Operating Manual for Calculating Electrical Risk and Reliability

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Introduction

This operating manual has been written based on the assumption that you have already read the paper titled "Calculating Electrical Risk and Reliability" (PCIC 94-3) presented at the 1994 PCIC conference, the paper titled "Improvements in Modeling and Evaluation of Electrial Power System Reliability" (PCIC 2000-2) presented at the 2000 PCIC conference, and the paper titled "Reliability of Various Industrial Substations" (ICPSD-03-7) presented at the 2003 ICPSD conference (IEEE Transactions on Industry Applications, July/August 2004, Volume 40, Number 4, Page 989-994) . It also assumes that you are familiar with the PC program Excel 2003 and that you have loaded the spreadsheet Model280 propst plus dong.XLS. This model has the ability to handle up to 280 zones at one time. The RAM table on this model contains about 140 different components. Users are cautioned that the failure and repair data shown in the model's RAM table may not represent typical industry failure and repair data. A system reliability analysis must always include verification of the RAM table data to assure accuracy of the analysis. The IEEE Gold book as well as a numerious other sources are available for obtaining equipment failure and repair data. Also, users are cautioned that the failure and repair data for a specific facility is strongly related to the facility's current and past preventive maintenance programs as well as the experience and abilities of the maintenance and engineering staff.

Theory Behind Model

The reliability calculations that the model is based upon are relatively straightforward and can be found in most textbooks on the subject. The following is a brief description of the computations used when combining items in series and parallel. First, we will review the definition of a few common terms. Most of these definitions and the equations can be found in the IEEE Gold Book (IEEE Std. 493-1997) and other textbooks.

Definitions

Annual Risk - The calculated financial losses of production due to an electrical system failure divided by the frequency (MTBF) of the failure.

Availability - A ratio that describes the percentage of time a component or system can perform their required function.

Component - A piece of electrical or mechanical equipment, a line or circuit, or a section of a line or circuit, or a group of items that is viewed as an entity for the purpose of reliability evaluation.

Failure - The termination of the ability of an item to perform a required function.

Failure rate - The mean number of failures of a component per unit exposure time.

Forced downtime - The average time per year a system is unavailable in between failures and expressed in hours per year.

Lambda (λ) - The inverse of the mean exposure time between consecutive failures. Lambda is typically expressed in either years per failure or millions of hours per failure.

MTBF - The mean exposure time between consecutive failures of a component or system. The mean time between failures is usually expressed in either failures per year or failures per million hours. For some applications measurement of mean time between repairs (MTBR) rather than mean time between failures may provide more statistically correct information.

MTTR - The mean time to repair a failed component. For a system, it is the total amount of time it is unavailable in between failures and is expressed in hours in both cases.

Point - Any place or location within the electrical system. The name or designation for a point is always the same as the name of the zone that the point is located within.

RAM Table - A lookup table in the model that displays the Lambda and MTTR for electrical components.

Reliability - An indication of the ability of a component or system to perform its intended function during a specified time.

Restore Time - In the model, the time to restore is the sum of the mean time to repair (MTTR) for the failure plus the computed time to restream or restart the connected process unit or load.

System - A group of components connected or associated in a fixed configuration to perform a specified function of distributing power.

Zone - A segment of a power distribution system in which a fault at any location within the segment or zone would have the common impact of causing the first upstream protective device to isolate the system

Single Component Analysis

Reliability and availability are necessary to describe the characteristics of the single component shown.

$$d_1 = \text{MTBF} \quad \text{(in hours)}$$

$$r_1 = \text{MTTR} \quad \text{(in hours)}$$

Reliability of components is frequently given as failures per million hours of operating time. Using these numbers, the Mean Time Between Failure (MTBF) can be calculated using:

$$d_1 = \text{MTBF} \quad \text{(in hours)}$$

$$d_1 = 10^6 \,/\, (\text{failures} \,/\, 10^6 \text{ hours})$$

The failure rate (λ) is given by:

$$\lambda = 1 \,/\, \text{MTBF}$$

and the component reliability (R_1) for one year is given by:

$$R_1 = e^{-(\lambda)(8760)}$$

For a single component, the availability (A) is given as the total operating time over the total time, or:

$$A = (\text{MTBF}) \,/\, (\text{MTBF} + \text{MTTR})$$

Systems with Components in Series

For the system shown below with three different components in series,
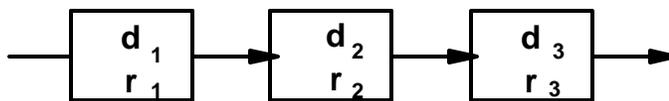
d = MTBF (in hours)
r = MTTR (in hours)

The characteristics of each individual component can be calculated using:

$$\lambda = 1 \,/\, d_i$$

$$A_i = d_i \,/\, (d_i = r_i)$$

$$R_i = e^{\lambda_i t}$$

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$$R_i = e^{\lambda_i (8760)} \quad \text{for one year}$$

Using these, the combined failure rate (failures per year) becomes:

$$l_S = l_1 + l_2 + l_3$$
or
$$l = R_1 * R_2 * R_3$$

Reliability of the system for one year:

$$R_S = e^{-l_S(8760)}$$

System availability :

$$A_S = A_1 * A_2 * A_3$$

Probability of failure during one year:

$$P_S = (1-R_S) * 100$$

MTBF:

$$MTBF = 1 / l_S$$

MTTR in hours:

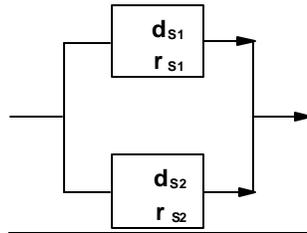$$MTTR = MTBF \left[(1 / A_S) - 1 \right]$$

Forced downtime:

$$FDT = (1 - A_S)$$

Systems with Redundant Components

Redundant Active Systems - Non-repairable

Reliability can be dramatically increased by installing a parallel (redundant) system. The simplest of these is a system that operates satisfactorily <u>if either on or both of two parallel components functions.</u>

The reliability for such a system for one year can be calculated using:

$$R_S = [\ 1 - (1 - R_{S1})(1 - R_{S2})]$$

the combined failure rate is:

$$\lambda_S = \ln (1\ /\ R_S)$$

the system availability is:

$$A_S = [\ 1 - (1 - A_{S1})(1 - A_{S2})$$

and the probability of failure during one year is:

$$P_S = (1 - R_S) * 100$$

Repairable Redundant Systems

<u>If the components can be repaired</u>, the reliability of the systems described above also becomes a function of the time required to repair the system.

Using a constant failure rate for two identical units, the stead-state availability is:

$$A = \mu\ /\ \lambda + \mu$$

where the repair rate (μ) is (MTTR) -1

and the MTBF is:

$$MTBF = \mu\ /\ (2\lambda^2)$$

For two different components in parallel, the MTBF is:

$$MTBF = (\lambda_a + \mu_b)(\lambda_b + \mu_a) + \lambda_a(\lambda_a + \mu_b) + (\lambda_b + \mu_a)\ /\ \lambda_a\lambda_b(\lambda_a + \lambda_b + \mu_a + \mu_b)$$

and the stead-state availability for n blocks is:

$$A = 1 - \prod_{i=1}^{n} (l_i / l_i + m_i)$$

or for two parallel Components:

$$A = 1 - [(l_1 / (l_1 + m_1))(l_2 / (l_2 + m_2))]$$

Common Cause

The common cause portion of the model was completely revised based on the findings reported in the third paper mentioned above in the "Introduction". Based on analysis performed primarily by Zhenfu (Joseph) Dong and reported in the paper, a more accurate methodology for integrating common cause failure modes for parallel sources was developed. Both the background and the formulas are presented in the paper and will not be repeated here. ***The lined out section shown below was the text describing the previous approach for addressing common cause.***

~~Redundancy calculations frequently lead to reliability numbers that are outside the realm of reason, for example one failure in a thousand years. In reality, even redundancy of components still leaves a chance that the parallel system will fail from a common-mode. Examples of this include common electrical connections, common alarm wiring, or the environment. In David Smith's book on Reliability[1] he suggests that these common modes can be considered by using a component in series with the redundant system as shown in **figure 1** below.~~
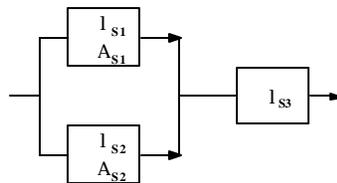
~~**Figure 1**~~

~~A reliability of between 1.0 and 0.1 times the reliability of the components in the individual redundant components provides results that are comparable with actual experiences. The default value in the model is 0.1. The model has three three default values of .95, .5, and .1 related to the likelihood of common cause. See Appendix A for additional information. These values are located at cells HR 578 - 580. These values can be changed by the user.~~

Dealing With Closed Tie Breakers

Because of the nature of the system configuration and the way Excel performs calculations, you will experience circular references when trying to perform reliability calculations on busses with closed tie breakers. The reason for this is that the reliability of the bus on the right is a function of the reliability of the bus on the left and vice versa. There are a couple of ways to overcome this problem. The first is to activate the iteration option in the Calculation option dialog box in Excel. This will provide relatively accurate results with no additional modification of the model. The regret

[1]David J. Smith, Reliability and Maintainability in Perspective

for this method is that the availability calculated for the two tie breaker busses would be 1.0, which will result in a MTTR for the two busses of zero (0). If the tie bus is not a significant portion of the study, this is probably acceptable, but if the study includes the tie bus, a different technique is suggested. **Figure 2** shows a modeling technique that involves adding additional "phantom" busses and "phantom breakers" and removing the tie breaker. The primary regret for this method is that some additional components will show up in the component summary table. The RAM table has a "Phantom" breaker that has a very large MTBF and a very small MTTR so that the addition of the components does not imact that system reliability.
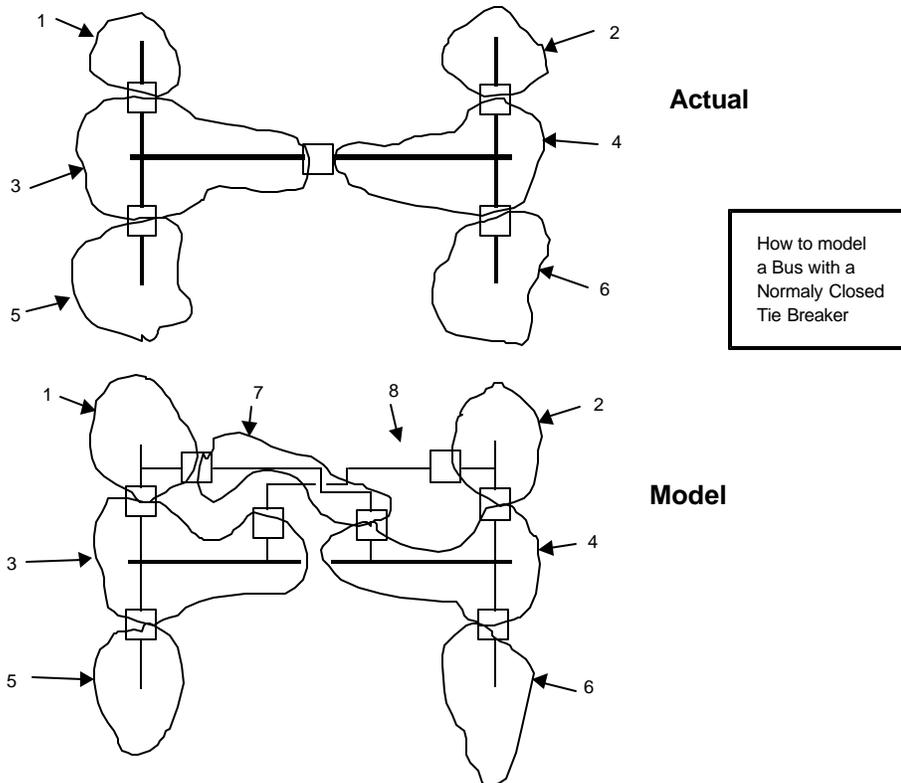
Figure 2

Open Tie Breakers

The use of open tie breakers needs to be addressed when modeling reliability. The use of a normally open tie breaker **will not prevent an event**. Therefore, they will not have an impact on the mean time between failures of the source down to the point in question. However, they will have an impact on the mean time to repair of the feeders departing from the substation or bus with the open tie breaker. Therefore if you have a normally open tie breaker that is supplying a bus, the mean time between failure for the feeders departing the bus will be the value calculated by the model for the normal source, but the mean time to repair will be the time required to initiate a closure of the tie breaker or reclosure, and not the mean time to repair value calculated by the model. To address this issue, one must go into the "Point Table" and manually enter a value for the MTTR for each feeder breaker departing from the bus for which the tie breaker is the alternate source. It is a good idea to highlight or otherwise mark cells that have been manually modified so that you can easily identify them when reviewing the model. [The value for MTTR can now be enterd directly into the column labeled "Mean Time to Repair" (column HO). ***The lined out text shown below describes the method previously used prior to the modification of the model updating the common cause section.*** , and then calculate the point availability based on the MTTR and the calculated lambda, using the formula: Availability = 8760/((λ) *(MTTR)+8760). This can be done by copying the formula from cell HL290 to the availability cell in column HL for the zone supplying the bus with the open tie breaker and also manually entering a value for the MTTR in column HO. The reason for doing this is that as shown in the equation above, if one knows any two of the three variables availability, MTTR, or λ you can calculate the third. In the model the value of availability and λ are derived for each point and then the value the MTTR is calculated. However, when we have a normally open tie breaker we know MTTR and λ and we must recalculate a new value of availability.

Transfer Switches

Transfer switches and normally open tie breakers. If transfer switches or normally open tie breakers are able to transfer or close quicker than the maximum time acceptable for the threshold of a power loss, then the two sources should be considered as normally CLOSED. If the transfer time is greater than the maximum time considered as the threshold for power loss, then the alternate source should be considered "open" and the MTTR for the normal source should be manually adjusted in the Point Table to a value equal to the transfer time for the feeder from the transfer switch or breaker.

MTTR Alert Feature

In order to easily identify points in which the forced downtown is below the user's acceptable level for power quality, conditional formatting has been added to the "MTTR" data column in the Point Table. The user can enter any value in Cell HP 288 to trigger an alert flag. The default value is set at 0.002777, which is 10 cycles. If the MTTR value for a point is less than this user set value, the value of the point MTTR will be displayed in bold Red text. The user then has the option to manually define the failure rate of the point to zero or any lower value. Note that the data for Point 0 essentially represents a point with a zero failure rate.

Sources and Loads

Utility sources are usually entered into the model in one of two ways. The first and recommended method is to to use the "Utility Supply Simulator" located on the "Utility" worksheet of the model. This simulator allows the user to model a number of different modes of functional failures. One comment on the use of the Utility Simulator is to make sure that you enter a quantity in column G. The Utility Simulator is linked to the last line item in the RAM table. When using the Simulator check to see that the value of the MTTR and MTBF on the simulator is the same as those on the RAM table, indicating that you have not inadvertently broken the link.

A description of the second method is included primarily for historical purposes and is not recommended, unless you are very familiar with the model and have a special need to customize a utility connection.

The second method, which was the first method used in the evolution of the model, involves going in and "fudging" some of the values in the point table. This method achieves the same results as the method above, but requires a more in-depth understanding of the model to make sure that the manually entered data is properly located. For those who wish to try this second method, the following describes some of the details of this technique.

As one works with the model you will discover that *Points* are reliability SUPPLIES OR SOURCES for zones. In simple terms *Points* are generators or batteries and zones are loads. A *Point* in an upstream *Zone* becomes the source for the downstream *Zone(s)*. Portions of the system that are natural sources such as utility supplies or generators must be initially modeled as a *Point*. This can be done in one of two ways. First, *Point* 0 represents a point of infinitely high reliability. It can be combined with a zone to achieve the desired reliability of the source. An alternate method is to manually enter data into the Point Table to represent the source. When this method is used, the manually entered Points are usually located at the bottom of the Point Table with the manually entered data description noted in the Consequences Table. When using this technique, it is suggested that the desired failure rate be entered and then the availability be increased or decreased until the desired MTTR is achieved in the model calculations. A calculator is built into the model for entering the failure rate and the repair rates to calculate the needed availability. This VALUE is then copied to the appropriate cell.

Devices such as generators not only represent sources, and should be entered as Points, but also represent components that can fail and should be represented in the RAM Table as a component with a given failure and repair rate.

For more complicated utility supplies, the modeling technique can be further enhanced with additional components as described below. The following example describes how one might model a utility source that had several different identifiable modes of failure.

Example

Let us consider a facility that has a single utility source. We have information on this source that would suggest the following history:

- The line has a single hit reclosure that takes 30 cycles to reclose. On average incidents on the supply causes the reclosure to operate 3 times per year
- The line has a history of external faults resulting in the lost of power at the fence-line once every other year. On average, the restoration time for each of these incidents is 8 hours.
- Historical data indicates that human error has resulted in losses of power on an average of once every 4 years. Restoration of power following these incidents is 1 hour.
- Historical data indicates that squirrels, snakes, possums, raccoons, birds, snakes, and other similar creates terminate their existence about once every other year, resulting in a 4 hour incident for restoring power.

One method to model such a supply would be to perform a statistical analysis of these four causes for failure, and develop a single equivalent failure and repair rate. However, assuming the incidents are independent, the Electrical Reliability Model can do this automatically for us.

The modeling technique would be to create a component in the RAM table for each of these causes. A good place to do this might be near the bottom of the RAM table where the Utility supplies are currently shown. As discussed in the model manual, items in the RAM table can be overwritten, and the new values will be reflected throughout the model. **Fig. 3** shows the default "Utility" items in the RAM table.

	C	D	E	F	G	M
110	**RAM Table Revision 5/11/94**		Hrs	Fail/yr	Days	Yrs/Fail
111	Equipment	Units	MTTR	Lambda	MTTR	1/Lambda
191	**Utility Company Supply Point A**	Each	2.00	0.050000	0.08	20.00
192	**Utility Company Supply Point A**	Each	2.00	0.100000	0.08	10.00
193	**Utility Company Supply Point B**	Each	6.00	1.000000	0.25	1.00
194	**Utility Company Supply Point C**	Each	8.00	1.250000	0.33	0.80

Figure 3 - Utility Sources in RAM Table (figure from older version of model)

The utility data for our example is entered into the RAM table as 4 identifiable components as shown below in **Fig. 4**.

	C	D	E	F	G	M
110	**RAM Table**		Hrs	Fail/yr	Days	Yrs/Fail
111	Equipment	Units	MTTR	Lambda	MTTR	1/Lambda
191	**Utility Recloser**	Each	0.01	3.000000	0.00	0.33
192	**Utility External fault**	Each	8.00	0.500000	0.33	2.00
193	**Utility Human error**	Each	4.00	0.250000	0.17	4.00
194	**Animals**	Each	4.00	0.500000	0.17	2.00

Figure 4 - RAM table modified with Utility Events (figure from older version of model)

The Utility incidents are now modeled by entering one of each of these components into the zone containing the utility supply. **Fig. 5** displays the entry of these components into Zone 1. If there were other components in the utility supply such as transformers, cables, switchgear, etc. you would also include these components in your analysis.

	A	B	C	D	E	F	G
3	**Study Title**						
4	**MTTR**	**Lambda**					Zone 1
5	**Factor**	**Factor**	Equipment	Units	MTTR	Lambda	Quantity
85	1.00	1.00	**Utility Recloser**	Each	0.01	3.000000	1
86	1.00	1.00	**Utility External fault**	Each	8.00	0.500000	1
87	1.00	1.00	**Utility Human error**	Each	4.00	0.250000	1
88	1.00	1.00	**Animals**	Each	4.00	0.500000	1

Figure 5 - Component Entry for Zone 1 (figure from older version of model)

We can then go to the "ZoneCalc" region of the model and review the results of the model's statistical analysis of the combination of all these incident failure and repair rates. **Fig. 6** displays the data.

	HI	HJ	HK	HL	HM	HN	HO	HP
1		Zlambda	ZREL	ZAVAIL	ZPROB	ZMTBF	ZMTTR	ZDOWN
2	zone1	4.250000	1.43%	0.999198518	98.57%	0.24	1.65	7.020986548

Figure 6 - ZoneCalc data for Zone 1 (figure from older version of model)

- The model indicates that the Lambda, or combined incident rate will be 4.2500 incidents per year.
- The percent reliability shown in column HK is a statistical value that is used for further calculations and has relatively little meaning to us.

- The availability of the electrical supply is 99.9198518%. This tends to clearly illustrate that talking about utility supplies in terms of percent availability is a relatively useless and meaningless term. You will seldom find a utility source that has an available of less than 99.8%.
- The percent probability is another statistical value that is used in later calculations that has little meaning to us.
- Column HN indicates that the combined Mean Time Between Failure will be .24 years and Column HO indicates that the combined Mean Time To Repair will be 1.65 hours. The statistical down time per year will be 7.02 hours per year.

The advantage of breaking utility incidents into individual identifiable components is that we can then assess the impact of the individual component and possibly obtain insight into which issue to work on first. For example, in this analysis, would it be better to get a mean dog with a short chain to keep the animals away, develop a training class and procedures to reduce human error, or trim the trees along the right-of-way to reduce reclosures? Using the model, we can go into the RAM table, change the MTBF and MTTR values for various components and see what impact they have on the system performance. Keep in mind that previous analysis has shown that improving the mean time between failure often has a ten fold payback over improving the mean time to repair.

Also, keep in mind that the components in the RAM table do not necessarily need to be just electrical components. An analysis of a location's variable speed drives included components such as bearings, proximity probes, couplings, motor rotor, motor stator, exciter controls, as well as the more conventional electrical devices such as transformers, cables, etc. An analysis of a typical heat tracing system included components such as mechanical damage, insulation, controllers, terminations, overjacket, etc. Human error is often entered as a single identifiable component in reliability analysis.

Before entering data into the model, the zones must be defined. The technique that is normally used and recommended is to draw a circle around sections of the one-line from the line side terminals of a protective device down to and including the line side terminals of the next downstream protective device. **Figure 7** is an example of how the zones are added to a one line.

GETTING STARTED

The following is a BASIC step by step approach to using the model. It is somewhat important that the user understand the layout of the model and the relationship between one section and the others. It is suggested that a new user review an existing model before attempting to create a new one. It is also suggested that the first system analysis should be a relatively simple and straightforward system. There is a copy of the actual spreadsheet used to analyze the Alternate standard network on the PCIC Web. This is a relatively simple system to review.

It is also assumed that the user of the model is familiar with the use and navigation of Microsoft Excel. Modification of cells or improper data entry can result in errors that can sometimes be very difficult to uncover. There are many hidden cells in the model used for background calculations. Troubleshooting serious errors often requires an indepth knowledge of the operation of the model. In almost every case in which errors have shown up, it has been a result of improper data entry for the zones. It is normal to have errors indicated for zones that are not used and the user should not be concerned about these. For example the blank model will have many #DIV/0 errors for empty zones. If you should experience an error in a zone that is used, it is recommended that you first check in the ZoneCalc section of the model. If there is an error indicated here it is most likely due to improper data entry in the involved zone. A common error is to use the space bar to "erase or delete" data entry. The model is looking only for numbers and cannot compute the value of a "space".

Loading and running the model
Load the latest spreadsheet model from the PCIC Web site.
You now have a blank 280 zone worksheet. Typically the blank worksheet would be "saved as" a file with a unique name related to the system being studied. The next step is to analyze your system and enter data.

PREPARING TO ENTER DATA
The **first step** to every study starts with the system One-Line diagram. In one form or another, you must have this. If you are working with an existing system, get a copy of the existing drawings. If you are doing conceptual studies, make pencil or electronic CAD sketches. The only devices that the One-Line diagrams must have are the circuit protective devices, i.e. breakers, fuses, reclosures, and the interconnective devices such as cables, transformers, and bus. You will need to know if the system switches and breakers are normally open or normally closed. As you will find out later, a new model must be created or the existing model modified for different switch configurations. With One-Line and pencil in hand the next step is to draw in the zones. **Fig. 7** on the next page shows how zones are typically sketched onto the One-Line. The methodology for drawing the zones is straight forward. A zone should encompass that portion of an electrical system affected by the opeation of a single protective device. Exactly where the transition from one zone to the next takes place tends to be a comprimize between speed and data accuracy. For example, when a removable power circuit breaker clears a fault, the transition from one zone to the next is actually at the internal contacts of the breaker element. However, we typically do not have failure and repair statistics for the line side of a breaker versus the load side. Therefore some comprimise is needed. The more typical break point for a zone will be at the line terminals of a protective device and circle everything down to the line terminals of the next protective device in the system. For example on **Fig. 7** note that Zone 2 starts at the line terminals of the breaker in Zone 1 and includes all the devices down to the line side of the feeder breakers in Zone 2. Note in Zone 6 that it goes to the line side of the fuse and also includes the transformer since there was not a transformer primary breaker. Zones 8, 9, and 10 are examples of how to handle a double ended bus. If you have a bus with normally closed tie breakers and you have not read the text, you will need to go back and do so now, and then add in the extra zones for each normally closed tie breaker. I normally start at the top of the One-Line and work my way down. You can stop anywhere you like. If you want to

obtain data for the entire system, you must obviously define zones for the entire system. Otherwise, you need only enter the portion of the system that you want to study. Do not worry if you skip over a zone or need to come back later and add additional zones. The numeric value assigned to a zone has no relevance. However, it is useful to number the zones so that it is easier to find it later on the drawing by looking for zones with similar numbers.

At this point, you should know about how many Zones you will have in the model. A single worksheet model will handle 280 zones. In the unlikely case that the system is larger than this, an additional 280 zone worksheet can be copied into the workbook. Data from one worksheet may be linked to another worksheet to share information.
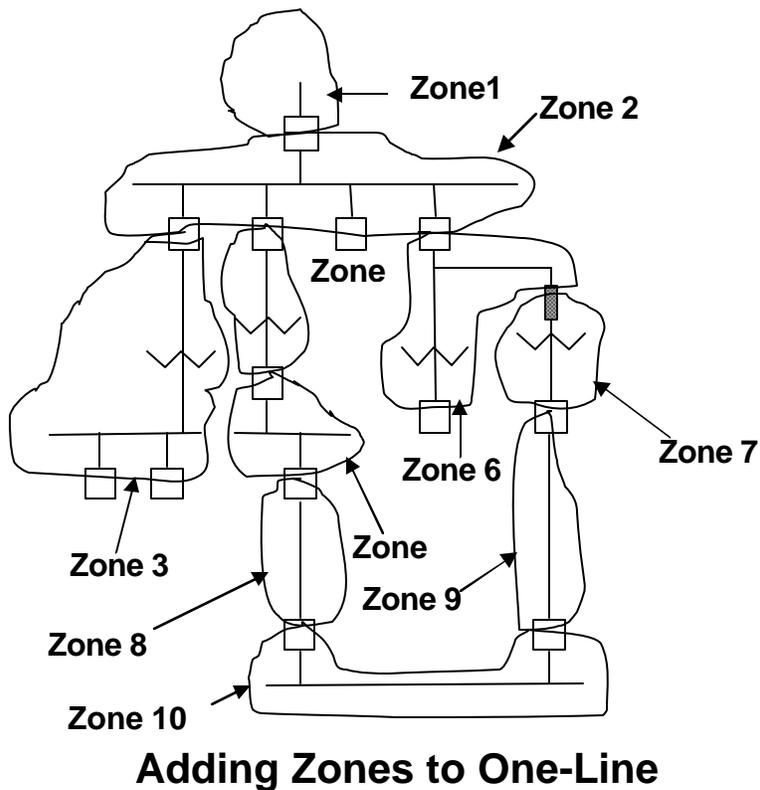

Adding Zones to One-Line

Figure 7

The **second step** is to review the RAM table and make sure it has the components that are in your system. Data for 142 components can be entered into the RAM table by the user. Sources of data can include the Gold Book, various IEEE electrical reliability papers and personal experience. RAM table data can vary significantly from site to site depending upon design, installation, and maintenance practices. People often challenge the accuracy of the RAM table data that is used in models. If you question or don't like the data, or don't think that it represents the performance of the

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equipment in your plant, just change it. The RAM table was designed to permit the user to enter any value and to perform an analysis using that value. The following is a brief explanation of data entry in the RAM table for each component.

Column A, MTTR Factor - This is a multiplication factor that can be used to temporarily adjust the component Mean Time To Repair. The default value is 1.00. You can observe that if you change the value from 1.0 to 2.0, the RAM table MTTR value in column G will remain unchanged, but the actual value used by the model, shown in column I will double. This feature is useful to perform quick what-if analysis without altering the actual RAM table data.

Column B, Lambda Factor - Similar to column A MTTR factor described above except that it is used to modify the component Lambda (1/MTBF) value.

Column C, Color Code - by changing the value in this column, you can change they way the RAM table data is displayed in the area on the model where data is entered. This is a useful aid when entering zone data. When a value of 0 is entered, the components listed in the data entry section of the model (column C) are very faint and almost invisible. A value of 1 will result in a bold black font, a value of 2 will result in a bold blue font, and a value of 3 will result in a bold red font. This will also result in the zone data being more boldly displayed. This feature is often useful when entering data. For example one may want to display all 480 volt equipment with a black font and all 5 kV equipment with a blue font. For a different model one may want to display all new equipment as one color and all old equipment as a different color. The color code has absolutely no impact on the model calculations. It is only a data entry navigation aid.

Column D, Failures in service - Depending upon the method used for gathering failure statistics you may want to differentiate between functional failures which result in a loss of service versus functional failures which do not result in a loss of service. For example if you track functional failures of power transformers and determine that 80% of the failures result in a loss of power (such as a winding failure) while 20% do not (such as a cooling fan failure), then you would enter a value of 80%. The value used in this column is dependent upon how component failure data is recorded.

Column E, Equipment - This column contains a description of the component or item that results in the functional failure of the zone. It can be an actual electrical device such as a cable or a breaker, or it can be a non-electrical device such as human error or varments.

Column F, Units - In order to have meaningful results you must be able to correlate the MTTR and Lambda to the method for counting devices. For example on transformers you may count them per winding or you may count them per unit. On breakers you may count them by each three phase device or by each single phase device. For cables you may count it by conductor feet or by circuit feet.

Column G, MTTR - This is the mean time to repair one unit device, measured in hours.

Column H, Lambda - This is the functional failure rate of one unit device, measured in failures per year. For example a value of 0.001 would represent the failure of one device in a population of 1000 over a period of 1 year. Mathematically this is the inverse of the Mean Time Between Failure, measured in years per failure.

Column I, Not used in this model. This column is reserved in the RAM table for use by future modeling techniques.

Column J, Model MTTR - this is the value in column G multiplied by the value in column A.

Column K, Model Lambda - this is the value in column H multiplied by the value in column B.

Column L, MTTR Days - this is the value in Column G converted from units of hours to days.

Column M, MTBF - this is the inverse of the value in column H.

The last item in the RAM table on row 149 is the "Utility Supply Simulator" and is linked to the "Utility" worksheet. The Utility Supply Simulator on the "Utility" worksheet can be used to derive a composite failure and repair value for various types of utility functional failures. The MTBF and MTTR from this worksheet is linked to the RAM table.

The **third step** is to enter data into the model for each zone. Open the "Model 280" worksheet. Move to cell B1 at the top left corner of the worksheet. This position is named *home*. Throughout the worksheet are several macro buttons labeled *GoHome*. Clicking on *GoHome* will bring you back to this location. At the *home* location, there are eight macro buttons. The button labelled *Zonetable* will move you to the zone table area for entering system configuration. This will be discussed later. There are six buttons showing a range of numbers with the first labeled *1-35*. The worksheet has six separate areas for entering zone data, with each area covering 35 zones. Clicking on a zone button will move to the section that covers the range of zones listed and properly split the spreadsheet. The eighth marco button is labelled *s/home.* There is a similar macro located at the upper left corner of each area where zone data is entered. Clicking on the *s/home* macro will un-split the worksheet and return you to the *home* position.

Also, located on the Excel Menu in the upper left corner is a "Name" box with a pull down menu. This is a very effective tool for navigating around the worksheet.

To enter data for zones 1 through 35, click on the 1-35 macro button. This will take you to the area for entering data for zones 1 through 35. On the left side of the screen is a listing of the devices from the RAM table. All modifications of the RAM table must be made on the RAM worksheet and will be reflected for each zone. The same RAM table must be used for all zones. Each zone is listed alongside the RAM table data. The quantity of each component in each zone should be entered in these cells.

The question of accuracy in entering data always comes up. Obviously the more accurate the input, the more accurate the output. However, for a large model, my personal feeling is that it is better to guess and be close, than to not enter the data at all. One nice feature of a spreadsheet is that you can always go back and change the data. Note that every cell for the zone data entry has a zero in it. If you have the display option set to show zero values you will see all the zeros. Otherwise, the cells will appear empty. Probably the single biggest error in entering data is to enter a number and later come back and remove it by entering a space (as with the spacebar) into the cell. Spaces will not compute and you will get error statements.

The **fourth step**, after entering all the zone data entry is to enter the system configuration. This is done in the Zone Table.

For this model every zone is interconnected to other zones in one of two ways. The first is called a series connection is where the top of one zone is connected to or supplied from a single point at the bottom of another zone. In fig. 3, every zone except Zone 10 is a series connected zone, with the top of each zone connecting to a single point higher in the system.

The second method of connecting a zone is what is called a parallel connection. This is where the top of a single zone is connected to or supplied from **two** points. Zone 10 in **Fig. 7** is an example of a parallel zone. **Fig. 8** below shows what the Zone Table would look like for the sample system shown previously in **Fig. 7**.

| | Series | | Czone | Point "1" | Parallel |
	Zone	Point			Point "2"
point1	1	0			
point2	2	1			

point3	3	2			
point4	4	2			
point5	5	4			
point6	6	2			
point7	7	2			
point8	8	5			
point9	9	7			
point10			10	8	9

Sample Zone Table for Model Shown in Figure 9

Figure 8

Zone 10 is the only zone on the model that is connected in parallel with two sources. Zone 1 is connected to Point 0, which is the Infinite point with unity reliability that is used as a starting point. You could actually reconstruct the configuration of the system without the one-line by using the Zone Table. As described earlier, every zone is connected either in series with other zones or in parallel with two other zones. Zones are always connected to either a single upstream point if it is a series configuration or to two upstream points if it is a parallel configuration.

Common Cause
For the parallel connected zone, the user should enter a "H, M, or L" common cause code. The user has the option to change the values used for common cause at Cells HR 580-582. If the user wants to further revise the common cause valued for a specific zone, a unique value can be entered in Column HP in the ZoneTable for the zones under review.
Note that on the zone table, if the user enters a zone as both series and parallel connected, the cell on the left with the point name will change from a gray format to a bold format with an aqua blue background. After entering the Zone Quantities and the Zone Table, hit F9 if you are in the manual calc mode and the spreadsheet will calculate all of the reliability related parameters for each zone and point (the manual calculation mode is suggested if you have a large model and a slow computer. Otherwise, automatic recalculation is suggested). Note that the spread sheet is configured so that when a point value is entered into the Zone Table in column HK for a series zone, the value for the zone will automatically be entered into column HJ. Likewise when parallel point values are entered into columns HM and HN, the common zone value (cZone) will be entered in column HL. The exception for this is for Point 1 in which a value must be entered for both the series Point and the Zone. Note that if any Zone other than Zone 1 is connected to Point 0, the value Zone must be manually typed over the formula in column HJ.

Now go to the ZoneCalc table (use the pull down menu in the "Name" box on the tool bar). Each of the zones in your model should have calculated values. The extra zones will have error symbols (#DIV0!). If any of your zones have errors, you made a mistake entering data and need to go back and make the correction. If you cannot easily find the data entry error, you may need to unhide the columns between AO and HI for the problem zone to seek additional clues.

Assuming your ZoneCalc table has no errors, the next step is to look at the Point Table. Again, each of your points should have calculated values and the extra points will have errors. Tracing errors in the Point Table is usually much more difficult than for the ZoneCalc table. If there is just one Point in question, find a similar point in your model (i.e. a series or parallel configuration) and then go to the ZoneTable. From there, work your way to the right into the detailed calculations and try to find differences between the point that calculates and the one that doesn't. Note that this section of the spreadsheet will always have errors for every point since it tries to calculate both series and parallel configuration values for every point.   There is not an easy way short of understanding the model to debug errors in this section.   Typical errors are not having zones

connected to existing points, having zones connected to themselves, or having zones connected both in parallel and in series.

Before looking at the outputs, there are a few more inputs that need to be entered. As described earlier, the user has the option to enter the common cause values located at HR578-580. The current model values of .1, .5, and .95 are our best guess at realistic common cause values for refinery and chemcial applications. Common cause only impacts zones connected in parallel. If you do not have any parallel connected zones, you do not need to be concerned with common cause. If you do have parallel connected zones it is probably worth while changing the common cause value used and seeing the impact that it has on the parallel connected zone. If the failure and repair rates for the two zones supplying the parallel zone are realistic, then the common cause value used should result in realistic failure and repair rates for the parallel zone.

Next you need to now enter date into the Unit Impact Table, located at HR 292. In row [HR 292 - IJ292] you enter the common names for the major process units or loads that are supplied by the system. Two rows below the names you then enter the cost impact to the business for having that individual load shut down for 24 hours. For example the unit name may be Distilling 3 and the 24 hour cost impact might be $150,000. We then move down the table and review the impact that loosing the power at **each point** will have on each of the units or loads. We can consider the direct impact of loosing power to a process unit, or we can consider the indirect impact that is related to the process factors such as the loss of feedstock to a downstream process unit or the loss of utilities to a process unit. The factors are entered as percentages with values from 0 to 100. A value of 100 would indicate that loss of that point would result in a 100% shutdown of the subject unit. If shutting down this unit would also result in the shutdown of another unit, even though it did not directly loose power, a value of 100 would also be entered for it.

Data must now be entered to model the time required to restart a process unit or load once the electrical failure has been repaired. This information is entered into the Consequences Table. There is a straight line non-linear model, as shown in **Fig. 9** used to predict the amount of time required to restream the process unit following a functional failure. Two values are needed to define the knee of the curve as shown on **Fig. 9**. The "Hours to reach Linear Cold Restart" shown on the X axis is a common value for all points in the model. This value is entered into cell IM 290.
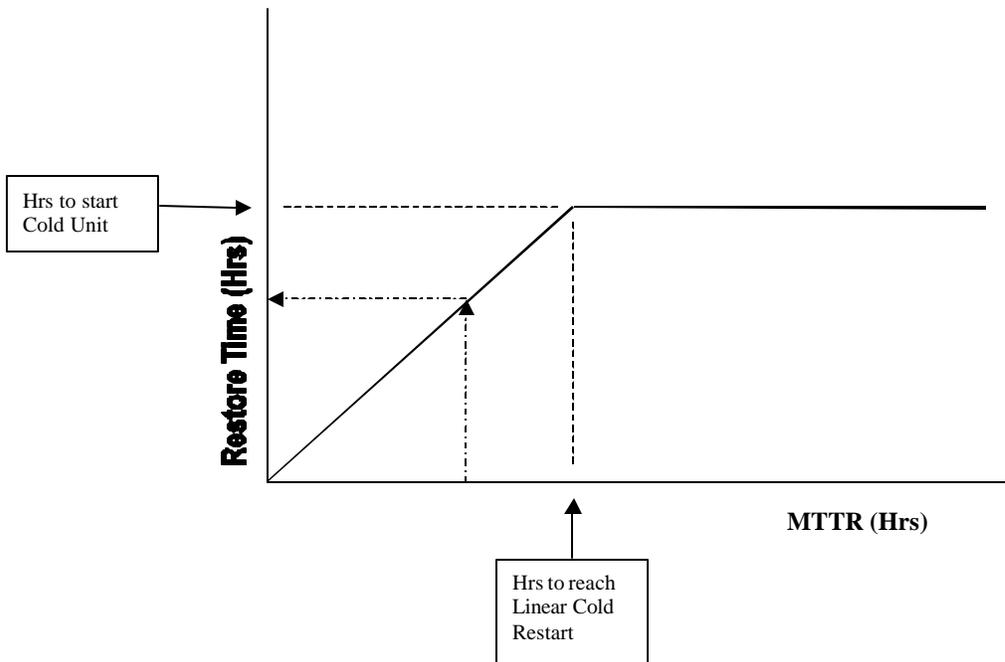
Fig. 9 Model for Calculating Restore Time

The value for Hours to Restart Unit Following Repair shown on the Y axis of **Fig. 9** is entered for each individual point in column IL starting on row 295. It is important to understand how this model works as it was intended to somewhat simulate the shutdown and restart of petroleum units. This model may or may not represent how the units you are modeling actually responds to upsets. In this model, if the MTTR is less than or equal to the value of hrs to reach Linear Cold Restart, then:
Restore time = (Hrs to start Cold Unit)(MTTR)/(Hrs to reach Linear Cold Restart). If the MTTR is greater than the value of the Hrs to reach Linear Colde Restart, the the restore time will equal the Hrs to start Cold Unit. The total downtime will equal the MTTR plus the Restore times.

While not necessary for a case study, there are columns IT and IU on the right side of the Consequences Table for entering a description of the loads and units supplied from each point.

The last data entry option for the model is the Lambda and MTTR modifiers for each Component. This data is entered in columns A and B on the left side of the RAM Table. Initially all values are set at 1.00. The purpose for these multipliers is to allow you to adjust your Master RAM Table values to fit a specific project or location. You may find that for a project or location the failure rate has been influenced by the past preventative maintenance program, the environment of the equipment and similar conditions. Thus, you may want to adjust the values used in the model. Likewise, the time to repair may be influenced by the availability of spare parts, the technical ability of the crafts, etc. Changing these multipliers changes the Lambda and MTTR values in the Zone RAM Tables but do not change the values in the Master RAM Table.

This completes all of the data entry for the study.

Output Information

The **Zone Calc table** looks at the reliability related statistics for each individual zone. The value of this data is that you can easily spot individual zones that have unusually high or low failure statistics.

The **Point Table** displays the reliability related statistics for each point in the system, taking into account the configuration of the system as described in the Zone Table.. When looking at the Point Table, it is interesting to notice the Percent Availability per year. The difference between a relatively unreliable point and a relatively reliable point is often almost undetectable. Also the relationship between Percent Reliability and the MTBF does not usually present an obvious correlation. The point to be made here is that talking about the actual statistical Reliability or Availability is not a very good way of describing electrical system performance. A better choice would be to use terms such as the Mean Time Between Failure or the Mean Time Between Repairs, and the Mean Time to Repair or the Mean Time To Restore. This describes the system performance in terms of hours per year or years per incident, which are terms that our customers better understand.

Consequences

The Consequences table displays most of the business related output results. Column IB shows the calculated cost for the loss of each point.. Column IE displays the total hours per year that the point will be down, Column IF displays the cost in dollars for each incident, and Column IG factors in the MTBF to determine the Annual risk associated with each point.. Note that these risk values do not include the cost for repairing the failure, and is only the production loss associated with not having the process unit(s) available to make product.

The Model Component Summary table provides a summary of all the components used in the system model, the combined failure statistics for each component, and some component statistics for the entire system. Excel has the ability to sort data. However, **DO NOT SORT THE DATA DIRECTLY IN THE TABLES** as this will scramble the formulas and provide useless results. Use the COPY and PASTE SPECIAL commands to copy the Values and Formats into a blank spreadsheet. The data can then be sorted in the new spreadsheet on any field desired. At the bottom of The Component Summary is a small table that displays some system information.

Description of Model

The 280 zone electrical reliability model is an Excel spreadsheet. The spreadsheet labeled MODEL280#.XLS is a model that can handle up to 280 different Zones.
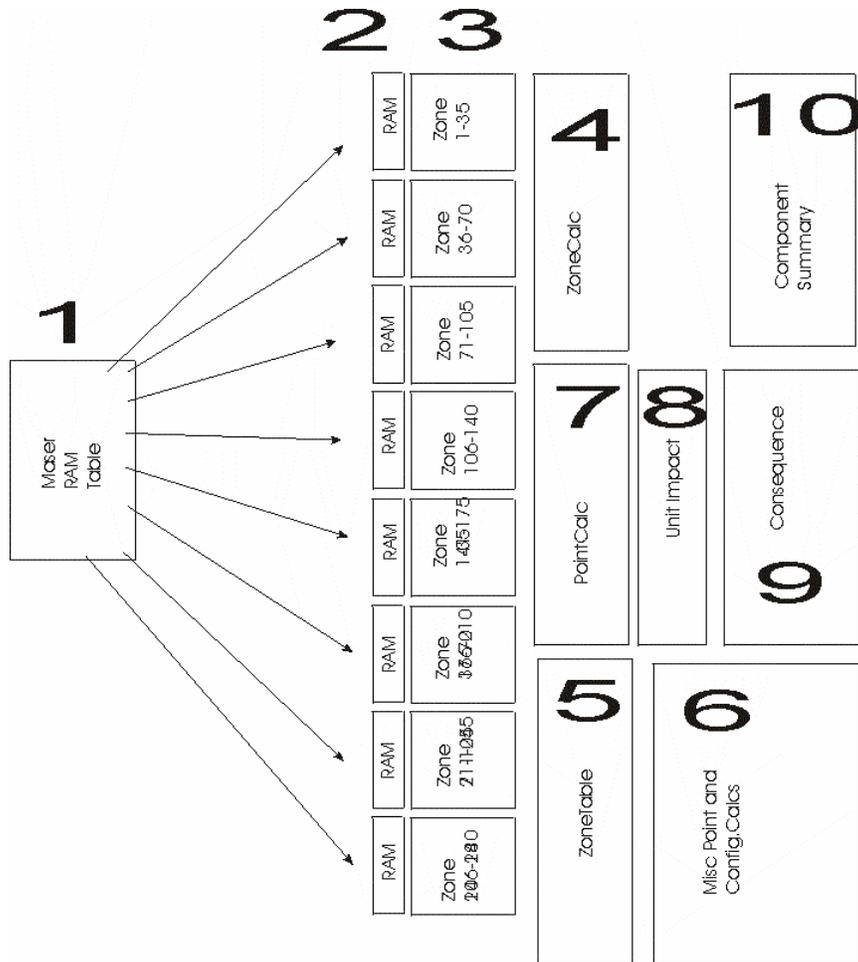
Fig. 10 Model Layout

Overview of Model

Before getting into some of the details of the model, it may be helpful to get an overall picture of the layout of the spreadsheet. **Fig. 10** shows the relative position of the various major areas of the model.

Item [1] is the RAM table. It is located on a separate worksheet. All data from the Master RAM Table [1] is duplicated on the RAM tables [2] for each of the eight areas for entering Zone data [3]. Area [4], called ZoneCalc is the location that displays the individual calculations for the components in each of the zones. Area [5] called the ZoneTable is the area where the configuration of all the zones is entered. Data from the ZoneCalc area [4] is combined with the configuration from the ZoneTable [5] to perform additional calculations in area [6]. The results of the various calculations for all the points are displayed in the area [7] called the PointCalc. Location [8] is called the unit impact table and is the location for entering the financial impact that each point has on the

operation of major units. Area [9] titled Consequences is the area that displays the financial risk and reliability calculations. Area [10] is the area titled Component Summary which displays the failure statistics for the components in the model.

Master RAM Table [Worksheet "RAM Table"]
The Master RAM table is the database that contains the electrical component reliability data. The data in this table can be manually changed or updated to fit the user's specific needs. A change in the Master RAM table date will be reflected throughout the model, including all eight of the Zone RAM Tables.

The RAM table was designed to permit the user to enter any value and to perform an analysis using that value. The following is a brief explanation of data entry in the RAM table for each component.

Column A, MTTR Factor - This is a multiplication factor that can be used to temporarily adjust the component Mean Time To Repair. The default value is 1.00. You can observe that if you change the value from 1.0 to 2.0, the RAM table MTTR value in column G will remain unchanged, but the actual value used by the model, shown in column I will double. This feature is useful to perform quick what-if analysis without altering the actual RAM table data.

Column B, Lambda Factor - Similar to column A MTTR factor described above except that it is used to modify the component Lambda (1/MTBF) value.

Column C, Color Code - by changing the value in this column, you can change they way the RAM table data is displayed in the area on the model where data is entered. This is a useful aid when entering zone data. When a value of 0 is entered, the components listed in the data entry section of the model (column C) are very faint and almost invisible. A value of 1 will result in a bold black font, a value of 2 will result in a bold blue font, and a value of 3 will result in a bold red font. This will also result in the zone data being more boldly displayed. This feature is often useful when entering data. For example one may want to display all 480 volt equipment with a black font and all 5 kV equipment with a blue font. For a different model one may want to display all new equipment as one color and all old equipment as a different color. The color code has absolutely no impact on the model calculations. It is only a data entry navigation aid.

Column D, failures in service - Depending upon the method used for gathering failure statistics you may want to differentiate between functional failures which result in a loss of service versus functional failures which do not result in a loss of service. For example if you track functional failures of power transformers and determine that 80% of the failures result in a loss of power (such as a winding failure) while 20% do not (such as a cooling fan failure), then you would enter a value of 80%. The value used in this column is dependent upon how component failure data is recorded.

Column E, Equipment - This column contains a description of the component or item that results in the functional failure of the zone. It can be an actual electrical device such as a cable or a breaker, or it can be a non-electrical device such as human error or varments.
Column F, Units - In order to have meaningful results you must be able to correlate the MTTR and Lambda to the method for counting devices. For example on transformers you may count them per winding or you may count them per unit. On breakers you may count them by each three phase device or by each single phase device. For cables you may count it by conductor feet or by circuit feet.

Column G, MTTR - This is the mean time to repair one unit device, measured in hours.

Column H, Lambda - This is the functional failure rate of one unit device, measured in failures per year. For example a value of 0.001 would represent the failure of one device in a population of 1000

over a period of 1 year. Mathematically this is the inverse of the Mean Time Between Failure, measured in years per failure.

Column I, Not used in this model

Column J, Model MTTR - this is the value in column G multiplied by the value in column A.

Column K, Model Lambda - this is the value in column H multiplied by the value in column B.

Column L, MTTR Days - this is the value in Column G converted from units of hours to days.

Column M, MTBF - this is the inverse of the value in column H.

The last item in the RAM table on row 149 is the "Utility Supply Simulator" and is linked to the "Utility" worksheet. The Utility Supply Simulator on the "Utility" worksheet can be used to derive a composite failure and repair value for various types of utility functional failures. The MTBF and MTTR from this worksheet is linked to the RAM table.

Zone Data [G5:G147 for Zone 1]
Each of the 280 Zones has a visible column for entering the quantity of electrical components within that zone. Each zone also has five hidden columns (located at columns AP through HH) for performing reliability calculations for that individual zone. The area for inputting zone quantities and performing zone component calculations is identical for every zone. The detailed calculations for each zone were hidden using conventional Excel commands. Quantities can be cut and pasted from one 280 zone model to another using conventional Excel cut and paste techniques. However, cut and paste techniques cannot be used on the older 35 zone and 70 zone models as the hidden columns were intermingled between the visible columns. The following will describe columns AP, AQ, AR, and AS for Zone 1. Column G, labeled "Quantity", is the area for manually entering the quantity of each electrical component. Column AP calculates the zone component failures per million hours using the following formula:

 Failures [Column AP] = Quantity [Column G] * λ [Column F] * 1000000 / (8760)

Failures
=G6*$F6*1000000/(8760)

Note that you will see the multiplier 8760 in many formulas. This is the number of hours in a year. The table shown for each formula is the actual formula copied from the model.

Column AQ calculates the zone component failure rate in failures per year using the following formula:

Failures/yr [Column AQ] = Column AP * 8760/1000000

Failure
Rate
=(AP6*8760)/1000000

Column AR calculates the component zone MTBF using the following formula:

Zone MTBF [Column AR] = 1/λ [Column AQ]

MTBF
=IF(AQ6<>0,1/ AQ6,0)

Column AS calculates the component zone Reliability using the following formula:

Reliability [Column AS] = $e^{-\lambda \text{[Column AQ]}}$

Reliability
=EXP(-AQ 6)

Column AT calculates the component zone Availability using the following formula:

Availability [Column AT] =(MTBF * 8760) / ((MTTR * 8760) + MTTR)

Availability
=IF(G6<>0,(AR6*8760/(AR6*8760+$E6)),1)

Zone Calculation Table [HI1:HP281]

The Zone Calculation Table is an area where combined reliability calculations are made for all the components within one zone. Column HJ is the calculation of the zone Lambda. If you look at the contents of cell HJ1, you will see a zero. This zero (0) is used for some of the internal calculations and should not be changed. The "Zlambda" that you see on that cell is actually a text object located on top of the cell. The Zone Lambda is calculated using the following formula:

Zone 1 λ [Column HJ] = SUM Zone Component λ's [Column AQ, Rows 6 thru 147]

Zlambda->	0
zone1	=SUM(AQ6:AQ147)

Column HK is the zone combined Reliability and is calculated using the following formula:

Zone Reliability [Column HK] = $e^{-\lambda \text{[Column HJ]}}$

ZREL
=EXP(-HJ2)

Column HL is the zone combined Availability and is calculated using the following formula:

Zone 1 Availability [Column HL] = Product each component Avail [AT6*At7*AT8*AT9......*AT147]

ZAVAIL
=PRODUCT(AT6:AT147)

Zone Table [HI585:HO864]

The zone table provides the format for entering the configuration of the electrical system into the model. It is based on the premise that each zone either is connected in series to one upstream point, or is connected in parallel upstream to two points. A *Point* is any point within a zone and represents the reliability of the system from the top down to that Point. Typically, a point will be shown as the lowest point within a zone. The Zone Table lists the 280 possible points of the model

on the left side. Note that Point 0 can be used in the model as an infinite point similar to an infinite bus used in fault studies, and is used to start at the top of the model.

For a series connection, you enter the table at the point being addressed. The table has a built in formula to then enter the number of the zone involved (which will be the same as the point name. Nothing is entered in the "Parallel" portion of the table.

For a Parallel connected point, one enters the number of the two upstream connecting points. Again, the model has a built in formula to then enter the number of the zone involved. The user also enters a common cause value for each parallel point using the letter "L", "M", or "H" to designate the low, medium or high common cause value shown at cells HR578-580.

A number of the cells in the Zone Table have conditional formatting. If Zones are entered as both series and parallel, the Point Name in Column HI will change to an aqua background to indicate the data entry error. If a zone is shown with a parallel connection, the common cause cell in column HP will change to an aqua background to alert the user to check the common cause factor.

The model then takes this input and calculates the following information:

NOTE – THE FOLLOWING SECTION OF THE MODEL HAS BEEN SIGNIFICANTLY MODIFIED AS A RESULT OF THE NEW METHODOLOGY FOR CALCULATING COMMON CAUSE. THIS SECTION OF THE MANUAL HAS NOT BEEN UPDATED TO REFLECT THE MODIFICATIONS. USERS CAN REVIEW THE METHODOLOGY DESCRIBED IN THE PAPER TITLED "Reliabioity of Various Industrial Substations" AND REVIEW THE FORMULAS CONTAINED WITHIN THE MODEL'S CELLS FOR ADDITIONAL INSIGHT INTO THE CALCULATION MECHANICS OF THE MODEL.

Series Zone Lambda [HQ 585]
This column of the table uses the number listed in the zone table for the series "zone" to look up its value in the Zone Calculation Table described above.

Zone
Lambda
=INDIRECT("hj"&(1+HJ585))

Series Point Lambda [HR 585]
This column of the table uses the number listed in the zone table for the series "point" to look up its value in the Point Table.

Point
Lambda
=INDIRECT("hj"&(295+HK585))

Parallel Common Zone Lambda [HS585]
This column of the table uses the number listed in the zone table for the parallel "c zone" to look up its value in the Point Table. (c zone stands for common zone)

CZone
Lambda

=INDIRECT("hj"&(1+HL585))

Parallel Point 1 and Point 2 Lambda [HT585 & HU585]

These columns of the table use the numbers listed in the zone table for the parallel "points" to look up its value in the Point Table.

Point 1
Lambda
=INDIRECT("hj"&(295+HM585))

Point 2
Lambda
=INDIRECT("hj"&(295+HN585))

Parallel Point 1 and Point 2 Forced DownTime (FDT) [HW585 & HX 585]

These columns of the table use the numbers listed in the zone table for the parallel "points" to look up the associated values in the Point Table.

Point 1
FDT
=INDIRECT("hp"&(295+HM585))

Point 2
FDT
=INDIRECT("hp"&(295+HN585))

Parallel 1||2 sub-calculation [HY585]

This column performs an intermediate calculation needed for calculating the Lambda for the parallel combination of points 1 and 2. The formula is as follows:

1||2 Sub Cal $= (\lambda_1 / 8760 * FDT_1) + (\lambda_2 / 8760 * FDT_2)$

point 1||2
sub-calc
=(HT585/8760*HW585)+(HU585/8760*HX585))

1||2 Lambda [HV585]

This column does an "if" calculation depending upon whether the lambda for point 1 is great than or less than the lambda for point 2.

If the failure rate (λ) for point 1 is greater than the failure rate (λ) for point 2 then the Lambda for the parallel combination is:

$\lambda_{(1||2)}$ = (point 1||2 sub cal) + λ_1 *HP585   [HP585 is factor for common cause]

If the failure rate (λ) for point 2 is greater than the failure rate (λ) for point 1 then the Lambda for the parallel combination is:

$\lambda_{(1||2)}$ = (point 1||2 sub cal) + λ_2 *HP585   [HP585 is factor for common cause]

1		2

Lambda
=IF(HT585>HU585, HY585+HT585*HP585,HY585+HU585*HP585)

Series & Parallel Total Lambda [HX184]

This column calculates the total lambda for the point by summing columns HT, HQ, HP, and HO.
This value is then entered as the value for the point lambda in the Point Table.

Series &
Parallel
Plambda
=HT187+HQ187+HP187+HO187

Series Point Availability [IA585]

For series connected points and zones this column looks up the availability for the indicated zone
and point and multiplies the two values together.

Series
Point
Avail
=(INDIRECT("hl"&(295+HK585)))*(INDIRECT("hl"&(1+HJ585)))

For 1>2 or 2>1 Parallel Availability [IB585 & IC585]

These two columns calculated the availability for parallel connected points and zones. The "For
1>2" column will calculate the correct answer only if the MTTR for point 1 is greater than the MTTR
for point 2. Likewise, the "For 2>1" column will calculate the correct answer only if the MTTR for
point 2 is greater than the MTTR for point 1. The spreadsheet calculates both values and then uses
an "if test" in column IB to select the right answer.

Parallel Availability (1>2) =
$(1 - Avail_1) * (1 - Avail_2) * ((1 / \lambda_{(1||2)}) /((MTTR_1 / (8760) + (1 / \lambda_{(1||2)}))))$

For 1>2
Parallel
Avail
=1-(1-(INDIRECT("hl"&(295+HM585))))* (1-INDIRECT("hl"&(295+HN585))))*((1/HV585) /(((INDIRECT("ho"&(295+HM585)))/8760)+(1/HV585)))

Parallel Availability (2>1) =
$(1 - Avail_1) * (1 - Avail_2) * ((1 / \lambda_{(1||2)}) /((MTTR_2 / (8760) + (1 / \lambda_{(1||2)}))))$

For 1<2
Parallel
Avail
=1-(1-(INDIRECT("hl"&(295+HM585))))* (1-(INDIRECT("hl"&(295+HN585))))*((1/HV585) /(((INDIRECT("ho"&(295+HN585)))/8760)+(1/HV585)))

Parallel
Avail

=IF((INDIRECT("hn"&(295+HM585)))>(INDIRECT("hn"&(295+HN585))), IB585, IC585)

Point Availability [IE585]

This column selects the correct value for the value of the point availability using the following logic:

If the value for the "series zone" is greater than zero, the model picks the series availability number in column HJ.

If the value for the "series zone" is zero, then it checks to see if the value for the "parallel common zone" is greater than zero. If it is, it picks the parallel availability. If both are zero, i.e. an unused point it enters the value 0.

Point
Avail
=IF(HJ585>0,IA585,IF(HL585>0,ID585,0))

Common Cause Factor [HP585]

The Common Cause Factor is used in the calculations for parallel connections described above. This value can be varied to influence the effects that common events have on both of the inputs to a parallel connection at the same time. This value can typically vary from values in the range of .01 or less for electronic type equipment to the value of .1 to 1.0, which is typically used in this model.

Point Table [HI295:HP575]

The point table is the location where all of the calculated results pertaining to the individual points are assembled.

	Failure	Reliability	Available	Prob of	Mean Time	Mean Time	Forced
Point	Rate	at point	per year	Failure/Yr	Between Fail	to Repair	Downtime
Table	(per year)	Percent	Percent	Percent	(Years)	(Hours)/Inc	(Hrs/Yr)
	PLAMBDA	PREL	PAVAIL	PPROB	PMTBF	PMTTR	PDOWN

Point Failure Rate per year [HJ296]

This is the calculated value from Column HZ585.

Failure
Rate
(per year)
PLAMBDA
0
=HZ585

Point Reliability in percent [HK296]

The point reliability is calculated using the formula:

PRel = $e^{-\lambda}$ Where λ is the value from column HJ.

Reliability
at point
Percent
PREL
1
=EXP(-HJ296)

Point Availability in percent [HL296]

The point availability is calculated in the Zone Table [Column IE 585].

Available
per year
Percent
PAVAIL
1
=IE585

Point Probability of Failure within 1 Year in percent [HM296]

The point reliability is calculated using the formula:

PProb of Failure = 1 - Point Reliability [Column HK]

Prob of
Failure/Yr
Percent
PPROB
0.00001
=1-HK296

Point MTBF [HN296]

The point MTBF is calculated using the formula:

Point MTBF = $(1 / \lambda$ [Column HJ] $)$

Mean Time
Between Fail
(Years)
PMTBF
10000000
=(1/HJ296)

Point MTTR [HO296]

The point MTTR is calculated using the formula:

Point MTTR = 8760 MTBF((1 / Avail) - 1))

Mean Time
to Repair
(Hours)/Inc
PMTTR
0.000001
=((8760*HN296/HL296)-8760*HN296)

Point Forced Downtime in Hrs. / Yr [HP296]

The point forced downtime is calculated using the formula:

Point Forced Downtime = (8760 - (8760 * Availability [Column HL]))

Forced
Downtime
(Hrs/Yr)
PDOWN
0.00001
=(8760-8760*HL296)

**[End of operating manual section that was impacted by updating the common cause modeling technique.]**

Unit Impact Table

The unit impact cost table is located at HQ290:IJ:575. This table allows 19 process units or loads to be manually listed at row 292 [HQ:IA]. At row 294, one can then enter the cost impact for having each unit down for 24 hours. In the matrix below the cost impact line, one then enters the impact that a failure of each individual point would have on the listed unit. The impact is entered as a percent (1 to 100) of the 24-hour cost impact. The percentage can reflect both direct impacts associated with a loss of power and indirect impacts such as the shutdown of a downstream unit because of the loss of the unit supplied by the point in question.

The **Point Cost per Day [Column IK295]** is calculated by summing the products of the percentages times the dollar cost impact for each unit and dividing by 100.

Point
Cost per
Day
=((HR$294*HR295)+(HS$294*HS295)+(HT$294*HT295)+(HU$294*HU295)+(HV$294*HV295)+ (HW$294*HW295)+(HX$294*HX295)+(HY$294*HY295)+(HZ$294*HZ295)+(IA$294*IA295)+ (IB$294*IB295)+(IC$294*IC295)+(ID$294*ID295)+(IE$294*IE295)+(IF$294*IF295)+(IG$294*IG295)+(IH$294*IH295)+(II$294*II295)+(IJ$294*IJ295))/100

Total Time To Repair and Restream Process Units The spreadsheet uses a simple non-linear model to determine the total time impact to a unit that an electrical failure will have. **Figure 11** graphically displays the model.

Model To Predict Time to Restart
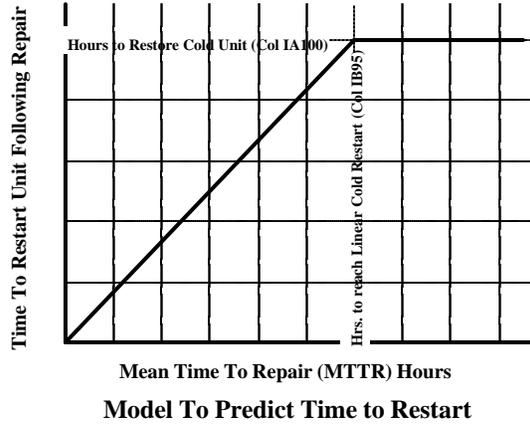
Figure 11

The X axis of the graph is the MTTR for the point. The Y axis is the time required to restream the unit connected to the point once the fault has been repaired. As you can see from the graph, the **Hours to Restart** is a linear function of the MTTR for MTTR values less than the **Hours To Reach a Linear Cold Restart [IK295]**. Once the MTTR exceeds the hours to reach a linear cold restart, the time to restart the unit becomes a constant value equal to the value entered in the column labeled **Hours to Restore Unit [column IL295].** The total time to repair and restart the unit is shown in the column labeled **Restore plus MTTR [column IM295]** and is equal to the sum of the Hours to Restart plus the MTTR. The spreadsheet uses the following formula to calculate the Hours to Restart:

Hrs to Restart when MTTR <= Cold Restart Hrs = MTTR * Hrs to Restore Unit /Cold Restart Hrs

Hrs to Restart when MTTR > Cold Restart Hrs = Hrs to Restore Unit

Note on restart time - There are endless ways of trying to model the amount of time that it will take to put a unit back on line following an electrical incident. This linear model was intended primarily for relatively simple refinery process units where the typical scenario would be that a very short disturbance usually results in little heat loss from the unit and it can usually return to normal quite quickly. However, as the outage becomes longer, the unit tends to loose heat and other resources, and restoration of production following the outage takes longer. At some point, you reach the knee in the models curve where durations beyond this point do not lengthen the startup. If your facility has units that require appreciable restart time no matter how short the duration of the problem then you would tend to reduce the "hours to reach linear cold restart". If your facility has units that require a great deal of time to restart following an extended power outage, then you would tend to increase the "hours to restore cold unit".

The total time to repair and restart the unit is shown in the column labeled **Restore plus MTTR [column ID100]** and is equal to the sum of the Hours to Restart plus the MTTR. The spreadsheet uses the following formula to calculate the Hours to Restart:

The Restore plus MTTR [column IM296] is the values calculated above plus the MTTR.

Restore
plus
MTTR
=IF(HO296 <IM290,HO296*IL296/IM290+HO296,HO296+IL296)

The Consequences in Hours per Year [IN296] is calculated using the following formula:

Consequences =((Hours to Restore plus MTTR) / MTBF)

Conseq
Hr/Yr
=IM296/HN296

The Dollars per Incident [IO296] is calculated using the following formula:

Dollars/Incident = ((Point Cost/day) / 24) * (Hours to Restore plus MTTR)

Dollars
per
Incident
=(IK296/24)*IM296

The Annual Risk [IP296] is calculated using the following formula:

Annual Risk = Dollars per incident / MTBF

Annual
Risk
=IO296/HN296

The Annual Risk Without Restore Time [IQ296] is calculated using the following formula:

Annual Risk Without = Dollars per incident for repair time only / MTBF
                    = ((MTTR / 24) * Costs per day) / MTBF

Annual
Risk
=((HO296/24)*IK296)/HN296

The Model Component Summary [IG3, IT149]
The Model Component Summary Table displays the total quantity of each component within the model and the statistical information pertaining to the total population of the component. It displays the failure rate, reliability, and availability for the entire component category. It also provides a summary of the total number of components in the model and the statistical failure rate for the entire population. Since details for these calculations have already been explained, they will not be repeated here.

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