TENNESSEE VALLEY PUBLIC POWER ASSOCIATION
(TVPPA)
Chattanooga, Tennessee

DISTRIBUTION SECONDARY CALCULATOR
(Project No. DSC-1)

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Table of Contents

TEXT

APPENDICES

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1. INTRODUCTION

The Distribution Secondary Calculator (DSC) was created by Patterson & Dewar Engineers, Inc. (P&D) for the Tennessee Valley Public Power Association (TVPPA) with the intent of aiding member-system staking technicians in the selection and analysis of electric facilities in their day-to-day work.

Consumer-owned utilities have been major contributors to the quality of life enjoyed by Tennessee Valley residents since the mid-1930s. Local electric systems are more than utilities – they are an active, necessary part of the communities they serve. The Valley's consumer-owned power distributors have only one purpose – to provide all ratepayers with the best energy services at the lowest possible cost consistent with sound business practices. It is the sincere hope of P&D that this software will aid member companies in fulfilling this purpose.

2. APPLICATION OVERVIEW

The DSC is stand-alone Windows-based personal computer (PC) software that calculates voltage drop, voltage sag (flicker) and fault current from the secondary connections of distribution transformers to the load connections. The DSC user can easily analyze balanced or unbalanced single-phase and three-phase systems for both overhead and underground construction. The main benefits of the DSC follow below:

- Easy to use and does not require detailed engineering knowledge. User can print on-screen results and save each scenario in a standard Windows file format.
- Contains database of standard specification data for equipment such as transformers, conductors, motors and HVAC systems that are typically encountered by an electric distributor. In addition, user defined equipment can be entered and stored.
- All standard systems and voltages encountered by an electric distributor are available for analysis, including paralleling conductors for secondary runs and services.
- User-modifiable default load power factor provided. Power factor for entire system calculated and displayed with results.
- User-modifiable default values for power cost (cents per kWh) and annual load factors provided. Losses for entire system calculated and displayed.
- Graphic display of analyzed circuit shown with input information and requested results. Units for inputs and results are volts, amps, kW, kVA, and percentage of base value.
- Industry standard data provided and compared to calculated results to determine if the results are within industry standard limits. This includes electrical limitations for equipment. Results of the comparison displayed on the standard output screen.

3. SOFTWARE INSTALLATION

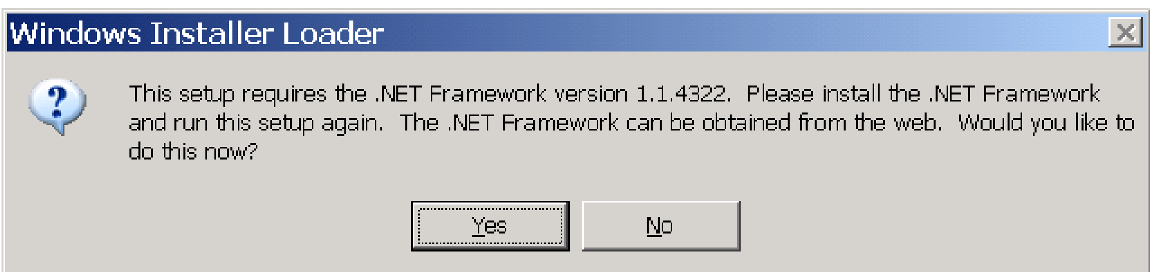
3.1. Hardware and Software Requirements

- Pentium or higher
- Windows XP (Not tested on other operating systems)
- Adobe Acrobat Reader 7.0 or higher (For viewing Manual)
- Microsoft .NET Framework Version 1.1 with Service Pack 1
- Recommended minimum display resolution of 1024 by 768 pixels
- Display DPI setting of Normal (96 DPI)

3.2. Installation

Insert the CD into a CD drive. Setup will run automatically[1]. Follow the on-screen instructions.

If Microsoft .NET Framework Version 1.1 with Service Pack 1 is not already installed, then the following advisory window will appear:



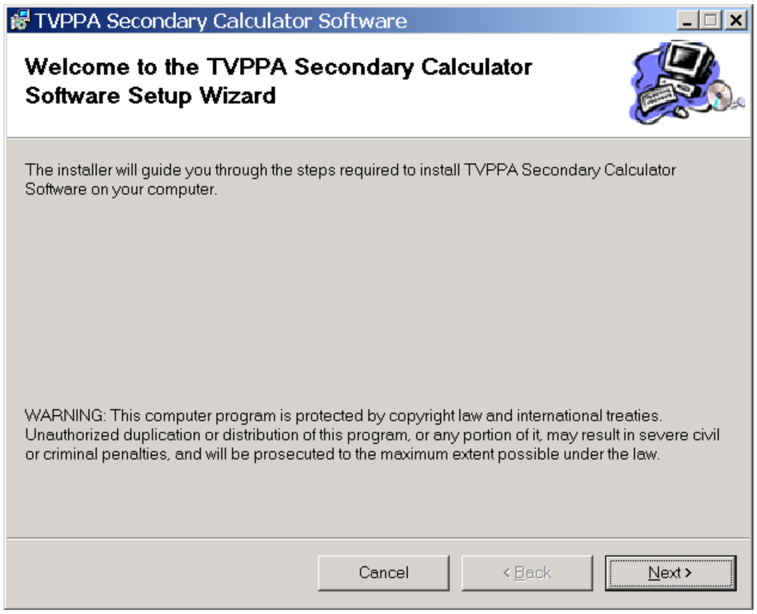
Selecting the **Yes** button will open the Microsoft downloads website, where the following two components can be downloaded and installed[2]:

1. .NET Framework Version 1.1 Redistributable Package
2. .NET Framework 1.1 Service Pack 1

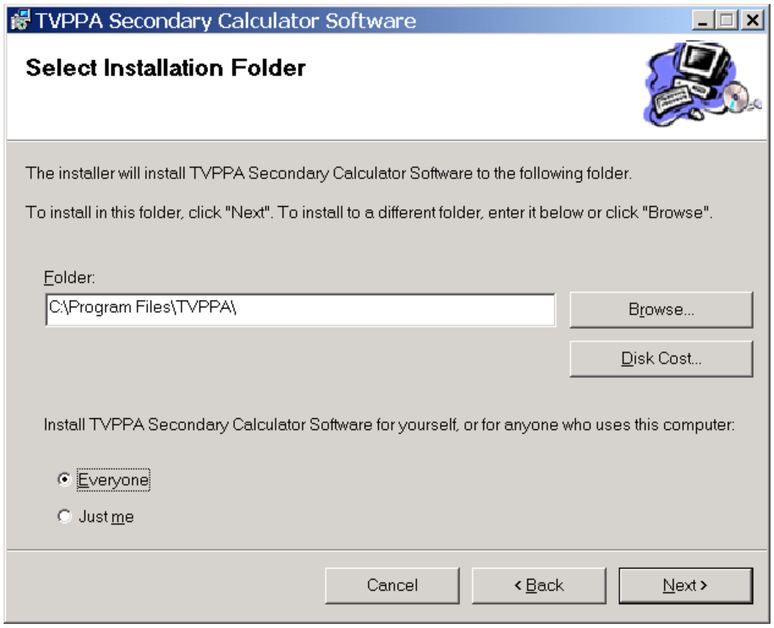
[1] If Setup does not run automatically, then run Setup.exe in the root directory of the CD to begin the installation process.

[2] If an Internet connection is not available, the components can be installed from the CD. The files are located in directories labeled in the same manner as shown above.

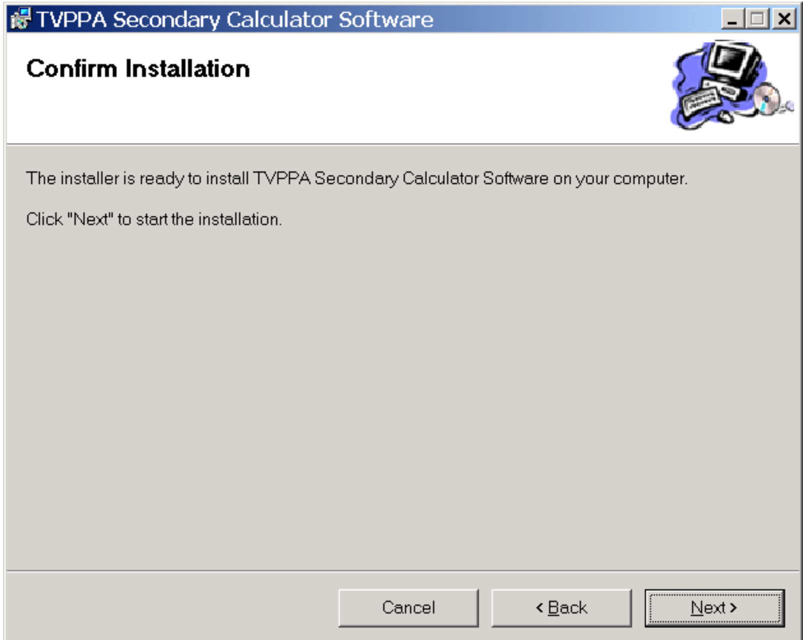
Once Microsoft .NET Framework Version 1.1 with Service Pack 1 is installed, running Setup will begin the installation of the DSC with the following screen:



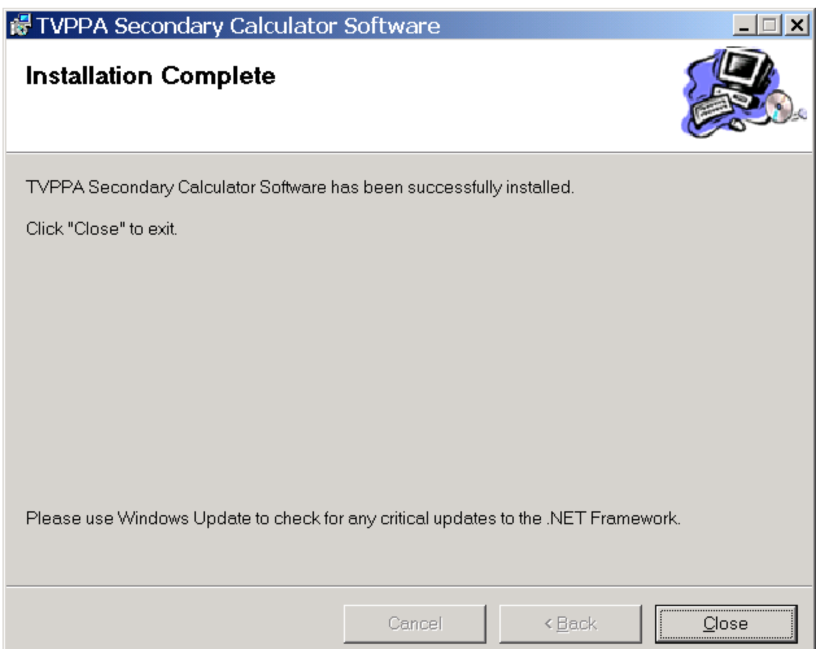
The next screen, depicted below, controls the installation directory and the user access of the DSC.



The next screen confirms the installation of the DSC.



The final screen shows successful completion of the installation.



Congratulations! The installation process is complete.

4. PROGRAM FUNCTIONS

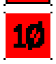
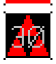
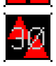
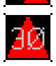
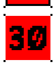
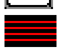
4.1. Definitions and Symbology

4.1.1. Definitions

Element - A digital representation of a physical piece of equipment.
Circuit Model - The digital representation of a physical circuit defined by individual elements.
Parent - The element that is at the source end of a secondary wire or service.
Child - The element that is at the load end of a secondary wire or service.
Transformer - Element used to represent a transformer or transformer bank.
Node - Element used to represent a wire junction point such as a pole or pedestal. The element itself has no electrical characteristics.
Load - Element used to represent a meter point and simulate the actual amount of current drawn at that point.
Schematic - The graphical representation of a physical circuit.
Wire Run - A set of secondary or service wires that include one (1) wire each per phase or leg and neutral.

4.1.2. Symbology

The DSC utilizes different graphical symbols to represent a secondary electrical circuit. The following is a list of the different symbols used for representing a model:

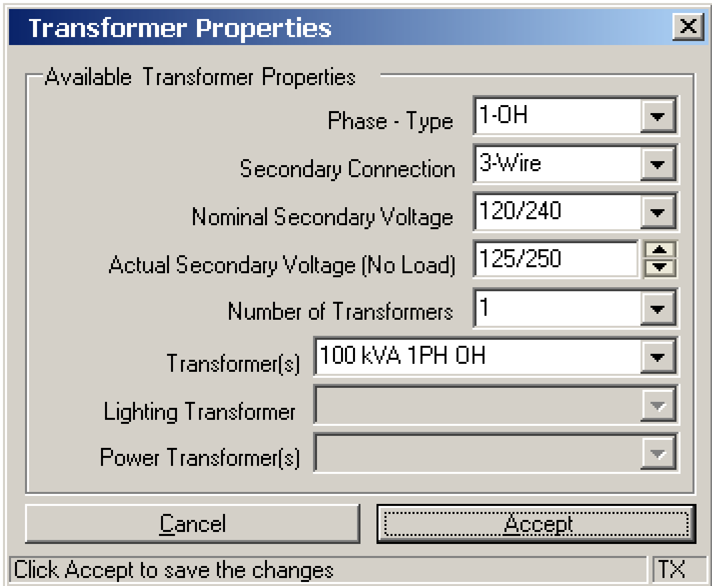
-  - Single-phase overhead transformer
-  - Single-phase underground transformer
-  - Three-phase overhead wye or closed-delta transformer bank
-  - Three-phase overhead open-delta transformer bank
-  - Three-phase overhead transformer
-  - Three-phase underground transformer
-  - Node
-  - Load
-  - Wire

4.2. Building Circuit Models

As with any electrical analysis software, the DSC must first have a digital representation of the secondary electrical circuit that needs to be analyzed. This digital representation is called a circuit model. The DSC utilizes a combination of graphics, input boxes and databases to build a circuit model.

4.2.1. Transformers

The first step in building a circuit model is to place the transformer. Activate the **Transformer Tool** by selecting the icon. A single click anywhere in the drawing space will place the transformer at that location and automatically open the **Transformer Properties** box.



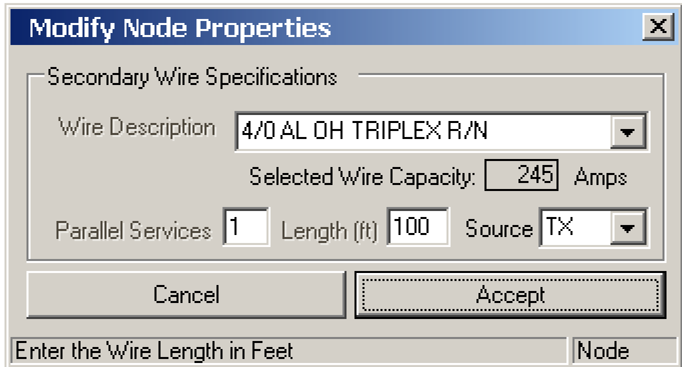
Input the specifications for the transformer using the available input boxes. The following is a brief description of each of the input boxes:

- Phase and Type - Selects the transformer as either single-phase or three-phase and the construction type as either overhead or underground.
- Secondary Connection - Selects the secondary side connection of the transformer as either 2-wire or 3-wire for single-phase and either wye, delta or open-delta for three-phase.
- Nominal Secondary Voltage - Selects the ANSI standard voltage for the selected secondary connection (Voltages divided with a "/" represent Line-to-Neutral voltage followed by Line-to-Line voltage).
- Actual Secondary Voltage (No Load) - Selects the actual voltage at the secondary connections of the transformer if measured with no load attached.
- Number of Transformers - Selects the number of transformers needed for the selected secondary connection.
- Transformer(s) - Selects sizes for single transformers and transformers included in a symmetrical bank.
- Lighting Transformer - Selects the size of the transformer that provides single-phase power in a delta or open-delta bank (Typically the largest transformer in the bank).
- Power Transformer(s) - Selects the size of the transformers that are used for providing three-phase power in a delta or open-delta bank (Sometimes referred to as "Kickers," they are typically the smaller transformers in the bank).

Once all appropriate selections have been made, select the **Accept** button to save the Transformer Properties. The **Cancel** button can be selected at any time to exit the Transformer Properties box without saving the information. Once a transformer has been placed, nodes or loads can be placed and connected to the transformer.

4.2.2. Nodes and Secondary

To place a node, activate the **Node Tool** by selecting the  icon. A single click anywhere in the drawing space will place the node at that location and automatically open the **Node Properties** box.



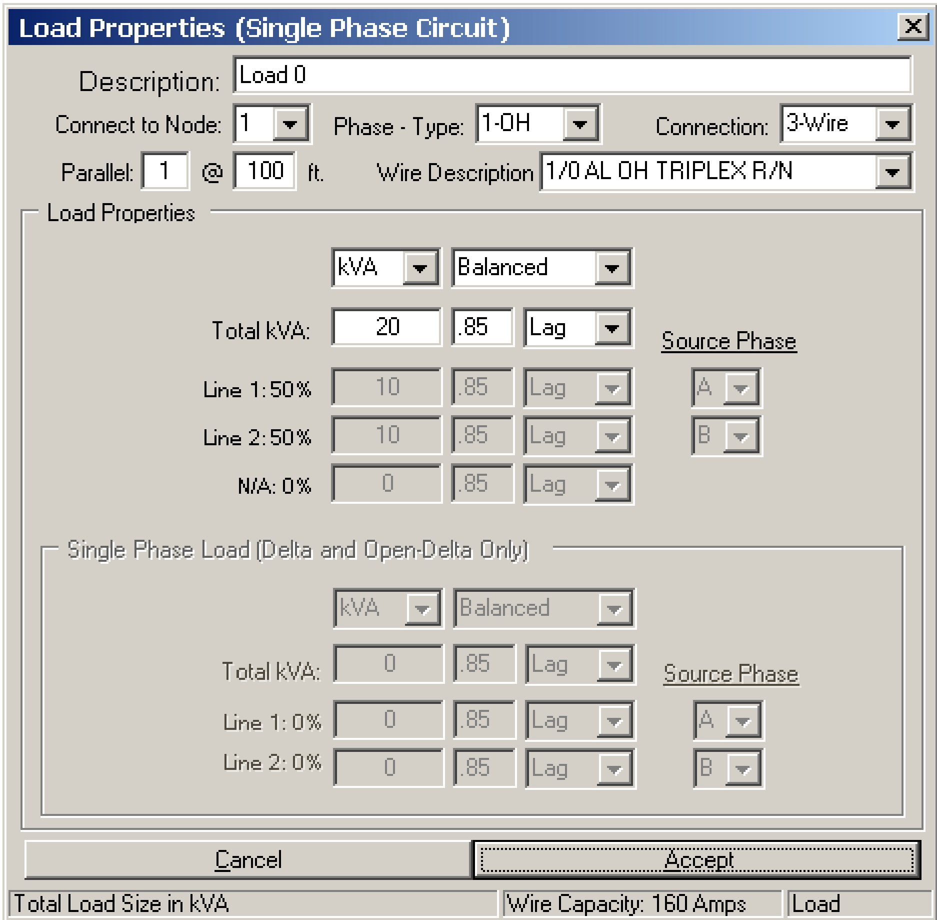
Input the specifications for the node using the available input boxes. The following is a brief description for each of the input boxes:

- Wire Description - Selects the secondary wire connected to the node.
- Parallel Wire Sets - Selects the number of complete secondary wire sets for the particular run of secondary.
- Length (ft) - Selects the one-way distance in feet for the particular run of secondary.
- Source Node - Selects the source feed node for the particular run of secondary.

When all appropriate selections have been made, select the **Accept** button to save the Node Properties. The **Cancel** button can be selected at any time to exit the **Node Properties** box without saving the information. Once a node has been placed, other nodes or loads can be placed and connected to it.

4.2.3. Loads and Services

To place a load, activate the **Load Tool** by selecting the icon. A single click anywhere in the drawing space will place the load at that location and automatically open the **Load Properties** box.



Input the specifications for the load using the available input boxes. The following is a brief description for each of the input boxes:

- Description - Used as a label for differentiating loads (Defaults to the Load number starting at 0).
- Connect to Node - Selects the source feed node for the load's service.
- Phase-Type - Selects the load as either single-phase or three-phase and the construction type for the service as either overhead or underground.
- Connection - Selects the service connection of the load as either 2-wire or 3-wire for single-phase and either 3-wire or 4-wire for three-phase.
- Wire Description - Selects the service wire connected to the load.
- Parallel Wire Sets - Selects the number of complete service wire sets for the load.
- Length (ft) - Selects the one-way distance in feet for the load's service.
- kVA/Amps Input Box - Selects the units of the load size as either kVA or Amps (Defaults to kVA).
- Balanced/Unbalanced Input Box - Selects the load as either balanced or unbalanced (Defaults to Balanced).

- Total kVA/Amps - Inputs total size and power factor of balanced loads. Displays the total size of unbalanced loads.
- Line #/Phase ?:% - Inputs individual line or phase size and power factor of unbalanced loads (Labels indicate the line or phase identification and the percentage of the total load). Displays the individual line or phase size and power factor of balanced loads.
- Source Phase - Selects the source feed phase of the associated line for single-phase loads in a three-phase wye circuit.

*Note: There are two sets of load-size inputs in the **Load Properties** box. The first set is the main set of load inputs, which is used for the majority of the load inputs. The second, special set of load inputs is used only when single-phase loads are to be represented in a Delta or Open-Delta circuit. Note that both sets of inputs are used for four-wire services in these circuits. The main set is for the three-phase portion of the load, and the special set is for the single-phase portion of the load (See Load and Voltage Drop Calculations in the Assumptions and Limitations section for explanation.).*

Once all appropriate selections have been made, select the **Accept** button to save the **Load Properties**. The **Cancel** button can be selected at any time to exit the **Load Properties** box without saving the information. Once a load has been placed, more loads and nodes can be placed or the circuit can be analyzed.

4.3. Saving Circuit Models

To save a circuit model, simply select **Save** or **Save As** under the **File** menu at the top left of the screen. The DSC defaults to a **Saved Projects** folder located in the programs installation directory.

4.4. Opening Saved Circuit Models

A circuit model that has been previously saved can be opened by selecting **Open** under the **File** menu at the top left of the screen. The **Open Project** box is displayed. Navigate to the appropriate directory and select the desired saved circuit. Selecting the **Open** button will open the selected circuit model. Selecting the **Cancel** button will exit the **Open Project** box without opening a circuit model.

4.5. Editing Existing Circuit Models

Sometimes the need arises to edit an existing circuit model. Once the circuit model to be edited is open, it can be changed by moving, adding, deleting or modifying the circuit elements.

To move an element, hover the pointer over the element. Left-click and hold while moving the pointer. The element will move with the pointer until the button is released, where the element will be placed in the new location (Note: The DSC does not adjust wire lengths automatically, so movement of elements is simply for the convenience and preference of the user).

Nodes and Loads can be added as described in the Building Circuit Models section. Transformer locations cannot be added due to the one (1) transformer limitation (See Limitations section).

An existing element's data can be modified by either double-clicking the element symbol or right-clicking on the element symbol and selecting the **Modify** option. The element's properties box will open as described in the Building Circuit Models section. However, all fields may not be available for modification, depending on the element and circuit configurations (See the Limitations section for more information).

To delete an existing element, right-click on the element symbol and select the **Delete** option. A delete confirmation box will open. Select **Yes** to delete the element or **No** to cancel the deletion (Note: Only elements that do not have children attached can be deleted).

4.6. Running Calculations

The DSC will calculate voltage drops, fault currents and voltage flicker levels for an entered circuit model.

4.6.1. Calculating Voltage Drops

To calculate voltage drops for the displayed circuit model, select the 

icon. The **Maximum Acceptable Voltage Drop** box will display.

A percentage value for the maximum acceptable voltage drop must be entered. This value defaults to the ANSI standard of 5.0% and is used for comparison to the calculated values. The results of this comparison are used to notify the user of potential excessive voltage drops in the circuit model. Selecting the **Accept** button will calculate and display the voltage drops for the circuit model. Selecting the **Cancel** button will exit to the previous mode without calculating any voltage drops.

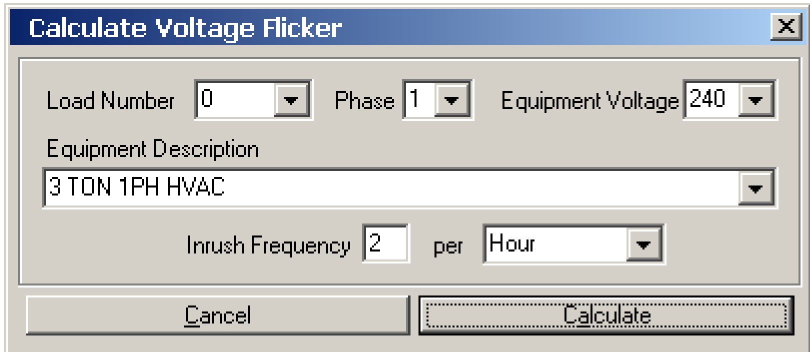
4.6.2. Calculating Fault Currents

To calculate fault currents for the displayed circuit model, select the 

icon. The calculated maximum available fault currents at the transformer and at each load will display.

4.6.3. Calculating Voltage Flicker

To calculate voltage flicker for the displayed circuit model, select the FL icon. The **Calculate Voltage Flicker** box will display.



Input the specifications for the voltage flicker causing equipment using the available input boxes. The following is a brief description for each of the input boxes:

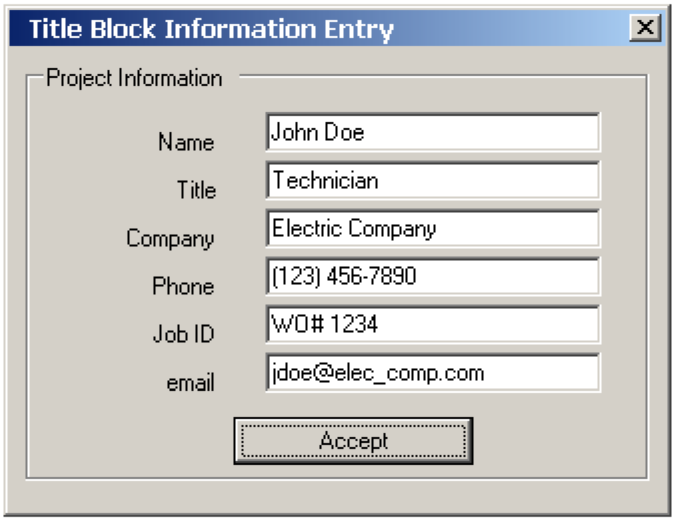
- Load Number - Selects the load at which the equipment is to be modeled.
- Phase - Selects the equipment as either single-phase (1) or three-phase (3).
- Equipment Voltage - Selects the operating voltage of the equipment.
- Equipment Description - Selects the type and size of the equipment (The available selections are from the database. If the desired equipment is not available for selection, then it must be added to the database. See the Editing Databases section of this manual).
- Inrush Frequency - Inputs the number of inrush operations (starts) that the equipment has in a specified period.
- per - Selects the time period (second, minute, hour or day) for which the "Inrush Frequency" is to occur.

Selecting the **Calculate** button will calculate and display the voltage flicker levels for the circuit model. Selecting the Cancel button will exit to the previous mode without calculating any voltage flicker levels.

4.7. Printing

4.7.1. Printing Schematics

To print the schematic for the displayed circuit model, select the **Print Schematic** option from the file menu. The **Project Information** box will display.



This information is optional; however, whatever is input will be printed in the title block of the schematic. Once the accept button is selected, the **Page Setup** box will display. This box is a standard Windows style print setup box for selecting and specifying print options. Selecting the **OK** button will display the **Print Preview** screen. This is also a standard Windows style screen that allows the user to preview how the schematic will appear when printed. If the preview is acceptable, the user can print by selecting the **Printer** icon. Close the **Print Preview** screen by selecting either the **Close** button or the **"x"** button (Note: Even though the schematic can be printed in portrait format, landscape format is recommended).

4.7.2. Printing Reports

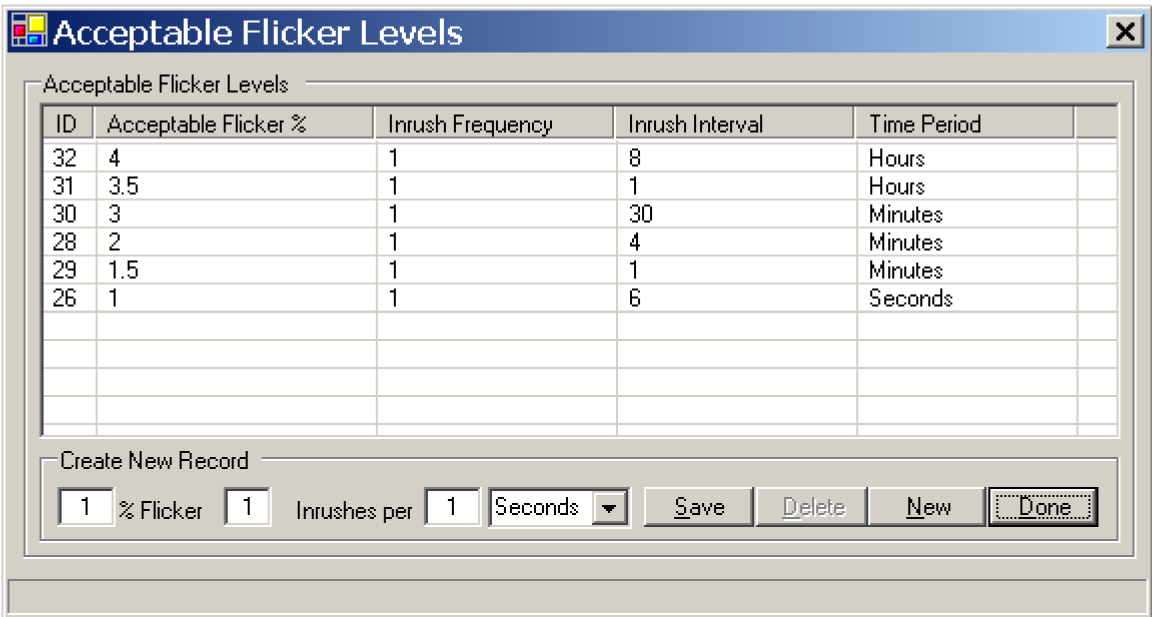
To print a report of the calculated results for the displayed circuit model, select the **Print Report** option from the file menu. The **Page Setup** box will display. This box is a standard Windows style print setup box for selection and specification of print options. Selecting the **OK** button will display the **Print Preview** screen. This is also a standard Windows style screen that allows the user to preview how the report will appear when printed. If the preview is acceptable, the user can print by selecting the **Printer** icon. Close the **Print Preview** screen by selecting either the **Close** button or the **"x"** button.

4.8. Editing Databases

The DSC uses five (5) different databases for modeling and calculating the data related to the entered circuit model. Each database is user-modifiable with the entry of an administrative password. The administrative password is defaulted to “DSC” when installed, but it can be changed by selecting the **Set Administrative Password** option from the **Tools** menu.

4.8.1. Acceptable Voltage Flicker

To edit the acceptable voltage flicker database, select **Acceptable Flicker Levels** from the **Edit Data** option under the **Tools** menu. After entering the administrative password, the **Acceptable Flicker Levels** box will display.



Input the acceptable levels for voltage flicker using the available input boxes. The levels that display initially are the levels currently stored in the database. The following is a brief description for each of the items in the box:

- ID - Number assigned by the software to hold the data’s place in the database.
- Acceptable Flicker % - Acceptable percentage of voltage flicker for circuit models including equipment with the defined inrush parameters that follow the value.
- Inrush Frequency - The number of inrush operations (starts) that is acceptable for the associated flicker level in a specified period.
- Inrush Interval - In combination with Time Period, specifies the period length for the number of inrush operations (starts) that is acceptable for the associated flicker level.
- Time Period - In combination with Inrush Interval, specifies the period length for the number of inrush operations (starts) that is acceptable for the associated flicker level.
- % Flicker - Inputs the Acceptable Flicker % of a new database entry.
- Inrushes - Inputs the Inrush Frequency of a new database entry.
- per (First Box) - Inputs the Inrush Interval of a new database entry.
- per (Second Box) - Selects the Time Period of a new database entry.

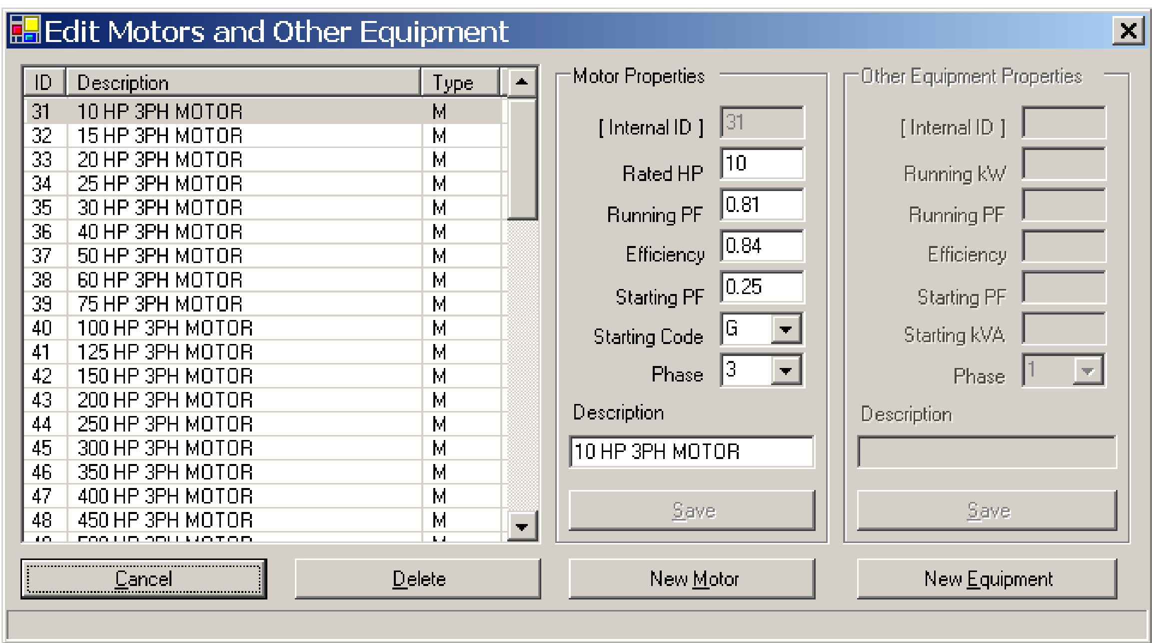
Selecting the **Save** button will enter the values from Voltage Flicker Level Entry into a new line in the database for use when calculating voltage flicker for entered circuit models.

Note: The default data is based on a step curve showing lower acceptable levels for shorter time periods and higher acceptable levels for longer time periods. It is possible to enter many different levels of acceptable flicker for various time periods. Care should be taken when making these selections to verify that the appropriate flicker level is associated with the intended time period.

Selecting the **Delete** button will remove the highlighted selection from the database. Selecting the **Done** button will exit the **Acceptable Flicker Levels** box.

4.8.2. Motors and Other Equipment

To edit the motors and other equipment database, select **Motors & Other Equipment** from the **Edit Data** option under the **Tools** menu. After entering the administrative password, the **Edit Motors and Other Equipment** box will display.



Data can be entered or edited by using the available input boxes. The ratings that display initially are the ratings currently stored in the database. The following is a brief description for each of the items in the box:

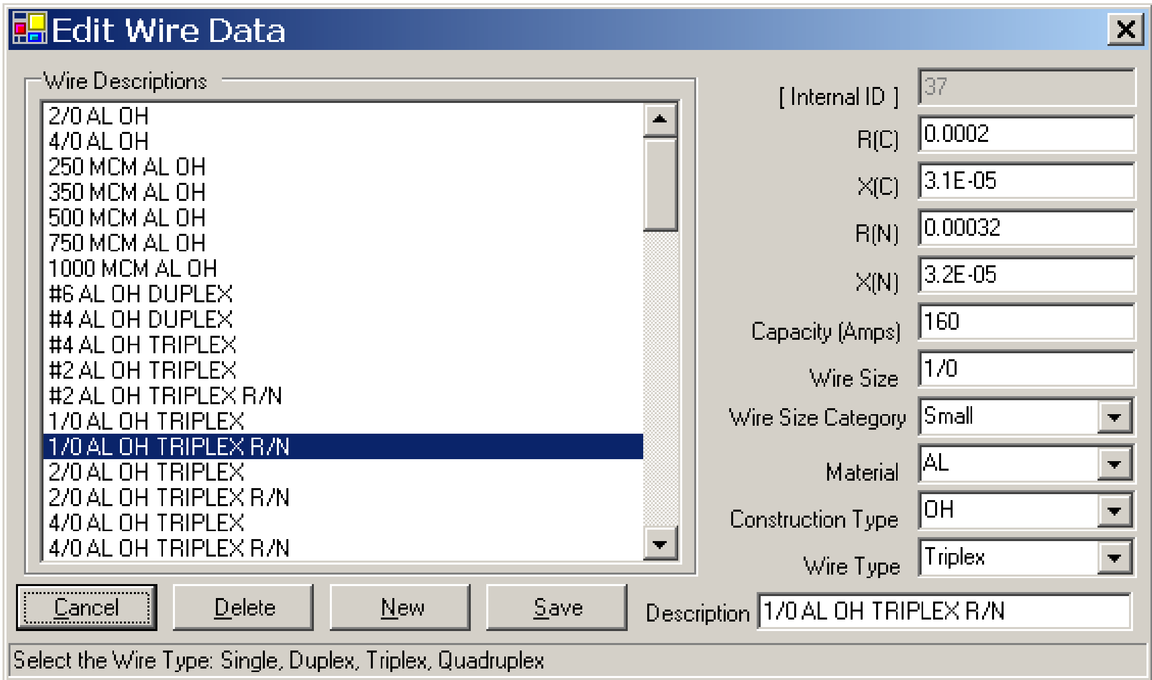
- ID - Number assigned by the software to hold the data's place in the database.
- Description - Describes the basic characteristics of the equipment and is used for selection purposes when running voltage flicker calculations.
- Type - Identifies the equipment as either a motor (M) or other equipment (O).
- Motor Properties, Internal ID - Same as "ID" listed previously.
- Motor Properties, Rated HP - Inputs the rated horsepower of a motor.
- Motor Properties, Running PF - Inputs the running power factor of a motor.
- Motor Properties, Efficiency - Inputs the efficiency of a motor.
- Motor Properties, Starting PF - Inputs the starting power factor of a motor.
- Motor Properties, Starting Code - Selects the NEC code letter of a motor.

- Motor Properties, Phase - Selects the motor as either single-phase (1) or three-phase (3).
- Motor Properties, Description - Inputs “Description” listed previously.
- Other Equipment Properties, Internal ID - Same as “ID” listed previously.
- Other Equipment Properties, Running kW - Inputs the running kilowatt rating of a piece of equipment.
- Other Equipment Properties, Running PF - Inputs the running power factor of a piece of equipment.
- Other Equipment Properties, Efficiency - Inputs the efficiency of a piece of equipment.
- Other Equipment Properties, Starting PF - Inputs the starting power factor of a piece of equipment.
- Other Equipment Properties, Starting kVA - Inputs the starting kVA of a piece of equipment.
- Other Equipment Properties, Phase - Selects the equipment as either single-phase (1) or three-phase (3).
- Other Equipment Properties, Description - Inputs “Description” listed previously.

Selecting the **Save** button will enter the values for the button’s corresponding **Motor Properties** fields or **Other Equipment Properties** fields into the database for use when calculating voltage flicker for entered circuit models. Selecting the **New Motor** or **New Equipment** buttons will clear the appropriate properties’ fields for the entry of a new motor or piece of equipment into the database (Note: The new entry will not be entered into the database until the corresponding **Save** button is selected). Selecting the **Delete** button will remove the highlighted selection from the database. Selecting the **Cancel** button will exit the **Edit Motors and Other Equipment** box.

4.8.3. Wire

To edit the wire database, select **Wire** from the **Edit Data** option under the **Tools** menu. Upon entering the administrative password, the **Edit Wire Data** box will display.



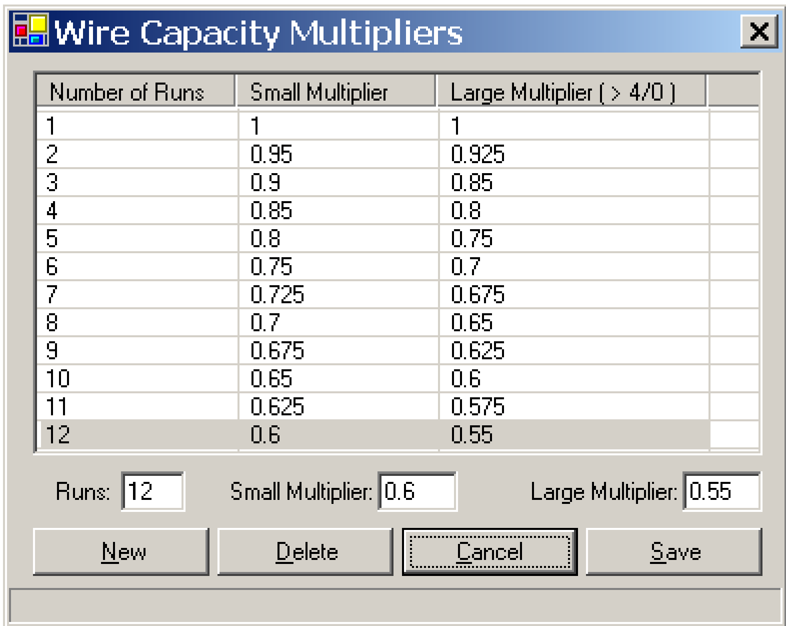
Data can be entered or edited by using the available input boxes. The ratings that display initially are the ratings currently stored in the database. The following is a brief description for each of the items in the box:

- Wire Descriptions - Describes the basic characteristics of the wire. The DSC uses this field for selection purposes when creating a circuit model.
- Internal ID - Number assigned by the software to hold the data's place in the database.
- R(C) - Inputs the resistance of the energized conductor in ohms per foot.
- X(C) - Inputs the reactance of the energized conductor in ohms per foot.
- R(N) - Inputs the resistance of the neutral conductor in ohms per foot.
- X(N) - Inputs the reactance of the neutral conductor in ohms per foot.
- Capacity (Amps) - Inputs the electrical capacity of the energized conductor in amps.
- Wire Size - Inputs the AWG or MCM size of the energized conductor.
- Wire Size Category - Selects the size category of the energized conductor (Small for 4/0 or smaller and Large for larger than 4/0).
- Material - Selects the wire's material as either aluminum (AL) or copper (CU).
- Construction Type - Selects the wire's construction type as either overhead (OH) or underground (UG).
- Wire Type - Selects the wire as either Single, Duplex, Triplex or Quadruplex conductor.
- Description - Inputs "Wire Descriptions" listed previously.

Select the **Save** button to enter the values into the database. Selecting the **New** button will clear the fields for the entry of new wire into the database (Note: The new entry will not be entered into the database until the **Save** button is selected). Selecting the **Delete** button will remove the highlighted selection from the database. Selecting the **Cancel** button will exit the **Edit Wire Data** box.

4.8.4. Wire Capacity Multipliers

To edit the wire capacity multipliers (These multipliers are used to de-rate the capacity of parallel runs of wire.) database, select **Wire Capacity Multipliers** from the **Edit Data** option under the **Tools** menu. After entering the administrative password, the **Wire Capacity Multipliers** box will display.



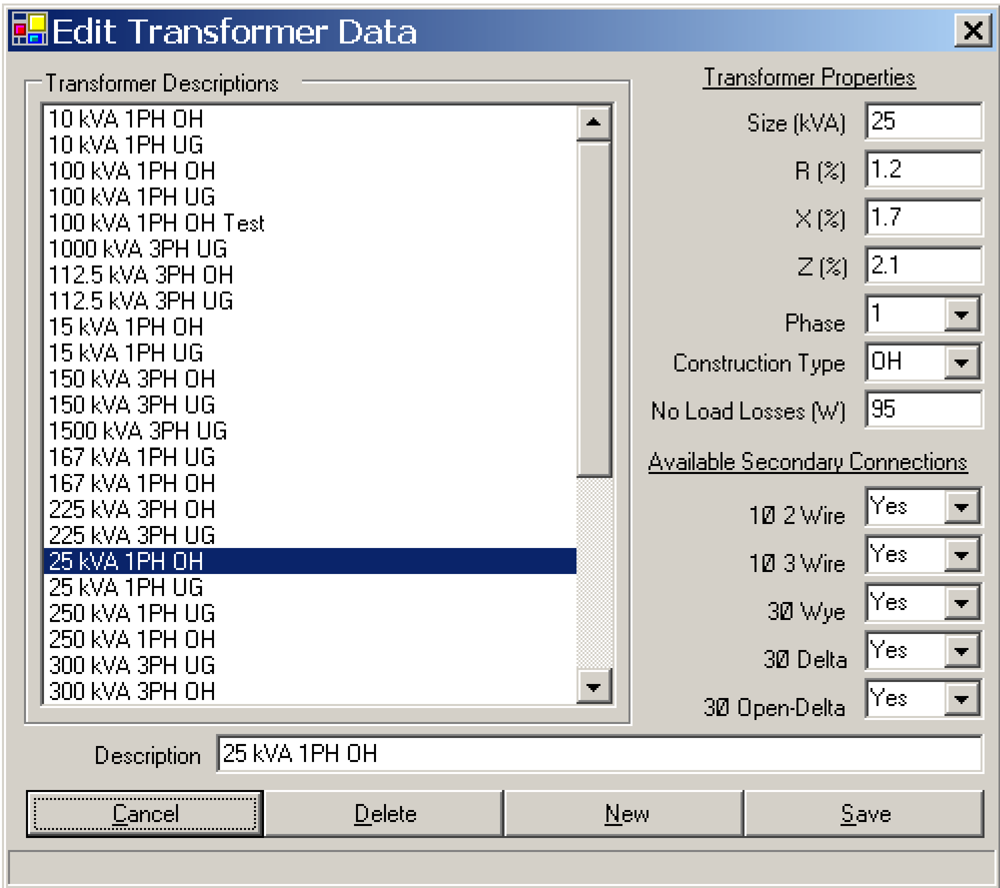
Input the multipliers using the available input boxes. The multipliers that display initially are the multipliers currently stored in the database. The following is a brief description for each of the items in the box:

- Number of Runs - Corresponds to the number of parallel wire runs in a secondary or service and is used for selection of the appropriate wire capacity multiplier when making calculations for an entered circuit model.
- Small Multiplier - Multiplier that is used when the wire size is 4/0 or smaller.
- Large Multiplier - Multiplier that is used when the wire size is larger than 4/0.
- Runs: - Inputs “Number of Runs” listed previously.
- Small Multiplier: - Inputs “Small Multiplier” listed previously.
- Large Multiplier: - Inputs “Large Multiplier” listed previously.

Selecting the **Save** button will enter the values into the database for use when calculating voltage drop for entered circuit models. Selecting the **New** button will clear the fields for the entry of new multipliers into the database (Note: The new entry will not be entered into the database until the **Save** button is selected). Selecting the **Delete** button will remove the highlighted selection from the database. Selecting the **Cancel** button will exit the **Wire Capacity Multipliers** box.

4.8.5. Transformers

To edit the transformer database, select **Transformers** from the **Edit Data** option under the **Tools** menu. After entering the administrative password, the **Edit Transformer Data** box will display.



Data can be entered or edited by using the available input boxes. The ratings that display initially are the ratings currently stored in the database. The following is a brief description for each of the items in the box:

- Transformer Descriptions - Describe the basic characteristics of the transformer. The DSC uses this field for selection purposes when creating a circuit model.
- Size (kVA) - Inputs the size of the transformer in kVA.
- R (%) - Inputs the resistance of the transformer in percent.
- X (%) - Inputs the reactance of the transformer in percent.
- Z (%) - Inputs the total impedance of the transformer in percent.
- Phase - Selects the transformer’s primary connection as either single-phase (1), two-phase (2) or three-phase (3).
- Construction Type - Selects the transformer’s construction type as either overhead (OH) or underground (UG).
- No Load Losses (W) - Inputs the watts consumed by the energized transformer without any load attached.
- 1Ø 2 Wire - Selects the availability (Yes or No) of a transformer for use in a circuit model with a single-phase 2-wire secondary transformer connection.

- 1Ø 3 Wire - Selects the availability (Yes or No) of a transformer for use in a circuit model with a single-phase 3-wire secondary transformer connection.
- 3Ø Wye - Selects the availability (Yes or No) of a transformer for use in a circuit model with a three-phase wye secondary transformer connection.
- 3Ø Delta - Selects the availability (Yes or No) of a transformer for use in a circuit model with a three-phase delta secondary transformer connection.
- 3Ø Open-Delta - Selects the availability (Yes or No) of a transformer for use in a circuit model with a three-phase open-delta secondary transformer connection.
- Description - Inputs “Transformer Descriptions” listed previously.

Select the **Save** button to enter the values into the database when calculating voltage drop, voltage flicker and fault currents for entered circuit models. Select the **New** button to clear the fields for the entry of a new transformer into the database (Note: The new entry will not be entered into the database until the **Save** button is selected). The **Delete** button removes the highlighted selection from the database. Selecting the **Cancel** button exits the user from the **Edit Transformer Data** box.

5. METHODOLOGY AND INTERPRETING RESULTS

5.1. Methodology and Operational Parameters

5.1.1. Service Development Procedures

The typical procedures, or steps, followed by an electric utility or power supplier to select and layout an electrical service for a new consumer generally fall into one of two categories: Routine (typical) services and major (non-routine) services. Routine services refer mainly to ordinary, day-to-day operations of a distributor and include applications such as residential, farms, street lighting, small subdivisions and small commercial loads. Major services are those required for large commercial/industrial loads that merit more thorough engineering supervision and review.

The procedures, or steps, for each of these categories may vary between organizations but can be generally summarized as follows under the categories indicated:

Category A - For Routine or Typical Services

- A1 - System engineering establishes economic design criteria and standards for system construction;
- A2 - Designer estimates new consumer load requirements using guidelines established by distributor;
- A3 - Designer stakes service using most acceptable and best route;
- A4 - Designer selects equipment based on the system standards and may check other options that may be readily apparent;
- A5 - Service is released by System Engineering for construction.

Category B - For Major on Non-routine Services

- B1 - System engineering estimates and validates the new consumer load;
- B2 - System engineering confirms adequacy of primary lines and substation capacity;
- B3 - System engineering with assistance from designer stakes service based on most acceptable and best route;
- B4 - System engineering reviews options for service and selects equipment based upon sound engineering and economic design criteria;
- B5 - Service is released by System Engineering for construction.

The DSC was primarily developed to aid system engineers and technicians in completing Steps A1, A4 and B4.

Following each step identified above is critically important. Service design is an art that requires solid tools, reliable data and proven experience. Properly researched estimates and sound judgment are equally important factors.

5.1.2. Operational Parameters

When determining the adequacy of a distribution secondary system, five operational parameters must be evaluated. Those parameters are:

- Load capacity
- Service voltage
- Service flicker
- Fault duty
- Economics

Selecting the appropriate equipment to meet the estimated service load requirements will result in reliable, satisfactory electric service at a reasonable and economical cost for both the power supplier and the consumer.

5.1.2.1. Load Capacity

Load capacity refers to the capability of the service transformer and secondary wire to handle the estimated peak load conditions for a defined load factor and a defined environmental condition (e.g. summer versus winter peaks, overhead versus underground, direct buried or in conduit, total electric or electric and gas). Transformers and secondary wire or cable are current-limited equipment that must not be operated above their design limits. Operation above the design limits will result in equipment failure, costly repair and rework, and significant power outages to the consumer.

5.1.2.2. Service Voltage

Service voltage refers to the voltage at the point of load utilization and must be supplied within the design limits of the equipment being served. Typically, equipment is designed to operate at plus or minus ten percent of the equipment nameplate. Two standards in the power distribution industry are the American National Standards Institute (ANSI) Standard C84.1, entitled *"Voltage Ratings for Utility Power Systems and Equipment"* and RUS Bulletin 169-4 entitled *"Voltage Levels on Rural Distribution Systems."* Appendix E summarizes these standards and guidelines and identifies the proper voltage levels that distributors and utilities are to maintain. The design "Range A" voltage levels in the standards should be utilized when designing services.

Voltage drops through the transformer and through the secondary wires are proportional to the current through them. Voltage is more of a driving force for service adequacy than capacity. Typically, service wires should be loaded less than 50 percent of full capacity to provide acceptable service voltage.

5.1.2.3. Service Flicker

Voltage drops refer primarily to continuous peak and worst-case loading conditions. Another voltage aspect that requires review is the voltage transient, which is caused by inrush currents that result from motor starting, capacitor switching, variable speed drives and general large load switching. Voltage fluctuation occurring in cycles of time is called flicker. If it occurs at a high percentage of base voltage, lighting and equipment functions will be impacted, causing irritation and annoyance to the consumer. Flicker allowances are a function of the percent voltage fluctuation and frequency in occurrence. The number of consumers served from the primary source feeder is also a factor. IEEE Standard 141 discusses and defines the general limitation of flicker that should be followed. The default voltage fluctuation limits used in the DSC are those established by TVA. They are summarized in Appendix F as well as other industry standards levels. As stated earlier, these default values can be changed at the discretion of the user.

5.1.2.4. Fault Duty

When finalizing the configuration of a service, the maximum available fault current at the service entrance is information the consumer needs. Typically, the consumer installs the service panel at his or her home or business. That service panel, with its main and circuit breakers, should have fault interrupting capability greater that the available fault current at the service entrance.

Residential service panels rated with 200 amperes continuous generally have mains and circuit breakers capable of interrupting fault currents of 10,000 amperes or less. Fault current calculations for such typical services are generally not requested by consumers. However, services requiring higher continuous current capacity generally have higher available fault currents. In these situations, the consumer often requests that the utility or distributor communicate what the maximum available fault current level is at the service point. The DSC includes fault current calculation capabilities that provide the utility or service provider this information, which allows the consumer to choose the adequate service entrance panel required.

5.1.2.5. Economics

When designing and establishing corporate standards for electric service, economics are the driving force behind what equipment is specified. A key economic consideration is the calculated losses of energy in the service equipment. These losses are a function of the current going through the equipment, the resistance in the equipment and how the load varies with time. Annual line losses are determined by finding the square of the current times the equipment resistance times the annual load factor of the load times the cost per kilowatt-hour. The DSC provides this calculation, which can be used by system engineers in establishing corporate standard and methods.

5.2. Interpreting Results

5.2.1. Load Capacity

The DSC determines that the service equipment (transformer and service wires) have adequate capacity to serve the estimated customer load. Once the voltage drop calculation function is used, the percent voltage drops are indicated for each phase. If the transformer or service conductor capacities are adequate, the calculations are shown in a green background box. If the capacities are exceeded, the prompt is shown in a red background box with a warning note. The warning note includes the calculated peak load amperes with the capacity amperes of the equipment referenced. Equipment capacity limits are listed in Appendix B with the basic environmental conditions on which the capacities were determined. Conditions that vary from that should be reviewed closely to ensure that equipment capacity levels are not exceeded.

Key conditions that may cause a variation of the capacities given in the appendix are ambient operating temperatures, multiple conductor runs per phase in conduits, and individual phase conductors in individual conduits, especially metal conduits. If ambient service conditions vary from the base, the DSC user should de-rate the equipment to fit the expected service conditions. The DSC includes a de-rating factor for multiple runs of conductors per phase. The de-rating factors used are given in Appendix B.

For per-phase service, conductors in individual conduits present another heat-buildup problem. In non-metallic conduit, there is very little heat buildup and conductor capacity does not need to be de-rated except for general conduit installation. Further de-rating is necessary for metallic conduit. Heat buildup from circulating currents in the conduit raises the operating temperature of the conductor. Such de-rating is beyond the scope of the DSC and should be handled directly by the system engineer. Very few electric service providers utilize metallic conduit these days, primarily due to economics, so the absence of this de-rating function does not extensively limit the DSC's functionality.

Customer loads that include either electronic equipment or drives that could promote harmonic distortion being injected into the power source can also contribute to equipment capacity overloads. Such evaluation is beyond the scope of the DSC. When such service circumstances arise, the system engineer is encouraged to refer to the latest edition of IEEE Standard 519, entitled "*Recommended Practices for Harmonic Control in Electrical Power Systems,*" for guidance.

Finally, one other issue that should be addressed concerning load capacity is how the peak load varies with time. The calculation of a load factor is an excellent method for analyzing this issue. Monthly Load Factor (MLF) is calculated by dividing the total estimated kilowatt-hours sold by the estimated peak kilowatt demand and then dividing that number by 730 hours (the number of total hours in a month). Conversely, the Annual Load Factor (ALF) is determined similarly, except annual quantities are used (with 8,760 hours being available in a year). Typical electric consumers on a utility have load factors that vary from 35 to 50 percent. The equipment load capacities provided in the DSC are based on such load factors. Consumers with load factors greater than these should be evaluated more closely by the system engineer to ensure that the equipment being specified can handle the high load factor load and that losses are carefully considered. High load factor loads require special service designs considerations and specification, especially transformers.

5.2.2. Voltage Drops

Electric service voltage standards (e.g. ANSI Std. C84.1 and RUS Bulletin 169-4) state that the service voltage at the customer service point (typically utility meter) under the Range A design standard should provide a voltage of no greater than 126 volts (on 120 base) and no lower than 114 volts. The calculated voltage drop from the primary transformer bushings to the service point should not exceed 4.0 volts (or 3.33%) for loads with lighting or 6.0 volts (or 5.0%) for non-lighting loads.

DSC provides the calculated voltage drop for each service component (e.g. transformer and each service wire sections) as well as the total drop to the various loads. Drops greater than set levels are indicated with an asterisk (*). The calculated drops of the components help the engineer or technician identify service portions that need to be revisited.

When designing services, it should be understood that if marginal conditions result (i.e. 10% of voltage drop limit), further scrutiny is warranted. Consumer loads are estimated quantities and, if underestimated, unsatisfactory service voltage may result. Design engineers and technicians should be conservative in their designs to ensure long-term service voltage.

5.2.3. Fault Currents

The DSC calculated fault currents are very conservative in nature. System primary source impedance from the service transformer primary bushings to the source substation, or delivery point, has been ignored. This means that the calculated fault current is higher than actual current conditions, which allows for future electrical system changes. The addition of closer substations/delivery points, up-rated substations, and up-rated primary lines are among the changes possible. Calculating the fault currents in this manner provides for a service design, including the consumer’s equipment, that is impervious to major primary system changes and, therefore, is adequate for long-term use.

Should the fault current level be determined marginal for customer use of standard service panel designs, further review may be warranted. Under such conditions, the system engineer may review the available fault conditions by utilizing a means outside of the DSC. The primary impedance can be added to the service impedance and this may lower the fault current to a level that would allow the customer to utilize standard, less expensive service panels. The system engineer is cautioned to revise the fault current level provided to the consumer only if it is determined that the primary system is very unlikely to be changed in the future.

5.2.4. Voltage Flicker

After calculating the voltage drop for a given, defined service, the voltage flicker can be calculated for any load point. Before the calculation can proceed, two service parameters must be defined: the number of inrushes per time period and the percent of allowable voltage flicker. A typical service may experience one inrush per 8 hour period, and an allowable secondary voltage change, or flicker, percentage of 4 percent is not uncommon. If the known inrush condition is predicted to occur less than once per day, this level can be increased to 6 percent, often with satisfactory results. Obviously, it is always understood that whenever inrush conditions create annoying conditions for a service’s consumer(s), changes in service design may be warranted and/or the consumer should consider ways of reducing the inrush level.

Flicker is perceived more by consumers having incandescent lighting and is generally annoying to consumers when the frequency of inrushes occurs multiple times a day.

5.2.5. Economics

After calculating voltage drop and peak loading for a given defined service, one can determine the service losses in dollars per year. The losses are broken down into individual service components (e.g. transformers, service wires, each leg, etc.). To calculate the losses, the annual load factor and the average cost per kilowatt-hour in dollars per year need to be input. A report listing all the losses by individual components and total circuit losses is generated. This dollar amount represents the annual estimated value of the losses at the cost indicated for the annual load factor entered. This value can be added to other service component costs to determine the economical performance of the service. For high-load factor loads, larger and higher capacity equipment can be justified to reduce losses and overall service costs.

6. ASSUMPTIONS AND LIMITATIONS

As with any computer software, the DSC has its limitations. To keep the software simple to use, several assumptions and approximations have to be made. However, these assumptions and approximations do not appreciably affect the accuracy of the calculations. In fact, most are considered to be standard practices for simplifying calculations for everyday use. The following subsections clarify the different assumptions and approximations used in the DSC.

6.1. General

First, the DSC makes all calculations based upon a symmetrical system. This means that items such as wire are considered to have the same impedance for each leg/phase in a span. Second, variations of impedance for temperature, air flow and other conditions are factored in with the equipment data contained in the database. The default data uses a defined standard for conditions; however, the user has the ability to change or add data to account for non-standard conditions, if desired.

6.2. Transformer Connections

The DSC limits the transformer connections to commonly accepted industry standards. These connections are single-phase 2-wire, single-phase 3-wire, three-phase wye, three-phase delta and three-phase open-delta. In addition, transformers are only allowed one location with no parallel connections.

6.3. Fault Calculations

The DSC makes fault calculations with the assumption that the primary impedance is zero. This technique will always give a higher fault current value than actually possible, but this is a standard industry practice for finding “worst case” values. Another assumption is that all current returns through the neutral conductor.

6.4. Load and Voltage Drop Calculations

All load and voltage calculations are based upon the users’ selection of an industry standard base voltage. The voltage is defined at the transformer, which is always considered to be a balanced voltage source with a positive phase sequence (clockwise rotation). The neutral at the transformer is also considered to be the ground reference point for the secondary system being analyzed. As with the fault calculations, all the current is assumed to return through the neutral conductor. One final note is that the DSC makes these calculations assuming a steady state for all load values.

7. CONCLUSION

The DSC represents a collaborative effort between Patterson & Dewar Engineers, Inc. (P&D) and the TVPPA to aid member staking technicians in the selection and analysis of electrical facilities. Every effort has been made to fully explain the functionality of the DSC and anticipate and anticipate likely questions. Should users have questions that are not addressed herein, please forward any inquiries to:

Tennessee Valley Public Power Association (TVPPA)
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TENNESSEE VALLEY PUBLIC POWER ASSOCIATION
(TVPPA)
Chattanooga, Tennessee

DISTRIBUTION SECONDARY CALCULATOR
(Project No. DSC-1)

APPENDIX A
Equal Employment Opportunity Statement
&
Legal Notice

EQUAL EMPLOYMENT OPPORTUNITY STATEMENT

This program is supported by assistance from the Tennessee Valley Authority (TVA), a Federal Agency. Under Title VI of the Civil Rights Act of 1964, Section 504 of the Rehabilitation Act of 1973, the Age Discrimination Act of 1975, and applicable TVA regulations at 18 CFR pts. 1302, 1307, and 1309, no person shall, on the grounds of race, color, national origin, handicap, or age, be excluded from participation in, be denied the benefits of, or otherwise be subjected to discrimination under this program. In addition, no qualified handicapped person shall, on the basis of handicap, be subjected to discrimination in employment (including hiring) under the program. If you feel you have been subject to discrimination as described above, you or your representative has the right to file a written complaint with TVA not later than 90 days from the date of the alleged discrimination. The complaint should be sent to Tennessee Valley Authority, Office of Equal Employment Opportunity, 400 Commerce Avenue, Knoxville, Tennessee, 37902. A copy of the applicable TVA regulations may be obtained on request by writing TVA at the address given above.

LEGAL NOTICE

TENNESSEE VALLEY PUBLIC POWER ASSOCIATION
(TVPPA)
Chattanooga, Tennessee

DISTRIBUTION SECONDARY CALCULATOR
(Project No. DSC-1)

APPENDIX B
Database Tables

TRANSFORMERS DATABASE

TRANSFORMERS (DESCRIPTION)	SIZE (kVA)	R (%)	X (%)	Z (%)	PHASE (1, 2, 3)	CONSTRUCTION TYPE (OH, UG)	NO LOAD LOSSES (W)	AVAILABLE SECONDARY CONNECTIONS				
								1PH 2-WIRE	1PH 3-WIRE	3PH WYE	3PH DELTA	3PH OPEN-DELTA
10 kVA 1PH OH	10	1.6	1.4	2.1	1	OH	59	Y	Y	Y	Y	Y
10 kVA 1PH UG	10	1.6	1.4	2.1	1	UG	59	N	Y	N	N	N
15 kVA 1PH OH	15	1.3	1.0	1.6	1	OH	77	Y	Y	Y	Y	Y
15 kVA 1PH UG	15	1.3	1.0	1.6	1	UG	77	N	Y	N	N	N
25 kVA 1PH OH	25	1.2	1.7	2.1	1	OH	95	Y	Y	Y	Y	Y
25 kVA 1PH UG	25	1.2	1.7	2.1	1	UG	95	N	Y	N	N	N
37.5 kVA 1PH OH	37.5	1.3	1.9	2.3	1	OH	139	Y	Y	Y	Y	Y
37.5 kVA 1PH UG	37.5	1.3	1.9	2.3	1	UG	139	N	Y	N	N	N
50 kVA 1PH OH	50	1.1	1.8	2.1	1	OH	180	Y	Y	Y	Y	Y
50 kVA 1PH UG	50	1.1	1.8	2.1	1	UG	180	N	Y	N	N	N
75 kVA 1PH OH	75	1.0	2.1	2.3	1	OH	255	Y	Y	Y	Y	Y
75 kVA 1PH UG	75	1.0	2.1	2.3	1	UG	255	N	Y	N	N	N
100 kVA 1PH OH	100	1.0	2.1	2.3	1	OH	320	Y	Y	Y	Y	Y
100 kVA 1PH UG	100	1.0	2.1	2.3	1	UG	320	N	Y	N	N	N
167 kVA 1PH OH	167	1.0	2.0	2.2	1	OH	485	Y	Y	Y	Y	Y
167 kVA 1PH UG	167	1.0	2.0	2.2	1	UG	485	N	Y	N	N	N
250 kVA 1PH OH	250	1.0	2.3	2.5	1	OH	575	Y	Y	Y	Y	Y
250 kVA 1PH UG	250	1.0	2.3	2.5	1	UG	575	N	Y	N	N	N
333 kVA 1PH OH	333	0.9	2.4	2.6	1	OH	700	Y	Y	Y	Y	Y
500 kVA 1PH OH	500	0.8	2.5	2.6	1	OH	1000	Y	Y	Y	Y	Y
75 kVA 3PH OH	75	1.0	3.0	3.2	3	OH	390	N	N	Y	Y	N
75 kVA 3PH UG	75	1.0	3.0	3.2	3	UG	390	N	N	Y	Y	N
112.5 kVA 3PH OH	112.5	1.1	3.2	3.4	3	OH	450	N	N	Y	Y	N
112.5 kVA 3PH UG	112.5	1.1	3.2	3.4	3	UG	450	N	N	Y	Y	N
150 kVA 3PH OH	150	1.0	3.4	3.5	3	OH	585	N	N	Y	Y	N
150 kVA 3PH UG	150	1.0	3.4	3.5	3	UG	585	N	N	Y	Y	N
225 kVA 3PH OH	225	1.0	3.4	3.5	3	OH	810	N	N	Y	Y	N
225 kVA 3PH UG	225	1.0	3.4	3.5	3	UG	810	N	N	Y	Y	N
300 kVA 3PH OH	300	1.0	3.8	3.9	3	OH	990	N	N	Y	Y	N
300 kVA 3PH UG	300	1.0	3.8	3.9	3	UG	990	N	N	Y	Y	N
500 kVA 3PH UG	500	1.0	3.9	4.0	3	UG	1350	N	N	Y	Y	N
750 kVA 3PH UG	750	1.0	5.7	5.8	3	UG	1650	N	N	Y	Y	N
1000 kVA 3PH UG	1000	1.0	5.7	5.8	3	UG	1900	N	N	Y	Y	N
1500 kVA 3PH UG	1500	1.0	5.7	5.8	3	UG	2550	N	N	Y	Y	N
2000 kVA 3PH UG	2000	1.0	5.7	5.8	3	UG	3000	N	N	Y	Y	N
2500 kVA 3PH UG	2500	1.0	5.7	5.8	3	UG	3250	N	N	Y	Y	N
62.5 kVA 3PH OPEN-DELTA UG	62.5	1.1	3.2	3.4	2	UG	234	N	N	N	N	Y

WIRE DATABASE

WIRE (DESCRIPTION)	R (C) (OHMS/FT)	X (C) (OHMS/FT)	R (N) (OHMS/FT)	X (N) (OHMS/FT)	WIRE CAPACITY (AMPS)	WIRE SIZE (AWG, MCM)	WIRE SIZE CATEGORY	MATERIAL (AL, CU)	CONSTRUCTION TYPE (OH, UG)	WIRE TYPE (S, D, T, Q)
#8 CU OH	0.000790	0.000130	0.000790	0.000130	80	8	SMALL	CU	OH	SINGLE
#6 CU OH	0.000500	0.000120	0.000500	0.000120	110	6	SMALL	CU	OH	SINGLE
#4 CU OH	0.000320	0.000110	0.000320	0.000110	160	4	SMALL	CU	OH	SINGLE
#2 CU OH	0.000200	0.000110	0.000200	0.000110	210	2	SMALL	CU	OH	SINGLE
1/0 CU OH	0.000130	0.000100	0.000130	0.000100	285	1/0	SMALL	CU	OH	SINGLE
2/0 CU OH	0.000100	0.000100	0.000100	0.000100	325	2/0	SMALL	CU	OH	SINGLE
4/0 CU OH	0.000063	0.000095	0.000063	0.000095	405	4/0	SMALL	CU	OH	SINGLE
250 MCM CU OH	0.000053	0.000092	0.000053	0.000092	440	250	LARGE	CU	OH	SINGLE
350 MCM CU OH	0.000038	0.000088	0.000038	0.000088	530	350	LARGE	CU	OH	SINGLE
500 MCM CU OH	0.000027	0.000084	0.000027	0.000084	650	500	LARGE	CU	OH	SINGLE
750 MCM CU OH	0.000018	0.000079	0.000018	0.000079	790	750	LARGE	CU	OH	SINGLE
1000 MCM CU OH	0.000014	0.000076	0.000014	0.000076	920	1000	LARGE	CU	OH	SINGLE
#4 AL OH	0.000510	0.000110	0.000510	0.000110	120	4	SMALL	AL	OH	SINGLE
#2 AL OH	0.000320	0.000110	0.000320	0.000110	155	2	SMALL	AL	OH	SINGLE
1/0 AL OH	0.000200	0.000100	0.000200	0.000100	200	1/0	SMALL	AL	OH	SINGLE
2/0 AL OH	0.000160	0.000100	0.000160	0.000100	225	2/0	SMALL	AL	OH	SINGLE
4/0 AL OH	0.000100	0.000095	0.000100	0.000095	290	4/0	SMALL	AL	OH	SINGLE
250 MCM AL OH	0.000085	0.000092	0.000085	0.000092	320	250	LARGE	AL	OH	SINGLE
350 MCM AL OH	0.000061	0.000088	0.000061	0.000088	385	350	LARGE	AL	OH	SINGLE
500 MCM AL OH	0.000043	0.000084	0.000043	0.000084	465	500	LARGE	AL	OH	SINGLE
750 MCM AL OH	0.000029	0.000079	0.000029	0.000079	580	750	LARGE	AL	OH	SINGLE
1000 MCM AL OH	0.000022	0.000076	0.000022	0.000076	670	1000	LARGE	AL	OH	SINGLE
#6 AL OH DUPLEX	0.000810	0.000036	0.000810	0.000036	70	6	SMALL	AL	OH	DUPLEX
#4 AL OH DUPLEX	0.000510	0.000034	0.000510	0.000034	90	4	SMALL	AL	OH	DUPLEX
#4 AL OH TRIPLEX	0.000510	0.000034	0.000510	0.000034	90	4	SMALL	AL	OH	TRIPLEX
#2 AL OH TRIPLEX	0.000320	0.000032	0.000320	0.000032	120	2	SMALL	AL	OH	TRIPLEX
#2 AL OH TRIPLEX R/N	0.000320	0.000032	0.000510	0.000034	120	2	SMALL	AL	OH	TRIPLEX
1/0 AL OH TRIPLEX	0.000200	0.000031	0.000200	0.000031	160	1/0	SMALL	AL	OH	TRIPLEX
1/0 AL OH TRIPLEX R/N	0.000200	0.000031	0.000320	0.000032	160	1/0	SMALL	AL	OH	TRIPLEX
2/0 AL OH TRIPLEX	0.000160	0.000030	0.000160	0.000030	185	2/0	SMALL	AL	OH	TRIPLEX
2/0 AL OH TRIPLEX R/N	0.000160	0.000030	0.000250	0.000031	185	2/0	SMALL	AL	OH	TRIPLEX
4/0 AL OH TRIPLEX	0.000100	0.000029	0.000100	0.000029	245	4/0	SMALL	AL	OH	TRIPLEX
4/0 AL OH TRIPLEX R/N	0.000100	0.000029	0.000160	0.000030	245	4/0	SMALL	AL	OH	TRIPLEX
1/0 AL OH QUADRUPLEX	0.000200	0.000031	0.000200	0.000031	140	1/0	SMALL	AL	OH	QUADRUPLEX
2/0 AL OH QUADRUPLEX	0.000160	0.000030	0.000160	0.000030	160	2/0	SMALL	AL	OH	QUADRUPLEX
4/0 AL OH QUADRUPLEX	0.000100	0.000029	0.000100	0.000029	210	4/0	SMALL	AL	OH	QUADRUPLEX
#8 CU UG	0.000790	0.000052	0.000790	0.000052	65	8	SMALL	CU	UG	SINGLE
#6 CU UG	0.000500	0.000051	0.000500	0.000051	80	6	SMALL	CU	UG	SINGLE
#4 CU UG	0.000320	0.000048	0.000320	0.000048	115	4	SMALL	CU	UG	SINGLE
#2 CU UG	0.000200	0.000045	0.000200	0.000045	155	2	SMALL	CU	UG	SINGLE
1/0 CU UG	0.000130	0.000044	0.000130	0.000044	215	1/0	SMALL	CU	UG	SINGLE

WIRE (DESCRIPTION)	R (C) (OHMS/FT)	X (C) (OHMS/FT)	R (N) (OHMS/FT)	X (N) (OHMS/FT)	WIRE CAPACITY (AMPS)	WIRE SIZE (AWG, MCM)	WIRE SIZE CATEGORY	MATERIAL (AL, CU)	CONSTRUCTION TYPE (OH, UG)	WIRE TYPE (S, D, T, Q)
2/0 CU UG	0.000100	0.000043	0.000100	0.000043	245	2/0	SMALL	CU	UG	SINGLE
4/0 CU UG	0.000063	0.000041	0.000063	0.000041	315	4/0	SMALL	CU	UG	SINGLE
250 MCM CU UG	0.000053	0.000041	0.000053	0.000041	345	250	LARGE	CU	UG	SINGLE
350 MCM CU UG	0.000038	0.000040	0.000038	0.000040	420	350	LARGE	CU	UG	SINGLE
500 MCM CU UG	0.000027	0.000039	0.000027	0.000039	515	500	LARGE	CU	UG	SINGLE
750 MCM CU UG	0.000018	0.000038	0.000018	0.000038	640	750	LARGE	CU	UG	SINGLE
1000 MCM CU UG	0.000014	0.000037	0.000014	0.000037	750	1000	LARGE	CU	UG	SINGLE
#4 AL UG	0.000510	0.000048	0.000510	0.000048	85	4	SMALL	AL	UG	SINGLE
#2 AL UG	0.000320	0.000045	0.000320	0.000045	115	2	SMALL	AL	UG	SINGLE
1/0 AL UG	0.000200	0.000044	0.000200	0.000044	150	1/0	SMALL	AL	UG	SINGLE
2/0 AL UG	0.000160	0.000043	0.000160	0.000043	170	2/0	SMALL	AL	UG	SINGLE
4/0 AL UG	0.000100	0.000041	0.000100	0.000041	225	4/0	SMALL	AL	UG	SINGLE
250 MCM AL UG	0.000085	0.000041	0.000085	0.000041	250	250	LARGE	AL	UG	SINGLE
350 MCM AL UG	0.000061	0.000040	0.000061	0.000040	305	350	LARGE	AL	UG	SINGLE
500 MCM AL UG	0.000043	0.000039	0.000043	0.000039	370	500	LARGE	AL	UG	SINGLE
750 MCM AL UG	0.000029	0.000038	0.000029	0.000038	470	750	LARGE	AL	UG	SINGLE
1000 MCM AL UG	0.000022	0.000037	0.000022	0.000037	545	1000	LARGE	AL	UG	SINGLE
#6 AL UG DUPLEX	0.000810	0.000036	0.000810	0.000036	70	6	SMALL	AL	UG	DUPLEX
#4 AL UG DUPLEX	0.000510	0.000034	0.000510	0.000034	90	4	SMALL	AL	UG	DUPLEX
1/0 AL UG TRIPLEX	0.000200	0.000031	0.000200	0.000031	160	1/0	SMALL	AL	UG	TRIPLEX
1/0 AL UG TRIPLEX R/N	0.000200	0.000031	0.000320	0.000032	160	1/0	SMALL	AL	UG	TRIPLEX
2/0 AL UG TRIPLEX	0.000160	0.000030	0.000160	0.000030	180	2/0	SMALL	AL	UG	TRIPLEX
2/0 AL UG TRIPLEX R/N	0.000160	0.000030	0.000250	0.000031	180	2/0	SMALL	AL	UG	TRIPLEX
4/0 AL UG TRIPLEX	0.000100	0.000029	0.000100	0.000029	240	4/0	SMALL	AL	UG	TRIPLEX
4/0 AL UG TRIPLEX R/N	0.000100	0.000029	0.000160	0.000030	240	4/0	SMALL	AL	UG	TRIPLEX
250 MCM AL UG TRIPLEX R/N	0.000085	0.000029	0.000130	0.000030	265	250	LARGE	AL	UG	TRIPLEX
350 MCM AL UG TRIPLEX R/N	0.000061	0.000028	0.000100	0.000029	320	350	LARGE	AL	UG	TRIPLEX
500 MCM AL UG TRIPLEX R/N	0.000043	0.000027	0.000061	0.000028	395	500	LARGE	AL	UG	TRIPLEX
1/0 AL UG QUADRUPLEX	0.000200	0.000031	0.000200	0.000031	150	1/0	SMALL	AL	UG	QUADRUPLEX
2/0 AL UG QUADRUPLEX	0.000160	0.000030	0.000160	0.000030	170	2/0	SMALL	AL	UG	QUADRUPLEX
4/0 AL UG QUADRUPLEX	0.000100	0.000029	0.000100	0.000029	225	4/0	SMALL	AL	UG	QUADRUPLEX
350 MCM AL UG QUADRUPLEX R/N	0.000061	0.000028	0.000100	0.000029	305	350	LARGE	AL	UG	QUADRUPLEX
500 MCM AL UG QUADRUPLEX R/N	0.000043	0.000027	0.000061	0.000028	420	500	LARGE	AL	UG	QUADRUPLEX
750 MCM AL UG QUADRUPLEX R/N	0.000029	0.000026	0.000043	0.000027	495	750	LARGE	AL	UG	QUADRUPLEX

WIRE CAPACITY MULTIPLIERS DATABASE

# OF SEC / SERV RUNS	WIRE CAPACITY MULTIPLIERS	
	WIRE SIZES 4/0 and smaller	WIRE SIZES larger than 4/0
1	1.000	1.000
2	0.950	0.925
3	0.900	0.850
4	0.850	0.800
5	0.800	0.750
6	0.750	0.700
7	0.725	0.675
8	0.700	0.650
9	0.675	0.625
10	0.650	0.600
11	0.625	0.575
12 or more	0.600	0.550

MOTORS DATABASE

MOTORS (DESCRIPTION)	RATED HP	PHASE (1, 3)	RUNNING PF	EFFICIENCY	STARTING PF	STARTING CODE
1/4 HP 1PH MOTOR	0.25	1	0.68	0.65	0.25	M
1/3 HP 1PH MOTOR	0.33	1	0.69	0.66	0.25	M
1/2 HP 1PH MOTOR	0.50	1	0.71	0.68	0.25	L
3/4 HP 1PH MOTOR	0.75	1	0.73	0.70	0.25	L
1 HP 1PH MOTOR	1.00	1	0.75	0.72	0.25	J
1-1/2 HP 1PH MOTOR	1.50	1	0.77	0.74	0.25	J
2 HP 1PH MOTOR	2.00	1	0.79	0.76	0.25	J
3 HP 1PH MOTOR	3.00	1	0.81	0.78	0.25	H
5 HP 1PH MOTOR	5.00	1	0.85	0.80	0.25	G
7-1/2 HP 1PH MOTOR	7.50	1	0.85	0.80	0.25	G
10 HP 1PH MOTOR	10.00	1	0.85	0.80	0.25	G
15 HP 1PH MOTOR	15.00	1	0.85	0.80	0.25	G
20 HP 1PH MOTOR	20.00	1	0.85	0.80	0.25	G
25 HP 1PH MOTOR	25.00	1	0.85	0.80	0.25	G
1 HP 3PH MOTOR	1.00	3	0.63	0.74	0.25	N
1-1/2 HP 3PH MOTOR	1.50	3	0.66	0.75	0.25	M
2 HP 3PH MOTOR	2.00	3	0.69	0.77	0.25	L
3 HP 3PH MOTOR	3.00	3	0.73	0.79	0.25	K
5 HP 3PH MOTOR	5.00	3	0.77	0.81	0.25	J
7-1/2 HP 3PH MOTOR	7.50	3	0.79	0.83	0.25	H
10 HP 3PH MOTOR	10.00	3	0.81	0.84	0.25	G
15 HP 3PH MOTOR	15.00	3	0.82	0.85	0.25	G
20 HP 3PH MOTOR	20.00	3	0.84	0.86	0.25	G
25 HP 3PH MOTOR	25.00	3	0.85	0.87	0.25	G
30 HP 3PH MOTOR	30.00	3	0.85	0.87	0.25	G
40 HP 3PH MOTOR	40.00	3	0.86	0.88	0.25	G
50 HP 3PH MOTOR	50.00	3	0.87	0.89	0.25	G
60 HP 3PH MOTOR	60.00	3	0.87	0.89	0.25	G
75 HP 3PH MOTOR	75.00	3	0.88	0.90	0.25	G
100 HP 3PH MOTOR	100.00	3	0.88	0.90	0.25	G
125 HP 3PH MOTOR	125.00	3	0.88	0.90	0.25	G
150 HP 3PH MOTOR	150.00	3	0.88	0.91	0.25	G
200 HP 3PH MOTOR	200.00	3	0.88	0.91	0.25	G
250 HP 3PH MOTOR	250.00	3	0.89	0.91	0.25	G
300 HP 3PH MOTOR	300.00	3	0.89	0.92	0.25	G
350 HP 3PH MOTOR	350.00	3	0.89	0.92	0.25	G
400 HP 3PH MOTOR	400.00	3	0.89	0.92	0.25	G
450 HP 3PH MOTOR	450.00	3	0.89	0.92	0.25	G
500 HP 3PH MOTOR	500.00	3	0.90	0.93	0.25	G

MOTOR STARTING CODE MULTIPLIERS

MOTOR STARTING CODE	MULTIPLIER
A	3.14
B	3.54
C	3.99
D	4.49
E	4.99
F	5.59
G	6.29
H	7.09
J	7.99
K	8.99
L	9.99
M	11.19
N	12.49
P	13.99
R	15.99
S	17.99
T	19.99
U	22.39

OTHER EQUIPMENT DATABASE

OTHER EQUIPMENT (DESCRIPTION)	RUNNING kW	PHASE (1, 3)	RUNNING PF	EFFICIENCY	STARTING PF	STARTING kVA
1 TON 1PH HVAC	0.90	1	0.90	0.90	0.25	9.64
1-1/2 TON 1PH HVAC	1.35	1	0.90	0.90	0.25	14.46
2 TON 1PH HVAC	1.80	1	0.90	0.90	0.25	19.28
2-1/2 TON 1PH HVAC	2.25	1	0.90	0.90	0.25	21.38
3 TON 1PH HVAC	2.70	1	0.90	0.90	0.25	25.66
3-1/2 TON 1PH HVAC	3.15	1	0.90	0.90	0.25	29.94
4 TON 1PH HVAC	3.60	1	0.90	0.90	0.25	30.35
4-1/2 TON 1PH HVAC	4.05	1	0.90	0.90	0.25	34.15
5 TON 1PH HVAC	4.50	1	0.90	0.90	0.25	37.94
3 TON 3PH HVAC	2.70	3	0.90	0.90	0.25	32.54
5 TON 3PH HVAC	4.50	3	0.90	0.90	0.25	48.20
7-1/2 TON 3PH HVAC	6.75	3	0.90	0.90	0.25	64.15
10 TON 3PH HVAC	9.00	3	0.90	0.90	0.25	75.88
15 TON 3PH HVAC	13.50	3	0.90	0.90	0.25	113.83
20 TON 3PH HVAC	18.00	3	0.90	0.90	0.25	151.77
25 TON 3PH HVAC	22.50	3	0.90	0.90	0.25	189.71
3,000 BTU 1PH HVAC	0.23	1	0.90	0.90	0.25	3.45
6,000 BTU 1PH HVAC	0.45	1	0.90	0.90	0.25	6.03
9,000 BTU 1PH HVAC	0.68	1	0.90	0.90	0.25	8.19
12,000 BTU 1PH HVAC	0.90	1	0.90	0.90	0.25	9.64
18,000 BTU 1PH HVAC	1.35	1	0.90	0.90	0.25	14.46
24,000 BTU 1PH HVAC	1.80	1	0.90	0.90	0.25	19.28

ACCEPTABLE VOLTAGE FLICKER LEVELS DATABASE

ACCEPTABLE FLICKER PERCENTAGE	INRUSH FREQUENCY	INRUSH INTERVAL	TIME PERIOD
1.0%	1	6	SECONDS
1.5%	1	1	MINUTES
2.0%	1	4	MINUTES
3.0%	1	30	MINUTES
3.5%	1	1	HOURS
4.0%	1	8	HOURS

TENNESSEE VALLEY PUBLIC POWER ASSOCIATION
(TVPPA)
Chattanooga, Tennessee

DISTRIBUTION SECONDARY CALCULATOR
(Project No. DSC-1)

APPENDIX C
Sample Calculations

Single-phase Example and Comparison with Full Report

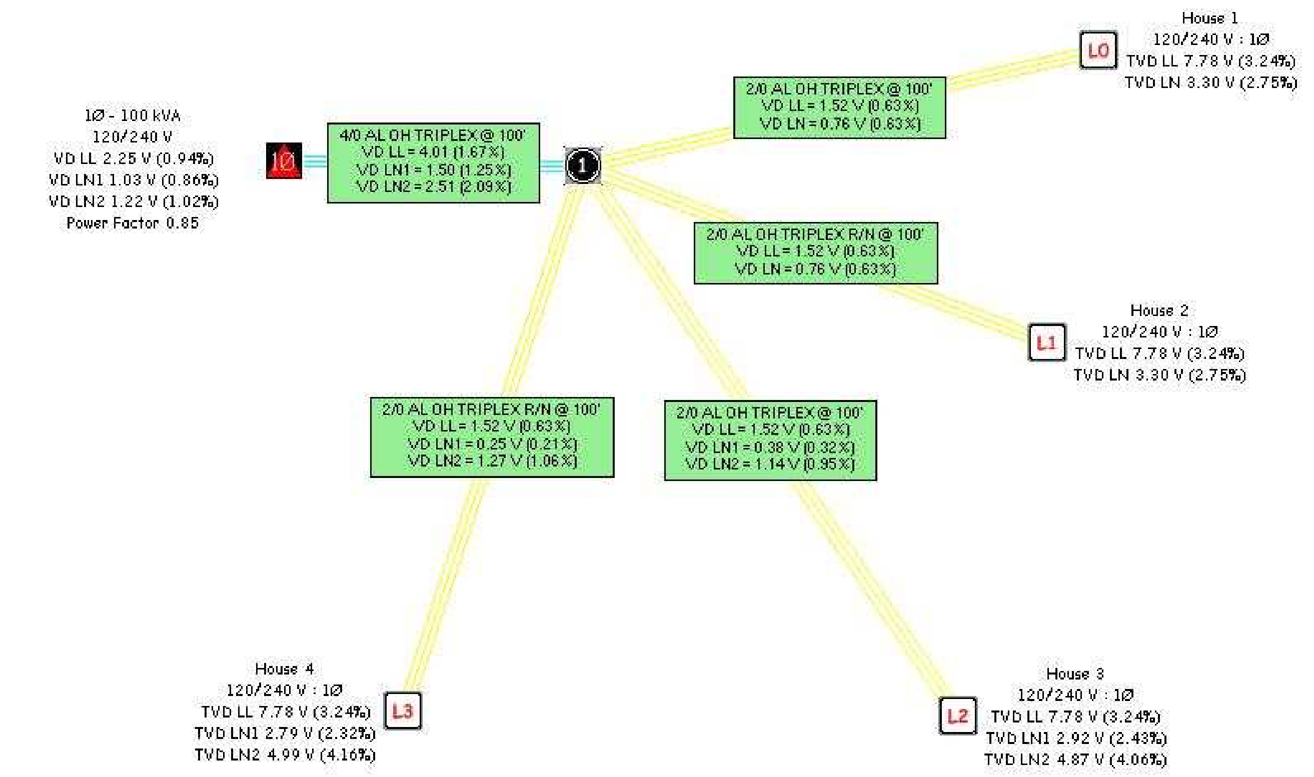

Figure C-1. Single-phase distribution system, 120/240V, with 100 kVA transformer and four 12 kVA houses as the load.

Creating the Circuit Model

Herein describes the steps taken to create the circuit model shown in Figure C-1 above. For a more in-depth description of the process for creating your own circuit model, please refer to section 4 of this manual.

First, there are certain conditions pre-defined, such as the size of the load(s), which the designer cannot alter. The conditions that are alterable will typically be the rating of the transformer and the size of the conducting material. When creating the circuit model, the components have to be input from the source to the load. This simply means that the user must start with the transformer, then go to the node (if there is one), and then finally describe the load itself. Components may be changed or appended after the fact, but the beginning process has the linear flow just prescribed.

The example illustrated above in Figure C-1 has the following unalterable conditions pre-defined: there are four houses with 12 kVA of load each and 0.85 power factors; two of the houses have balanced loads and two of them have unbalanced loads; the two houses with unbalanced loads both have 5 kVA in the first leg and 7 kVA in the second leg; there is a pole (node) 100 feet from the transformer between it and the loads; and from this pole (node), the four houses are each located 100 feet away.

Single-phase Example and Comparison with Full Report (continued)

- Transformer

Given these starting conditions, the user may choose/design the transformer that will be adequate for these demands. Whether there is single-phase and/or three-phase power available in the system, it is determined from the transformer. However, the types of load that are being supplied will have their own set demands on which type of phasing and voltage is preferred. The typical house is a single-phase 120/240 V load. Therefore, this example uses a transformer with these parameters.

The next step is choosing the kVA rating of the transformer. With four houses at 12 kVA a piece, the summed total power would be 48 kVA.[1] Ideally there are no variations, spikes, flicker, or unbalanced loads and a transformer with a rating of 48 kVA could be chosen. Since ideal circumstances are rare, load variations, demand spikes due to household appliances, and unbalanced loads are everywhere. The designer must take all this into account.

With these factors in-mind, there are a few generic 'rules-of-thumb' that can be followed. In a case such as this where the summed total power has been determined to be 48 kVA, the rating of the transformer should equal the total load plus a safety factor that is 15 to 25% of the total load. Using a 25% safety factor, the rating of the transformer would need to be 60 kVA to serve the load in this example. Since most transformers are of a standard size, the designer would typically only have transformers with ratings of 50 kVA, 75 kVA or 100 kVA available for this level of load. In many cases, the designer may only have a choice between 50 kVA and 100 kVA transformers, for which the conservative choice would be a 100 kVA transformer to accommodate the recommended safety factor.

For this example, a 100 kVA transformer has been chosen to provide extra leeway with all the issues described above, as well as the possibility of an expansion taking place in this neighborhood in the form of yet another house on this one transformer. While such a possibility is atypical, this scenario should be considered. If the load exceeds the transformer rating, the DSC will report an associated error, allowing the designer to realize the problem and make the appropriate corrections by resizing the transformer.

- Conducting Wire

Once the transformer has been chosen, it is time to select the conducting wire between the transformer and the loads. As described earlier, the pole (node) is located 100 feet away from the transformer, so this defines the length of the conducting wire connecting the transformer to the pole (node). Likewise, the length of the conducting wires running between this pole (node) and the individual loads is also pre-defined at 100 feet each.

The length of the wire aside, the type and size of wire must also be selected. The type of wire has two main aspects: 1) type of material and, 2) type of packaging for the wire(s). The type of material is usually an easy selection. Copper has become very expensive, so aluminum has all but replaced it in the utility industry as the preferred conducting wire. As far as the packaging, triplex conductor wire has been selected for this example to maintain the availability of both 120 and 240 V to each of the houses in this 3-wire system. Although triplex is the typical for situations such as this, single conductor wires might also be utilized in this application.

---

[1] The DSC does not compensate for load diversity; therefore, the user must take this into account when entering the load sizes. For this example, the assumption is made that the total load at any given time will be 48 kVA (12 kVA for each of the 4 houses).

Single-phase Example and Comparison with Full Report (continued)

- Conducting Wire (continued)

In an example such as this where there is a pole (node) between the loads and the transformer, it is typical for the wire between the transformer and the pole (node) to be larger or at least the same size as the wire between the pole (node) and the loads. The size for each conducting wire must be determined next. Automatically choosing the largest conducting wire possible is usually not feasible due to availability, expense, and construction limitations. The advantage of the DSC is that it aids in the selection of the most appropriate conducting wire for the application with tools like the Voltage Drop Calculation. The Voltage Drop Calculation tool will display possible problems with a circuit model due to undersized components. Using the methodology of starting at the smallest sized triplex AL OH (UG is also applicable, but for demonstration purposes this example is overhead) conducting wire and then running the DSC's Voltage Drop Calculation, each component's size can be re-evaluated and adjusted based upon what kind of problems the DSC describes. Typical problems seen are current through the conducting wire exceeding rated capacity or total voltage drop from the transformer to the load exceeding acceptable industry standards.

The end result of the type and size of conducting wire chosen for this example can be seen above in Figure C-1. Between the transformer and the pole (node) is 4/0 AL OH Triplex, and between the pole (node) and the loads are varying forms of 2/0 AL OH Triplex. This example utilizes reduced neutral (R/N) wiring to some of the loads to demonstrate the differences in voltage drop that will be discussed below in the Comparison section.

Demonstration of Flicker Analysis

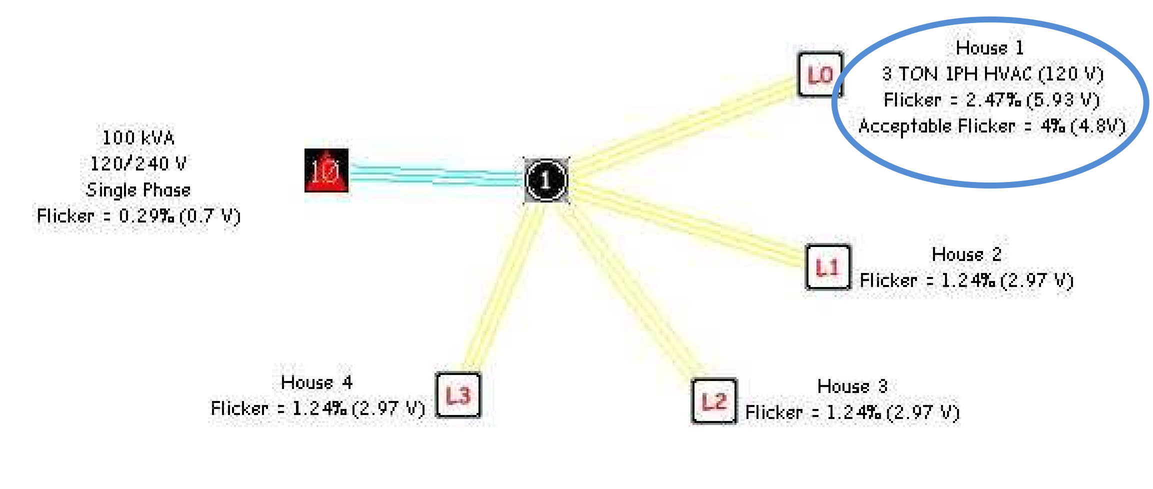

Figure C-2. Single-phase 120/240V system with flicker due to HVAC on House 1.

Depicted above in Figure C-2 is a demonstration of flicker analysis. For more information about flicker, please refer to Section 5.1.2.3 of this manual. In this case, a 3-ton single-phase HVAC unit is turning on at a frequency of once a day on House 1. As can be seen, the flicker affects all four house loads in this system, but the house that directly utilizes the HVAC unit has the worst flicker. Fortunately, a unit of this size with this starting frequency does not cause extreme flicker in this system and remains within Acceptable Flicker levels.

Single-phase Example and Comparison with Full Report (continued)

Comparison of Utilizing R/N Conducting Wire with Balanced and Unbalanced Loads

The purpose of the four house loads in this example is to provide a comparison between balanced and unbalanced loads as well as R/N versus non-R/N conducting wire. This comparison is depicted in Figure C-1 above after utilizing the DSC's Voltage Drop Calculation tool.

House 1 and House 2 are balanced loads of 12 kVA with 0.85 power factors. House 1 has 2/0 AL OH Triplex conducting wire while House 2 has 2/0 AL OH Triplex R/N conducting wire. As can be seen from the lack of difference between the total voltage drops, utilizing either R/N or non-R/N conducting wire to supply a balanced load provides the same electrical characteristics. However, the advantage of utilizing R/N conducting wire is physical. It is smaller and lighter than the non-R/N variety, making it easier to install and maintain.

House 3 is the same as House 1 in every aspect except that it is an unbalanced load. The total line-to-line voltage drop of both houses is equivalent at 7.78 V. When analyzing the total line-to-neutral voltage drops, distinctions can be seen between the balanced and unbalanced loads. For the balanced load, House 1, the load is 6 kVA on each leg. For the unbalanced load, House 3, the first leg has a load of 5 kVA while the second leg has a load of 7 kVA. The analysis shows that the first leg of House 3 has a lower line-to-neutral voltage drop than the first leg of House 1 and vice versa for the second leg.

House 3 and House 4 are unbalanced loads with the loading as described above for House 3. House 3 has 2/0 AL OH Triplex conducting wire while House 4 has 2/0 AL OH Triplex R/N conducting wire. In the case of unbalanced loads, having the conducting wire with a reduced neutral does make a difference in the total voltage drop. When comparing the second leg's total line-to-neutral voltage drop between House 3 and House 4, it is seen that House 4 (the load with R/N conducting wire) has a larger voltage drop. In some situations, the larger voltage drop due to the reduced neutral could cause one leg to exceed the total allowable voltage drop limits. Therefore, it can be advantageous from an electrical standpoint to utilize the non-R/N variety of conducting wire when dealing with unbalanced loads. However, there still are the physical disadvantages of the larger and heavier wire that must be considered.

Single-phase Example and Comparison with Full Report (continued)

Report with Voltage Drop and Flicker Calculation

Transformer

100 KVA : 120/240 V (1Ø Circuit)

	Line 1	Line 2	Line to Line	Neutral
Current	183 A (22 KVA)	217 A (26 KVA)		33 A (4 KVA)
TX VD	1.03V (0.9%)	1.22V (1.0%)	2.25V (0.9%)	
	Total Power Factor 1 = .85		Total Power Factor 2 = .85	

Secondary Wire

1 - 4/0 AL OH TRIPLEX @ 100' : Max Amps = 245 : Connects Node 1 to TX

	Line 1	Line 2	Line to Line	Neutral
Through Current	183 A	217 A		33 A
Wire VD	1.50V (1.3%)	2.51V (2.1%)	4.01V (1.7%)	
Total VD	2.54V (2.1%)	3.73V (3.1%)	6.26V (2.6%)	

Figure C-3. DSC Report, page 1, transformer details.

Single-phase Example and Comparison with Full Report (continued)

Report with Voltage Drop and Flicker Calculation (continued)

Load #0

House 1 (1Ø Circuit)
Base Voltage 120/240 V
Service Wire = 1 - 2/0 AL OH TRIPLEX @ 100'

Current

Leg 1	Leg 2	Neutral
50 A	50 A	0 A
PF1 .85 (Lag)	PF2 .85 (Lag)	

Voltage Drop

	Leg 1	Leg 2	Leg to Leg
Svc Wire VD	0.76V (0.6%)	0.76V (0.6%)	1.52V (0.6%)
Total VD	1.26V (1.1%)	1.26V (1.1%)	2.52V (1.1%)

Fault Current

Line to Line	Line to Neutral
3,840 A	2,104 A

Flicker (Maximum Threshold of 2%)

3 TON 1PH HVAC		
Flicker	**Starts**	**On Load**
2.47%	1 per Day	0

Figure C-4. DSC Report, page 2, Load 0 (House 1) details.

Single-phase Example and Comparison with Full Report (continued)

Report with Voltage Drop and Flicker Calculation (continued)

Load #1

House 2 (1Ø Circuit)
Base Voltage 120/240 V
Service Wire = 1 - 2/0 AL OH TRIPLEX R/N @ 100'

Current

Leg 1	Leg 2	Neutral
50 A	50 A	0 A
PF1 .85 (Lag)	PF2 .85 (Lag)	

Voltage Drop

	Leg 1	Leg 2	Leg to Leg
Svc Wire VD	0.76V (0.6%)	0.76V (0.6%)	1.52V (0.6%)
Total VD	1.26V (1.1%)	1.26V (1.1%)	2.52V (1.1%)

Fault Current

Line to Line	Line to Neutral
3,840 A	1,828 A

Flicker (Maximum Threshold of 2%)

3 TON 1PH HVAC		
Flicker	**Starts**	**On Load**
1.24%	1 per Day	0

Figure C-5. DSC Report, page 3, Load 1 (House 2) details.

Single-phase Example and Comparison with Full Report (continued)

Report with Voltage Drop and Flicker Calculation (continued)

Load #2

House 3 (1Ø Circuit)
Base Voltage 120/240 V
Service Wire = 1 - 2/0 AL OH TRIPLEX @ 100'

Current

Leg 1	Leg 2	Neutral
42 A	58 A	17 A
PF1 .85 (Lag)	PF2 .85 (Lag)	

Voltage Drop

	Leg 1	Leg 2	Leg to Leg
Svc Wire VD	0.38V (0.3%)	1.14V (0.9%)	1.52V (0.6%)
Total VD	0.63V (0.5%)	1.89V (1.6%)	2.52V (1.1%)

Fault Current

Line to Line	Line to Neutral
3,840 A	2,104 A

Flicker (Maximum Threshold of 2%)

3 TON 1PH HVAC		
Flicker	**Starts**	**On Load**
1.24%	1 per Day	0

Figure C-6. DSC Report, page 4, Load 2 (House 3) details.

Single-phase Example and Comparison with Full Report (continued)

Report with Voltage Drop and Flicker Calculation (continued)

Load #3

House 4 (1Ø Circuit)
Base Voltage 120/240 V
Service Wire = 1 - 2/0 AL OH TRIPLEX R/N @ 100'

Current

Leg 1	Leg 2	Neutral
42 A	58 A	17 A
PF1 .85 (Lag)	PF2 .85 (Lag)	

Voltage Drop

	Leg 1	Leg 2	Leg to Leg
Svc Wire VD	0.25V (0.2%)	1.27V (1.1%)	1.52V (0.6%)
Total VD	0.50V (0.4%)	2.02V (1.7%)	2.52V (1.1%)

Fault Current

Line to Line	Line to Neutral
3,840 A	1,828 A

Flicker (Maximum Threshold of 2%)

3 TON 1PH HVAC		
Flicker	**Starts**	**On Load**
1.24%	1 per Day	0

* Denotes a value that has exceeded the recommended maximum voltage drop threshold of 5 %
Project Filename: Example - 1ph 120-240V correct.scs

Figure C-7. DSC Report, page 5, Load 3 (House 4) details with footnote that appears at bottom of every page of the report automatically.

Depicted above in Figures C-3 through C-7 is the DSC report for the circuit model shown in Figures C-1 and C-2. Two significant notes are: 1) whether or not flicker analysis details will be printed and, 2) whether the load is balanced or unbalanced.

Details from conducting a Flicker Analysis will be placed at the bottom of all pages in the report describing loads (see circled portion of Figure C-4 above). These details will only appear on the report if a Flicker Analysis is conducted for the circuit model before the report is printed.

If a load is balanced, the Neutral column in the Current section of the report for that load will be zero. However, if a load is unbalanced, the Neutral column will be something other than zero, as shown by the circle in Figure C-6 above.

Three-Phase Wye Example

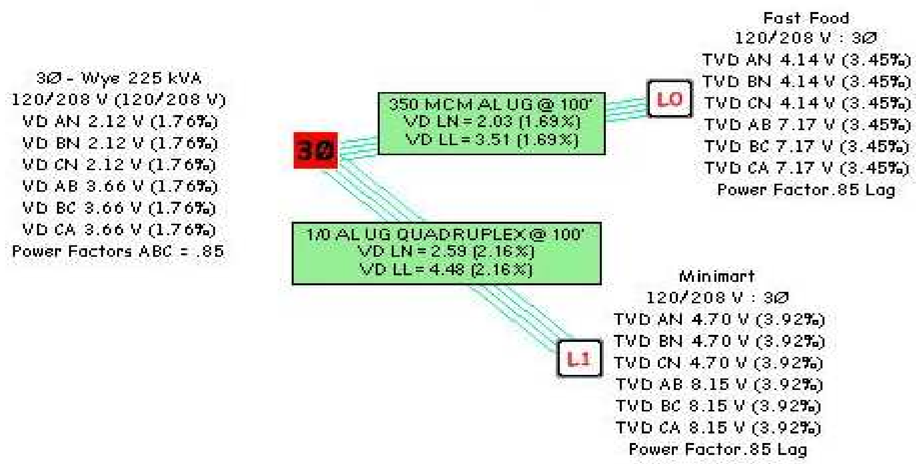

Figure C-8. Three-phase Wye distribution system with a 225 kVA transformer, one Fast Food restaurant load of 100 kVA and one Minimart load of 50 kVA.

Creating the Circuit Model

Depicted above in Figure C-8 is an example of a three-phase Wye distribution system. The process of creating this circuit model is very similar to creating a single-phase distribution system, as discussed at the beginning of this appendix.

As with any situation, there are certain pre-defined conditions. In this case, those conditions are the load sizes and the distance of the loads from the transformer. One load is a Fast Food restaurant with a balanced 100 kVA at a 0.85 power factor and the second load is a Minimart with a balanced 50 kVA at a 0.85 power factor. The distance from either load to the transformer is approximately 100 feet. With these type loads it is typical to see underground conducting wire running from a three-phase 120/208 V Wye pad-mounted transformer with a 4-wire scheme.

Using the conditions above, the kVA rating for the three-phase 120/208 V UG Wye transformer must be determined. Given that the total load to be served from the transformer is 150 kVA, and then using the previously mentioned ‘rule-of-thumb’ of a plus 25% safety factor, a transformer rated at 182.5 kVA is required. However, in the utility industry, there are no standard pad-mounted transformers with such a kVA rating. Typically what is available are 225 kVA or 300 kVA rated transformers. For the purposes of this example, a 225 kVA three-phase 120/208 V UG Wye transformer has been selected.

In this example, the loads are connected directly to the transformer with two separate conducting wires. Since one load is larger than the other, it will more than likely require a larger conducting wire. The same method as described earlier for the single-phase distribution system is utilized: start with small conducting wire, run the Voltage Drop Calculation tool, and re-evaluate the components of the system until no problems are apparent. From this method the conducting wires depicted in this example are determined. For the Fast Food restaurant’s 100 kVA load, the smallest possible wire is a 350 MCM AL UG. For the Minimart’s 50 kVA load, the smallest possible wire is a 1/0 AL UG Quadruplex.

Three-Phase Closed Delta Example

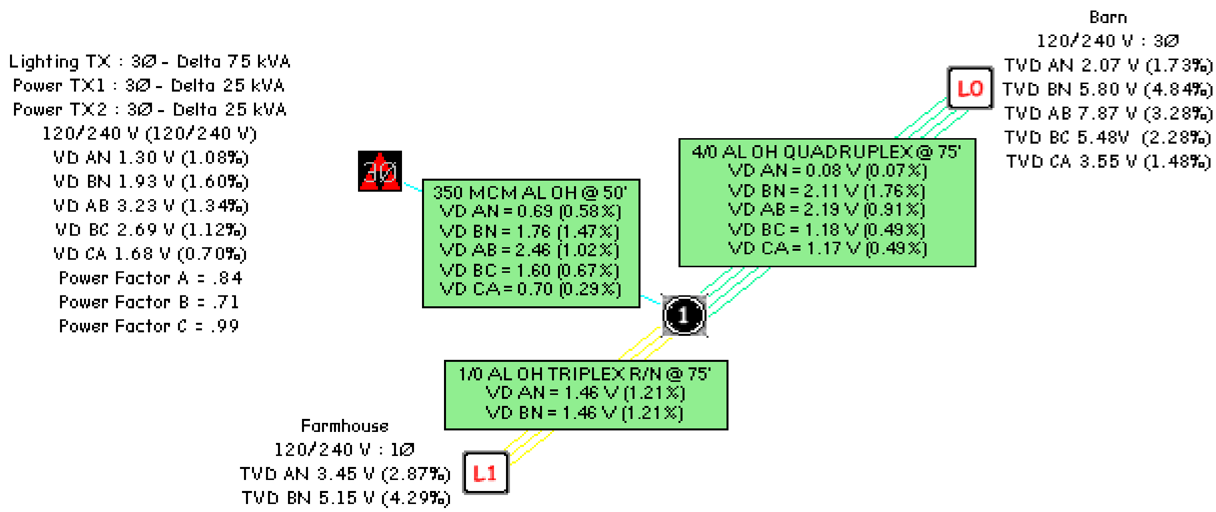

Figure C-9. Three-phase Closed Delta distribution system with a 50 kVA Lighting transformer and two 25 kVA Power transformers, one Barn with a balanced three-phase 30 kVA load and an unbalanced single-phase load with 5 kVA on Leg 1 and 15 kVA on Leg 2, and one Farmhouse with a balanced 25 kVA single-phase load. All power factors are 0.85.

Creating the Circuit Model

Depicted above in Figure C-9 is an example of a three-phase Closed Delta distribution system. The process of creating this circuit model is basically the same as previously used with the single-phase distribution system and the three-phase Wye distribution system.

The pre-defined conditions for this case are the load sizes and the distance of the loads from the transformer bank. The first load is a Barn with a balanced three-phase 30 kVA load at a 0.85 power factor and an unbalanced single-phase load with 5 kVA at a 0.85 power factor on Leg 1 and 15 kVA at a 0.85 power factor on Leg 2. The other load is a Farmhouse with a balanced single-phase 25 kVA load at a 0.85 power factor. The distance from either load to the node (pole) is 75 feet and the distance from the node (pole) to the pole-mounted transformer bank is 50 feet. With these type loads it is typical to see 120/240 V with a 4-wire scheme for the three-phase/single-phase Barn and a 3-wire scheme for the single-phase Farmhouse. For the purposes of this example, all facilities are assumed to be overhead.

Using the conditions above, the kVA ratings for the three-phase 120/240 V OH Closed Delta's lighting and power transformers must be calculated. The calculations used by the DSC to determine the exact loading of each transformer in a Closed Delta bank are very complex and are dependent upon the impedances of the transformers as well as the size and type of loads. For this reason, a less accurate but simpler method of estimating transformer sizes is presented here.

Three-Phase Closed Delta Example (continued)

Creating the Circuit Model (continued)

The easiest way to choose the kVA rating of the lighting transformer needed is to meet the following condition:

$$lighting\ xfmr\ rating \geq 1.25 \times \left(total\ 1ø\ load + \frac{1}{3} \times total\ 3ø\ load\right)$$

Given that in this example the total single-phase load is 45 kVA and the total three-phase load is 30 kVA, the lighting transformer needs to have a kVA rating of at least 68.75 kVA. The smallest standard size transformer that can be used has a rating of 75 kVA, which is what was chosen for this example. It should be noted that the "1.25" in the above equation is a safety factor for typical load unbalance and inrush. If a severe unbalance is expected in a system, then a larger transformer may be necessary. Alternatively, in some cases, a smaller transformer can be utilized. In any case, the DSC will provide a warning for overloaded transformers.

The easiest way to choose the kVA ratings of the power transformers needed is to meet the following condition:

$$power\ xfmr\ rating \geq \frac{total\ 3ø\ load}{\sqrt{3}}$$

Given that the total three-phase load in this example is 30 kVA, each power transformer should have a rating of at least 17.32 kVA. The smallest standard size transformer that can be used has a rating of 25 kVA, which is what was chosen for this example.

The same method used previously is utilized: start with small conducting wire, run the Voltage Drop Calculation tool, and re-evaluate the components of the system until no problems are apparent. Thus the conducting wires depicted in this example are determined. For the conducting wire running between the transformer and the node (pole), the most reasonable size is found to be 350 MCM AL OH. For the Barn's load, the smallest possible wire is a 4/0 AL OH Quadruplex. For the Farmhouse's load, the smallest possible wire is a 1/0 AL OH Triplex R/N. R/N is used for the Farmhouse because its single-phase load is balanced and the R/N conducting wire is a lighter choice than the non-R/N variety.

Three-Phase Open Delta Example with Errors, Then Corrected

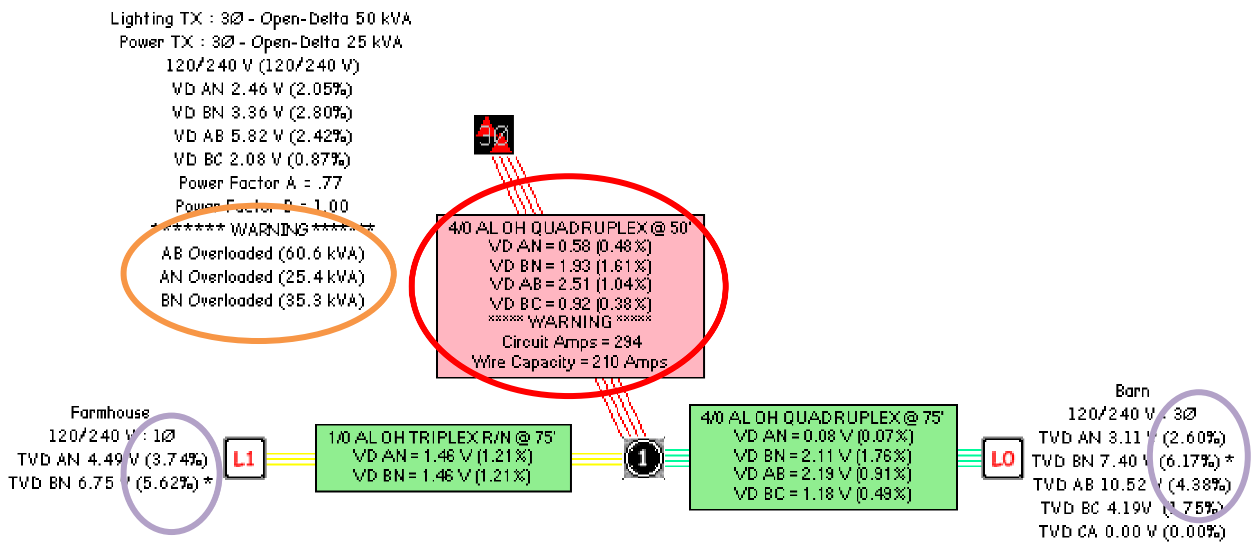

Figure C-10. Three-phase Open Delta distribution system with a 50 kVA Lighting transformer and a 25 kVA Power transformer, one Barn with a balanced three-phase 30 kVA load and an unbalanced single-phase load with 5 kVA on Leg 1 and 15 kVA on Leg 2, and one Farmhouse with a balanced 25 kVA single-phase load. All power factors are at 0.85.

Creating the Circuit Model – Problems to be Fixed

Depicted above in Figure C-10 is a first attempt to set up an Open Delta distribution system circuit model. For comparison purposes, this distribution system services the same loads as those described earlier in the Closed Delta example presented in this appendix. An examination of Figure C-10, shows several problems with this circuit model.

In any circuit model setup, there are always three possible problems that might appear. One is the overloading of a transformer. The DSC will indicate this problem via a WARNING notice under the transformer's label (notice the orange-circled portion of Figure C-10). Another problem might be the overloading of conducting wire. The DSC indicates this via a red WARNING label on the conducting wire's icon (see red circle in Figure C-10). The last problem that may appear is excessive voltage drop. The DSC indicates total voltage drops beyond the user input limit with asterisks (*) next to the calculated total voltage drop (TVD) of the load(s) (see purple circles in Figure C-10). For this example, the limit was input as a 5.0% total voltage drop.

Correcting for Insufficient Transformer Capacity

The first problem for correction in this example is the insufficient capacity of the transformer bank. As for the Closed Delta bank, the calculations used by the DSC to determine the exact loading of each transformer in an Open Delta bank are very complex and are dependent on the size and type of loads. Therefore, the same less accurate but simpler method of estimating transformer sizes is presented here. This method is valid in this case, since an Open Delta bank is basically the same as a Closed Delta bank with one of the Power transformers removed. The estimates are considerably less conservative for the Open Delta bank, but should be adequate in most cases.

Three-Phase Open Delta Example with Errors, Then Corrected (continued)

Correcting for Insufficient Transformer Capacity (continued)

As before, the easiest way to choose the kVA rating of the lighting transformer needed is to meet the following condition:

$$lighting\ xfmr\ rating \geq 1.25 \times (total\ 1ø\ load + \frac{1}{3} \times total\ 3ø\ load)$$

Given that in this example the total single-phase load is 45 kVA and the total three-phase load is 30 kVA, the lighting transformer needs to have a kVA rating of at least 68.75 kVA. Also, notice from Figure C-10 that the loading on BN of the transformer bank is 35.3 kVA. This is the half-winding load of the lighting transformer. Due to the load unbalance, the actual kVA rating of the lighting transformer needs to be at least 70.6 kVA (twice the largest half-winding load). In any case, the smallest standard size transformer that can be used has a rating of 75 kVA. As can be seen below in Figure C-11, a 75 kVA lighting transformer has been chosen to meet this condition and the overloading problem on the transformer has been remedied.

Even though the transformer overloading was corrected in this example with a larger lighting transformer, for demonstration purposes the process of estimating the Power transformer kVA rating is presented. Also as before, the easiest way to choose the kVA ratings of the power transformer needed is to meet the following condition:

$$power\ xfmr\ rating \geq \frac{total\ 3ø\ load}{\sqrt{3}}$$

Given that the total three-phase load in this example is 30 kVA, the power transformer should have a rating of at least 17.32 kVA. The smallest standard size transformer that can be used has a rating of 25 kVA, which is what was chosen for this example.

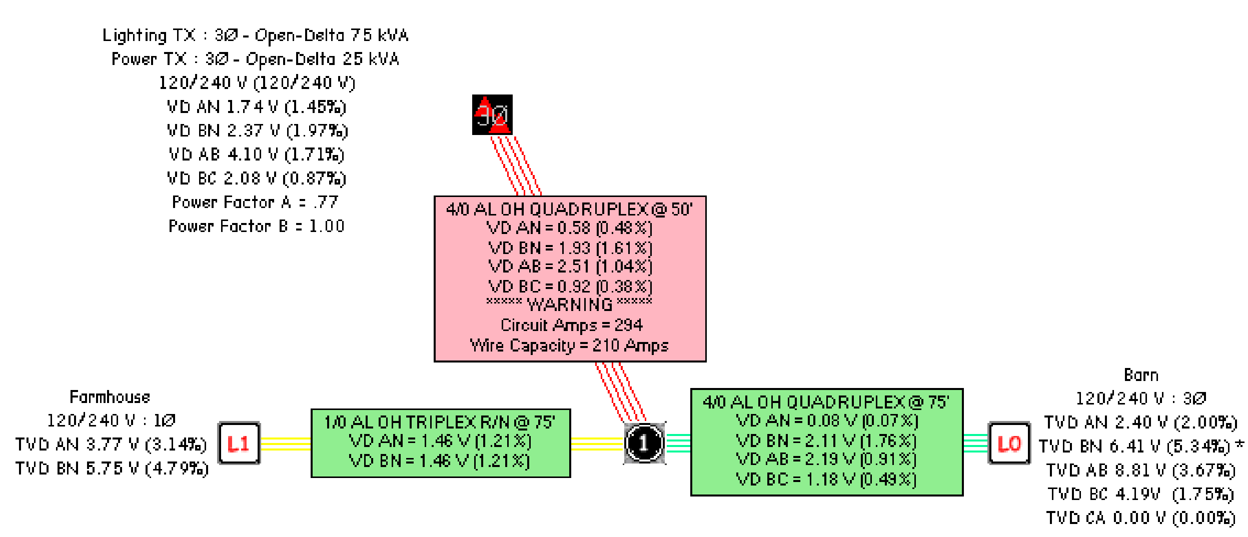

Figure C-11. Three-Phase Open Delta distribution system, transformer overloading corrected.

Three-Phase Open Delta Example with Errors, Then Corrected (continued)

Correcting for Insufficient Capacity on the Conducting Wire

The next problem to correct in this example is the overloaded conducting wire between the transformer and the node (pole). Fortunately, increasing the wire size for capacity will also decrease the amount of voltage drop due to this piece of conducting wire. Consequently, the total voltage drop will also decrease and perhaps be reduced to acceptable levels.

After increasing the size of the conducting wire between the transformer and the node (pole) until its capacity could meet the demand, it is found that the smallest conducting wire for this application is 250 MCM AL OH. See Figure C-12 below for an illustration of the removal of the capacity warning seen in Figure C-10. However, it should be noted that the total voltage drop still exceeds the 5.0% limit meaning the size of the conducting wire may have to be increased again.

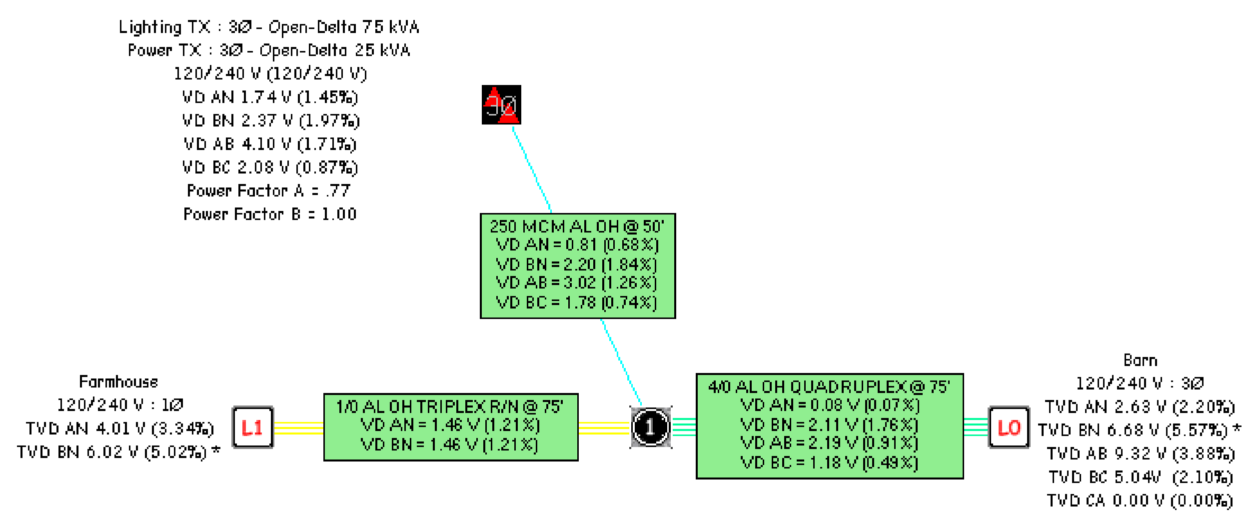

Figure C-12. Three-Phase Open Delta distribution system, conducting wire overloading corrected.

Three-Phase Open Delta Example with Errors, Then Corrected (continued)

Correcting for Total Voltage Drop (TVD)

Finally, the last problem in this example for correction is the reduction of the total voltage drop. A good 'rule-of-thumb' to follow here is that if multiple loads have an excessive voltage drop, then the main supplying conductor wire should be the first suspect. Further examination of Figure C-12 reveals that there is indeed some substantial voltage drop occurring across the line section between the transformer and the node (pole). Increasing the wire size will decrease this voltage drop. If certain conditions of this example had been different (i.e. the total voltage drop was excessive on only one of the loads), then the individual service conducting wire could have been increased in size to fix the problem.

Depicted below in Figure C-13 is this example of an Open Delta distribution system after being fully corrected. It turns out that increasing the size of the conducting wire between the transformer and the node to 500 MCM AL OH was needed to complete the process of correcting the problems in this system.

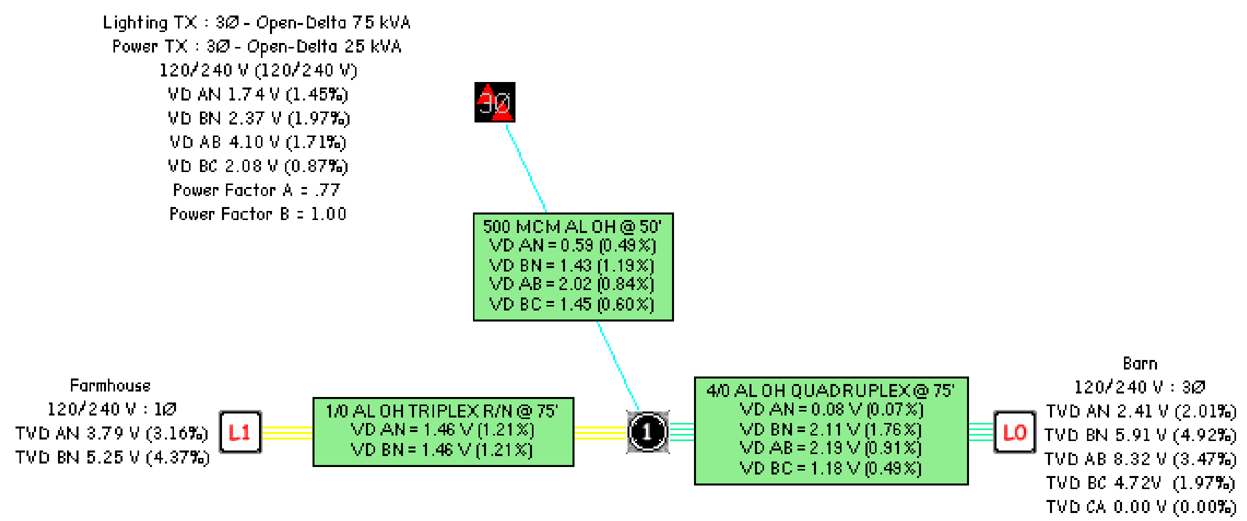

Figure C-13. 3-Phase Open Delta distribution system, fully corrected.

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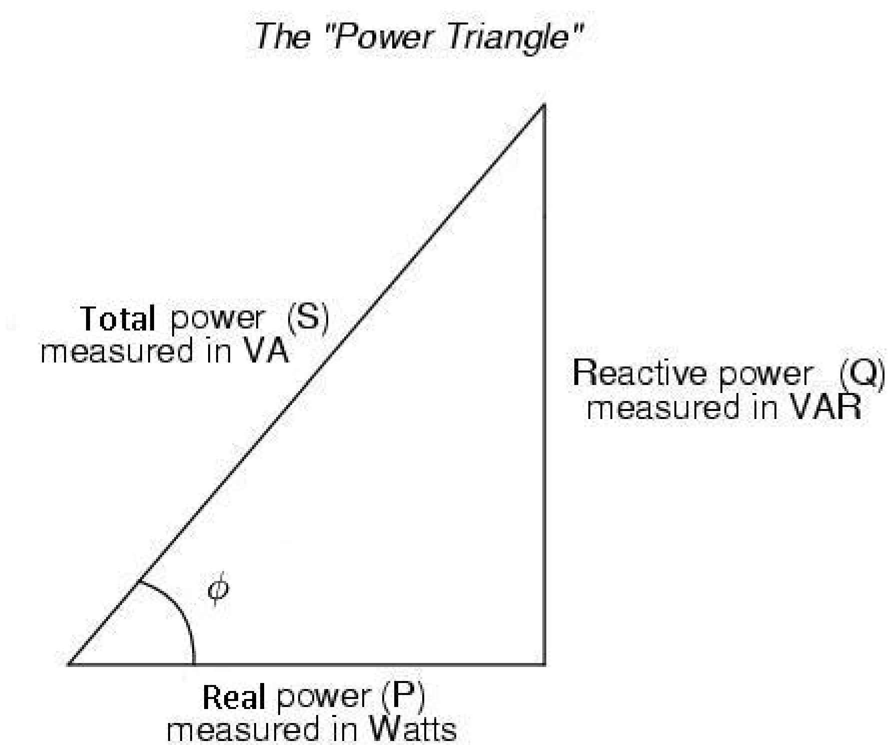
Chattanooga, Tennessee

DISTRIBUTION SECONDARY CALCULATOR
(Project No. DSC-1)

APPENDIX D
Basic Equations

1. Power Triangle

The Total Power in a distribution system is the combination of Real Power and Reactive Power components. The Real Power is the component that results in a net transfer of energy in one direction or, in laymen's terms, it is the portion of the Total Power that does the work. On the other hand, the Reactive Power is the component due to stored energy, which returns to the source on each cycle. This is the portion of the Total Power that just takes up space or, in other words, reduces the capacity of a distribution system. Distribution systems can inherently have Reactive Power, which results in the need to have corrective equipment in the system to reduce the Reactive Power. This in turn allows as much Real Power as possible to reach the load. A distribution system that does not have any Reactive Power is the most efficient for energy transfer. This is evident from the fact that the Total Power equals the Real Power in such systems.



The overall relationship between the Total, Real, and Reactive Power can be explained trigonometrically, as diagramed above in the Power Triangle. The power factor, which can be determined from the phase angle, ϕ, is the ratio between the Real and Total Power.

2. Total Power

$$S = \sqrt{P^2 + Q^2}$$

S - VA, volt-amps, measurement of Total Power, also referred to as Apparent Power
P - W, watts, measurement of Real Power, also referred to as True Power
Q - VAR, measurement of Reactive Power, also referred to as Imaginary Power

This equation shows that Total Power is a combination of Real and Reactive Power.

3. Power Factor

$$pf = \cos(\phi)$$

pf - power factor
ϕ - radians or degrees, phase angle phi

The power factor is a statement of the efficiency of Real Power to Total Power in the distribution system. It can be determined from the phase angle (ϕ) between the Total Power and Real Power. This is also the angle between the current and voltage.

4. Real Power

$$P = S \times pf$$

P - W, watts, Real or True Power
S - VA, volt-amps, Total or Apparent Power
pf - power factor

This equation identifies Real Power as simply the Total Power adjusted by the power factor. The closer the power factor is to unity (1), the more efficient the transmission of real power is from the source to the load. In other words, the Real Power equals the Total Power.

5. Reactive Power

$$Q = S \times \sin(\cos^{-1}(pf))$$

Q - VAR, Reactive or Imaginary Power
S - VA, volt-amps, Total or Apparent Power
pf - power factor

This equation identifies Reactive Power as a trigonometric function of Total Power and the power factor. In this case, when the power factor is unity (1), the Reactive Power is equal to zero (0).

6. Total Load Current

$$I_{SLD} = \frac{S_{LD} \times 1000}{V}$$

I_{SLD} - A, Amps, load current as dependent on the Total Power for leg or phase
S_{LD} - kVA, kilovolt-amps, Total or Apparent Power for leg or phase of load
V - V, volts, voltage rating of the system or transformer in question

Typically, the VA rating of a piece of equipment is given in kVA, or VA x 10^3. The purpose of the 1000 multiplier in this equation is to convert the typical kVA rating of a piece of equipment, i.e. a transformer, to VA so that when the voltage rating is taken into consideration, the result is in standard Amps with no prefixes or orders of magnitude to worry about.

NOTE - Since unbalanced analysis is being conducted, the above equation is used for 3ø load currents by calculating each phase current with their respective phase voltages.

7. Impedance

$$Z = \sqrt{R^2 + X^2}$$

Z - Ω, Ohms, total impedance
R - Ω, Ohms, resistance
X - Ω, Ohms, reactance

Impedance describes a measure of opposition to current and is a combination of the resistance and reactance in a distribution system. Resistance is the real component of impedance and Reactance is the reactive component of impedance. Conducting wires as well as other equipment in a distribution system have different levels of resistance and reactance associated with them. For example, a conducting wire of a specific length has more impedance than a conducting wire of the same material and a shorter length.

This equation shows that the total impedance has the same relationship to resistance and reactance as Total Power has to Real and Reactive Power.

8. Wire Resistance

$$R_W = L \times R_{\Omega/ft}$$

R_W - Ω, Ohms, inherent resistance of wire after its total length has been taken into consideration
L - Feet, wire length
$R_{\Omega/ft}$ - Ω per foot, inherent resistance of wire as a function of length
(Often published in units of Ω per 1000 feet in reference tables)

NOTE - This formula is equally applicable for computing the following parameters with the respective inputs exchanged:

R_N - Resistance of Neutral wire in Ohms
X_W - Reactance of Wire in Ohms
X_N - Reactance of Neutral wire in Ohms

9. Transformer Resistance

$$R_{xfmr} = R_{\%xfmr} \times \frac{V^2}{kVA_{xfmr} \times 100{,}000}$$

R_{xfmr} - Ω, Ohms, resistance of the transformer
$R_{\%xfmr}$ - numerical value given as a percentage to represent the transformer's resistance
V - V, volts, voltage rating of the secondary transformer
kVA_{xfmr} - kVA, kilovolt-amps, transformer's kVA rating

The purpose of this equation is to convert the typically-given rated percentage impedance of the transformer into an impedance with Ohms units.

The 100,000 multiplier in the denominator is a combination of two converting factors. One factor is that 1000 must be multiplied to the kVA rating of the transforming to convert it from kVA to VA. The other factor is that the percentage resistance of the transformer must be converted from percentage to decimal format by dividing by 100. These considerations must be taken into account in order to determine the resistance of the transformer in Ohms.

NOTE - This formula is equally applicable for computing the following parameter with the respective inputs exchanged:

X_{xfmr} - Transformer's reactance in Ohms
Z_{xfmr} - Transformer's impedance in Ohms

10. Voltage Drop Due to System Components

In an energized distribution system, there will be voltage drop due to the system's components themselves. This will happen most noticeably with the transformer and the lengths of conducting wire between the source and the load. Below are detailed equations for the various conditions when voltage drop due to these components will take place. All equations utilize phasors for calculations, just as the software does. The results the software displays are displayed as magnitudes for ease of understanding.

- Voltage Drop, Transformer, Single-phase

$$V_{d,1øxfmr} = I \times Z_{xfmr}$$

$V_{d,1øxfmr}$ - V, volts, voltage drop across the 1ø transformer
I - A, Amps, current flowing through the 1ø transformer
Z_{xfmr} - Ω, Ohms, total impedance of transformer

- Voltage Drop, Transformer, Three-phase

$$V_{d,3øxfmr} = \sqrt{3} \times I \times Z_{xfmr}$$

$V_{d,3øxfmr}$ - V, volts, phase voltage drop across the 3ø transformer
I - A, Amps, phase current flowing through the 3ø transformer
Z_{xfmr} - Ω, Ohms, total phase impedance of transformer

- Voltage Drop, Conducting Wire, Single-phase

$$V_{d,1øW} = 2 \times I \times Z_W$$

$V_{d,1øW}$ - V, volts, voltage drop across the conducting wire for single-phase loads
I - A, Amps, current going through the conducting wire
Z_W - Ω, Ohms, total equivalent impedance of the conducting wire

- Voltage Drop, Conducting Wire, Three-phase

$$V_{d,3øW} = \sqrt{3} \times I \times Z_W$$

$V_{d,3øW}$ - V, volts, voltage drop across the conducting wire for three-phase loads
I - A, Amps, current going through the conducting wire
Z_W - Ω, Ohms, total equivalent impedance of the conducting wire

11. Fault Current

Calculating the fault current under various conditions aids the customer in choosing adequate fault-interrupting protection. As will be described below, there are several different types of faults that can occur on the energized line. Therefore, all must be considered and the worst-case scenario determined. See Section 5.1.2.4 & 5.2.3 in the main text for more information.

- Fault Current, Single-phase, Line-to-Line

$$I_{F,1ø,LL} = \frac{V_{LL}}{\sqrt{(R_{xfmr} + 2 \times R_W)^2 + (X_{xfmr} + 2 \times X_W)^2}}$$

$I_{F,1ø,LL}$ - A, Amps, single-phase fault current of a line-to-line fault
V_{LL} - V, volts, line-to-line voltage
R_{xfmr} - Ω, Ohms, equivalent resistance of the transformer
R_W - Ω, Ohms, equivalent resistance of the conducting wire
X_{xfmr} - Ω, Ohms, equivalent reactance of the transformer
X_W - Ω, Ohms, equivalent reactance of the conducting wire

- Fault Current, Single-phase, Line-to-Neutral

$$I_{F,1ø,LN} = \frac{V_{LN}}{\sqrt{(0.375 \times R_{xfmr} + R_W + R_N)^2 + (0.5 \times X_{xfmr} + X_W + X_N)^2}}$$

$I_{F,1ø,LN}$ - A, Amps, single phase fault current of a line-to-neutral fault
V_{LN} - V, volts, line-to-neutral voltage
R_{xfmr} - Ω, Ohms, equivalent resistance of the transformer
R_W - Ω, Ohms, equivalent resistance of the conducting wire
R_N - Ω, Ohms, equivalent resistance of the neutral wire
X_{xfmr} - Ω, Ohms, equivalent reactance of the transformer
X_W - Ω, Ohms, equivalent reactance of the conducting wire
X_N - Ω, Ohms, equivalent reactance of the neutral wire

- Fault Current, Three-phase

$$I_{F,3ø} = \frac{V_{LL}}{\sqrt{3 \times ((R_{xfmr} + R_W)^2 + (X_{xfmr} + X_W)^2)}}$$

$I_{F,3ø}$ - A, Amps, three-phase fault current
V_{LL} - V, volts, line-to-line voltage
R_{xfmr} - **Ω**, Ohms, equivalent resistance of the transformer
R_W - **Ω**, Ohms, equivalent resistance of the conducting wire
X_{xfmr} - **Ω**, Ohms, equivalent reactance of the transformer
X_W - **Ω**, Ohms, equivalent reactance of the conducting wire

- Fault Current, Three-phase, Line-to-Line

$$I_{F,3ø,LL} = \frac{\sqrt{3}}{2} \times I_{F,3ø}$$

$I_{F,3ø,LL}$ - A, Amps, fault current of a line-to-line fault in a three-phase system
$I_{F,3ø}$ - A, Amps, three-phase fault current

NOTE - This fault current is linearly related to the three-phase fault current already described above.

- Fault Current, Three-phase, Line-to-Neutral

$$I_{F,3ø,LN} = \frac{V_{LN}}{\sqrt{(R_{xfmr} + R_W + R_N)^2 + (X_{xfmr} + X_W + X_N)^2}}$$

$I_{F,3ø,LN}$ - A, Amps, fault current for a line-to-neutral fault in a 3-phase system
V_{LN} - V, volts, line-to-neutral voltage
R_{xfmr} - **Ω**, Ohms, equivalent resistance of the transformer
R_W - **Ω**, Ohms, equivalent resistance of the conducting wire
R_N - **Ω**, Ohms, equivalent resistance of the neutral wire
X_{xfmr} - **Ω**, Ohms, equivalent reactance of the transformer
X_W - **Ω**, Ohms, equivalent reactance of the conducting wire
X_N - **Ω**, Ohms, equivalent reactance of the neutral wire

12. Annual Load Factor

$$ALF = \frac{kWh}{8760 \times kW_{pk}}$$

ALF - Annual load factor, ranging from 0 to 1, with a typical value of approximately 0.5, or 50%
kWh - kWh, kilowatt-hours, the total amount of kilowatt-hours consumed that year
kW_{pk} - kW, kilowatt, the peak value of kilowatt consumption as it occurred that year

The 8760 multiplier stems from the total amount of hours in a given year. For a leap year, this multiplier changes to include the extra day. The annual load factor is a useful ratio for comparing the usage to the peak of kilowatt-hours in a given year. This ratio also becomes useful in the equations to be discussed below, and eventually in determining annual losses.

13. Loss Factor

$$LF = 0.84 \times ALF^2 + 0.16 \times ALF$$

LF - Loss factor, exclusively utilizes the annual load factor that has been previously calculated
ALF - Annual load factor, ranging from 0 to 1, with a typical value of approximately 0.5, or 50%

Loss factor is a formula developed from experience and by experiment to reflect how peak load demands and currents vary over a year for loss calculating purposes. The above formula is used primarily for rural electric distributor calculations (Refer to REA Bulletin 60-9 dated May 1980).

14. Annual kWh Losses

$$Loss_{kWh} = 8.76 \times I^2 \times (R_{xfmr} + R_W + R_N) \times LF$$

$Loss_{kWh}$ - kWh, kilowatt-hours, kilowatt-hours used due to losses in the system
I - A, Amps, current in the system
R_{xfmr} - Ω, Ohms, equivalent resistance of the transformer
R_W - Ω, Ohms, equivalent resistance of the conducting wire
R_N - Ω, Ohms, equivalent resistance of the neutral wire
LF - Loss factor

The 8.76 multiplier is a combination of two factors. The first factor is the total amount of hours in a given year (8760 hours). For a leap year, this multiplier changes to include the extra day. The second factor is the value of 1000 that is used to produce a final product with the units of kWh. (8760/1000 = 8.76)

15. Annual Loss Cost

$$ALC = Loss_{kWh} \times rate_{\$/kWh}$$

ALC - \$, annual loss cost, the annual cost due to losses in the system
$Loss_{kWh}$ - kWh, kilowatt-hours, kilowatt-hours used due to losses in the system
$rate_{\$/kWh}$ - \$/kWh, dollars per kilowatt-hour, the average cost of a kilowatt-hour of energy

The rate variable is a blended annual average cost of both demand and energy charges divided by the total kilowatt-hours purchased by the distributor.

TENNESSEE VALLEY PUBLIC POWER ASSOCIATION (TVPPA)
Chattanooga, Tennessee

DISTRIBUTION SECONDARY CALCULATOR
(Project No. DSC-1)

APPENDIX E
Industry Service Voltage Standard Summary

Industry Service Voltage Standard Summary

The following summarizes the key industry standards and design criteria for electric service voltage. Readers are encouraged to refer to the documents referenced for further details and explanations.

Voltage Conditions:

1. Voltage levels will be maintained in accordance with the latest RUS Bulletin 169-4 and/or the latest edition of the American National Standards Institute (ANSI) Standard C84.1. The ANSI Standard defines "Range A" and "Range B" voltage limits as follows:

Range A - Service Voltage

Electric supply systems shall be so designed and operated that most service voltages are within the limits specified for this range. The occurrence of service voltages outside these limits is to be infrequent.

Range A - Utilization Voltage

User systems shall be so designed and operated such that, with service voltages within Range A limits, most utilization voltages are within the limits specified for this range. Utilization equipment shall be so designed and rated to give fully satisfactory performance throughout this range.

Range B - Service and Utilization Voltages

This range includes voltages above and below Range A limits that necessarily result from practical design and operating conditions on supply and/or user systems. Although such conditions are a part of practical operations, they shall be limited in extent, frequency and duration. When they occur, corrective measures shall be undertaken within a reasonable time to improve voltages to meet Range A requirements.

Insofar as practicable, utilization equipment shall be designed to give acceptable performances in the extremes of this range of utilization voltage, although not necessarily as good performance as in Range A.

Table 1. **Voltage Ranges ANSI Standard C84.1 (120 volt base)**

Range	Minimum			Maximum
	Utilization Voltage*			
	Non-lighting loads	Loads including lighting	Service Voltage	Utilization & Service Voltage
A	108	110	114	126
B	104	106	110	127

*Note: Caution should be exercised in using minimum utilization voltage, as in some cases they may not be satisfactory for the equipment served. For example, where existing 220-volt motors are used on 208-volt circuits, the minimum utilization voltage permitted would not be adequate for the operation or motors.

Voltage Conditions: (continued)

2. Basic RUS Recommended Design Criteria:
   a) Rural electric distribution systems should be designed and operated to meet the voltage level requirements of “Range A” in ANSI C84.1-1970. Users’ utilization electrical equipment of all types will generally be designed to give satisfactory performance in this range.
   b) It is recognized that maintaining voltage levels within “Range A” on all parts of the system at all times cannot be ensured. Due to the economics of operation, there may be some system voltages that fall in extremes of “Range B” and even beyond. This may occasionally occur as the feeder reaches its design loading limit at annual or semi-annual peak loads.
   c) When voltages frequently extend into “Range B”, they should be corrected to conform to “Range A” requirements within a reasonable time. If voltages on any part of the system fall outside the limits of “Range B”, corrective actions should be taken immediately to bring these voltages within “Range B” requirements within a reasonable time.

Some types of utilization equipment will not perform satisfactorily or efficiently at the extremes of “Range B” voltages. Many types of utilization equipment may fail to operate and may be seriously damaged or suffer shortened operating life outside “Range B” voltage limits,. Voltages above these limits of Range B may be especially damaging to the users’ equipment.

Table 2. Voltage Drops for Rural Electric Distribution System Design (120 volt base)

	Maximum Volts Drop	**Percent Volts Drop**
Substation regulated bus (output) to last distribution transformer (primary)	8	6.67 %
Distribution transformer (primary) to service delivery connection to consumers’ wiring (meter or entrance switch)	4	3.33 %
Utility service delivery point (meter or entrance switch) to consumers’ utilization terminal (outlet):		
Loads including Lights	4	3.33 %
Non-lighting Loads	6	5.00 %

Voltage Conditions: (continued)

3. Basic RUS Recommended Operating Conditions
   Voltage level and limit values are based on the following:

   a) The outgoing substation voltage is regulated by a suitable voltage regulator as defined in Section A, Substations, of this exhibit.
   b) The regulator voltage band width setting does not exceed two volts on a 120-volt base.
   c) Voltage values used are at the center of the voltage regulator band width.
   d) All voltage regulators, whether at the substation or out on the line, have properly set and functioning line drop compensation (LDC).
   e) Only sustained voltages apply to these levels and limits. The flicker and variations caused by motor starting, equipment switching, variation of voltage within the voltage regulator band width, and similar short duration variations are not considered.
   f) Refer to RUS Bulletin 169-27, *Voltage Regulator Application On Rural Distribution Systems*, for detailed guidelines on voltage regulator installation and appropriate settings for voltage level, bandwidth, time delay, range of regulation, and line drop compensation (LDC).

Table 3. Voltage Level Limits and Spread for Rural Electric Distribution Systems.
(Measured at center of regulator bandwidth - 120-volt base)

	Voltage Levels (Volts)		**Voltage Spread**
	Minimum	Maximum	(Volts)
Substation Regulated Bus with Regulator:			
Line Drop Compensator in Use	122	126	4
Distribution Transformer Primary Terminals:			
Adjacent to substation bus	122	126	4
At end of line (8-Volt drop)	118	122	4
Service Connection (Meter Socket):			
At transformer nearest substation bus	118	126	8
At end of line (8-Volt drop on primary)	114	122	8
Point of Consumer Utilization:			
At transformer nearest to substation bus (Lighting load)	112	126	14
(Non-lighting loads)	108	126	18
At 8-volt drop on primary (Lighting load)	110	122	12
(Non-lighting load)	108	122	14

Voltage Conditions: (continued)

4. Voltage input to Distribution Substations
   The voltage input to distribution substations should be kept within limits as follows:

   a) Substation voltages are kept within the design limits of the substation transformers and other equipment.
   b) The substation voltage regulator can maintain the voltages on its output bus within the limits given in the Table 3.

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(TVPPA)
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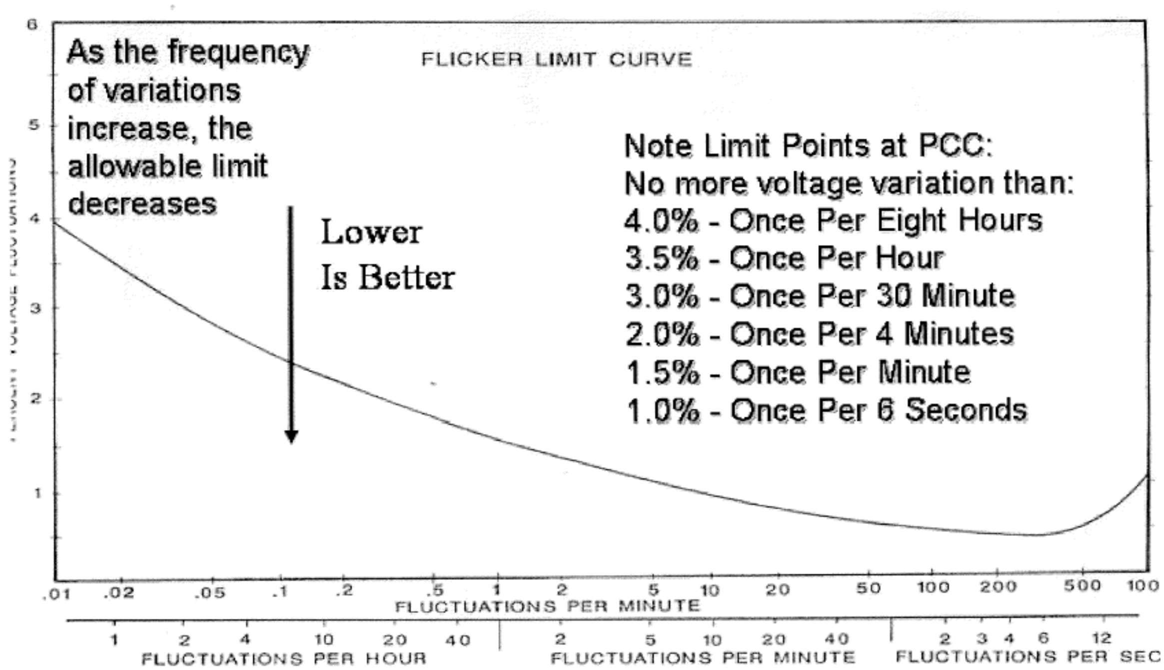
(Project No. DSC-1)

APPENDIX F
TVA Flicker Limit Guideline

TVA's Guidelines for Voltage Disturbing Loads Provides Guidelines For Evaluating The Impact of Disturbing Loads – TVA Flicker Limit Curve



PCC - Denotes Point of Common Coupling (typically at meter)

Voltage Fluctuation & Flicker Limits By Various Industry Standards†

Frequency of Fluctuations or Inrushes	TVA	Western Utility	IEEE Std 141		1925 GE Flicker Studies		Northwest Utility		RUS Bull. 160-3	
			BOI	BOV	BOI	BOV	BOI	BOV	Few Cons.	Many Cons
Once per 8 hours	4.0%	6.0%							7.8%	3.3%
Once per hour	3.5%	4.0%	6.0%	2.7%	7.0%	2.5%	7.2%	2.5%	6.7%	2.5%
Once per 30 minutes	3.0%	4.0%	4.9%	2.1%	5.2%	2.2%	6.3%	2.0%	6.7%	2.5%
Once per 4 minutes	2.0%	2.5%	3.0%	1.0%	2.0%	1.0%	2.8%	0.8%	5.0%	2.5%
Once per minute	1.5%	1.5%	1.9%	0.7%	1.8%	0.6%	2.0%	0.6%	2.9%	1.7%
Once per 6 seconds	1.0%	1.5%	1.2%	0.4%	0.7%	0.4%	0.6%	0.4%	2.5%	1.3%

BOV- Borderline of Visibility
BOI- Borderline of Irritation
†- See voltage flicker standards summary file - *Volt Flicker Allowance Stds.pdf*

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(Project No. DSC-1)

APPENDIX G
Acknowledgements
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References

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