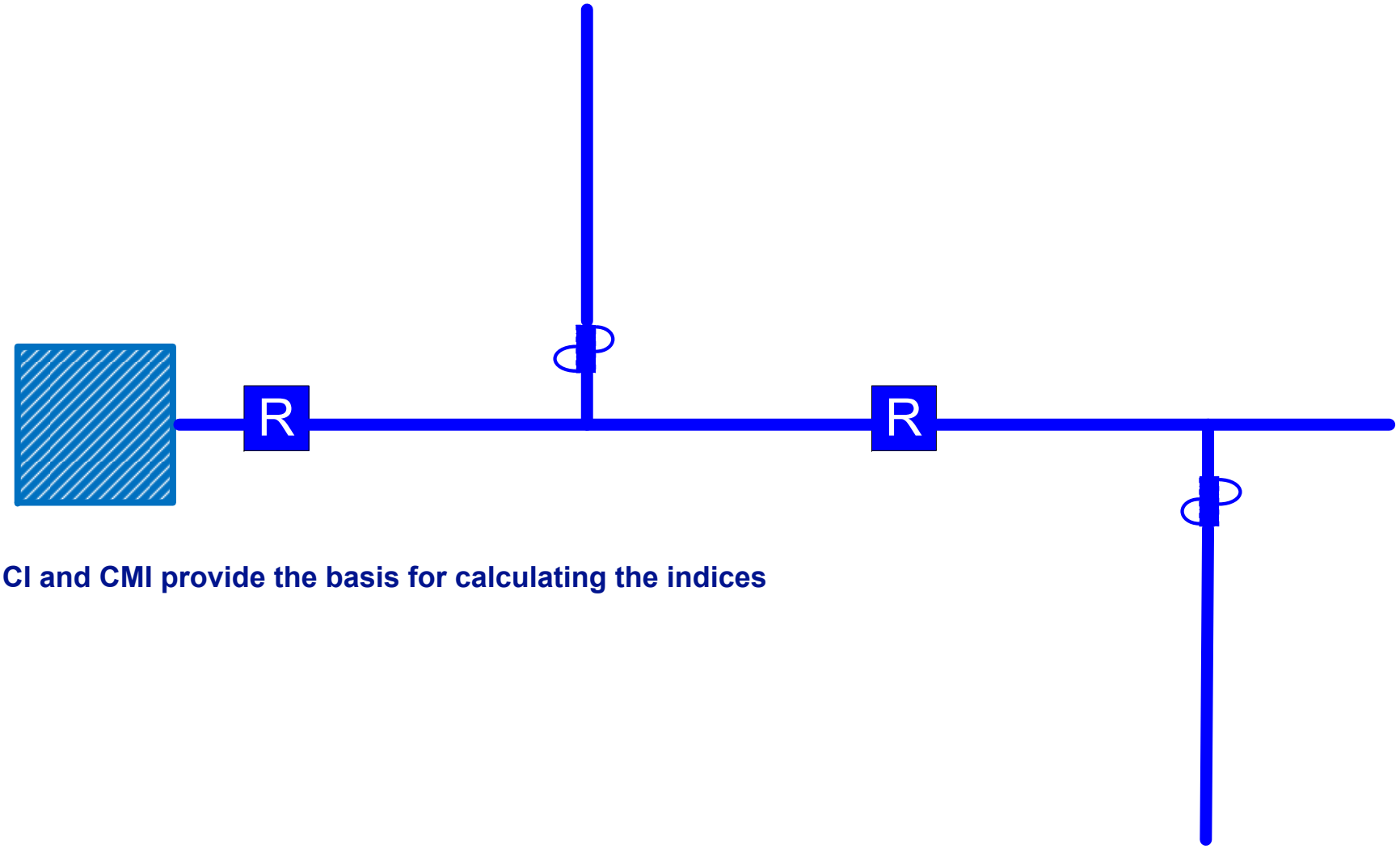
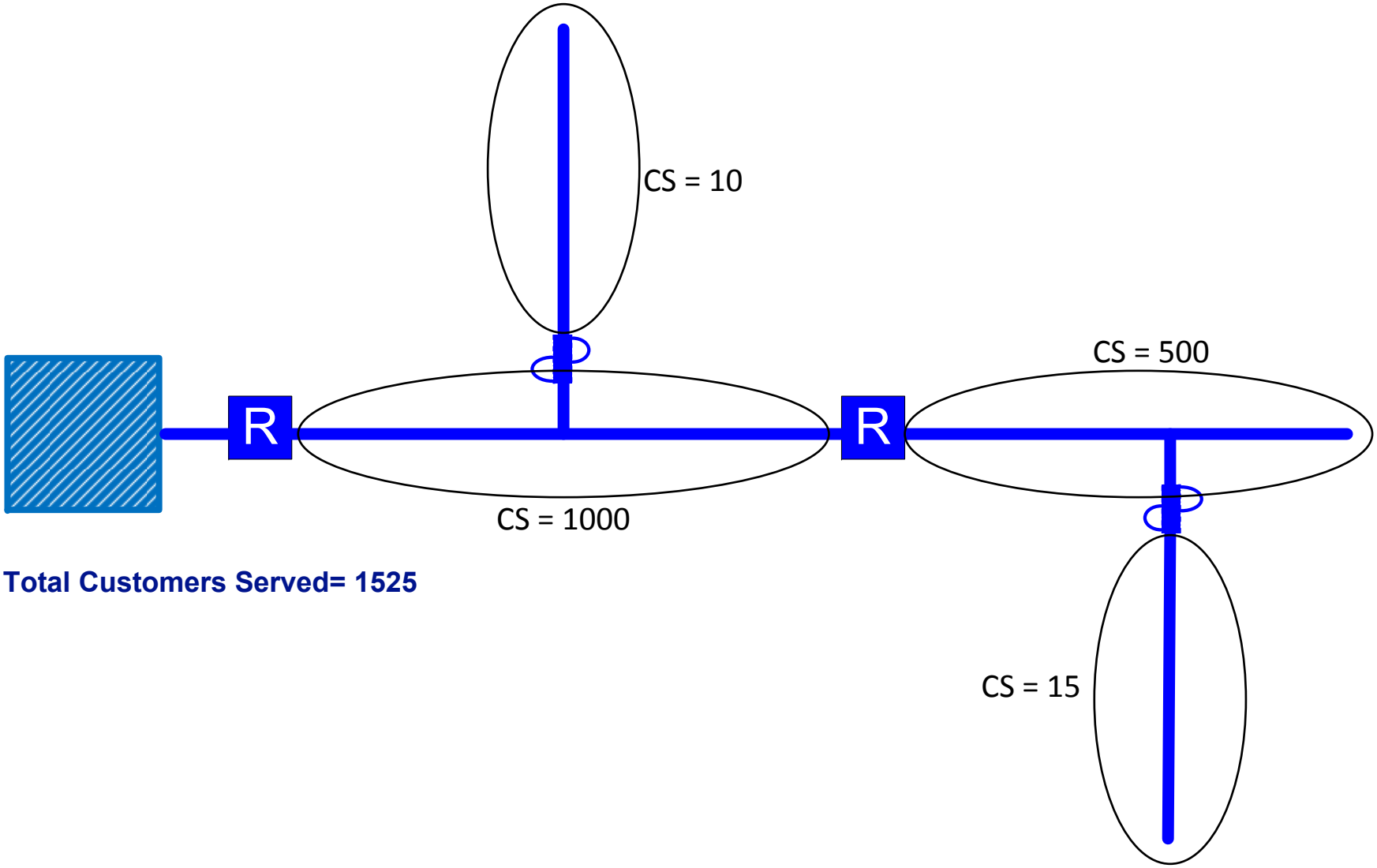
Typical Distribution Feeder- Calculate CI and CMI



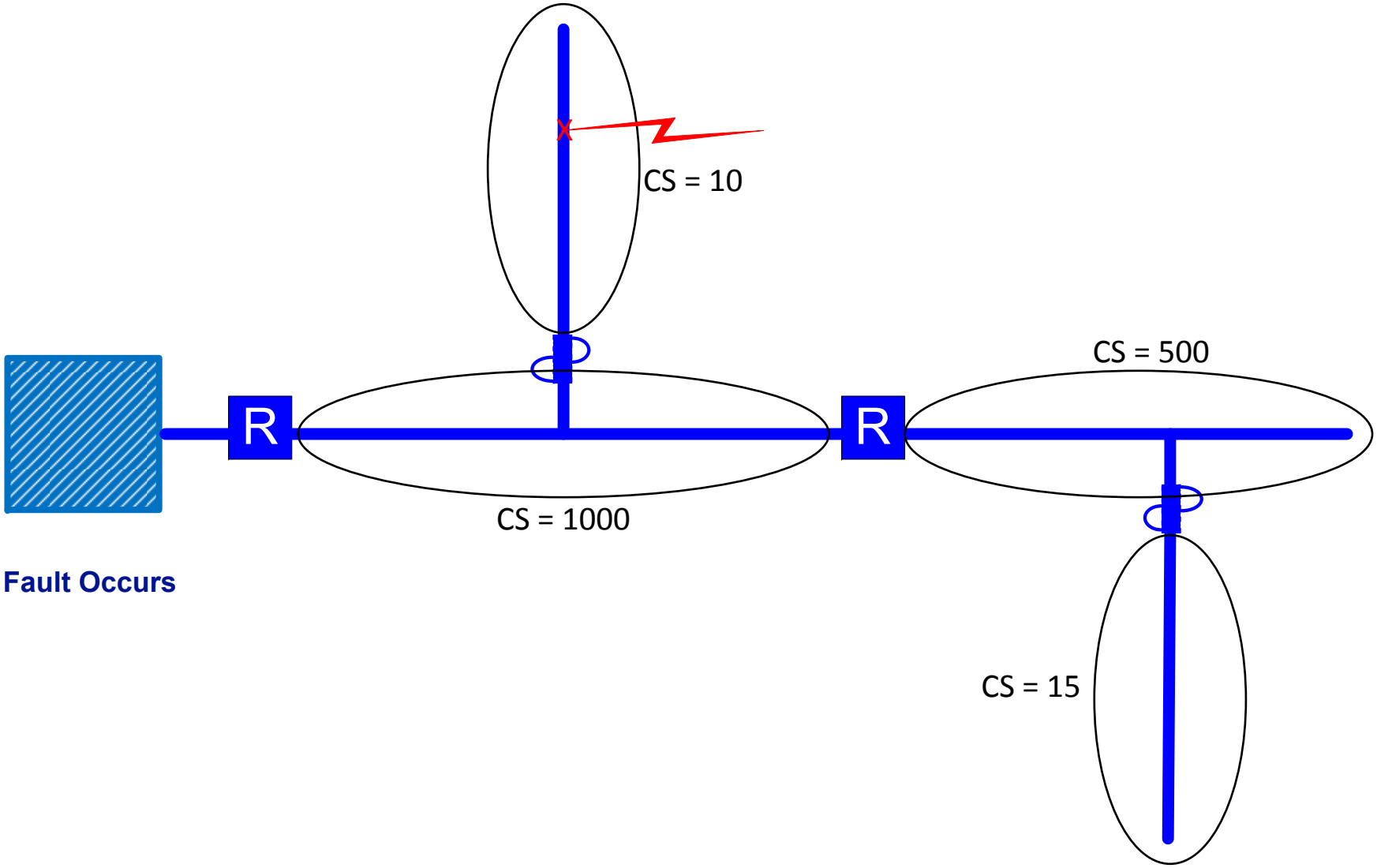
CI and CMI provide the basis for calculating the indices

Customers Served by Branch



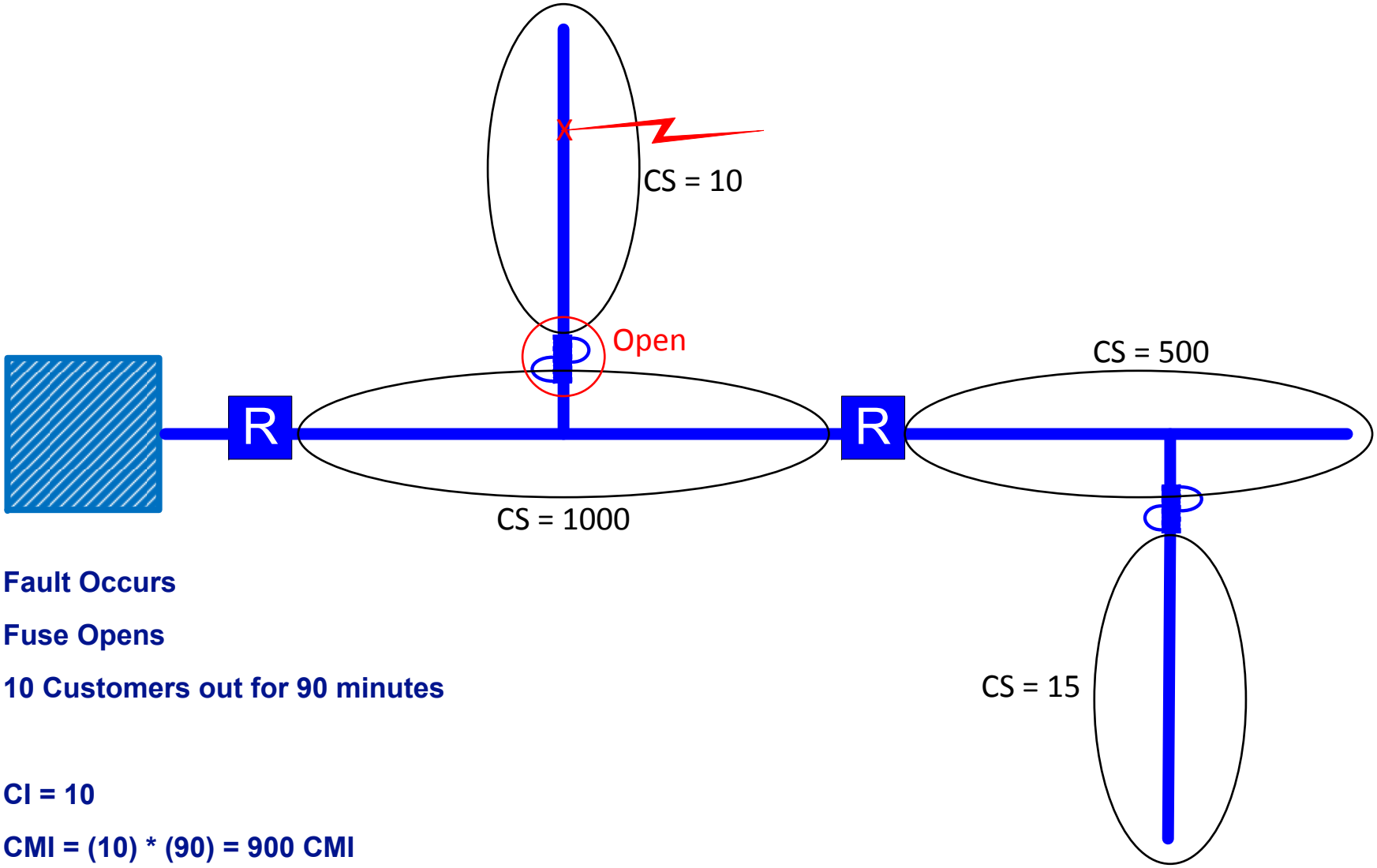
Total Customers Served= 1525

Simple Fault



Fault Occurs

Simple Fault



Fault Occurs

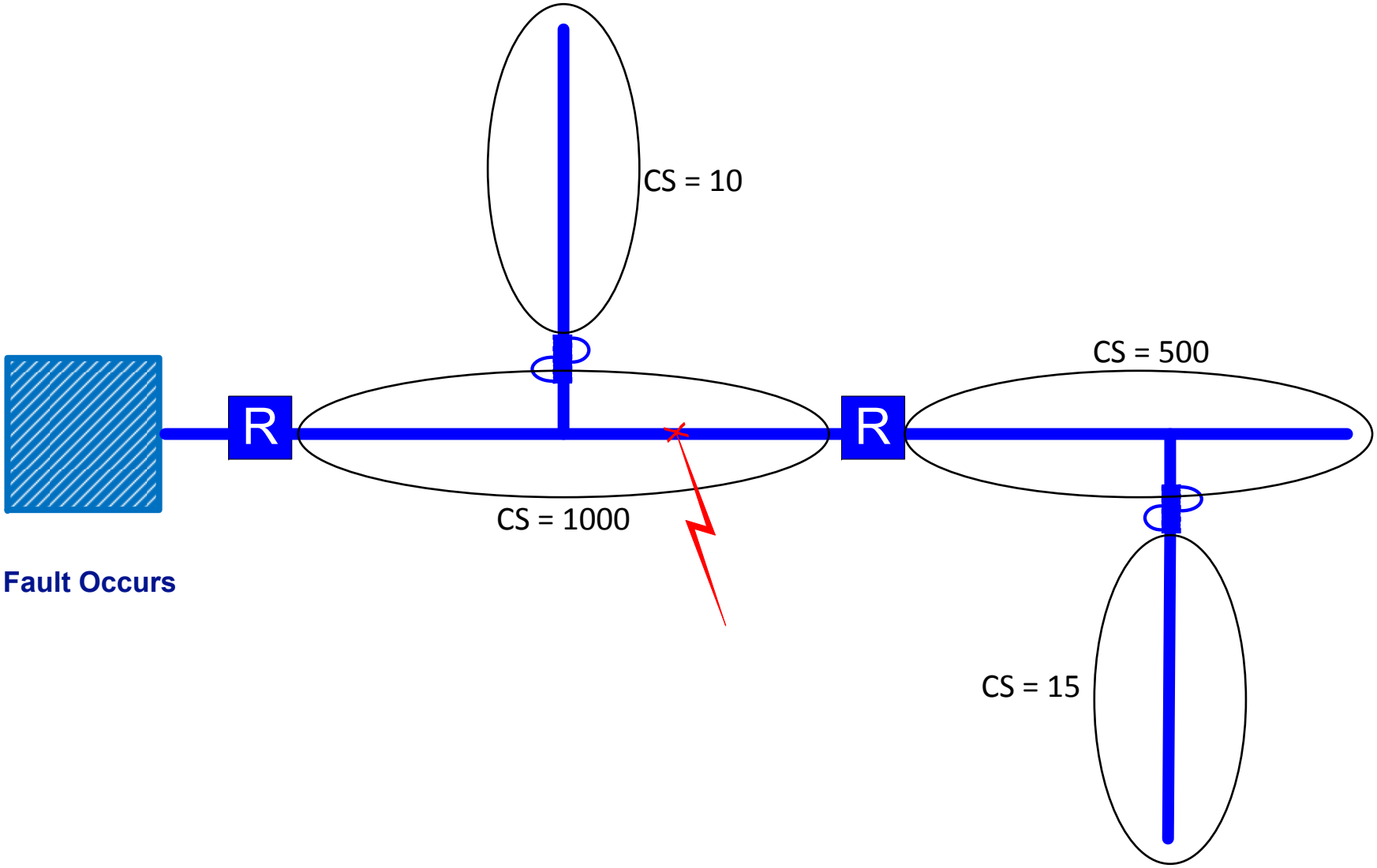
Fuse Opens

10 Customers out for 90 minutes

CI = 10

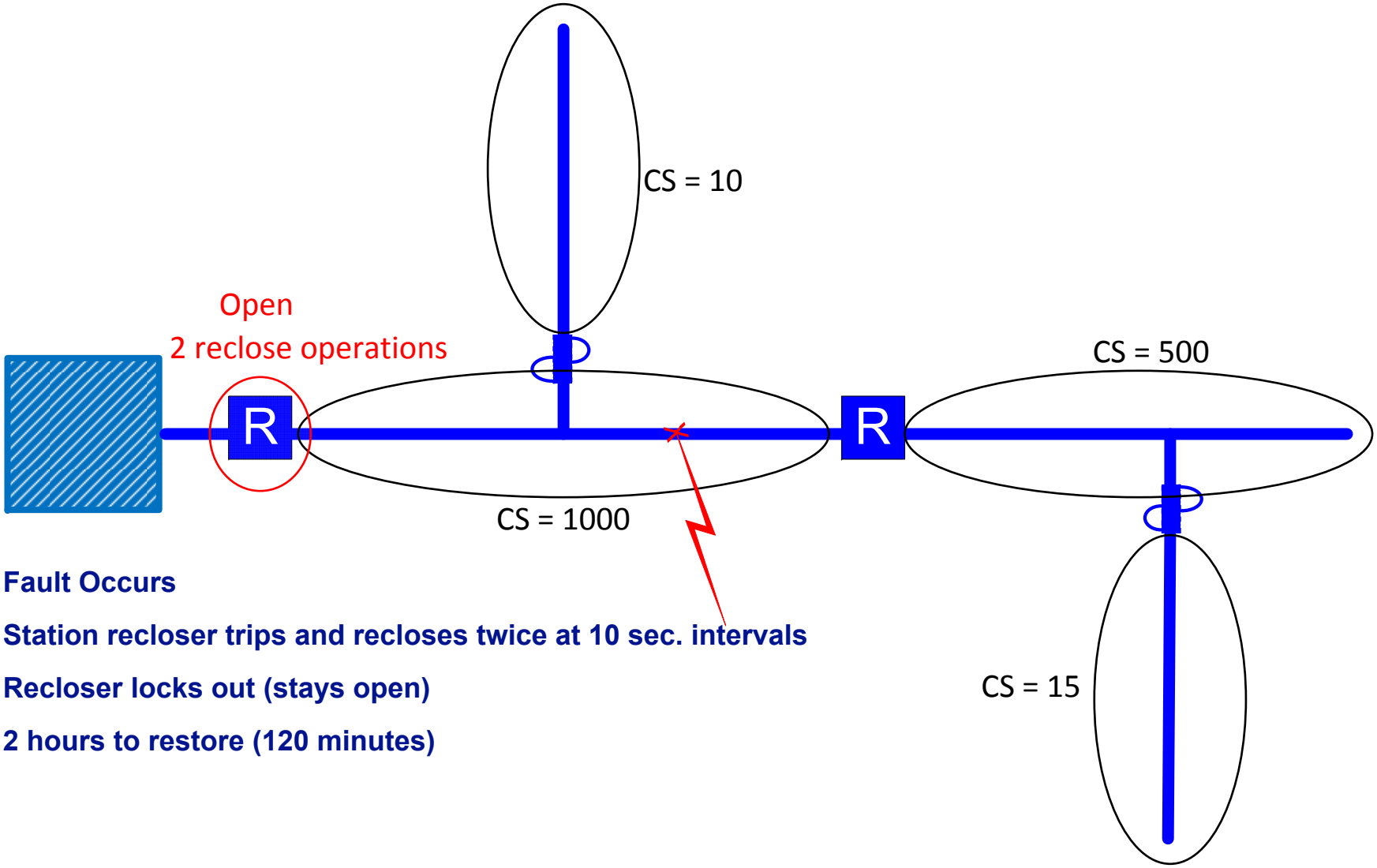
CMI = (10) * (90) = 900 CMI

Recloser Operation



Fault Occurs

Recloser Operation



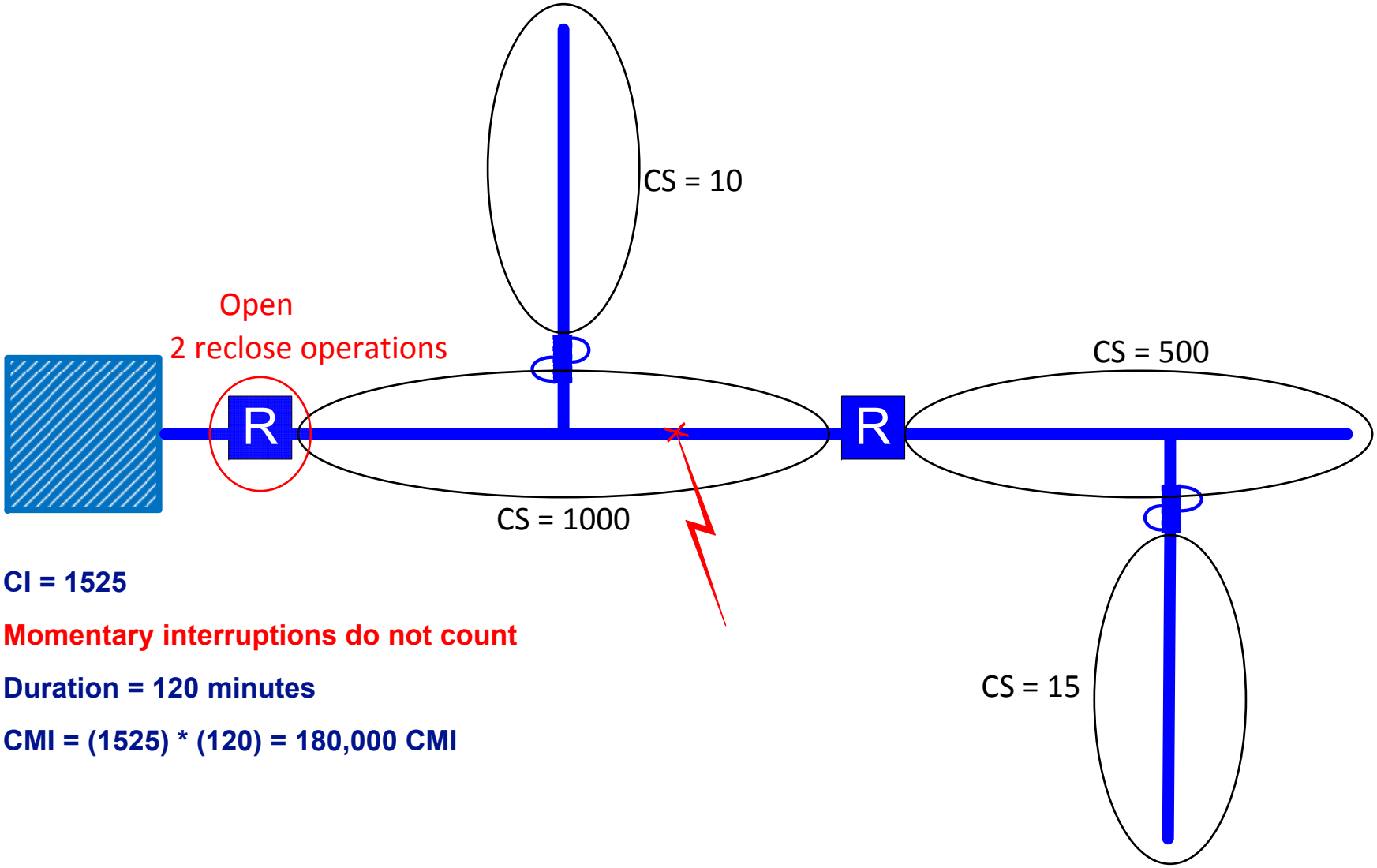
Fault Occurs

Station recloser trips and recloses twice at 10 sec. intervals

Recloser locks out (stays open)

2 hours to restore (120 minutes)

Recloser Operation



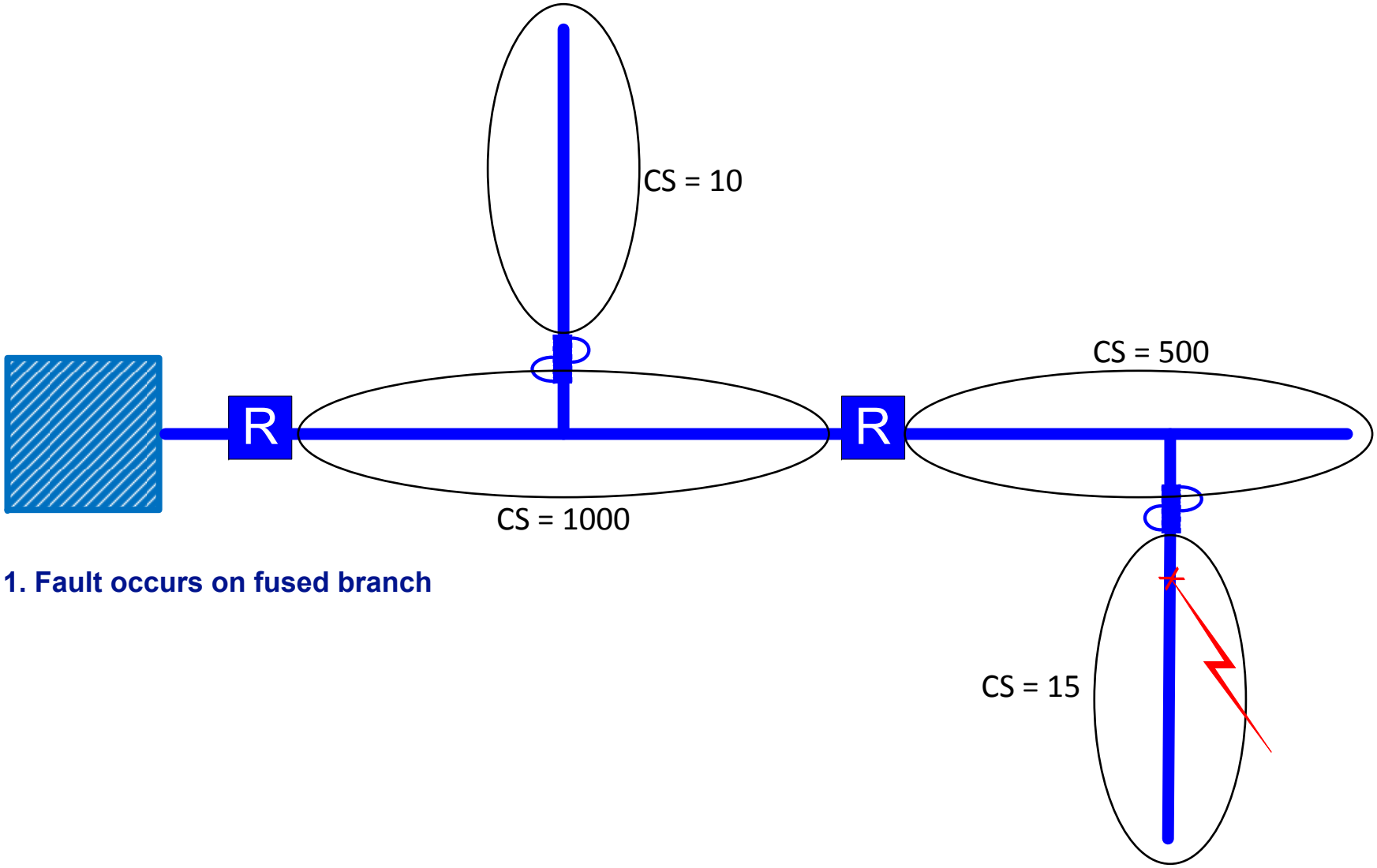
CI = 1525

Momentary interruptions do not count

Duration = 120 minutes

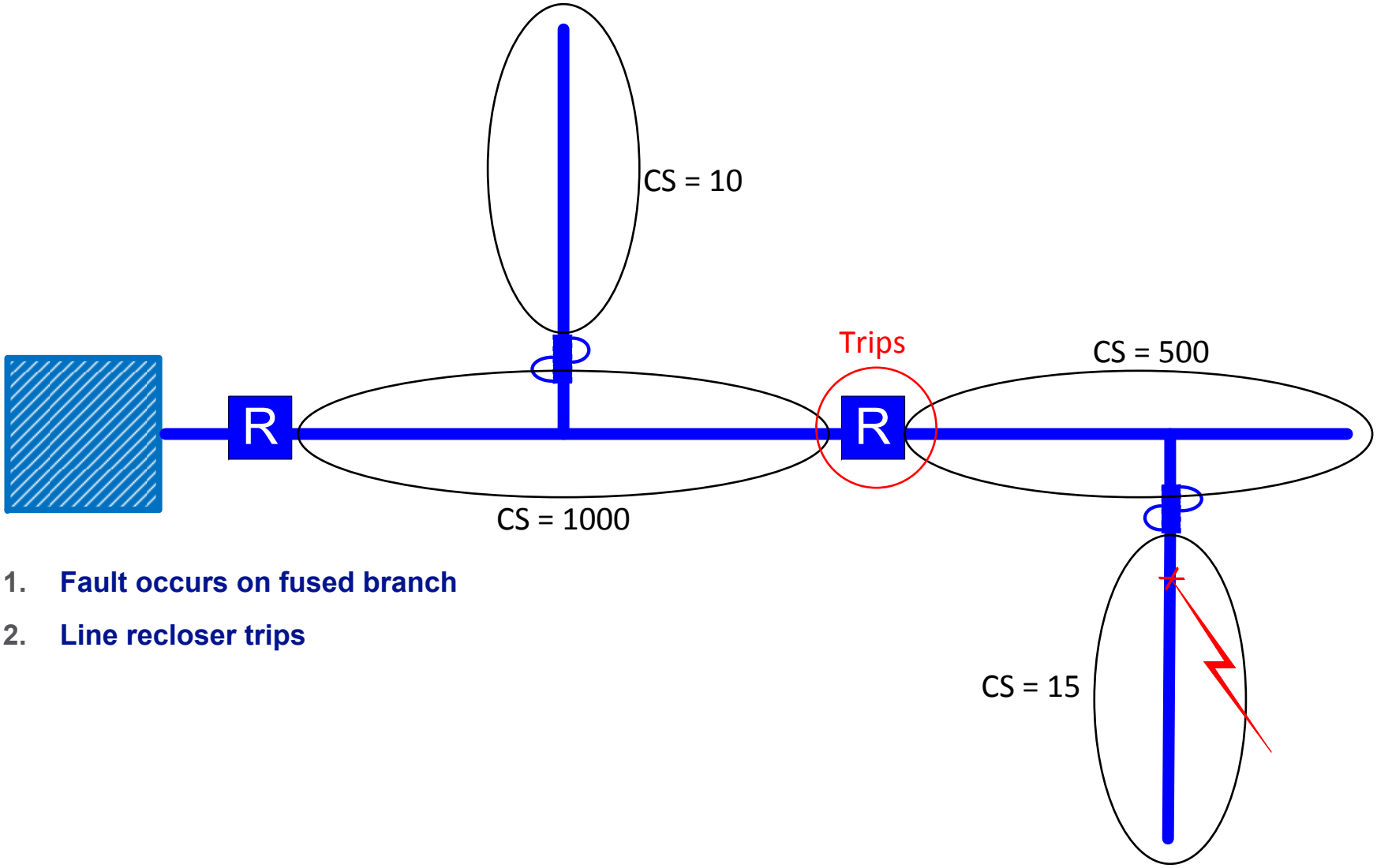
CMI = (1525) * (120) = 180,000 CMI

Recloser With Fuse Save



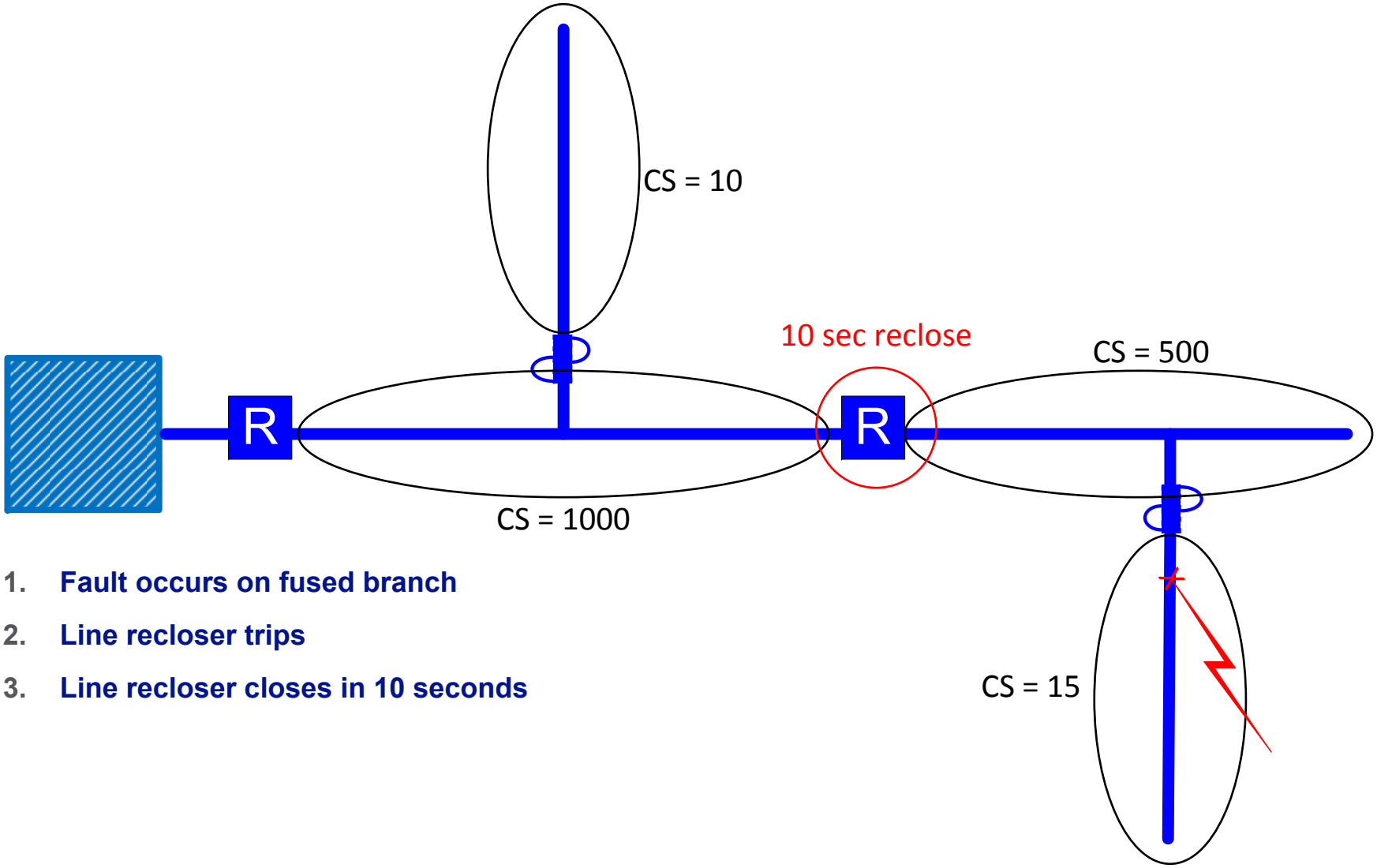
1. Fault occurs on fused branch

Recloser With Fuse Save



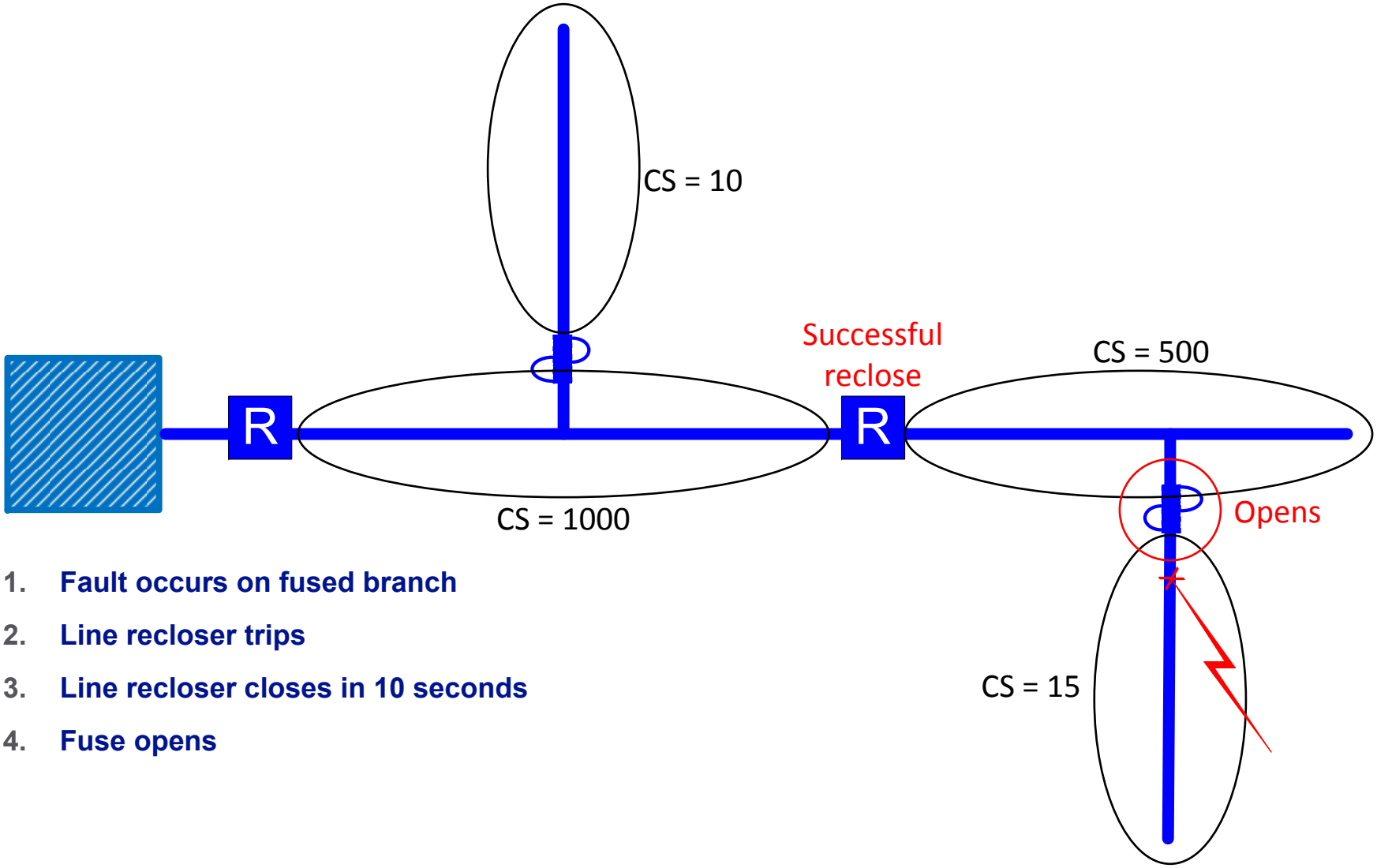
1. **Fault occurs on fused branch**
2. **Line recloser trips**

Recloser With Fuse Save



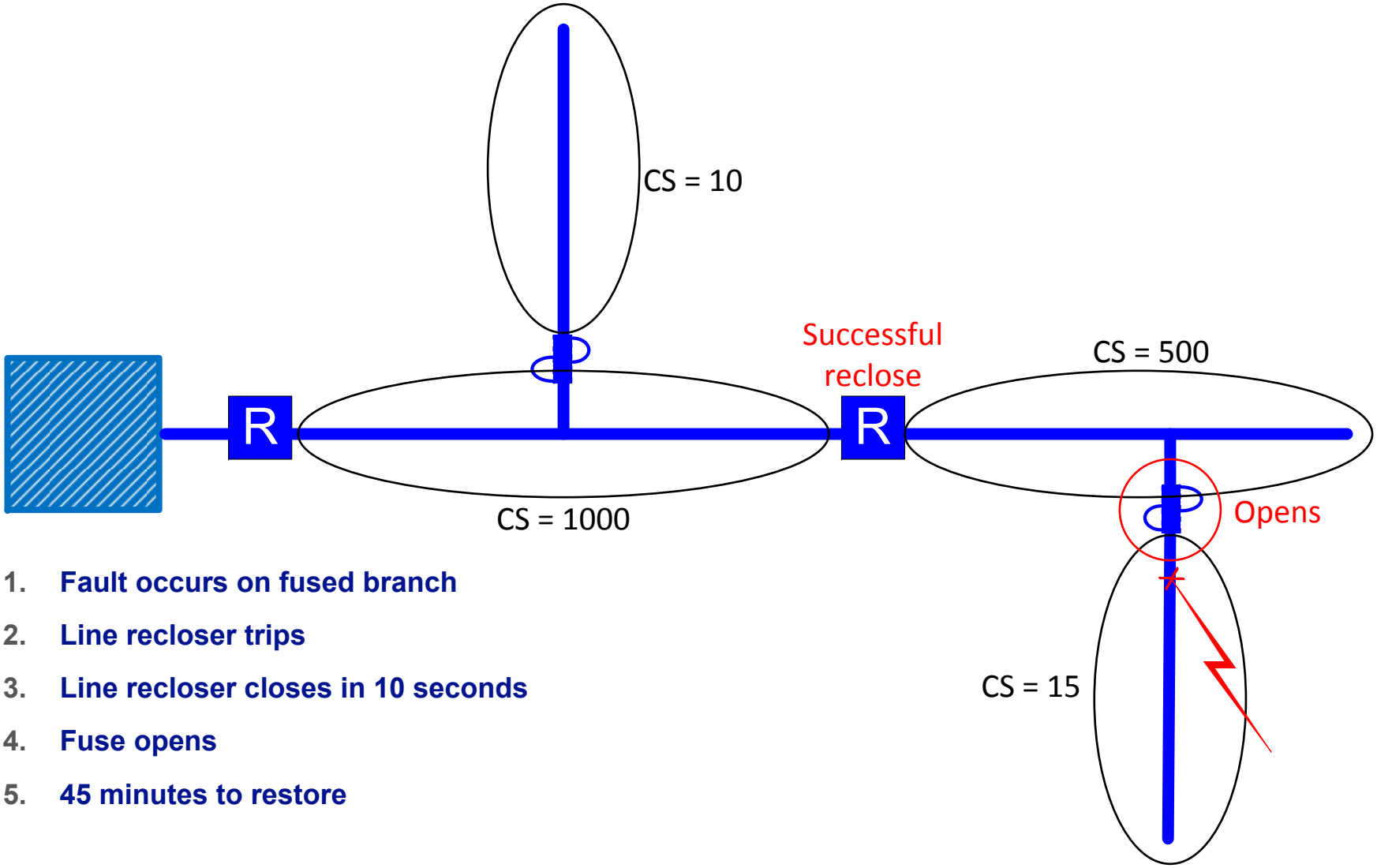
1. **Fault occurs on fused branch**
2. **Line recloser trips**
3. **Line recloser closes in 10 seconds**

Recloser With Fuse Save



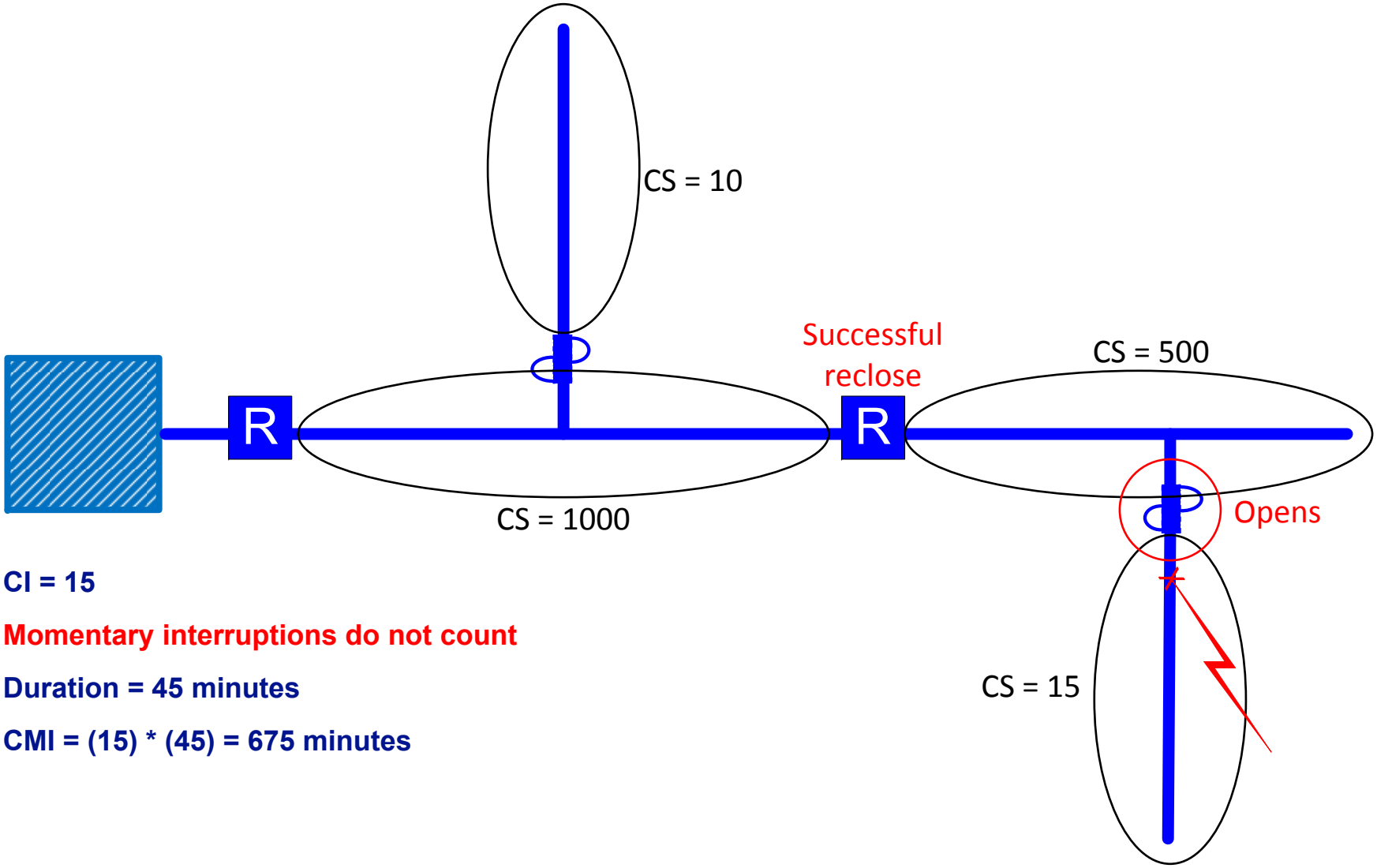
1. **Fault occurs on fused branch**
2. **Line recloser trips**
3. **Line recloser closes in 10 seconds**
4. **Fuse opens**

Recloser With Fuse Save



1. **Fault occurs on fused branch**
2. **Line recloser trips**
3. **Line recloser closes in 10 seconds**
4. **Fuse opens**
5. **45 minutes to restore**

Recloser With Fuse Save



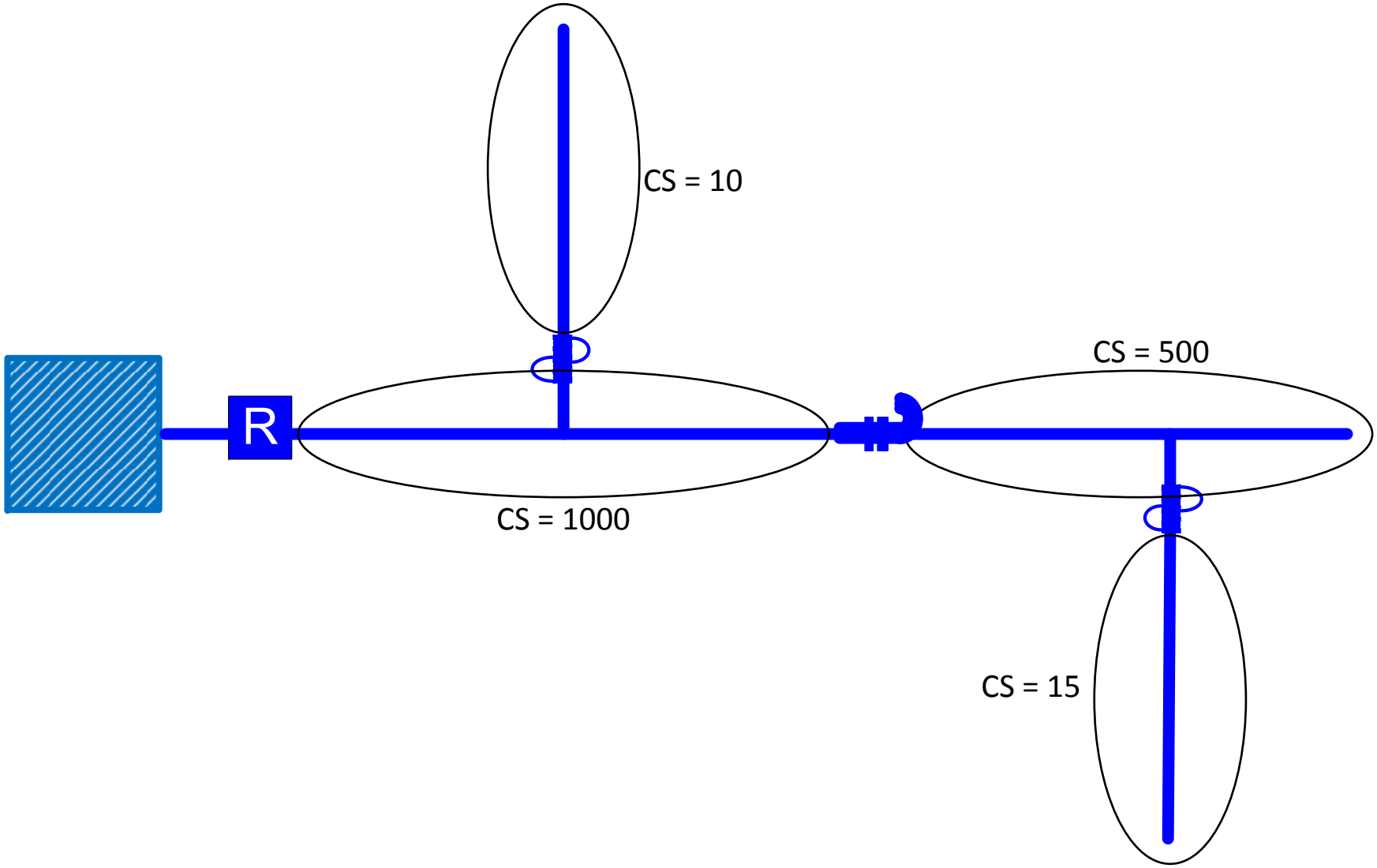
CI = 15

Momentary interruptions do not count

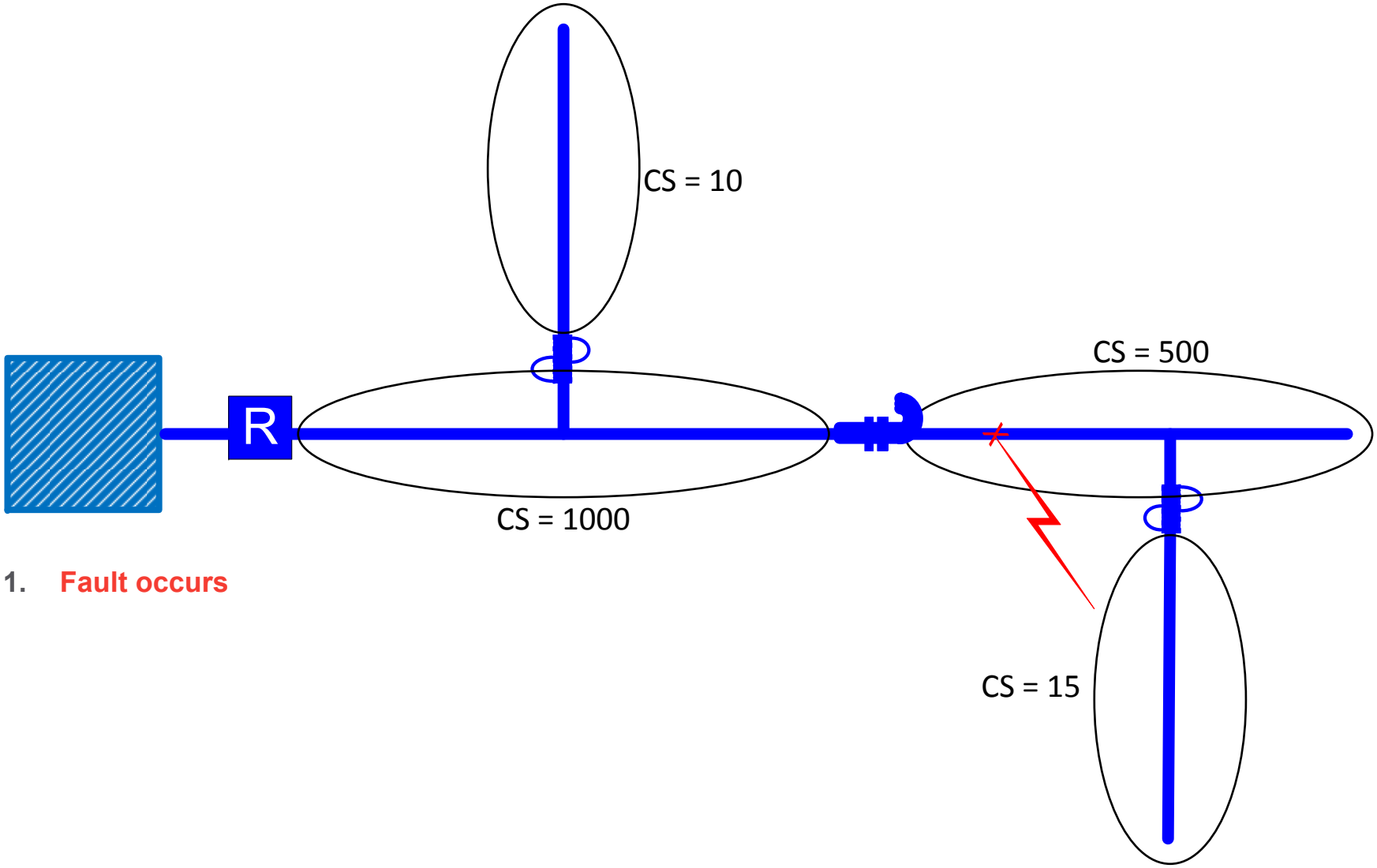
Duration = 45 minutes

CMI = (15) * (45) = 675 minutes

Step Restoration

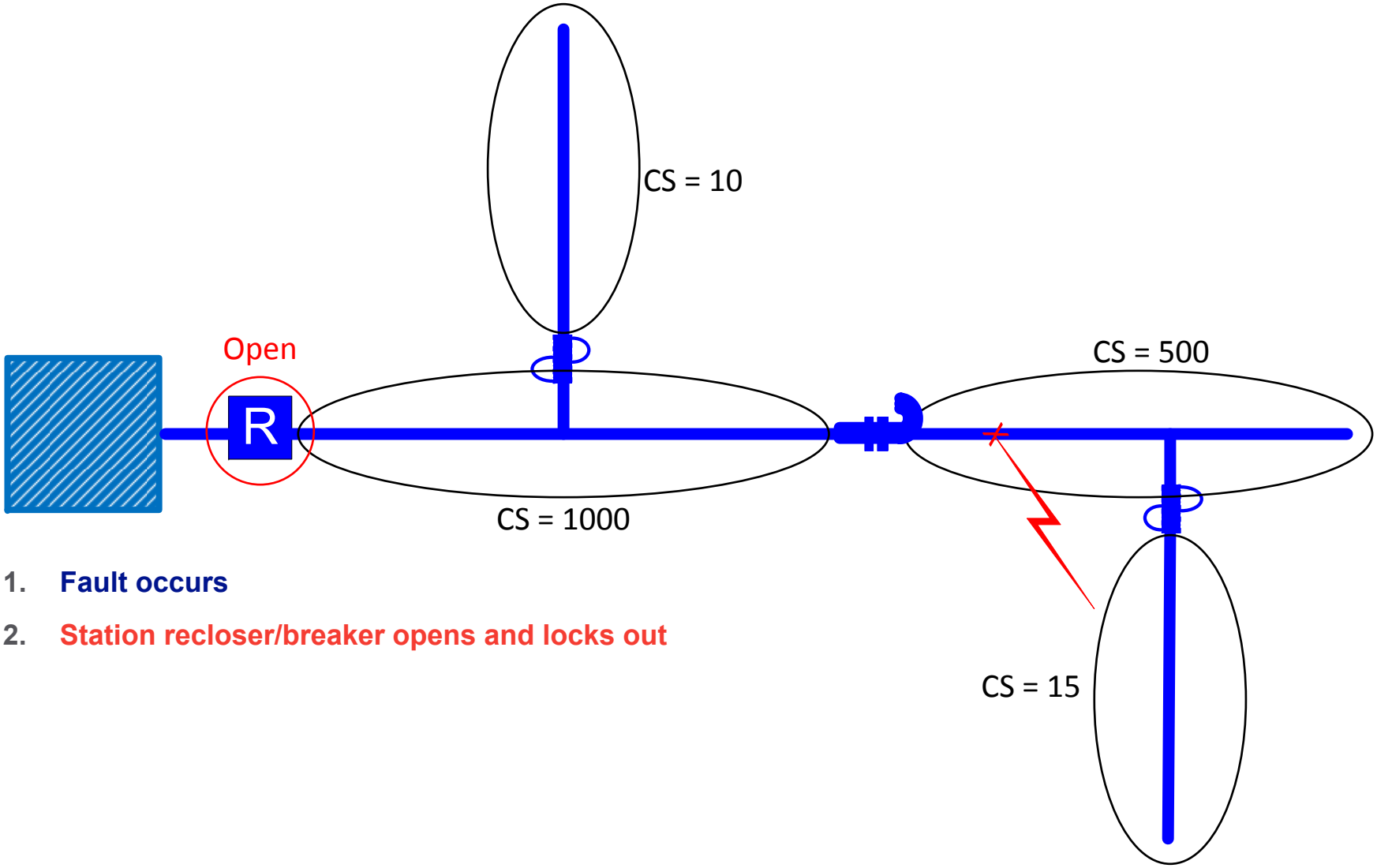


Step Restoration



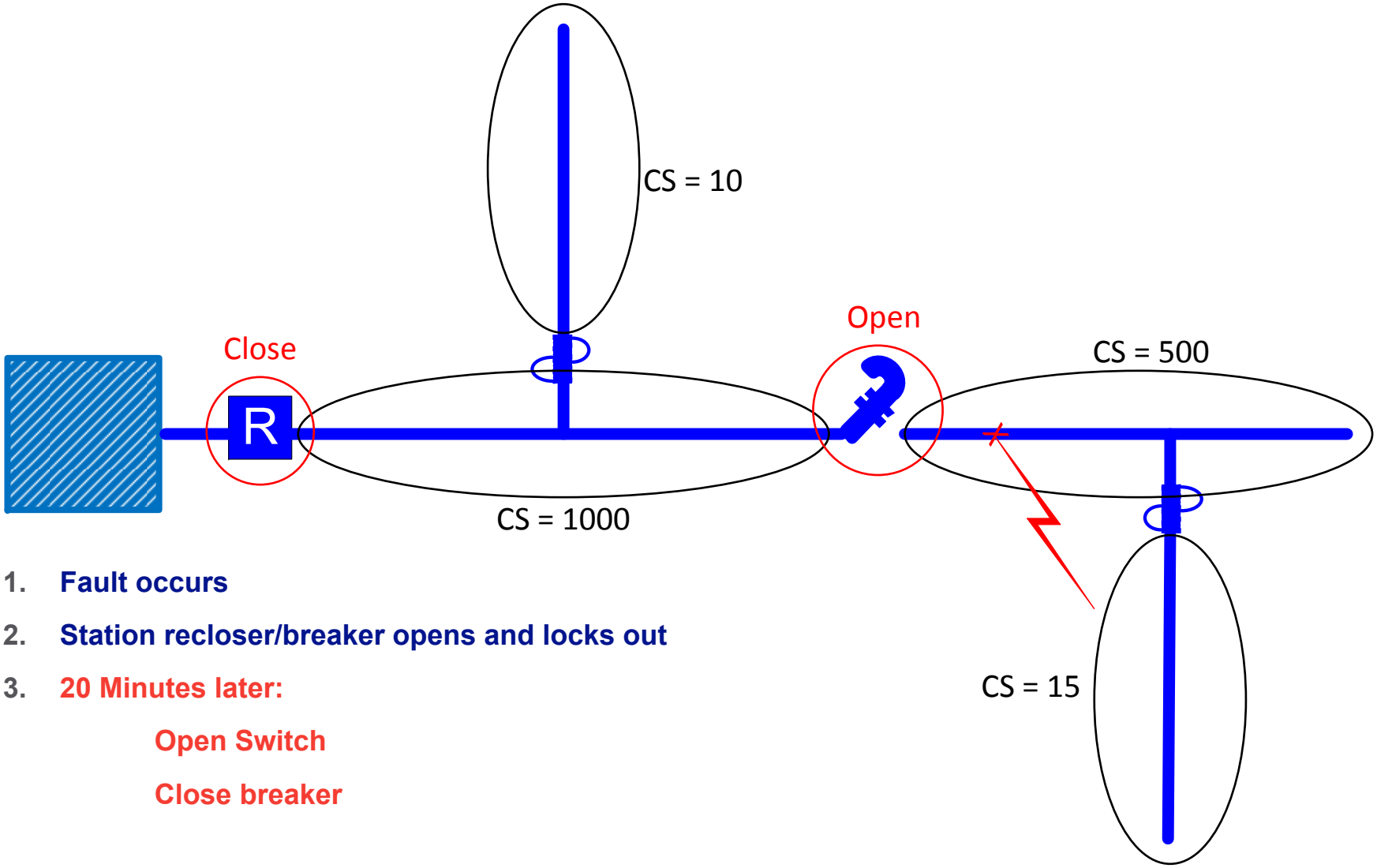
1. **Fault occurs**

Step Restoration



1. **Fault occurs**
2. **Station recloser/breaker opens and locks out**

Step Restoration

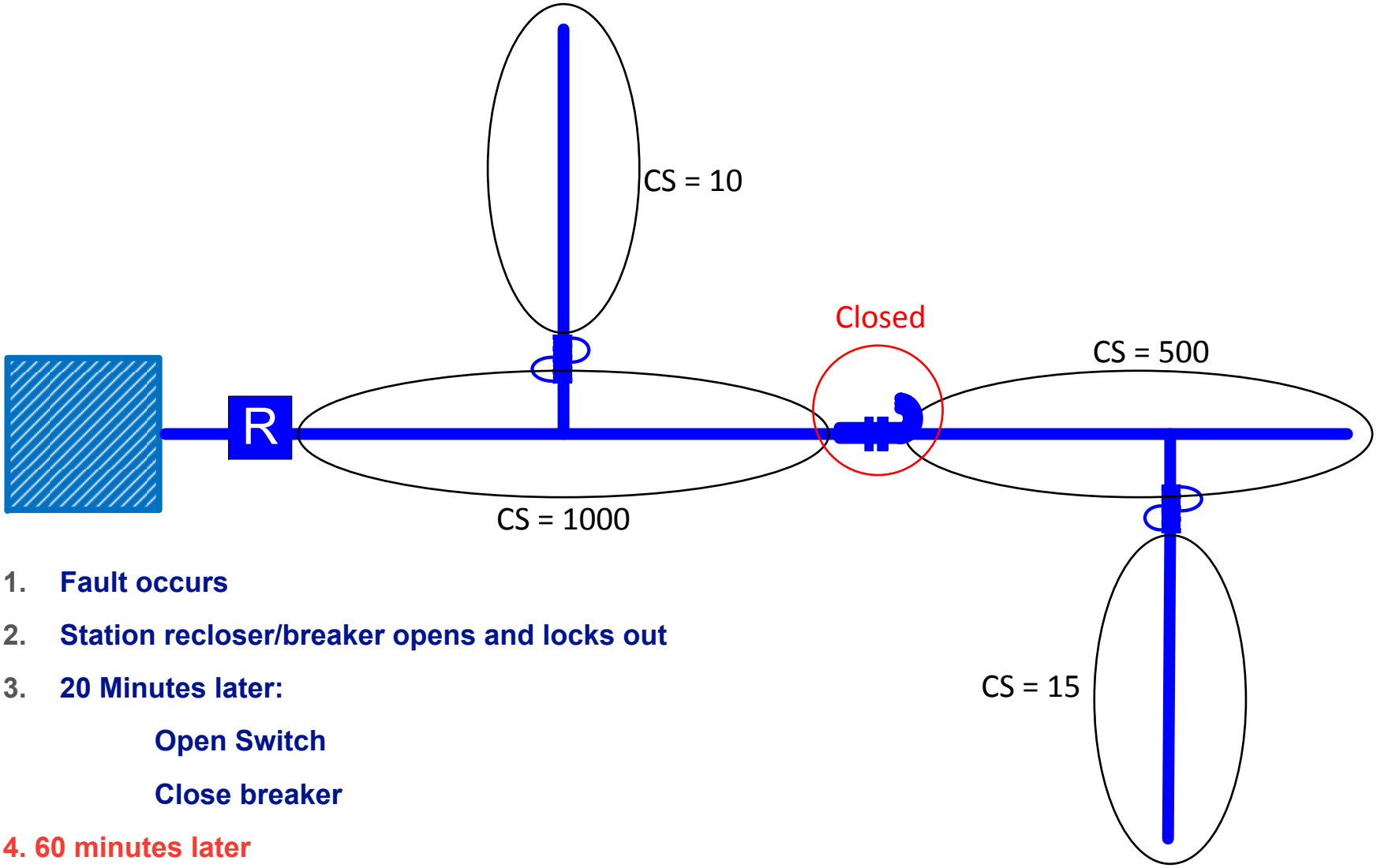


1. **Fault occurs**
2. **Station recloser/breaker opens and locks out**
3. **20 Minutes later:**

   Open Switch

   Close breaker

Step Restoration

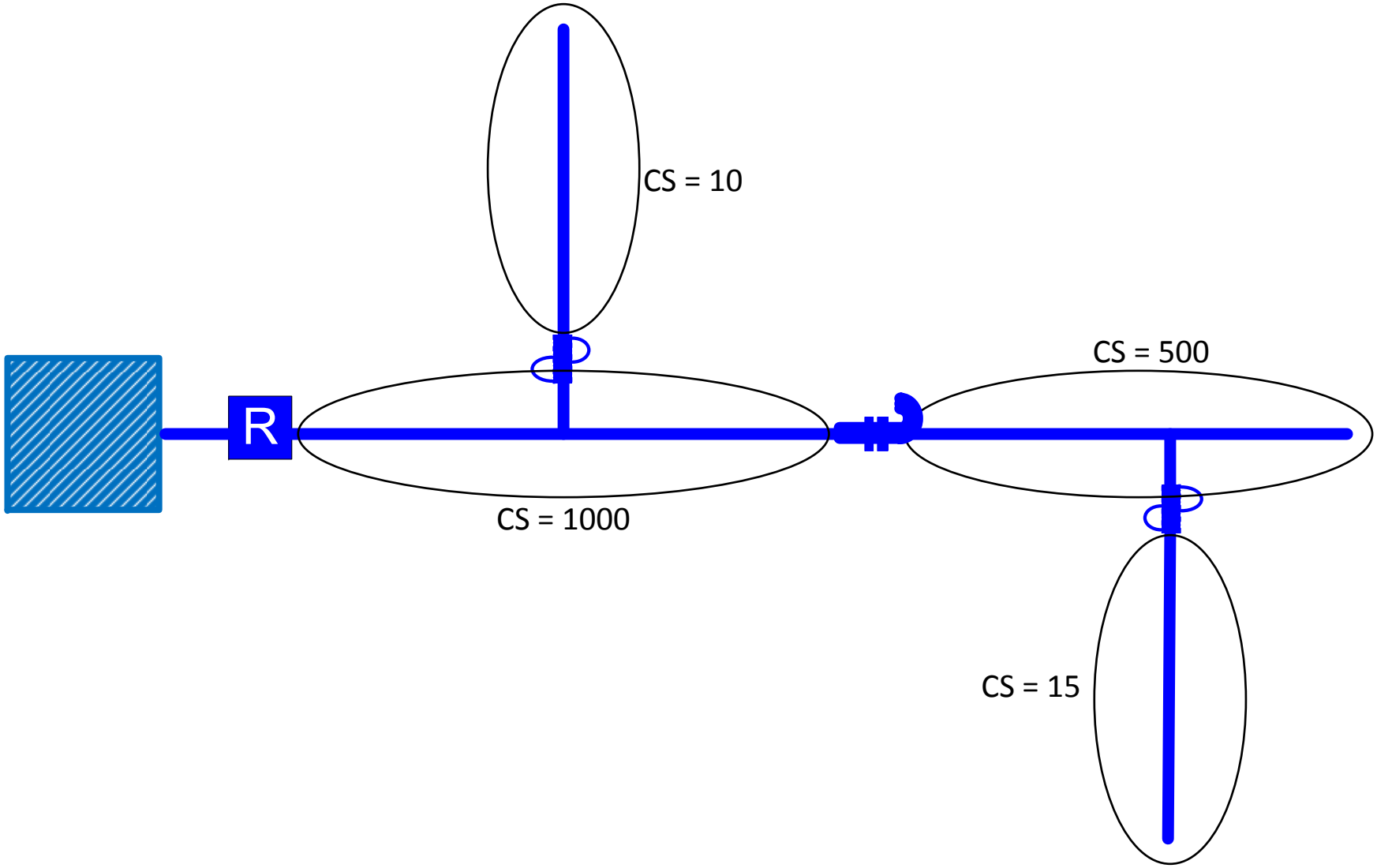


1. **Fault occurs**
2. **Station recloser/breaker opens and locks out**
3. **20 Minutes later:**
   - **Open Switch**
   - **Close breaker**

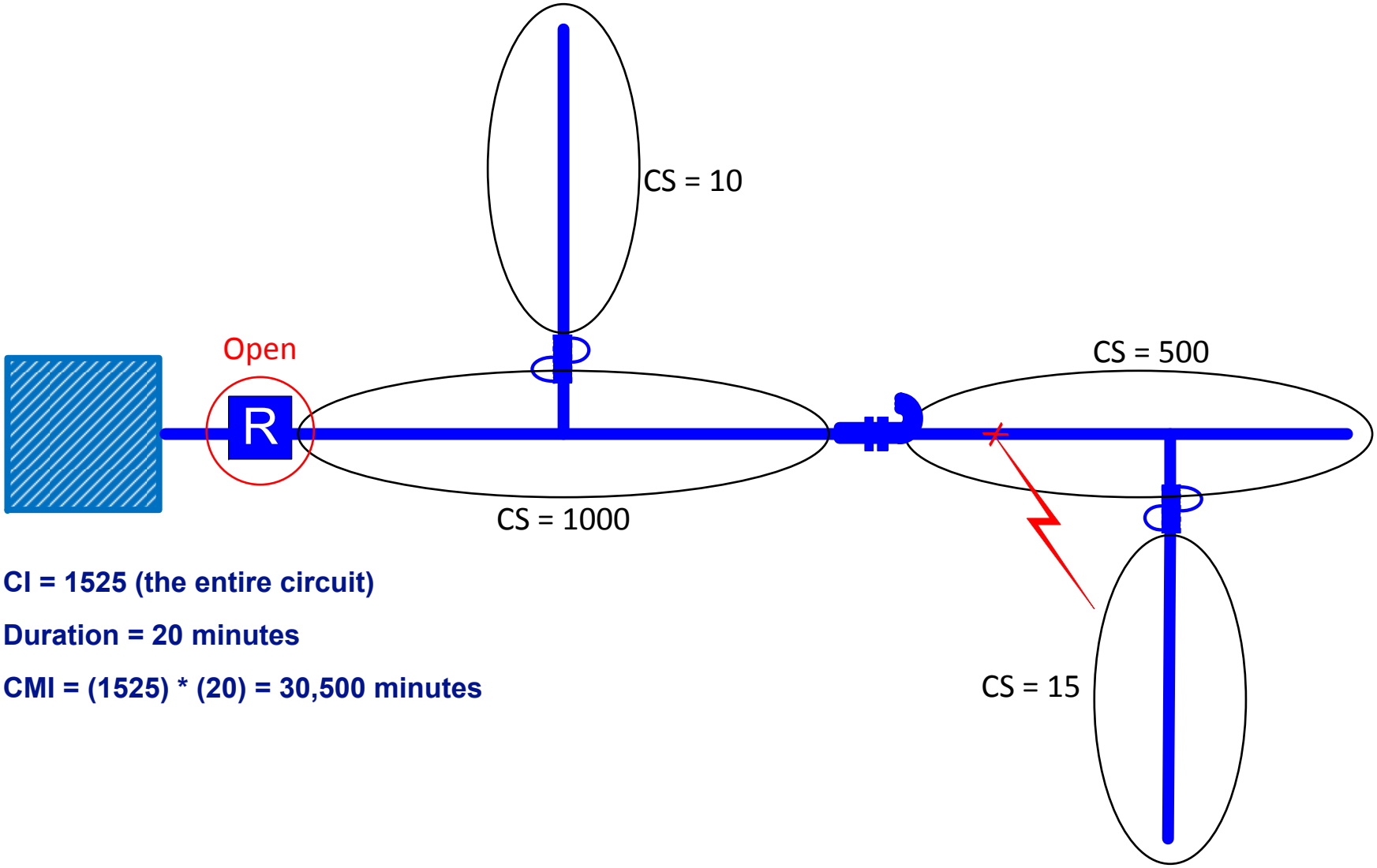
4. 60 minutes later

- **Close switch**
- **All customers restored**

Step Restoration



Step 1

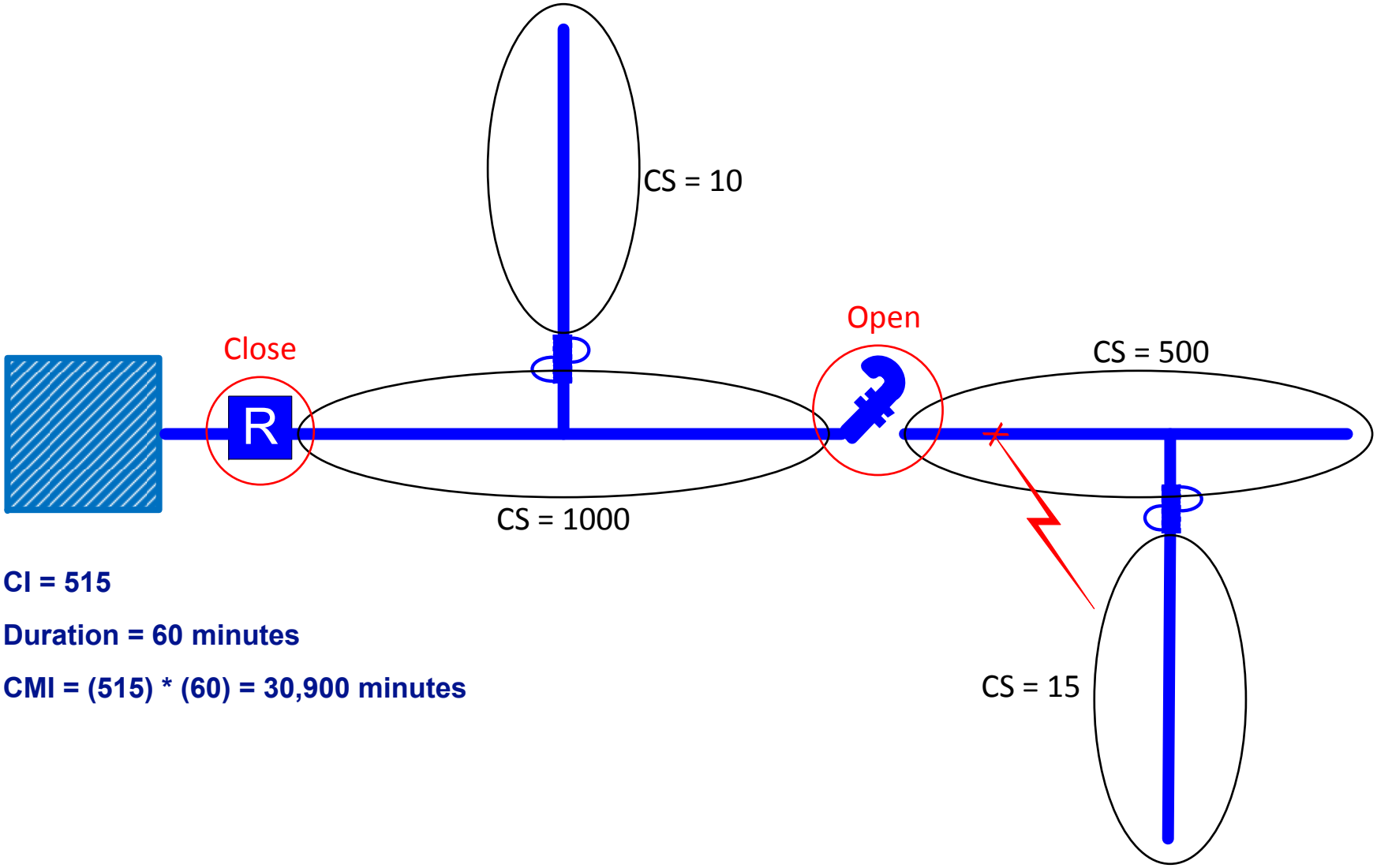


CI = 1525 (the entire circuit)

Duration = 20 minutes

CMI = (1525) * (20) = 30,500 minutes

Step 2

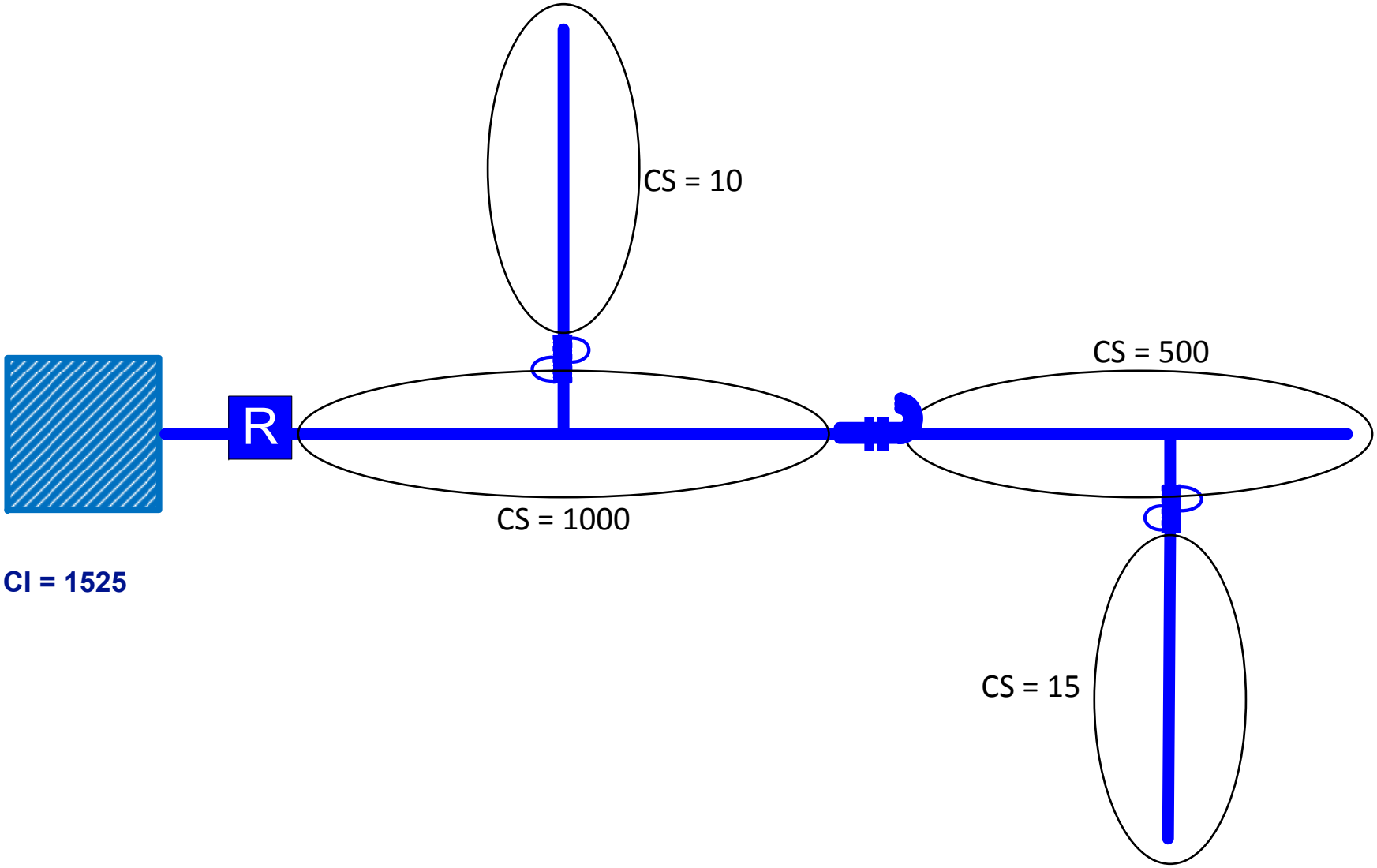


CI = 515

Duration = 60 minutes

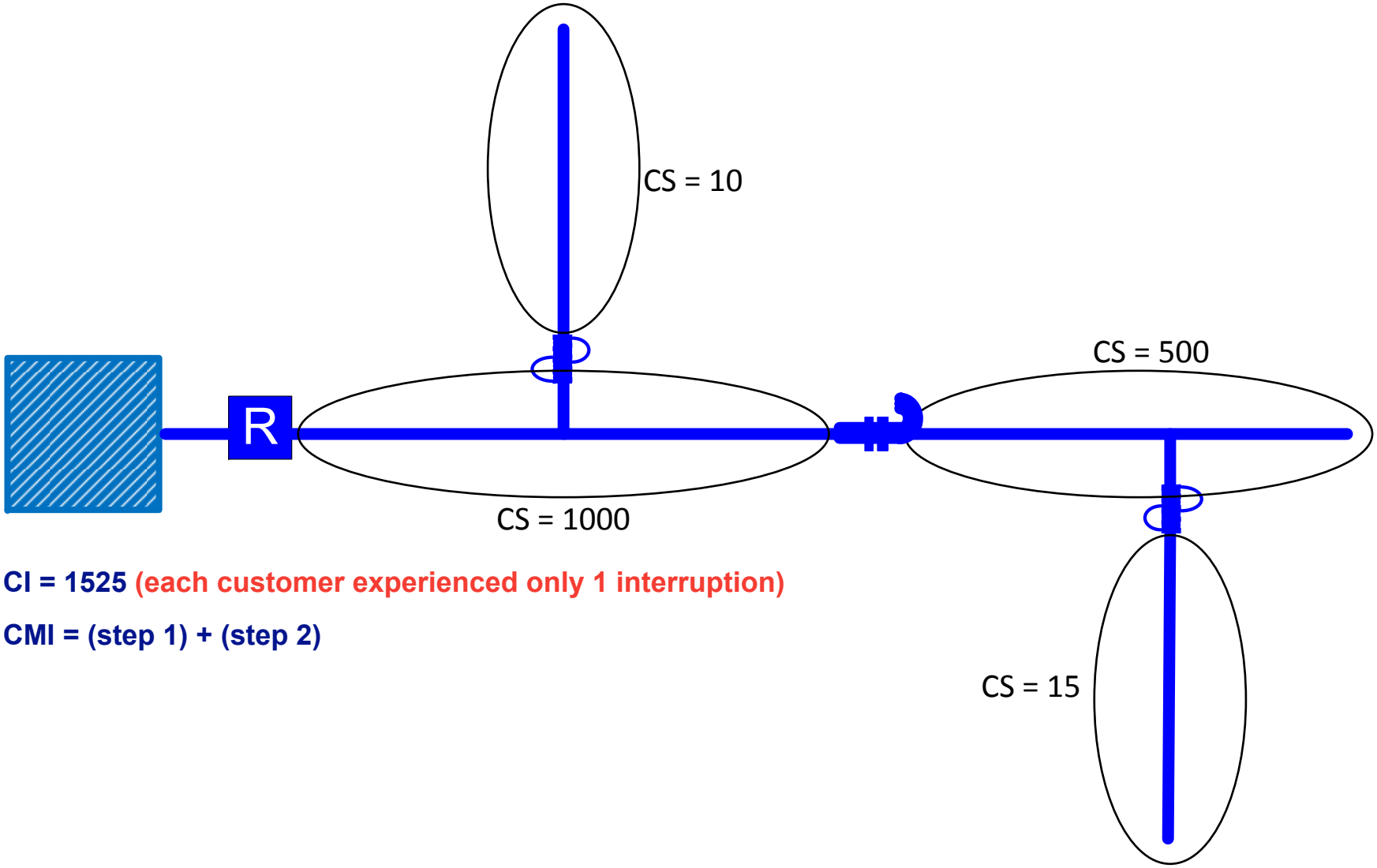
CMI = (515) * (60) = 30,900 minutes

Event Total



CI = 1525

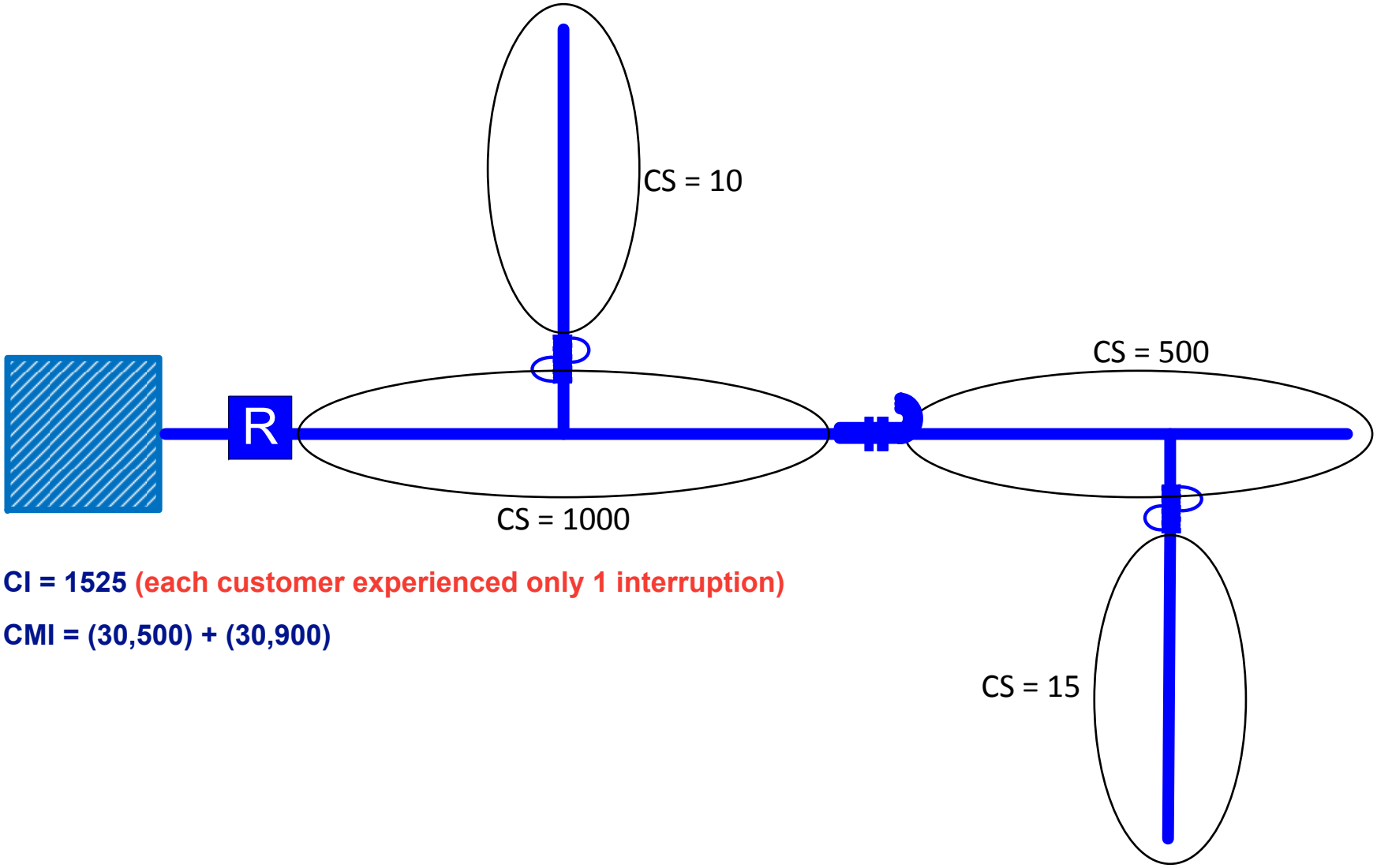
Event Total



CI = 1525 **(each customer experienced only 1 interruption)**

CMI = (step 1) + (step 2)

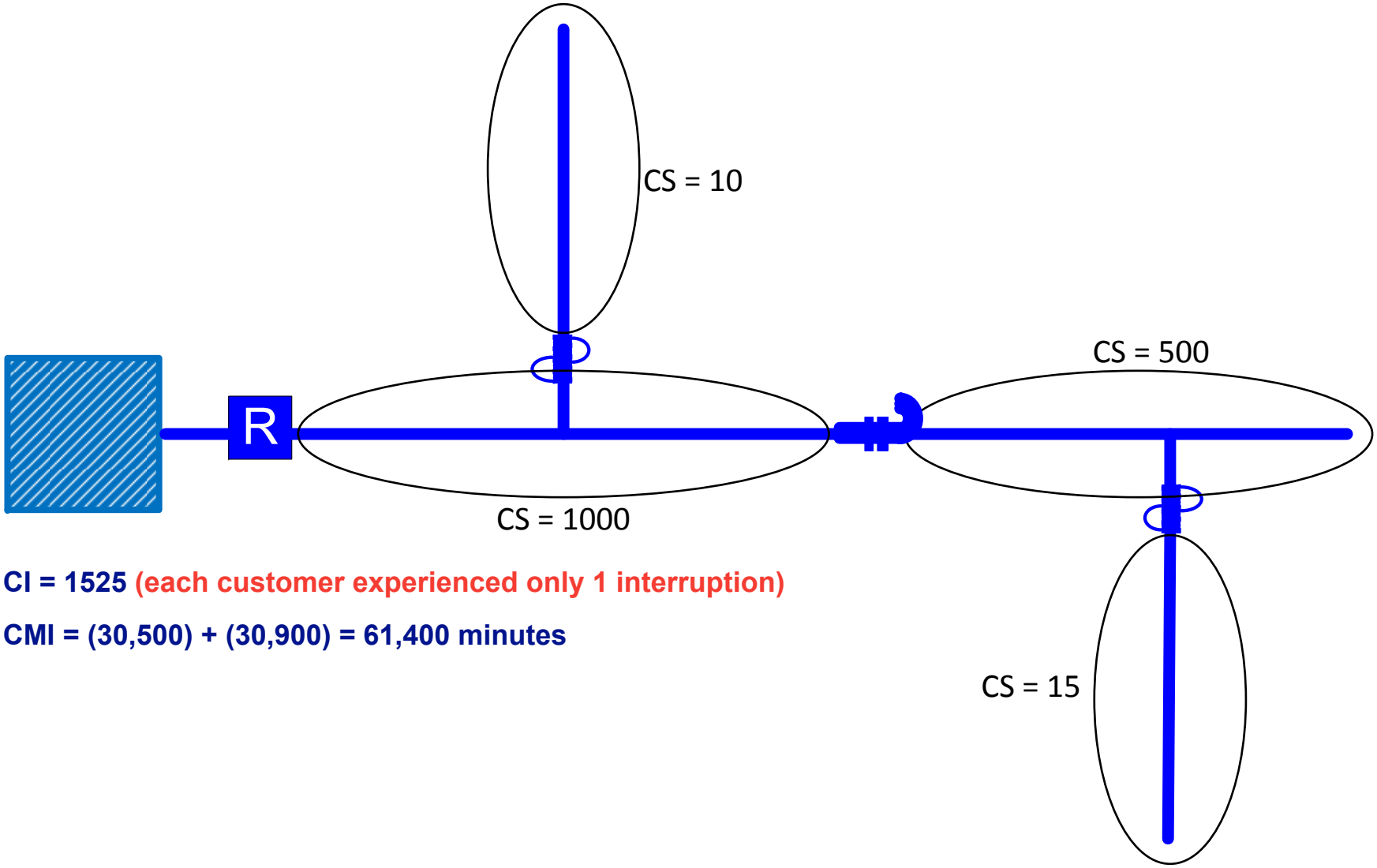
Event Total



CI = 1525 **(each customer experienced only 1 interruption)**

CMI = (30,500) + (30,900)

Event Total



CI = 1525 (each customer experienced only 1 interruption)

CMI = (30,500) + (30,900) = 61,400 minutes

Calculating SAIFI, SAIDI and CAIDI

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Total of All Events

4 events in our universe:

Event	Type	CI	CMI
1	Fuse Branch	10	900
2	Feeder Outage	1,525	180,000
3	Fuse Save	15	675
4	Step Restoration	1,525	61,400
	Total	3,075	242,975

Assume that this is the only feeder in our system

Calculate SAIFI, SAIDI, and CAIDI

Calculate: SAIFI, SAIDI, CAIDI

CS = 1,525

CI = 3,075

CMI = 242,975

$$SAIFI = \frac{\text{CI}}{\text{CS}} = \frac{3075}{1525} = 2.02$$

$$SAIDI = \frac{\text{CMI}}{CS} = \frac{242975}{1525} = 159$$

$$CAIDI = \frac{CMI}{CI} = \frac{242975}{3075} = 79$$

$$CAIDI = \frac{\text{SAIDI}}{\text{SAIFI}} = \frac{159}{2.02} = 79$$

Let’s Expand Our Universe

Four Feeders

Feeder	CS	CI	CMI
1	1,525	3,075	242,975
2	2,200	3,000	120,000
3	800	875	50,000
4	2,000	200	15,000

Let’s Expand Our Universe

Four Feeders

Feeder	CS	CI	CMI
1	1,525	3,075	242,975
2	2,200	3,000	120,000
3	800	875	50,000
4	2,000	200	15,000
Total	6,525	7,150	427,975

Maybe this is an entire utility, maybe it’s a town or district

Calculate: SAIFI, SAIDI, CAIDI

CS = 6,525

CI = 7,150

CMI = 427,975

$$SAIFI = \frac{\text{CI}}{\text{CS}} = \frac{7150}{6525} = 1.10$$

$$SAIDI = \frac{\text{CMI}}{CS} = \frac{427975}{6525} = 66$$

$$CAIDI = \frac{CMI}{CI} = \frac{427975}{7150} = 60$$

$$CAIDI = \frac{\text{SAIDI}}{\text{SAIFI}} = \frac{66}{1.10} = 60$$

Some Lesser Known Cousins

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CAIFI and CTAIDI

CAIFI: Customer Average Interruption Frequency Index

CTAIDI: Customer Total Average Interruption Duration Index

Similar to SAIFI and SAIDI EXCEPT Only includes customers that actually experienced an interruption

$$\text{CAIFI} = \frac{\text{CI}}{\text{Total number of distinct customers interrupted}}$$

$$\text{CTAIDI} = \frac{\text{CMI}}{\text{Total number of distinct customers interrupted}}$$

CAIFI and CTAIDI

Why?

Let's say that a company's overall reliability is:

SAIDI = 90 minutes

SAIFI = 1.5

But half the company is served by a secondary network that hasn't and an interruption in the past ten years.

Is that important?

Averages can deceive

$CEMI_n$ and CELID

$CEMI_n$: Customers Experiencing Multiple Interruptions

CELID: Customers Experiencing Long Interruption Durations

Intended to give a view of the relative number of customers with reliability below some threshold

$$\text{CEMIn} = \frac{\text{Tot num of customers that experienced n or more sustained interruptions}}{\text{CS}}$$

$$\text{CELID} = \frac{\text{Tot num customers that experienced S or more hours duration}}{\text{CS}}$$

These are both measured in PERCENT

Momentary: MAIFI, $MAIFI_E$, $CEMSMI_n$

MAIFI: Momentary Average Interruption Frequency Index

$MAIFI_E$: Momentary Average Interruption Event Frequency Index

$CEMSMI_n$: Customers Experiencing Multiple Sustained Interruption and Momentary Interruption Events

Momentary: MAIFI, $MAIFI_E$, $CEMSMI_n$

MAIFI: Momentary Average Interruption Frequency Index- Similar to SAIFI

$MAIFI_E$: Momentary Average Interruption Event Frequency Index- Excludes momentaries associated with a sustained interruption (counts events)

$CEMSMI_n$: Customers Experiencing Multiple Sustained Interruption and Momentary Interruption Events- Similar to $CEMI_n$

Load Based: ASIFI, ASIDI

ASIFI: Average System Interruption Frequency Index

ASIDI: Average System Interruption Duration Index

Similar to SAIFI and SAIDI but based on kVA rather than customers

$$\text{ASIFI} = \frac{\text{Total connected kVA of load interrupted}}{\text{Total connected kVA served}} = \frac{(\text{kVA})}{(\text{kVA})}$$

$$\text{ASIDI} = \frac{\text{Connected kVA duration of load interrupted}}{\text{Total connected kVA served}} = \frac{(\text{kVA})(\text{Minutes})}{(\text{kVA})}$$

Lies, Damn Lies, and Statistics

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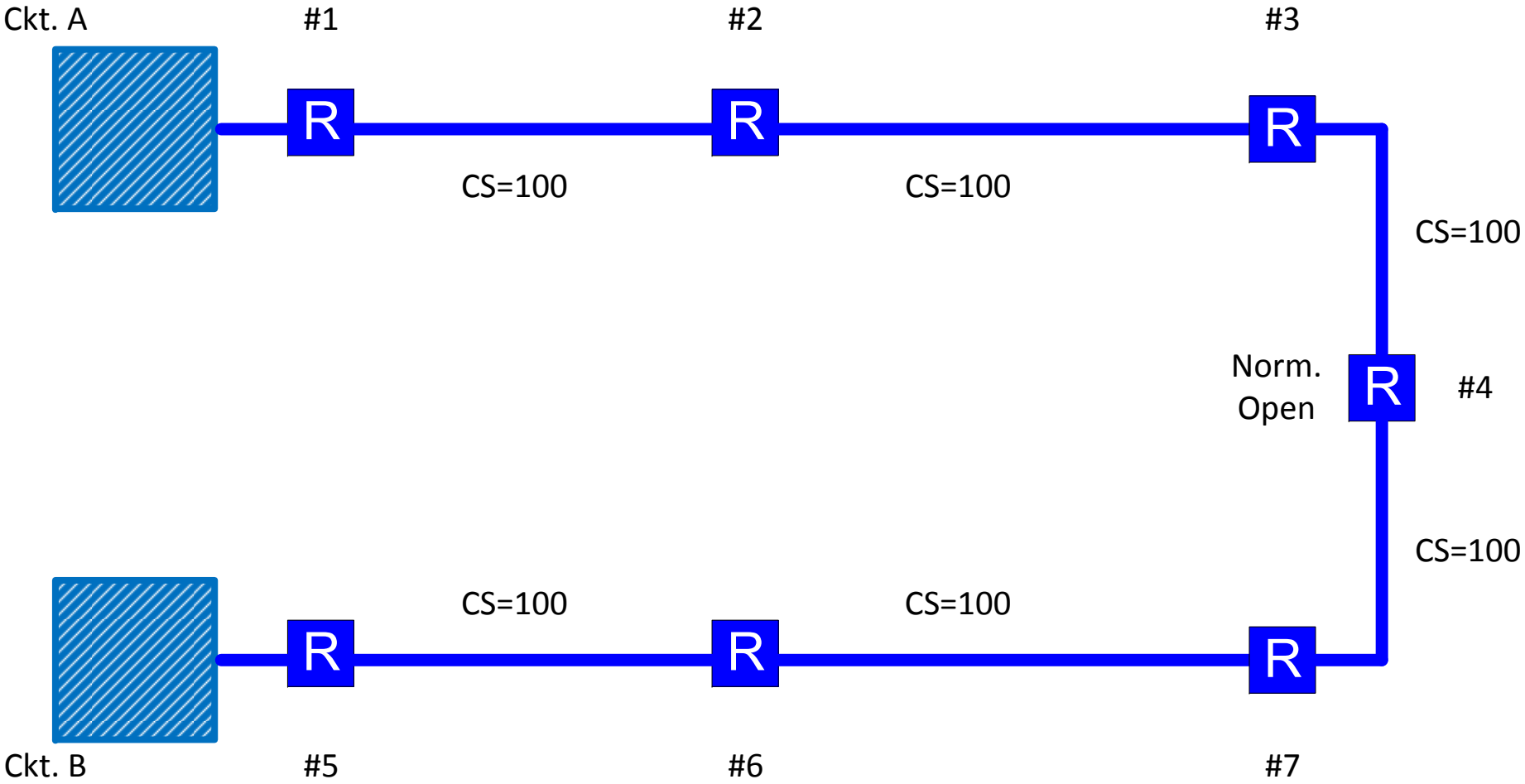
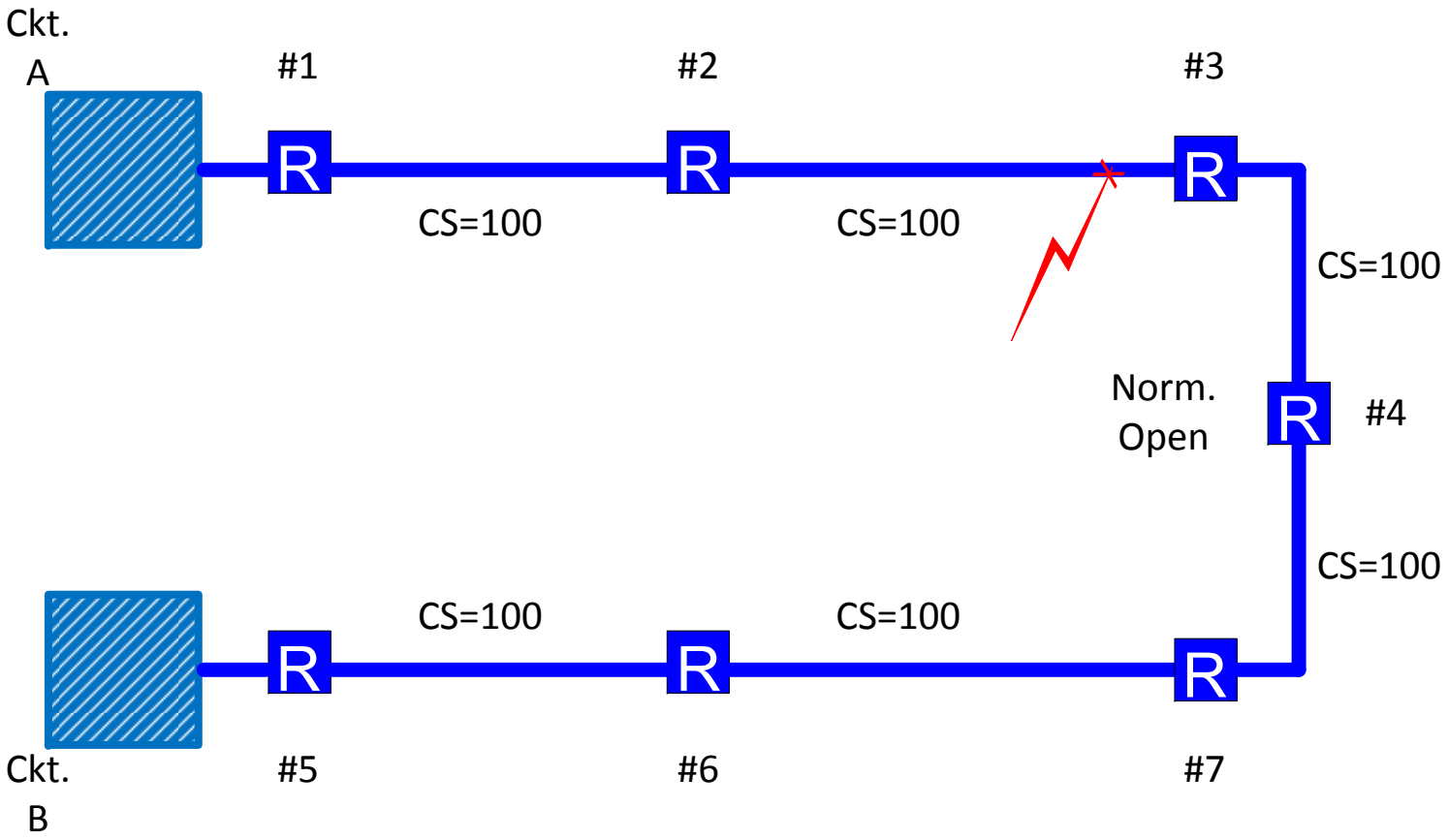
Effect of Distribution Automation



Simple two feeder system

CS = 600

Seven switches

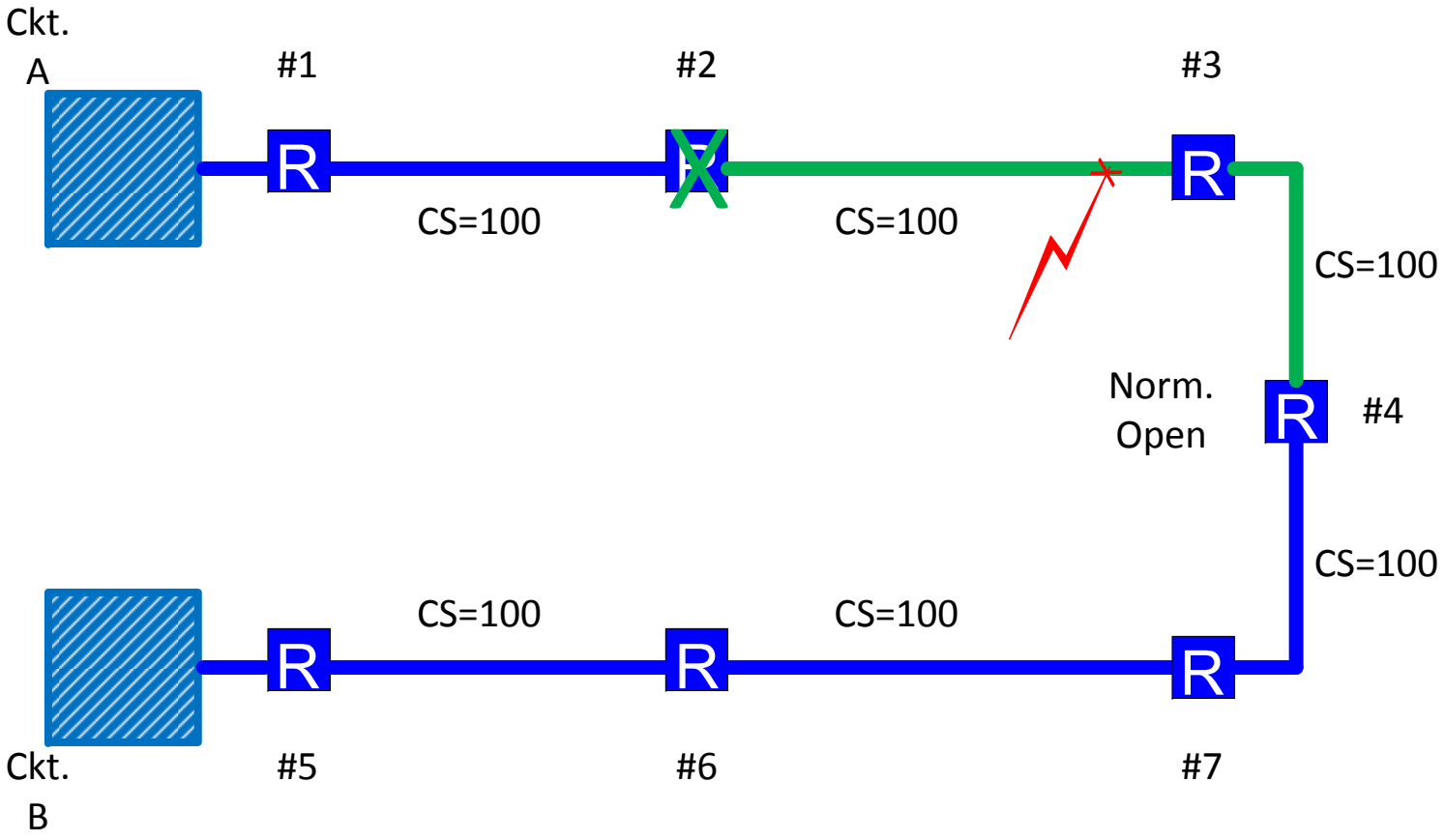


Assume:

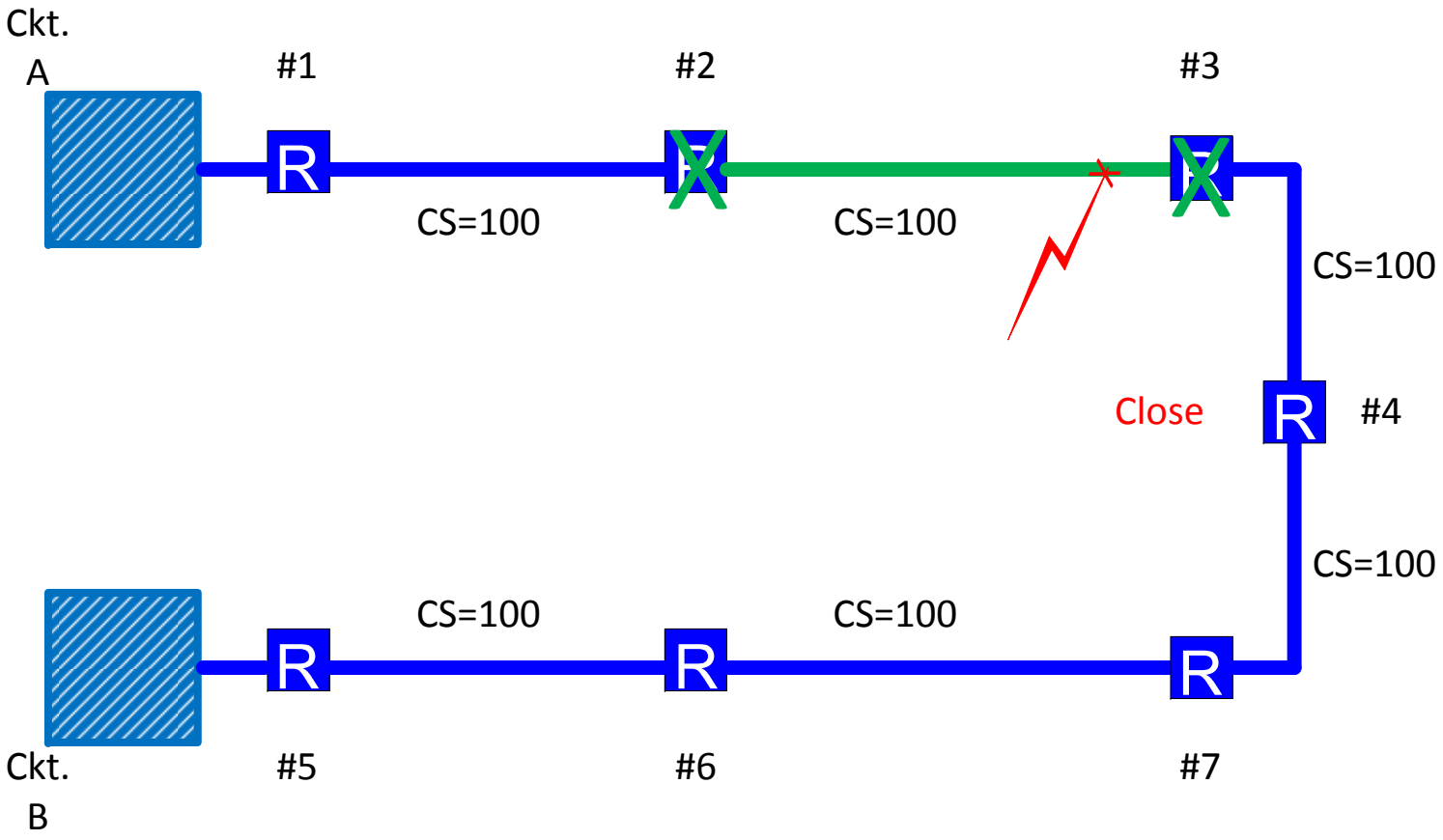
No automation

Manual switching time: 20 minutes

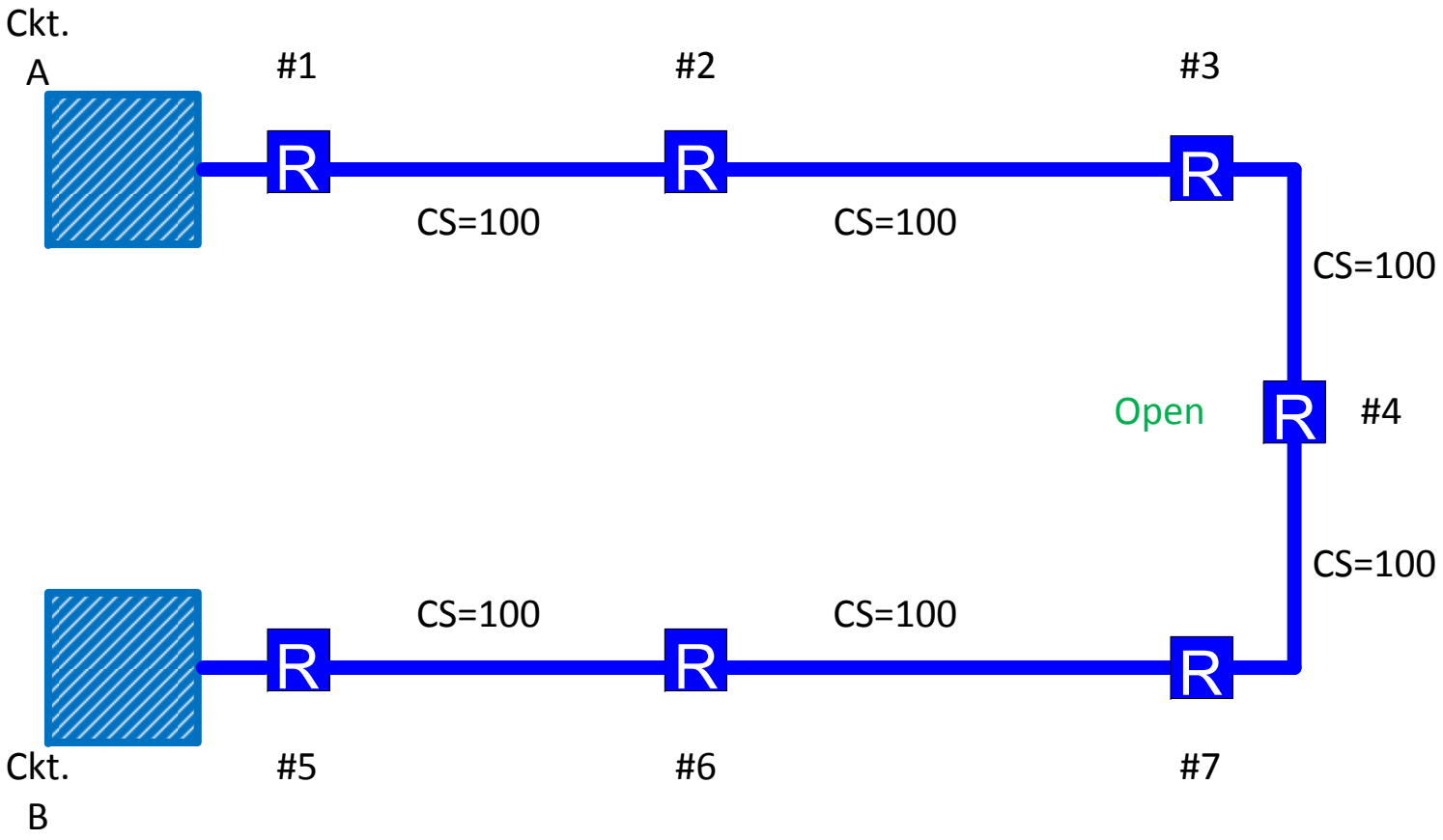
Repair time: 60 minutes



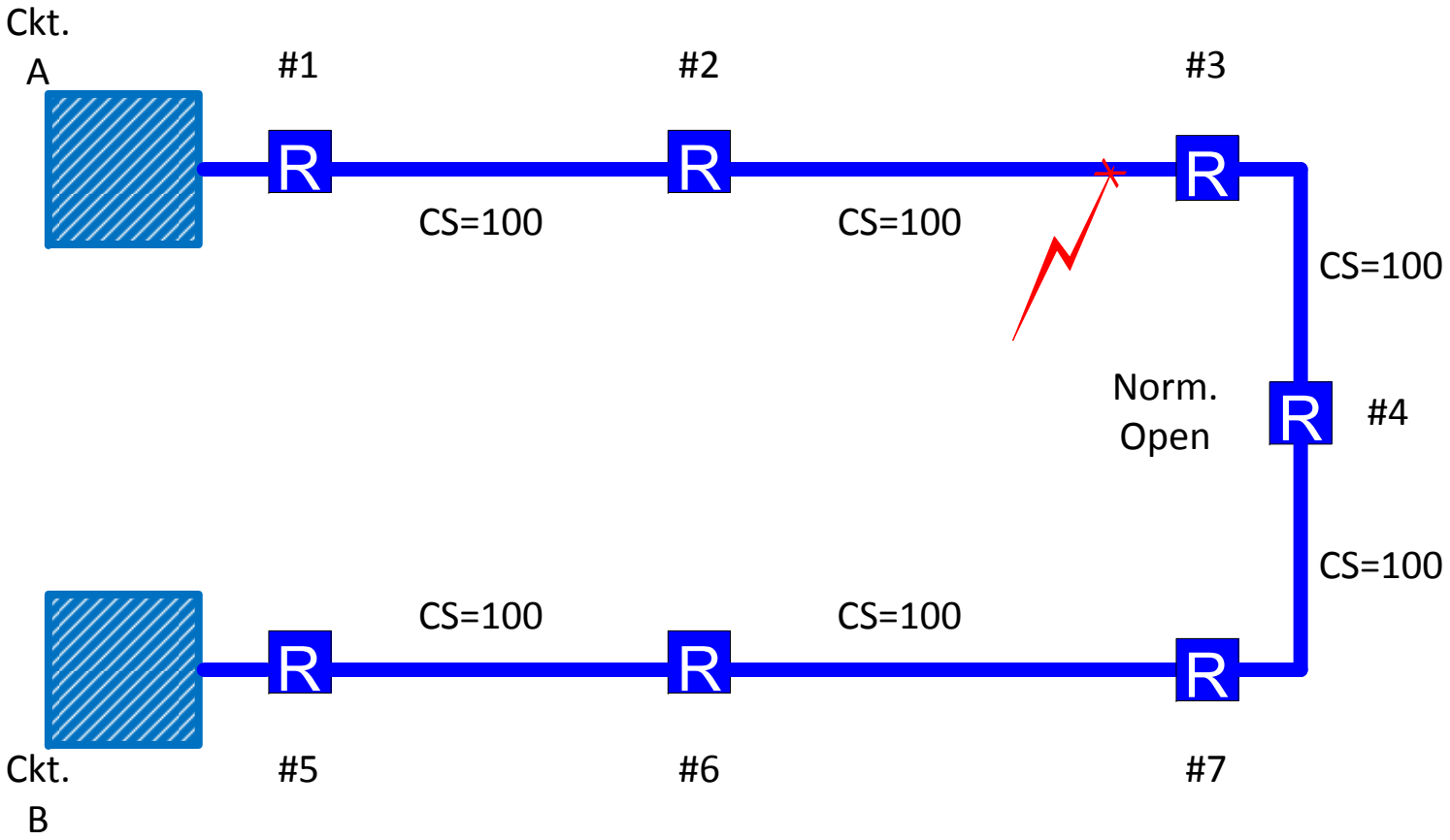
Time	Action	Cust out
	Fault	
0:00	#2 open auto	200



Time	Action	Cust out
	Fault	
0:00	#2 open auto	200
	#3 open manually	
0:20	#4 close manually	100



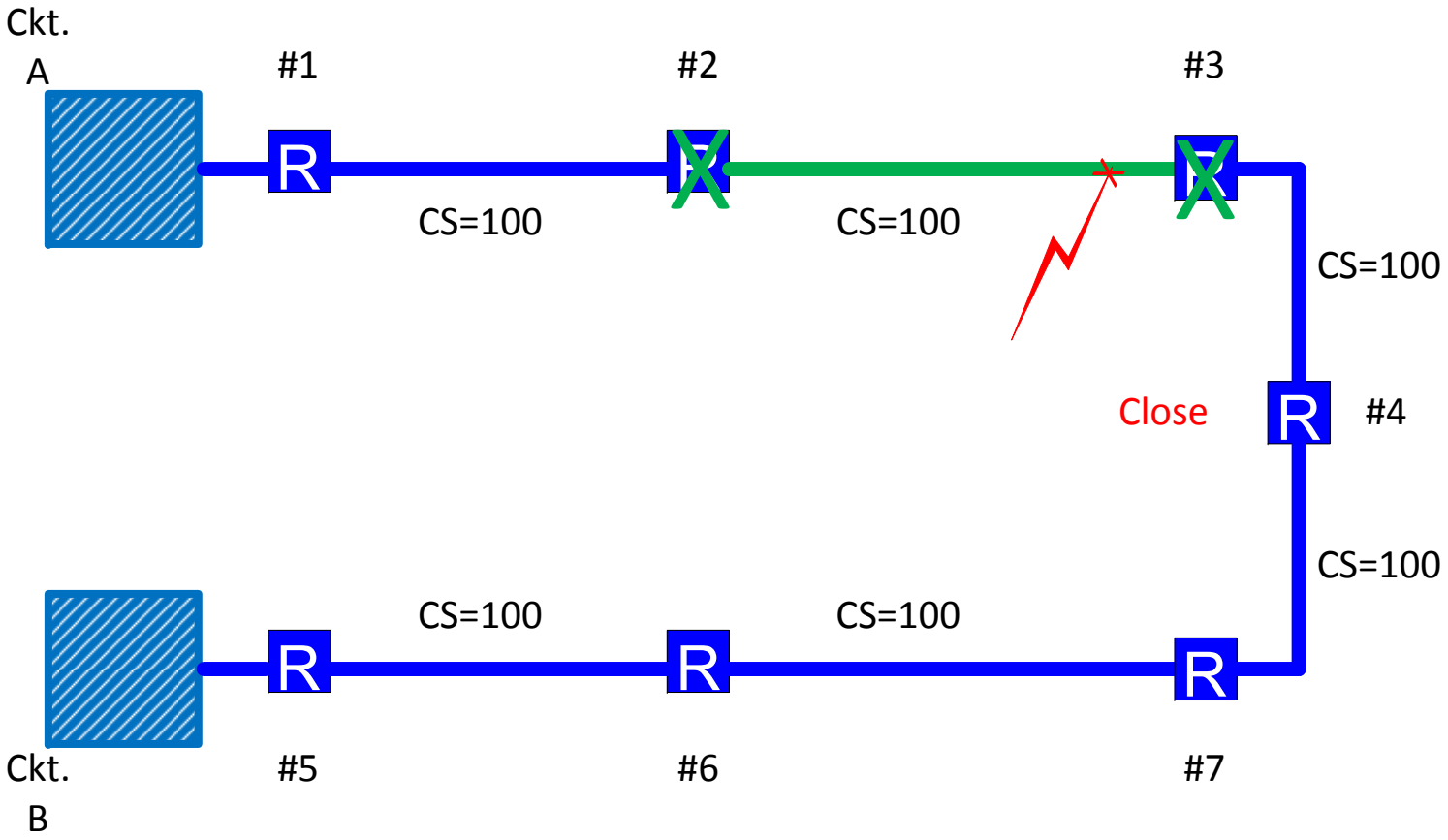
Time	Action	Cust out
	Fault	
0:00	#2 open auto	200
	#3 open manually	
0:20	#4 close manually	100
	#3 close manually	
	#2 close manually	
1:20	#4 open manually	0



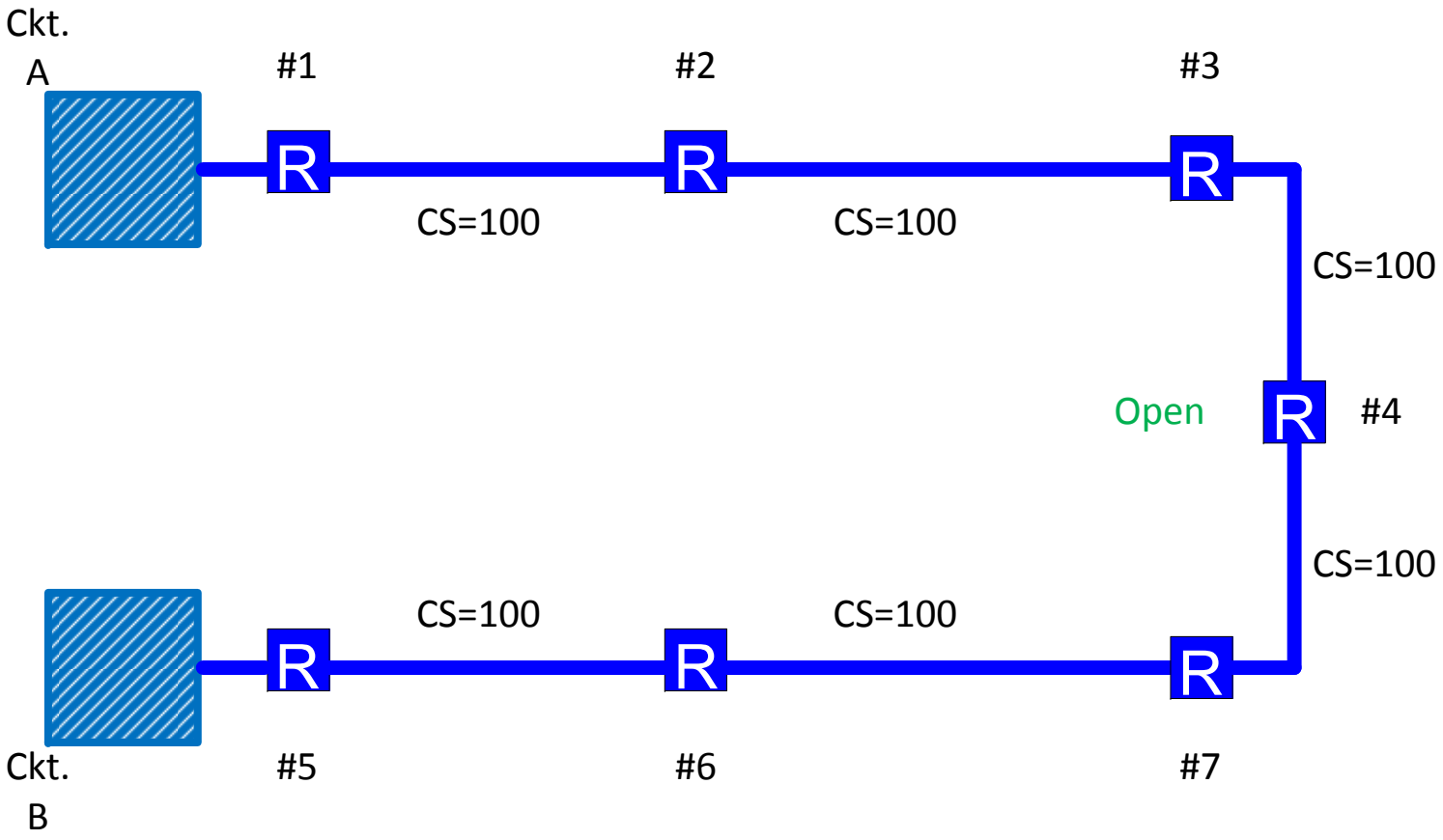
Assume:

Distribution Automation

Repair time: 60 minutes



Time		Cust out
0:00	Fault	100
	#2 opens auto	
	#3 opens auto	
	#4 closes auto	



Time		Cust out
0:00	Fault	100
	#2 opens auto	
	#3 opens auto	
	#4 closes auto	
1:00	#2 close manually	0
	#4 open manually	

Compare CAIDI (How quickly the utility restores power)

Without Automation

2 Steps

CS = 600

Step	Duration (Min)	CI	CMI
1	20	200	4,000
2	60	100	6,000
Total	80		10,000

$$\text{CAIDI} = \frac{\text{CMI}}{\text{CI}} = \frac{10000}{200} = 50$$

With Automation

1 Step

CS = 600

Step	Duration (Min)	CI	CMI
1	60	100	6,000
Total	60		6,000

$$\text{CAIDI} = \frac{\text{CMI}}{\text{CI}} = \frac{6000}{100} = 60$$

Compare CAIDI (How quickly the utility restores power)

Without Automation

2 Steps

CS = 600

Step	Duration (Min)	CI	CMI
1	20	200	4,000
2	60	100	6,000
Total	80		10,000

$$\text{CAIDI} = \frac{\text{CMI}}{\text{CI}} = \frac{10000}{200} = 50$$

$$\text{SAIFI} = \frac{\text{CI}}{\text{CS}} = \frac{200}{600} = 0.67$$

$$\text{SAIDI} = \frac{\text{CMI}}{\text{CS}} = \frac{10000}{600} = 17$$

With Automation

1 Step

CS = 600

Step	Duration (Min)	CI	CMI
1	60	100	6,000
Total	60		6,000

$$\text{CAIDI} = \frac{\text{CMI}}{\text{CI}} = \frac{6000}{100} = 60$$

$$\text{SAIFI} = \frac{\text{CI}}{\text{CS}} = \frac{100}{600} = 0.17$$

$$\text{SAIDI} = \frac{\text{CMI}}{\text{CS}} = \frac{6000}{600} = 10$$

Availability: ASAI

ASAI: Average Service Availability Index

$$\text{ASAI} = \frac{\text{Customer Hours Service Available}}{\text{Customer Hours Service Demand}}$$

Usually expressed as a decimal or a percent

ASAI

What's a good available number?

How many think:

0.99?

0.999?

0.9999?

ASAI

What's a good available number?

How many think:

0.99? – Two 9's

0.999? – Three 9's

0.9999? – Four 9's

ASAI

ASAI	Annual Hours	Hours Available	SAIDI Hours	SAIDI Minutes
0.99	8,760	8,672	87.6	5,256

ASAI

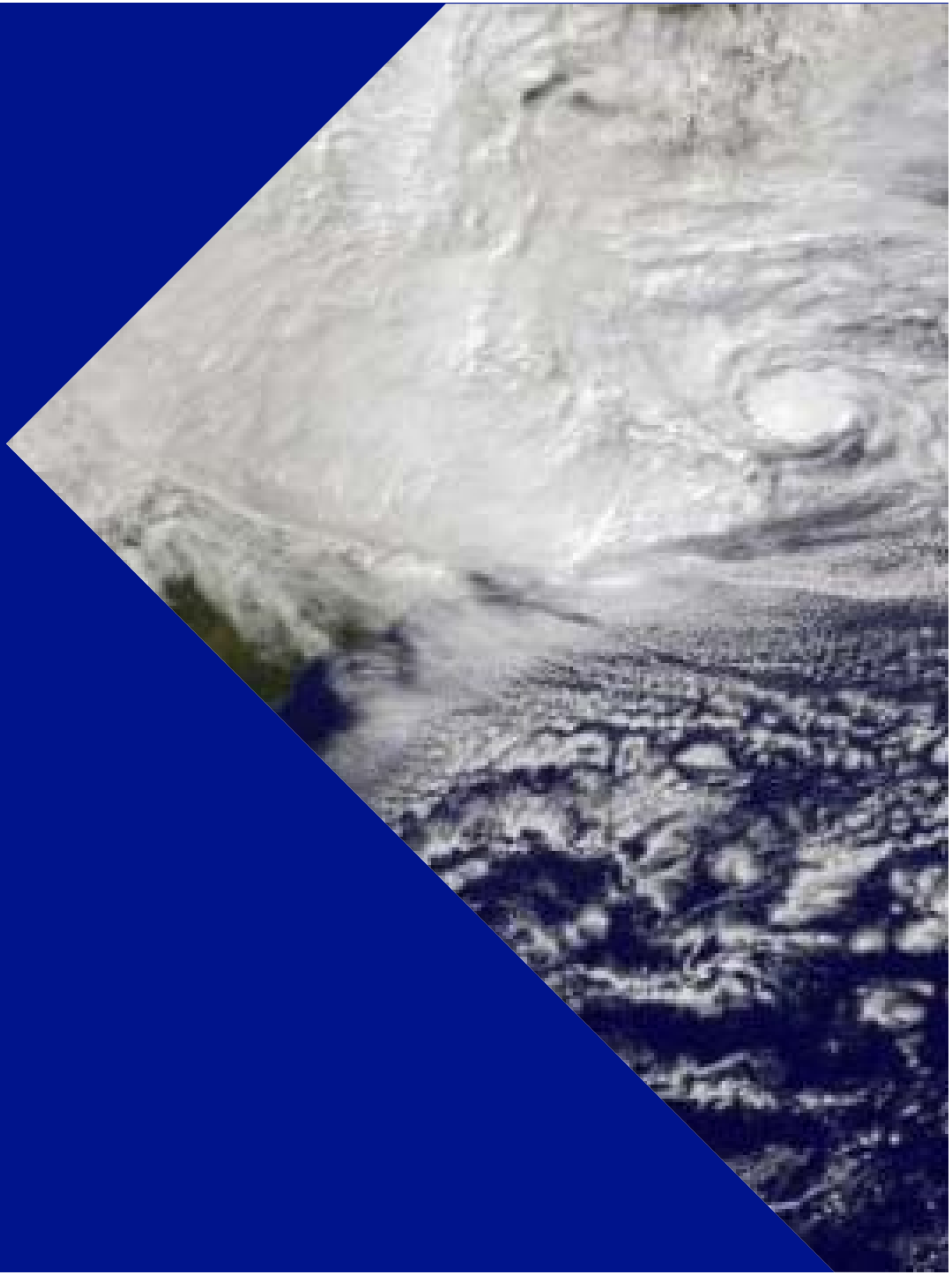
ASAI	Annual Hours	Hours Available	SAIDI Hours	SAIDI Minutes
0.99	8,760	8,672	87.6	5,256
0.999	8,760	8,751	8.8	526

ASAI

ASAI	Annual Hours	Hours Available	SAIDI Hours	SAIDI Minutes
0.99	8,760	8,672	87.6	5,256
0.999	8,760	8,751	8.8	526
0.9999	8,760	8,759	0.9	53

You better have something better than “three 9’s”

Some days are diamond,
Some days are stone



nationalgrid

Storms/Major Events

Usually reliability is reported two ways:

- **Including ALL events**
- **Excluding MAJOR events**

Why?

What level of service is reasonable and economical?

What's a major event?

Definitions vary by utility, regulator, and/or others

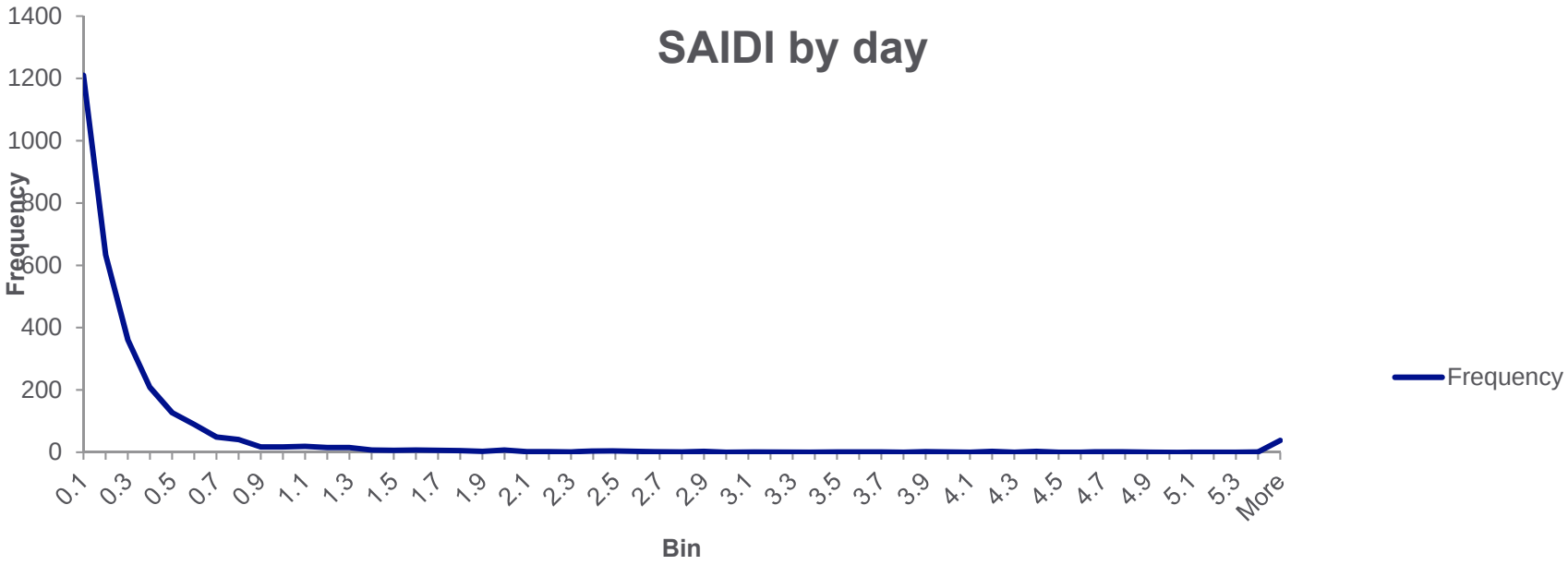
Some typical definitions:

- **Named Storms**
- **Declaration of Emergency**
- **Worst x% of Days**
- **Specifically exclusion by regulators**
- **"Not our fault"**

IEEE-1366:

2.5 β Method

Background

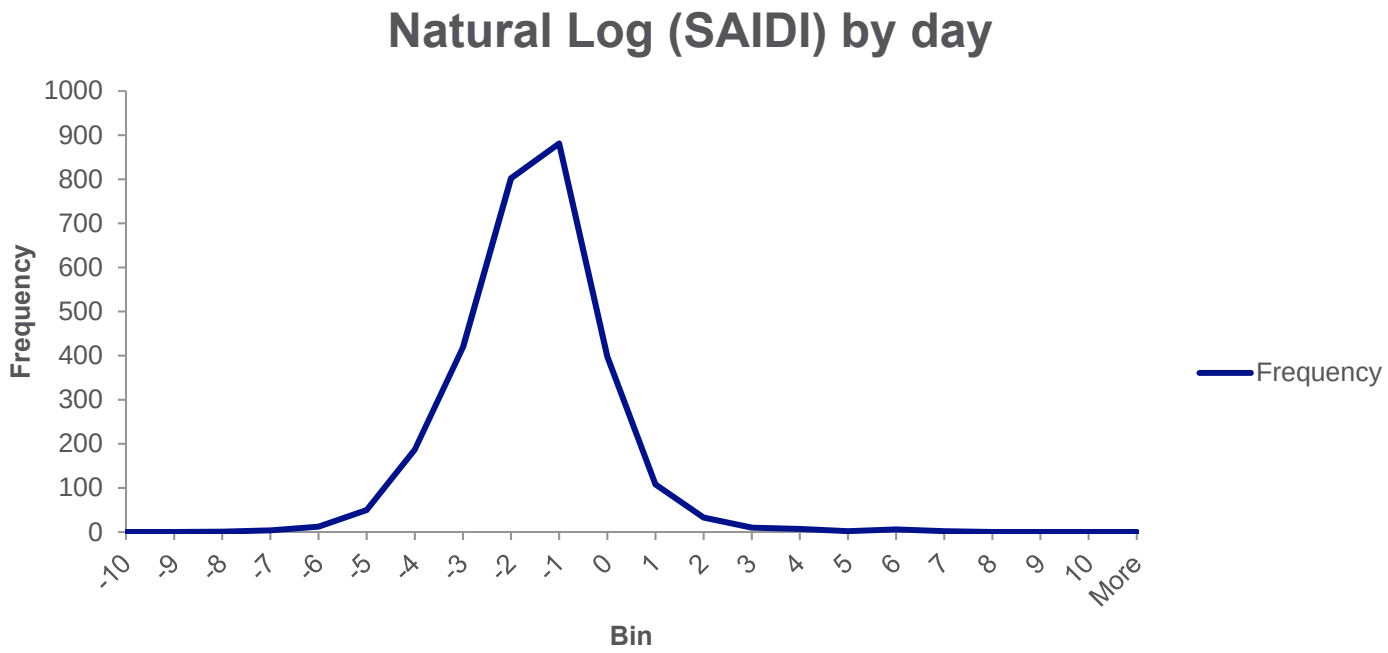


Eight years of data from one utility

Vast majority of days are at one end

But there are outliers

Background



Ln (SAIDI) is a reasonable bell curve (“log-normal distribution”)

2.5 β Method

For complete discussion see IEEE-1366

- **The method relies on calculating SAIDI/day**
- **It determines a threshold (SIADI/day) above which a day is classified as a MAJOR EVENT DAY (MED)**
- **That Threshold is defined as:**

$$T_{MED} = e^{(\alpha + 2.5\beta)}$$

Don’t be Intimidated!

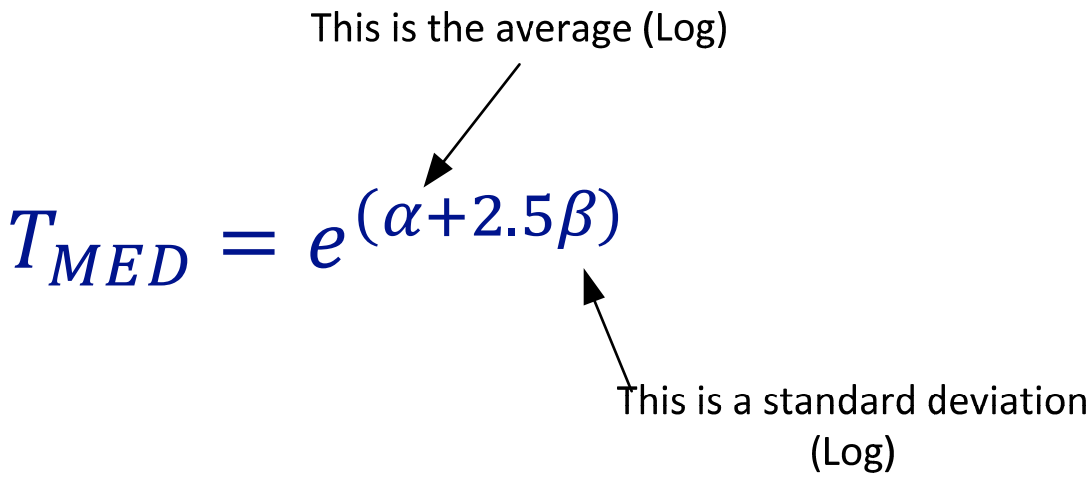
$$T_{MED} = e^{(\alpha + 2.5\beta)}$$

Don’t be Intimidated!

This is the average (Log)

$$T_{MED} = e^{(\alpha + 2.5\beta)}$$

Don’t be Intimidated!



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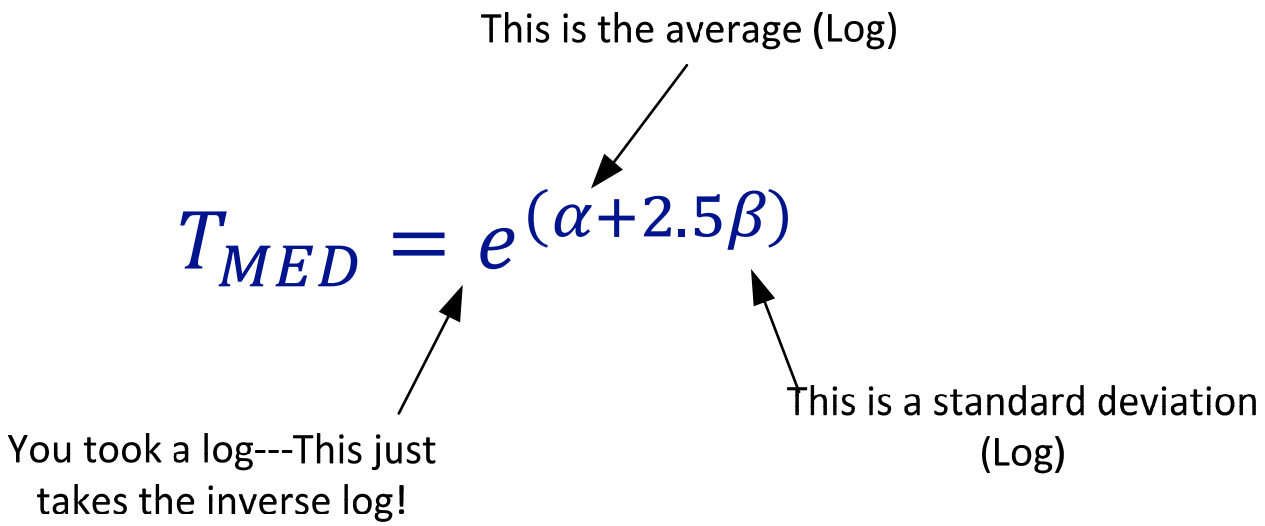

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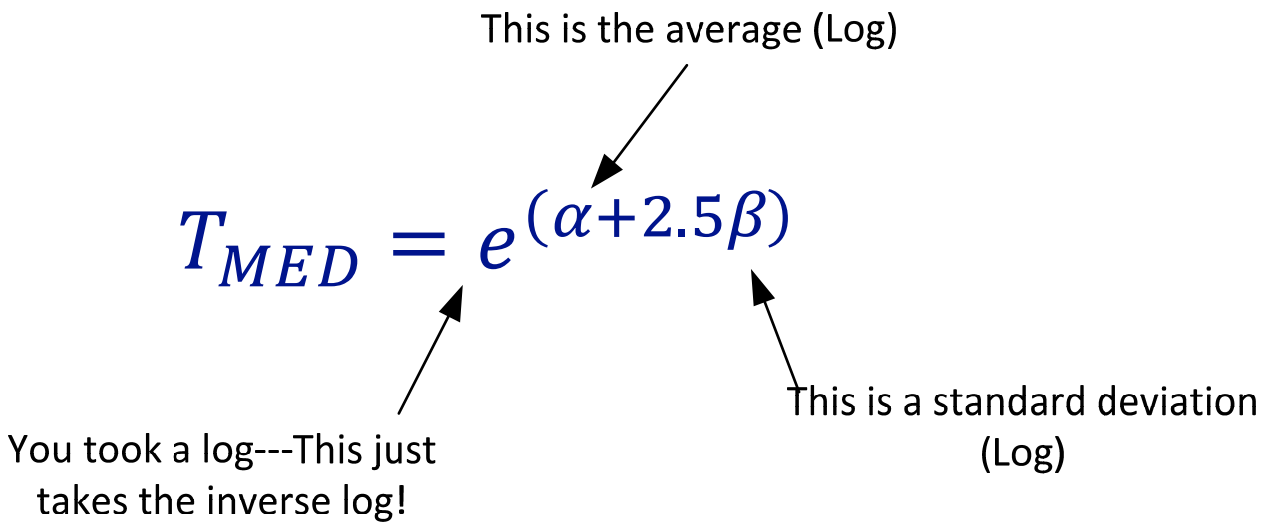

Basically, two and a half standard deviations on an average!

Calculating T_{MED}

Step 1: Don't Panic!

Step 2:

In a table:

Collect daily SAIDI for five years

Days with no interruptions will be excluded

Calculate Ln(SAIDI) for each day

Find α

Find β

Calculate T_{MED}

$$T_{MED} = e^{(\alpha + 2.5\beta)}$$

Calculating α and β

α is the average of Ln(SAIDI)

β is the standard deviation of Ln(SAIDI)

It's easier than it sounds

Develop the Spreadsheet

Typically use 5 years worth of data

Calculate CMI and SAIDI for each day

Date	SAIDI/day (min)	ln(SAIDI/day)
Dec 1, 1993	26.974	3.295
Dec 2, 1993	0.956	-0.046
Dec 3, 1993	0.131	-2.033
Dec 4, 1993	1.292	0.256
Dec 5, 1993	4.25	1.447
Dec 6, 1993	0.119	-2.127
Dec 7, 1993	0.13	-2.042
Dec 8, 1993	12.883	2.556
Dec 9, 1993	0.226	-1.487
Dec 10, 1993	13.864	2.629
Dec 11, 1993	0.015	-4.232
Dec 12, 1993	1.788	0.581
Dec 13, 1993	0.41	-0.891
Dec 14, 1993	0.007	-4.967
Dec 15, 1993	1.124	0.117
Dec 16, 1993	1.951	0.668
Dec 17, 1993	0.329	-1.112
Dec 19, 1993	0.281	-1.268
Dec 20, 1993	1.81	0.593
Dec 21, 1993	0.25	-1.388
Dec 22, 1993	0.021	-3.876
Dec 23, 1993	1.233	0.209
Dec 24, 1993	0.996	-0.004
Dec 25, 1993	0.162	-1.818
Dec 26, 1993	0.288	-1.244
Dec 27, 1993	0.535	-0.626
Dec 28, 1993	0.291	-1.234
Dec 29, 1993	0.6	-0.511
Dec 30, 1993	1.75	0.56
Dec 31, 1993	3.622	1.287

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Dec 30, 1993	1.75	0.56
Dec 31, 1993	3.622	1.287

Calculate α and β

Average=	-0.557
Standard Dev=	1.91

Calculate T_{MED}

$$T_{MED} = e^{(\alpha + 2.5\beta)}$$

α = -0.557

β = 1.91

T_{MED} = 66.7 Minutes

This T_{MED} is used to evaluate the next year

For 2019, Calculate T_{MED} using 2014 – 2018 data

Apply T_{MED}

T_{MED} is 66.7

Any day where SAIDI >66.7 is a Major Event Day

Date	SAIDI/Day
Jan 1, 1994	0.24
Jan 2, 1994	0.014
Jan 3, 1994	0.075
Jan 4, 1994	2.649
Jan 5, 1994	0.666
Jan 6, 1994	0.189
Jan 7, 1994	0.009
Jan 8, 1994	1.117
Jan 9, 1994	0.111
Jan 10, 1994	8.683
Jan 11, 1994	0.277
Jan 12, 1994	0.057
Jan 13, 1994	0.974
Jan 14, 1994	0.15
Jan 15, 1994	0.633
Jan 16, 1994	0.434
Jan 17 1994	5.7
Jan 18, 1994	0.109
Jan 19, 1994	0.259
Jan 20, 1994	1.142
Jan 21, 1994	0.262
Jan 22, 1994	0.044
Jan 23, 1994	0.243
Jan 24, 1994	5.932
Jan 25, 1994	2.698
Jan 26, 1994	5.894
Jan 27, 1994	0.408
Jan 28, 1994	237.493
Jan 29, 1994	2.73
Jan 30, 1994	8.11
Jan 31, 1994	0.046

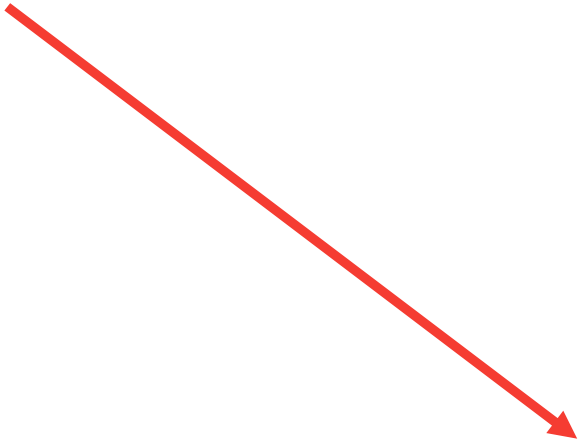
Apply T_{MED}

T_{MED} is 66.7

Any day where SAIDI >66.7 is a Major Event Day

Jan. 28 is a Major Event Day

Date	SAIDI/Day
Jan 28, 1994	237.493



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Jan 31, 1994	0.046

An Actual Dataset

Day	Events	CI	CMI	CS	SAIDI	Natural Log SAIDI
1/12/2011	2	362	20198	12496	1.6164	0.4802
2/25/2011	1	1	86	12517	0.0069	-4.9805
3/1/2011	1	7	469	12512	0.0375	-3.2838
3/22/2011	1	2	127	12512	0.0102	-4.5903
4/13/2011	1	9	630	12516	0.0503	-2.9890
5/2/2011	1	6	80	12532	0.0064	-5.0540
5/4/2011	1	6	1542	12532	0.1230	-2.0952
5/6/2011	2	214	10908	12532	0.8704	-0.1388
5/11/2011	1	23	5428	12532	0.4331	-0.8367
5/12/2011	1	4	608	12532	0.0485	-3.0259
5/19/2011	1	616	30619	12532	2.4433	0.8933
5/21/2011	1	35	6440	12532	0.5139	-0.6658
5/24/2011	1	174	15611	12532	1.2457	0.2197
5/27/2011	1	3	234	12532	0.0187	-3.9807
6/4/2011	1	20	4000	12565	0.3183	-1.1446
6/6/2011	1	1564	79764	12565	6.3481	1.8482
6/9/2011	2	4	421	12565	0.0335	-3.3960
6/22/2011	1	15	5115	12565	0.4071	-0.8987

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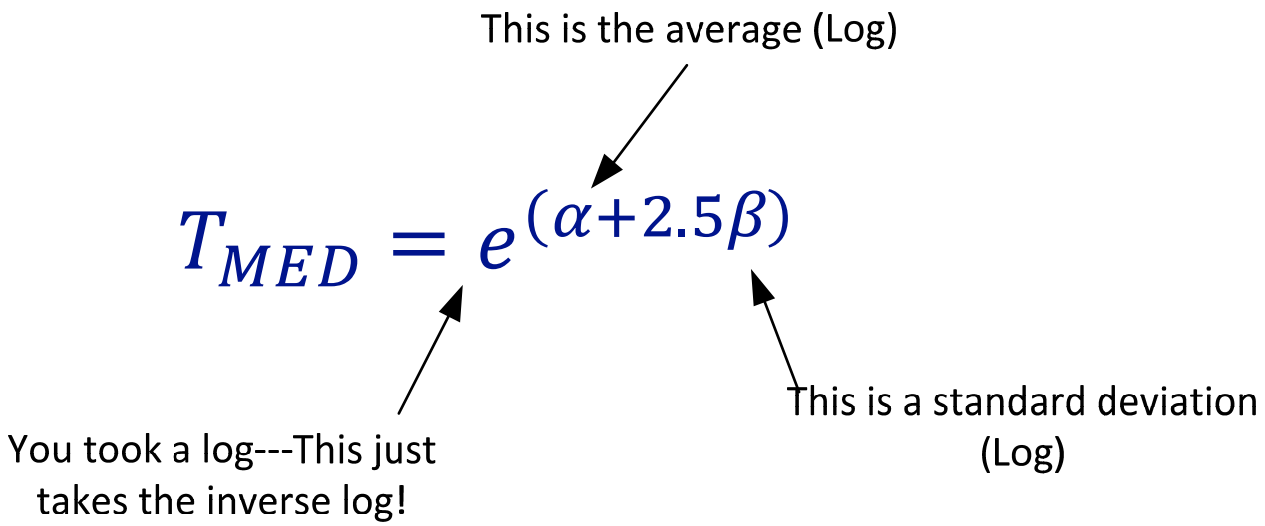

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