

Operating Manual for Calculating Electrical Risk and Reliability Using the 2000-2 PCIC Reliability Model

Revision 6, May 18, 2000
John Propst Equilon Enterprises LLC

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John Propst Equilon Enterprises, LLC
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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 and the paper titled "Improvements in Modeling and Evaluation of Electrical Power System Reliability" (PCIC 2000-2) presented at the 2000 PCIC conference. It also assumes that you are familiar with the PC program Excel and that you have loaded the spreadsheet Model2000-2 pcic.XLS. The 2000-2 pcic.xls model is a scaled down 70 zone model of the model currently being used by the author. This was primarily done to reduce the size of the model from almost 8 megs down to about 2.5 megs. While some RAM table data has been included to provide guidance for the user, most of the actual RAM data has been deleted to preserve the proprietary nature of the data. However, users are able to populate the RAM table with data derived either from sources such as the Gold Book or from personal experience and data.

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.

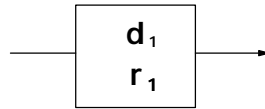
Restore Time - In the model, the time to restore is the sum of the mean time to repair (MTTR) for the failure plus the computed time to restream or restart the connected process unit or load.

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.



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

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

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:

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

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

The failure rate (λ) is given by:

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

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

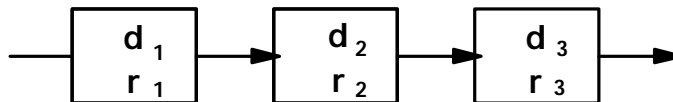
$$R_1 = e^{-(\lambda)(8760)}$$

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,



$$d = \text{MTBF (in hours)}$$

$$r = \text{MTTR (in hours)}$$

The characteristics of each individual component can be calculated using:

$$\lambda = 1 / d_i$$

$$A_i = d_i / (d_i + r_i)$$

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

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

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

$$\lambda_s = \lambda_1 + \lambda_2 + \lambda_3$$

or

$$\lambda = R_1 * R_2 * R_3$$

Reliability of the system for one year:

$$R_s = e^{-\lambda_s(8760)}$$

System availability :

$$A_s = A_1 * A_2 * A_3$$

Probability of failure during one year:

$$P_s = (1 - R_s) * 100$$

MTBF:

$$MTBF = 1 / \lambda_s$$

MTTR in hours:

$$MTTR = MTBF [(1 / A_s) - 1]$$

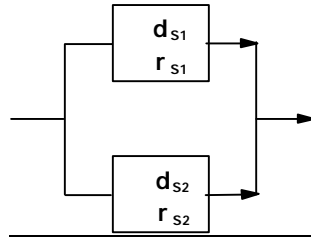
Forced downtime:

$$FDT = (1 - A_s)$$

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 if either on or both of two parallel components functions.



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

If the components can be repaired, 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 steady-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 steady-state availability for n blocks is:

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

or for two parallel Components:

$$A = 1 - [(\lambda_1 / (\lambda_1 + \mu_1))(\lambda_2 / (\lambda_2 + \mu_2))]$$

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 Reliability¹ 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.

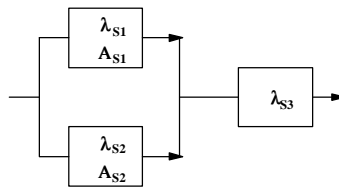


Figure 1

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 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 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.

¹David J. Smith, Reliability and Maintainability in Perspective

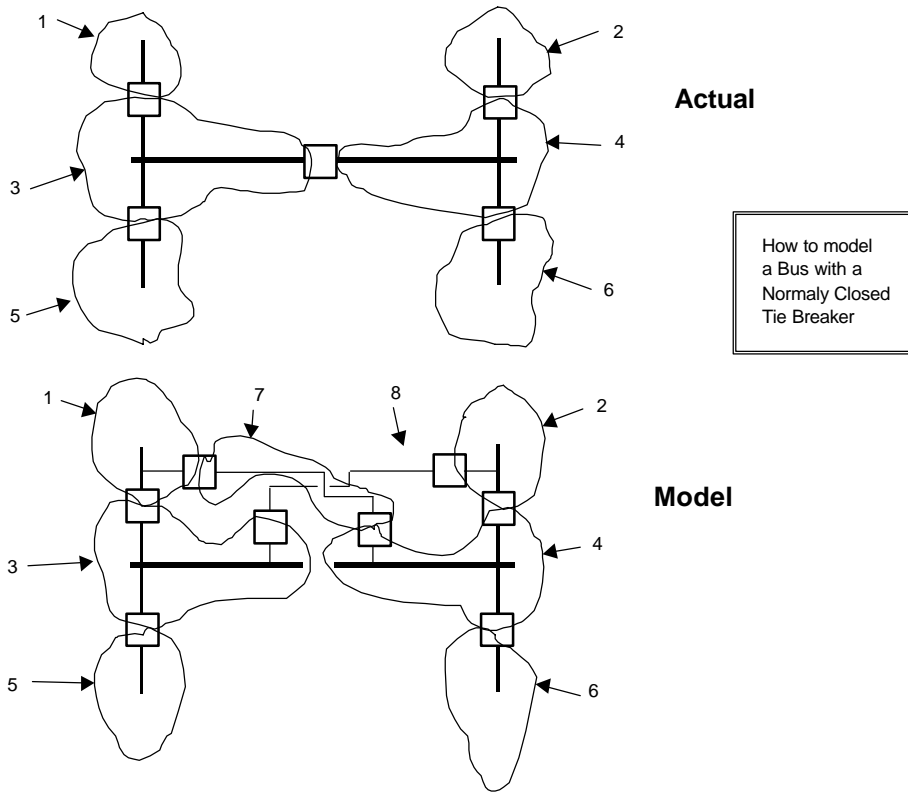


Figure 2

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 failure of the source down to the point in question. However, they will have an impact on the mean time to repair. Therefore if you have a normally open tie breaker that is supplying a bus, the mean time between failure 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 the point for which the tie breaker is the alternate source, and then calculate the point availability based on the MTTR and the calculated lambda, using the formula: $Availability = 8760 / ((\lambda) * (MTTR) + 8760)$. 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.

Sources and Loads

Utility sources are usually entered into the model using the utility supply simulator on the utility worksheet of the model. The simulator can be modified as needed to address utility disturbance issues that result in power disturbances.

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 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 3** 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.

Loading and running the model

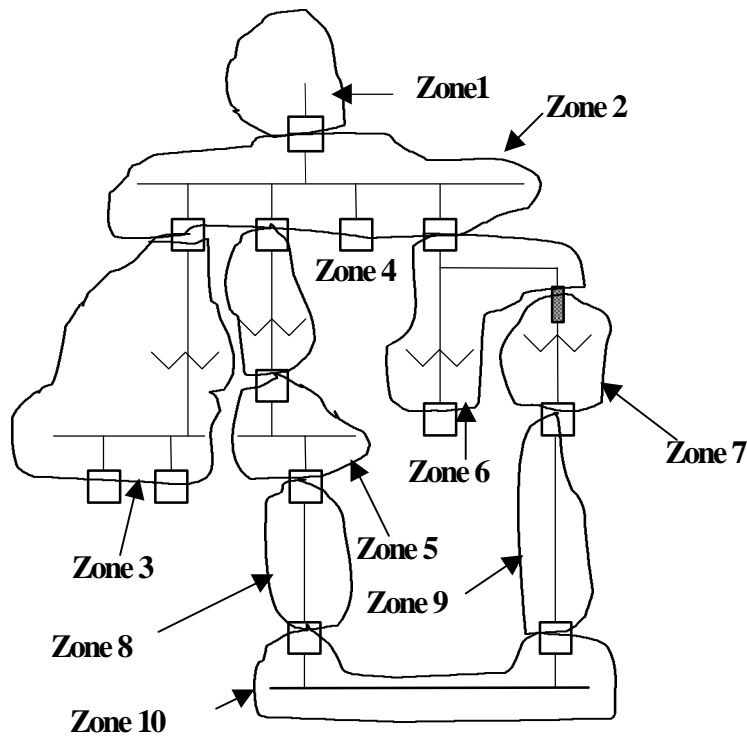
- Load the spreadsheet titled 2000-2pcic.xls.

You now have a blank 70 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. 3** 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 operation of a protective device. Exactly where the transition from one zone to the next takes place tends to be a compromise 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 compromise 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. 3** 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 70 zones. In the unlikely case that the system is larger than this, an additional 70 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 3

The **second step** is to review the RAM table and make sure it has the components that are in your system. A few examples are shown in the RAM table. 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 I use in models. My typical response is that if you don't like the data, or don't think that it represents the performance of the 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 the 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, Model MTTR - this is the value in column G multiplied by the value in column A.

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

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

Column L, 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" 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 four 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 two buttons showing a range of numbers with the first labeled 1-35. The worksheet has two 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 fourth macro 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. 3** is an example of a parallel zone. **Fig. 4** below shows what the Zone Table would look like for the sample system shown previously in **Fig. 3**.

	Series Zone	Point	Czone	Point "1"	Parallel 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 4

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.

For the parallel connected zone, the user should enter a "H, M, or L" common cause code. 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. 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 data 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 lose 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. 5** used to predict the amount of time required to restart the process unit following a functional failure. Two values are needed to define the knee of the curve as shown on **Fig. 5**. 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.

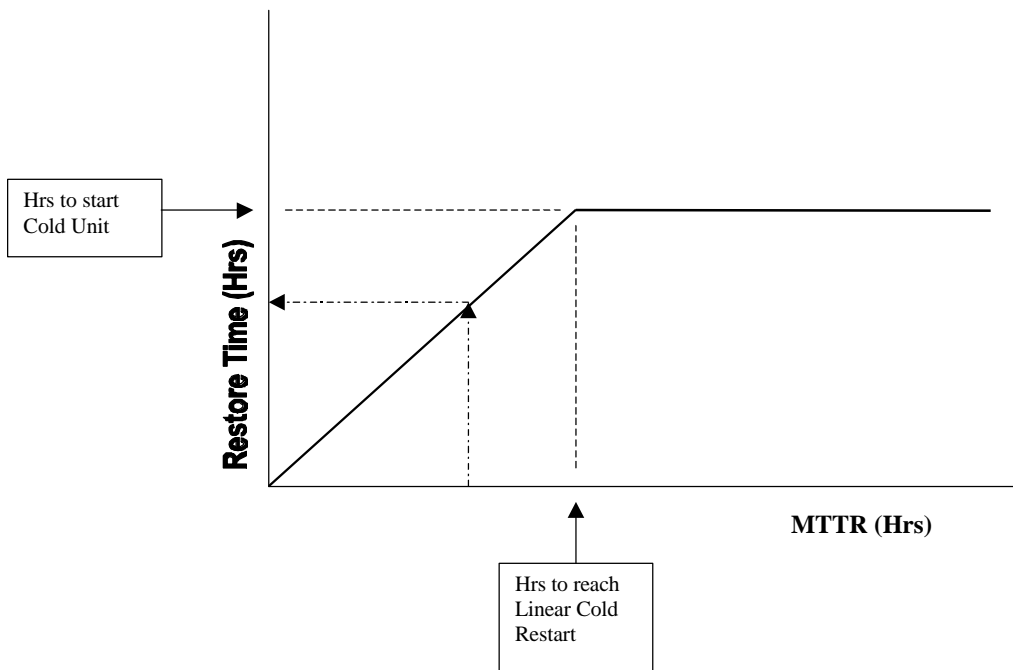


Fig. 5 Model for Calculating Restore Time

The value for Hours to Restart Unit Following Repair shown on the Y axis of **Fig. 5** 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: $\text{Restore time} = (\text{Hrs to start Cold Unit})(\text{MTTR})/(\text{Hrs to reach Linear Cold Restart})$. 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 electrical reliability model is an Excel spreadsheet. The spreadsheet labeled MODEL2000-2.pci.XLS is a model that can handle up to 70 different Zones.

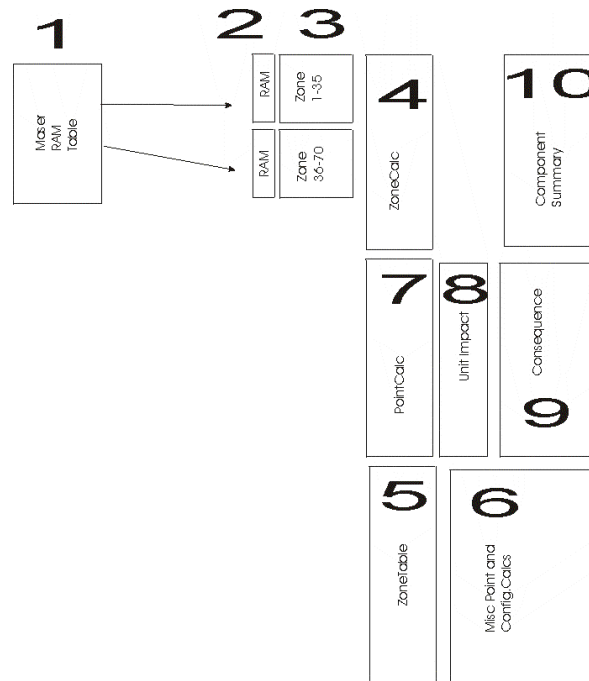


Fig. 6 Model Layout

Overview of Model

It may be helpful to have an overall picture of the layout of the spreadsheet. **Fig. 6** 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 two 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.

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