



CPFLOW for Power Tracer and Voltage Monitoring

*Voltage Collapse Monitor
Final Project Report*

Power Systems Engineering Research Center

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Power Systems Engineering Research Center

CPFLOW for Power Tracer and Voltage Monitoring

Voltage Collapse Margin Monitor
Final Report

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Executive Summary

This final project report describes CPFLOW (Continuation Power Flow), a comprehensive software tool for tracing power system steady-state behaviors due to large or small variations in loads, generation, transactions, interchanges, and imports and exports. CPFLOW is designed for the analysis of large-scale power systems and can trace a solution curve through the 'nose' point without the numerical difficulties of repeated power flow solvers. It can generate P-V, Q-V, and P-Q-V solution curves by varying any combination of:

- bus P and/or Q loads plus real power generation at P-V buses
- area P and/or Q loads plus real power generation at P-V buses
- system P and/or Q loads plus real power generation at P-V buses
- power interchanges
- power transactions
- power imports or exports.

CPFLOW can be used in a variety of applications such as:

- monitoring voltage behaviors due to load and generation variations to detect such problems as voltage dip and collapse
- evaluating maximum interchange capability
- evaluating maximum available transfer capability
- tracing of power system behaviors due to load and/ generation variations with/without control devices
- conducting coordination studies of control devices for steady-state security enhancements
- evaluating the effects of different load models on voltage stability, transfer capability among other system condition variables of interest.

CPFLOW supports power system analysis of the following transactions and transmission services:

- Point-to-point MW transactions
- Slice-of-the-system sales
- Network service.

CPFLOW has several advantages over repetitive power flow solvers. It is more reliable in obtaining the solution curve, especially for ill-conditioned power flow equations. It is faster through its use of an effective predictor, adaptive step-length selection, and efficient I/O operations. Finally, CPFLOW is more versatile. It uses parameterizations that give the user the flexibility to easily analyze changes in real and/or reactive loads, and in real generation at P-V buses.

The program works with Windows 95 or later and Windows NT 3.51 or later. It is able to process power systems with up to 32,627 buses.

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Chapter 1

Overview of CPFLOW

This final project report describes CPFLOW (Continuation Power Flow), a comprehensive software tool for tracing power system steady-state behaviors due to large or small variations in loads, generation, transactions, interchanges, and imports and exports. CPFLOW can generate P-V, Q-V, and P-Q-V curves with the ability to vary a combination of the following:

- general bus (P and/or Q) loads plus real power generations in P-V buses
- area (P and/or Q) loads plus real power generations in P-V buses
- system (P and/or Q) loads plus real power generations in P-V buses
- power interchanges
- power transactions
- power import or export.

CPFLOW is designed for the analysis of large-scale power systems in order to trace the solution curve through the 'nose' point without any numerical difficulty. The main advantages of CPFLOW over repetitive power flow solvers are:

- Reliability: CPFLOW is more reliable than repeated power flow solvers in obtaining the solution curve, especially for ill-conditioned power flow equations;
- Speed: CPFLOW is faster than the repeated load flow approach through the use of an effective predictor, an adaptive step-length selection, and efficient I/O operations; and
- Functionality: CPFLOW is more versatile than repeated power flow solvers due to the use of parameterizations such that general bus real and/or reactive loads, area real and/or reactive loads, or system-wise real and/or reactive loads, and real generations in P-V buses (e.g., those determined by economic dispatch or participation factor) can vary.

1.1 Applications of CPFLOW

CPFLOW can be used in a variety of applications such as:

- the monitoring of voltage behaviors due to load and generation variations to detect problems such as voltage dip and voltage collapse
- the evaluation of maximum interchange capability
- the evaluation of maximum available transfer capability
- the tracing of power system behaviors due to load and/ generation variations with/without control devices
- coordinate studies of control devices for steady-state security enhancements.
- the evaluation of the effect of different load models on voltage stability, transfer capability, and so on.

CPFLOW supports one or several of the following power transactions and transmission services:

- Point-to-point MW transactions - the real power at one load bus of the receiving area varies while the others remain fixed and the real power at one generator bus of the sending area varies while the others remain fixed;
- Slice-of-the-system sales - both the real and reactive power demands at a load bus of the receiving area vary and the real power generation at some collection of generators of the sending bus varies while the others are fixed; and
- Network service - the real and/or reactive power demands at some collection of load buses of the receiving area vary and the real power generation at some collection of generators of the sending bus varies while the others are fixed.

1.2 Modeling Capability

CPFLOW simulates realistic operating conditions or expected future operating conditions under proposed multiple power transactions. To this end, the activation of control devices and the accurate representation of power transactions are included in the simulations. The control devices include: (i) switchable shunts and static VAR compensators, (ii) ULTC transformers, (iii) ULTC phase shifters, (iv) static tap changers and phase shifters, (v) DC networks. In order to completely describe the actual power flow in the interconnected systems and, in particular, the parallel flows on adjacent systems, a detailed nonlinear power flow analysis of the interconnected system must be performed.

CPFLOW has a range of modeling capabilities, as described below.

1. Generators

Generators are modeled as active and reactive power sources that also provide voltage control. The MVAR output of each on-line generator is adjusted during power flow solutions in order to control the voltage of the local bus (the bus where the generator is connected) or a remote bus. The generator's MVAR output has fixed limits.

2. Base Case Loads

Loads can be modeled as constant power (P-Q), constant current (I), constant impedance (Z) or any linear combination thereof. The tool can also accept nonlinear load models as long as they are expressed as nonlinear functions of voltage.

3. Load Variation

In the traditional CPFLOW program, the load variation (increment) is modeled as constant P-Q load, which usually yields conservative result. In this new program version, a user can select different combinations of ZIP load models for the proposed load variations and evaluate the system's stationery behavior under the proposed load model.

4. Control Devices

The following control devices are modeled:

- Switchable shunts and static VAR compensators
- Interchange schedules
- ULTC transformers
- ULTC phase shifters
- Static tap changers and phase shifters

5. DC Network (up to 25 DC transmission lines)

1.3 Input Data Format

CPFLOW can import power flow data in the following formats:

- EPRI
- BPA
- IEEE
- PECO
- PTI.

The current GUI version of CPFLOW only supports PTI raw data input. The current production version of CPFLOW can handle power systems of up to 32,627 buses.

Chapter 2

Technical Description of CPFLOW

2.1 Introduction

This chapter provides a technical description of CPFLOW. In addition, CPFLOW has been extended for the generation of ZIP-V curves for tracing power system steady state behavior due to load and generation variations. This chapter describes this extension, too.

Load models are known to have profound impacts on power system behaviors. It is well-recognized that the constant P-Q load model leads to unsatisfactory simulation results of power system static behaviors. This is due to the assumption of fixing power demands for varying operating conditions. The commonly-used nonlinear load model, the ZIP-model (which combines loads of constant current, constant power, and constant impedance), is popular for modeling the nonlinear behaviors of loads. The ZIP-model often leads to accurate results in simulating power system static behaviors.

P-V, Q-V, and P-Q-V curves have been widely used to analyze power system behavior under varying loading conditions. Voltage stability and loadability analyses are examples of the application of these curves in power system analysis. These curves are obtained, during varying loading/generation conditions, under the assumption that the constant P-Q load component of a bus (or a collection of buses) varies, with the constant current load and constant impedance load being kept indeed “constant”. Even though the physical meaning of these curves can be readily explained and these curves serve their purpose well, they tend to be on conservative in predicting system limits such as voltage stability or loadability limit. Since the ZIP-model is so popular, it makes the most sense to allow the components constant current load and constant impedance load to vary as well to model load variation in power systems.

We do not to evaluate the assumption of fixing the values of constant current loads and constant impedance loads in generating the P-V curve, Q-V curve, or P-Q-V curves; instead, we show that the assumption can be relaxed and a new class of curves, called ZIP-V curves, can be generated. ZIP-V curves represent power system quasi-steady-state behaviors as all the values of constant Z, I, P-Q (ZIP) vary and their variations are uniform. The ZIP-V curve can become an I-V, Z-V, IP-V, ZP-V or IZ-V curve when the values of the corresponding component are kept constant. A new set of parameterized power flow equations is proposed. An extension to CPFLOW is used to generate illustrative ZIP-V curves.

2.2 CPFLOW with ZIP Load Variation

Let $P_i \equiv P_{gi} - P_{di}$ and $Q_i \equiv Q_{gi} - Q_{di}$. The lowercase g represents generation and the lowercase d represents load demand. The set of power flow equations can be represented in compact form as:

$$f(x) = \begin{bmatrix} P(x) - P \\ Q(x) - Q \end{bmatrix} = 0, \text{ where } x = (V, \theta)$$

Parameters can be added to these equations to investigate the steady-state behavior of the power system under slow variation of both loading conditions and real power redispatches. For example, to trace the power system state from the base-case load-generation condition $[P_d^0, Q_d^0, P_g^0]$ to a new load-generation condition $[P_d^1, Q_d^1, P_g^1]$, then the following parameterized power flow equations can be formed:

$$F(x, \lambda) \equiv f(x) - \lambda b = 0 \quad (2-1)$$

where the load-generation vector b is

$$b \equiv \begin{bmatrix} P^1 - P^0 \\ Q^1 - Q^0 \end{bmatrix} \quad (2-2)$$

It follows that the parameterized power flow equations (2-1) become the base-case power flow equations when $\lambda = 0$ so that

$$F(x, 0) = \begin{bmatrix} P(x) - P^0 \\ Q(x) - Q^0 \end{bmatrix} = 0 \quad (2-3)$$

When $\lambda = 1$, the parameterized power flow equations (2-1) simulate the static behaviors of the power system at the new load-generation condition $[P_d^1, Q_d^1, P_g^1]$, as described by

$$F(x, 1) = f(x) - b = \begin{bmatrix} P(x) - P^1 \\ Q(x) - Q^1 \end{bmatrix} = 0 \quad (2-4)$$

As shown in the above procedure, we can investigate the effects of varying real power generations as well as varying load demands on power system steady-state behaviors by analyzing the set of parameterized power flow equations (2-1). In fact, we can parameterize any change in PQ loads in conjunction with any change in P generations by selecting an appropriate vector b .

Repetitive power flow calculations are frequently used to investigate potential voltage stability problems with respect to a given parameter increase pattern. The calculations generate the so-called P-V or Q-V curve along the parameter increase direction. With this approach, an operating point is claimed to be the potential voltage instability/collapse point if it is the first point (along the parameter increase direction) at which the power flow equations do not converge.

Several issues arise regarding the use of repetitive power flow calculations. First, the point where the power flow calculations diverge (which is determined by a numerical failure) does not necessarily represent the maximum loading point (or transfer capability point) of the power

system, which is a physical limitation of the system. In fact, the maximum loading point should be determined based on the physical limitation of the underlying power network configuration, the loading condition, the parameter increase direction, etc. The point should not be determined based solely on the mathematical limitation of a numerical method.

Second, the point where power flow calculations fail to converge may vary depending on which numerical method was used to solve the power flow equations. For instance, it is likely that the point where the Newton method fails to converge is different from the point where the coupled-Newton method fails to converge.

It is known that the set of power flow equations is ill-conditioned near its “nose point,” making the Newton method diverge in the neighborhood of nose points. From the viewpoint of numerical analysis, this is due to the fact that, at the nose point (i.e., the saddle-node bifurcation point), the Jacobian matrix has one zero eigenvalue, thus causing the set of power flow equations to be ill-conditioned.

Recently, considerable progress has been made in generating P-V and Q-V curves using an approach based on continuation methods (continuation power flow). Continuation methods, sometimes called curve tracing or path following, are useful tools to generate solution curves for general nonlinear algebraic equations with a varying parameter. CPFLOW was designed to make calculations using continuation methods. Continuation methods overcome the numerical difficulty of ill-conditioning as described below.

First, we treat λ as another state variable:

$$X_{n+1} = \lambda \quad (2-5)$$

Then, we introduce a new parameter s ; the mathematical meaning of s is the arc length on the solution curve, which is defined as follows:

$$\sum_{j=1}^{n+1} (x_j - x_j(s))^2 = (\Delta s)^2 \quad (2-6)$$

It can be shown that the new set of equations (2-1) and (2-6) is numerically well-conditioned, even at the nose point. CPFLOW solves these augmented power flow equations to obtain a solution curve passing through the nose point without encountering the numerical difficulty of ill-conditioning.

When one applies the continuation method to the parameterized power flow equation (2-1) to compute P-V curves, only the constant PQ portion of a load varies, while the constant current portion and constant impedance portion are indeed kept “constant.” As such, the physical meaning of these curves may be easily explained but the load model may not be accurate. Load models are known to have significant impacts on simulating power system behaviors. In order to accurately characterize the voltage behavior of a power system, it is necessary to use accurate

load models in the computation of P-V and Q-V curves. For a power system of n buses, the equations for the i th bus can be expressed as:

$$\begin{cases} P_{0i} - \sum_{j=1}^n v_i v_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) + \lambda (\Delta P_{gi} - \Delta P_{li}) = 0 \\ Q_{0i} - \sum_{j=1}^n v_i v_j (G_{ij} \sin \delta_{ij} + B_{ij} \cos \delta_{ij}) + \lambda (\Delta Q_{gi} - \Delta Q_{li}) = 0 \end{cases} \quad (2-7)$$

where P_{0i} and Q_{0i} are the base-case real and reactive power injections at bus i respectively. v_i is the voltage magnitude at bus i . G_{ij} and B_{ij} are the real part and imaginary parts of the network admittance between bus i and bus j respectively. δ_{ij} is the angle difference between bus i and bus j . ΔP_g is the proposed real generation variation at bus i . ΔQ_{gi} , the proposed reactive generation variation at bus i , is a kept constant. Finally, ΔP_{li} and ΔQ_{li} are the proposed real and reactive load variations at bus i .

Without losing generality, equation (2-7) can be rewritten in the following form:

$$\begin{cases} f_p(\delta, v) + \lambda \Delta G_p - \lambda \Delta L_p = 0 \\ f_q(\delta, v) - \lambda \Delta L_q = 0 \end{cases} \quad (2-8)$$

where $f_p(\delta, v), f_q(\delta, v) \in R^n$ are the set of base-case power flow equations. $\Delta G_p \in R^n$ is a proposed real generation variation. $\Delta L_p, \Delta L_q \in R^{2n}$ are the proposed real and reactive load variations respectively.

We now model the load variation as a composition of ZIP (constant impedance, constant current, and constant PQ) format and this composition keeps constant during the process of load variation. Using this ZIP model, the load variation is modeled as follows:

$$\begin{cases} \Delta L_p = a_{1p} v^2 + a_{2p} v + a_{3p} \\ \Delta L_q = a_{1q} v^2 + a_{2q} v + a_{3q} \end{cases} \quad (2-9)$$

where $a_{1p}, a_{2p}, a_{3p}, a_{1q}, a_{2q}, a_{3q} \in R^{n \times n}$ are diagonal coefficient matrices and represent the constant impedance, constant current and constant PQ portion respectively of the load variation and $v \in R^n$ is the voltage magnitude vector.

Substituting (2-9) into (2-8), we have the following new set of parameterized power flow equations with parameter variations modeled by ZIP variations

$$\begin{cases} f_p(\delta, v) + \lambda \Delta G_p - \lambda (a_{1p} v^2 + a_{2p} v + a_{3p}) = 0 \\ f_q(\delta, v) - \lambda (a_{1q} v^2 + a_{2q} v + a_{3q}) = 0 \end{cases} \quad (2-10)$$

It is traditional to have only the constant PQ load component vary but keep the load components of constant impedance and constant current fixed. In this case, the coefficient matrices a_{1p} , a_{1q} and a_{2p} , a_{2q} become zero matrices and the new set of parameterized power flow equations (2-10) is reduced to the traditional set of parameterized power flow equations (2-2).

We next show how to apply CPFLOW to solve the new set of parameterized power flow equations (2-10). Combining equation (2-10) and (2-6) gives the following augmented (parameterized) power flow equations:

$$\begin{cases} f(\delta, v) + \lambda \Delta G - \lambda(a_1 v^2 + a_2 v + a_3) = 0 \\ \sum_{j=1}^{n+1} (x_j - x_j(s))^2 = (\Delta s)^2 \end{cases} \quad (2-11)$$

where

$$a_1 = \begin{bmatrix} a_{1p} \\ a_{1q} \end{bmatrix}, a_2 = \begin{bmatrix} a_{2p} \\ a_{2q} \end{bmatrix} \text{ and } a_3 = \begin{bmatrix} a_{3p} \\ a_{3q} \end{bmatrix}$$

$$f(\delta, v) = \begin{bmatrix} f_p(\delta, v) \\ f_q(\delta, v) \end{bmatrix}, G = \begin{bmatrix} G_p \\ 0 \end{bmatrix}$$

Solving equations (2-11) produces the desired ZIP-V curves.

2.3 Numerical Solution Using CPFLOW

In this section we describe CPFLOW's numerical approach to solving power flow equations and show how to modify the original CPFLOW program to solve the new set of parameterized power flow equations (2-11).

2.3.1 Predictor

The predictor in CPFLOW is used to find the approximation of the next point in the solution curves. CPFLOW uses two predictor approaches: secant and tangent. The secant method, extrapolating the next solution point based on the previous solution points in the solution curve, is not affected by the load model used in the computation. The tangent method, using the tangent at the current point to predict the next solution point, is affected by the load model used.

We define the power flow state variable vector X as follows:

$$X = [\delta_1, \dots, \delta_n, v_1, \dots, v_n, \lambda]^T$$

Differentiating with respect to the arc length s , we have:

$$\frac{dX}{ds} = \left[\frac{d\delta_1}{ds}, \dots, \frac{d\delta_n}{ds}, \frac{dv_1}{ds}, \dots, \frac{dv_n}{ds}, \frac{d\lambda}{ds} \right]$$

where arc length is defined as:

$$\Delta X \bullet \langle \Delta X \rangle^T = (\Delta s)^2$$

Differentiating both sides of the equation (2-11), it follows that:

$$D \bullet \frac{dX}{ds} = 0 \quad (2-12)$$

$$D = \begin{bmatrix} \frac{\partial f}{\partial \delta} & B & C \end{bmatrix} \quad (2-13)$$

where

$$B = \frac{\partial f}{\partial v} - (2a_1V + a) \lambda \quad C = \Delta G - (a_1V^2 + a_2V + a_3)$$

$$\frac{\partial f}{\partial v} = \begin{bmatrix} \frac{\partial f}{\partial v_1} & \dots & \frac{\partial f}{\partial v_n} \end{bmatrix}$$

$$\frac{\partial f}{\partial \delta} = \begin{bmatrix} \frac{\partial f}{\partial \delta_1} & \dots & \frac{\partial f}{\partial \delta_n} \end{bmatrix}$$

and $V \in R^{n \times n}$ is a diagonal matrix of voltage magnitude at each bus.

The following equation is required to ensure that the scalar s is the arc length on the solution curve:

$$\frac{dX}{ds} \bullet \left[\frac{dX}{ds} \right]^T = 1 \quad (2-14)$$

The tangent vector along the solution curve $\frac{dX}{ds}$ is obtained by solving the set of equation (2-12), (2-13) and (2-14).

The predicted vector at the next solution point X_{i+1} by the tangent method becomes:

$$X_{i+1} = X_i + h \frac{dX_i}{ds} \quad (2-15)$$

where h is the step size of arc length s , X_i is the i^{th} solution in the solution curve

2.3.2 Corrector

The corrector solves the augmented equations with the predicted point as the initial guess. In principle, any effective numerical procedure for solving a set of non-linear algebraic equations can be used for a corrector. In CPFLOW, we use the Newton-Raphson method in which the system Jacobian matrix plays an important role.

To accommodate the ZIP load model in the load variations, we derive the Jacobian matrix considering ZIP load variation as follows:

$$J = \begin{bmatrix} D \\ E \end{bmatrix}$$

D is given in (2-13) and E is

$$E = 2(X - X(s))^T$$

Note that the required modifications only appear on the diagonal elements and the arc length s related elements.

Chapter 3

Basic Instructions for Using CPFLOW

This chapter provides basic instructions for the use of the CPFLOW program, Version 4.1. We assume that the reader has a basic working knowledge of Windows operating system conventions, including how to use a mouse and standard menus and commands, and how to open, close, and save files. For help with any of these techniques, the reader can refer to the documentation that accompanied the computer or a manual for Windows.

3.1 Installation

3.1.1 System requirements

1. A PC with Windows 95 or later, Windows NT 3.51 or later
2. A minimum of 10 MB hard disk space, 32 MB physical memory

3.1.2 Packing List

1. System files:
 - CPGUI.EXE: Main program
 - CPGUI.INI: Configuration file
 - PSYM: Symbol file
 - PSYM.IDX: Symbol file
 - ATC.DOC: Manual File
2. Sample project files:
 - IEEE50.psf: Power flow Data file
 - IEEE50.pwr: Project file with One-line diagram
3. Sample power system data file:
 - IEEE50 power system data file in PTI format

3.1.3 Installation Procedure

1. Create directory C:\CPGUI.
2. Copy cpgui.zip to C:\CPGUI and use PKUNZIP to expand it.
3. Copy cpgui.ini to C:\WINDOWS or C:\WINNT (depending on your operating system).

If you install the system files in a directory other than C:\CPGUI, follow the steps below to adjust the configuration:

1. Create the directory where you want to put the system files.
2. Copy cpgui.zip to that directory and use PKUNZIP to expand it.
3. Use any text editing tool to edit cpgui.ini and change the “system path” from C:\CPGUI\ to the directory where you want to put the files.
4. Copy cpgui.ini to C:\WINDOWS or C:\WINNT (depending on your operating system).

3.2 System Settings

3.2.1 Power Flow Setting

Selecting the menu item "Power Flow Setting" under "Analysis" pops up the following setting dialog box:

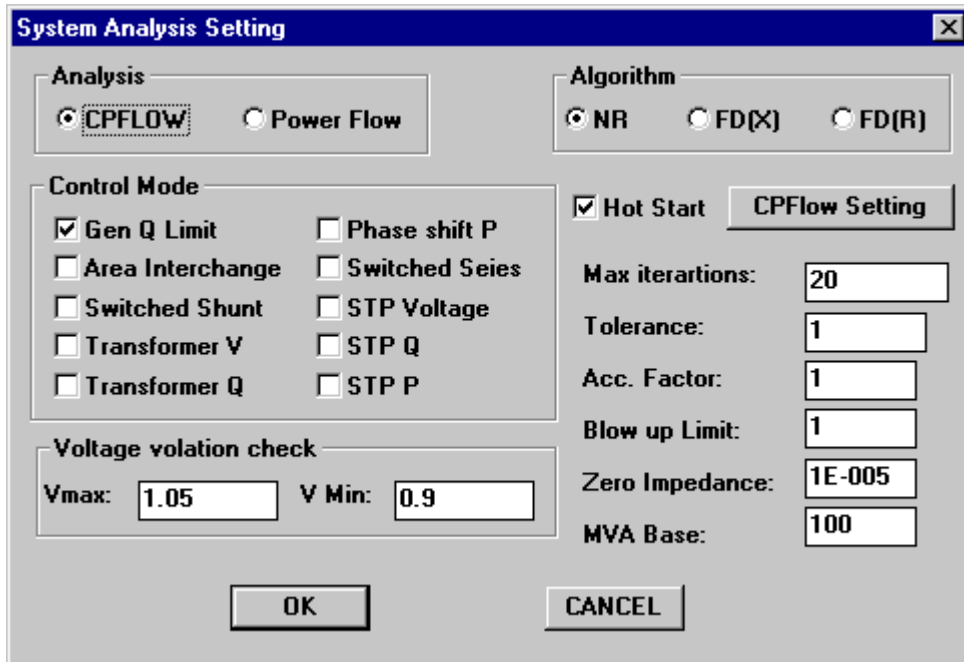


Figure 3.1 The System Analysis Setting panel

This dialog box provides a basis panel for a user to change basic computation parameters such as the solution algorithm (currently only Newton Raphson is available), control model, and convergence criterion. From this panel, the user can ask the program to conduct a regular power flow computation or a CFLOW computation. Users can also activate or deactivate a particular control mode by checking or unchecking the corresponding check box. Furthermore, users can enter the desired values for fields such as convergence criterion, maximal iteration number, voltage violation criterion, etc.

Some of the parameters on this panel are defined as follows:

- Max iterations: the maximum number of iterations involved in solving a single power flow solution point.
- Tolerance (MW or MVAR): the maximum MW or MVAR mismatch allowed for each bus in solving a single power flow solution point.
- Acceleration factor: the multiplier that is used to reduce the change in voltage magnitude when a bus is switched between PQ type to PV. This is useful for avoiding oscillations. This multiplier is not used in conjunction with any other control device.

- Blow up (delta v): the maximum update in voltage magnitude allowed for any bus. If the largest update is greater than this preset value, then power flow computation terminates in a nonconvergent state.
- Zero impedance threshold: the minimum absolute value allowed for each complex line impedance in the power system. If a line impedance magnitude is less than the threshold, then the line is removed and the two buses are combined into a single bus.

3.2.2 CPFLOW Setting

A dialog box to configure CPFLOW is activated by clicking on the button reading "CPFLOW Setting" in the above panel.

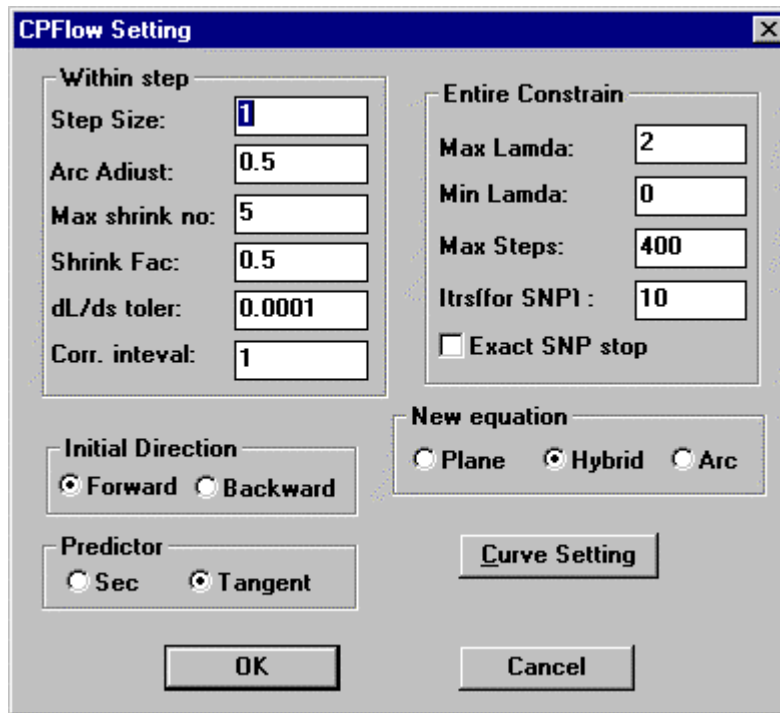


Figure 3.2 The CPFLOW Setting Panel

Some of the most important parameters are explained as follows:

- minimum lambda value: the minimum value for the physical parameter λ . If λ runs smaller than λ_{min} during a CPFLOW computation, the continuation method terminates.
- maximum lambda value: the maximum value for the physical parameter λ . If during a continuation run $\lambda > \lambda_{max}$, then the continuation method terminates.
- maximum number of steps: the maximum number of steps allowed in a continuation trace. If the maximum number is reached, then the trace terminates.

3.2.3 P-V Curve Setting

The dialog box to configure P-V curves is triggered by clicking on a button reading "Curve Setting" in the CPFLOW setting panel. Through this panel, a user can tell the program how to

choose the X-axis when plotting a P-V curve. The first two options tell the program to use λ as the X-axis. At this time, they are identical. While the third option instructs the program to use the total generation, the last option uses the total load of the examined power system as the X-axis of the P-V curve.

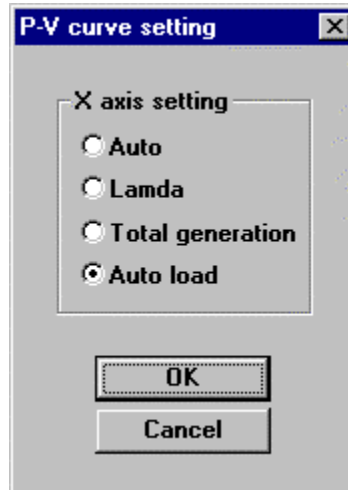


Figure 3.3 The P-V curve setting panel

3.3 Running CPFLOW

In this section, we will provide a demonstration of the working of CPFLOW Version 4.1. A detailed explanation of each step is given.

3.3.1 Running the Test Program

1. Launch CPGUI.exe.
2. FILE-OPEN-select 97f3a..
3. Click on the “Map” icon at the top of the screen to bring up a panoramic map view of the system one-line diagram.
4. Grab the red box displayed within the map picture and move it around to pan across the system one-line diagram and examine its details more closely.
5. To set up a transaction:
 - a. ANALYSIS—CPFLOW INITIAL—SET TRANSACTION—DIALOG BOX
 - BY AREA (Transactions within an area)
 - BY BUS (Bus-to-Bus transactions)
 - BY TRANSACTION (Transactions between areas)
 (Select BY TRANSACTION and do a 5000 MW transaction from area 5 to area 63 as follows: first, enter 5000 in the box labeled P and enter nothing in the box labeled Q. To send in the area, enter 5. In the next box, select GENERATION. To receive an area, enter 63. In the last box, select LOAD. Make sure that Q Proportional is checked. Make sure that the three fields under the heading load model group are 1,0,0 respectively. This setup will initiate a transaction from area 5 to area 63 by raising generation in area 5 and

synchronously increasing load in area 63. The process is done while maintaining a constant power factor on the load side. Click on OK.)

b. ANALYSIS—CPFLOW INITIAL—SET MONITOR—FROM DIALOG BOX
(This sets up buses to monitor during the process)

Enter 37742,37743 (for bus 37742,37743) and select OK

c. ANALYSIS—RUN ANALYSIS (to execute). Click on START in the Procedure Monitor box to start the program.

While the program is running you will notice two curves forming in the PV Curve box. These are the nose curves for bus 37742,37743. The “x’s” are voltage violation points for the system. When the program is done (that is, when the thermometer has filled up in the procedure Monitor box), the nose of the curve is at 0.8, indicating that 0.8×5000 or 4000 MW is the max power transfer under the transaction that was entered. Even though bus 37748 was selected as an example, the max transfer point is the same for the system regardless of what bus is monitored and the voltage violations occur at the same transfer point regardless of what bus is monitored. If the user makes the PV-curve box larger and double-click on any of the X’s, the voltage violation that occurs at that transfer level can be seen.

3.3.2 Import PTI Raw Data File

1. Select a data format under the submenu "import data" of the menu "File" to start an import dialog box. For example, import a data file in PTI format:



Figure 3.4 The panel for importing a PTI raw data file

2. Open the desired PTI file.
3. Follow the instructions to input the system scope.

Note: The import PTI file function only works before a project is loaded. The program automatically generates a project with the same name as the imported PTI file, so that the next

time only the generated project needs to be opened instead of re-importing the PTI file. In our current setting, a pwr file and a psf file with the same name (different extensions) make a project.

3.3.3 Generating PV, Q-V, and ZIP-V Curves due to Power Transactions

1. Set a power transaction's detailed setting

Select a Menu item under menu "Analysis"->"CPFLOW INITIAL"->"SET TRANSACTION->DIALOG BOX". A dialog box pops up:

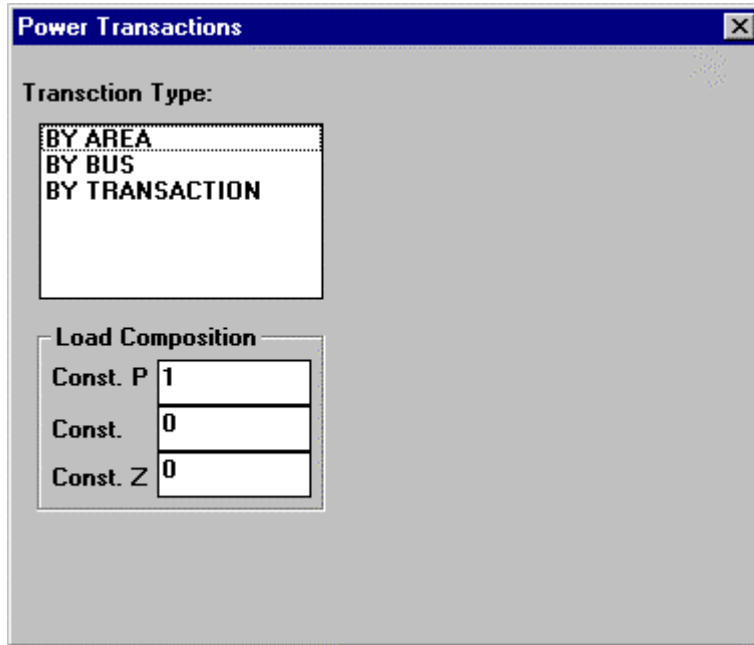


Figure 3.5 Setting up a proposed power transaction

The list box to the left lists various forms of power transactions that are supported in the program that this system can set. Pointing and clicking on the desired transaction type activates the corresponding fields for users to specify the desired power transaction.

A user can select one or a combination of the three transaction types which are listed in the list box to set transactions. In the program, a transaction is comprised of a set of a certain number of real (and /or reactive) power increases (and/or decreases) on one or a collection of loads (and/or generators). The design of three transaction types in the dialog box provides users with the necessary convenience to enter the desired transaction quickly.

The details of each transaction type are as follows:

1. Selecting "BY BUS" offers a user the possibility to enter the desired power change for each bus. A user can specify the bus name, the amount of the power change and the way

to change power (increase generator or decrease load) on each particular bus or bus collection through the fields to the right.

2. Selecting "BY AREA" offers a user the capability to enter the desired power change for specific areas. A user can specify the area number, the amount of the power change and the way to change power (increase generator or decrease load) for one area or area collection through the fields to the right, if the actual power changes for each bus within the desired areas are uniform. The economic dispatch function is not included.
3. Selecting "BY TRANSACTION" offers a user the ability to enter a complete transaction (for example, transfer 300 MW power from area A to Areas B, C, D) in one step. A user can specify the sending areas, receiving areas, amount of power transfer and the way to change power (increase generator or decrease load) through the fields to the right, if the actual power changes for each bus within the involved areas are uniform. The economic dispatch function is not included.

For example, we select "BY TRANSACTION". The dialog box changes to the following form:

The screenshot shows a dialog box titled "Power Transactions". It has a "Transaction Type" list with three options: "BY AREA", "BY BUS", and "BY TRANSACTION" (which is selected and highlighted in blue). Below this list is a "Load Composition" section with three input fields: "Const. P" with the value "1", "Const." with the value "0", and "Const. Z" with the value "0". To the right of these fields is a checked checkbox labeled "Q Proportional". On the far right, there are several input fields: "P:" with the value "0", "Q:" with the value "0", "Send Area" (an empty text box), "Rec. Area" (an empty text box), and a dropdown menu with a downward arrow. At the bottom of the dialog are "OK" and "Cancel" buttons.

Figure 3.6 The complete transaction panel under "BY TRANSACTION"

On the right, there are seven fields.

- The first field allows the user to enter the total amount of transferred real power.
- The second field allows the user to enter the total amount of transferred reactive power.
- The third field allows the user to enter sending areas. Multiple areas can be input, separated by commas.
- The fourth field allows the user to enter the way for the sending area to support the transaction. There are two available options: Generation and Load. Choosing

Generation tells the system to increase the generation at the sending areas to support the transaction. Choosing Load tells the system to decrease the load at the sending areas so that the surplus generation can be used to support the transaction.

- The fifth and sixth fields are used to enter the information about the receiving areas.
- The seventh field is used to instruct the system on how to handle the reactive power. If this field is checked, the program changes the reactive power proportionally to the real power no matter what value was input in the second field. Otherwise, the program uses the Q value input in the second field to change the reactive power.

Now we will discuss the check box "Q Proportional." This check box offers the user a way to handle proposed reactive power changes flexibly. If this box is checked, the proposed reactive power change will be conducted proportionally to the proposed real power change no matter what value the user enters in the Q field. Otherwise, the program will use the value in the Q field to propose the reactive power change.

The Q transaction only works for load changes. It represents the Q limit for the generation change, which can be seen from the transaction window after you click OK from the set transaction dialog box. The proposed reactive power change for a generator is thus actually a proposed reactive power limit change in the analysis. We do not maintain the power factor for a generator.

The current version of the program does not support the real power limit for a generator. This will be incorporated into a future version of CPFLOW.

The three fields in the left lower area are new and are used to enter a load model to generate ZIP-V curves for the involved load variation. These three fields respectively represent the portion of constant PQ load, portion of constant current load, and constant impedance load. Adding this new area in this window is intended to offer a convenient and straightforward way for a user to enter a desired load model for involved load variations. It does not mean that different load models can be set for different transactions within a simulation scenario. Only the last load model entered is accepted and takes effect on all of the load variations involved within a single scenario.

1. Repeat step 1 to set simultaneous transactions.
2. Set Monitor Components:

There are two ways to set the monitor components.

- Select monitored components in the GUI
 - 1) Select the Menu item "from GUI" under the menu "Analysis"->"CPFLOW Initial"->"Set Monitor" to activate this function.
 - 2) Click on the desired buses or branches on the one-line diagram to set the monitored components.

Note: The program treats the generation, the substation and the distributions center as a group of buses. When one of these components is clicked, a dialog box that lists all the buses in the group pops up and allows the user to choose the monitored bus from the group.

- Enter the monitored bus from a dialog box.
 - 1) Select the Menu item "from Dialog Box" under the menu "Analysis"->"CPFLOW Initial"->"Set Monitor" to activate the following dialog box.

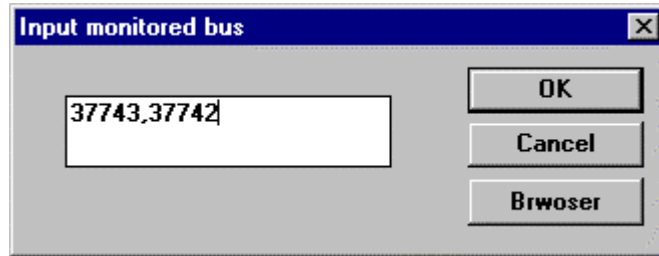


Figure 3.7 Setting up monitored buses

- 2) Enter the monitored bus numbers, separated by commas, and click OK. Note: The maximum number of monitored buses is 8.
- 3) The other way to enter monitored buses is through a bus browser window that is shown as follows. A bus browser lists all the buses in the system and is activated by clicking on the browser button in the above dialog box. A user is able to select one bus or a set of buses from this window and click start to append the selection to the monitored bus window.

3. Run Analysis

Select "Run Analysis" under the menu "Analysis" to start the analysis. During the analysis, the program does the following three tasks:

- It draws P-V curves for the monitored buses.

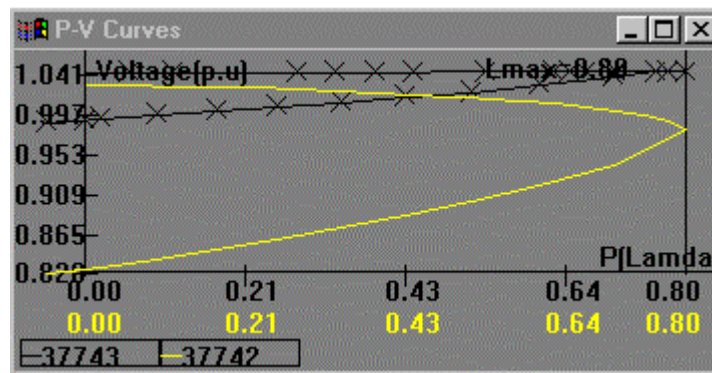


Figure 3.8 P-V curve for constant PQ load model

- It generates a process bar and colors it green to indicate where the system is. When the program find a maximal lambda value which corresponds to the nose point in P-V curves, the lambda value will be displayed in the bar area. If that value is less than 1.0, the program colors the remaining area of the bar in red to indicate that the system is unable to conduct the proposed transactions.
- The power flow information for the monitored buses and branches is stored in the files "bus.dat" and "brn.dat" under the same directory where the project files are.

3.4 CPFLOW Post-Processing and Output Analysis

In this section, we describe the output analysis and post-processing capability of CPFLOW.

3.4.1 General Output

1. The power flow information for the monitored buses and branches is stored in files "bus.dat" and "brn.dat" under the directory C:\CPGUI.
2. The P-V curves generated by the program are shown on the screen.
3. The cross sign "×" on the P-V curve indicates that a voltage violation at some buses occurs at the operating point. Double-clicking on the sign will trigger a new window that lists all the buses experiencing a voltage violation.

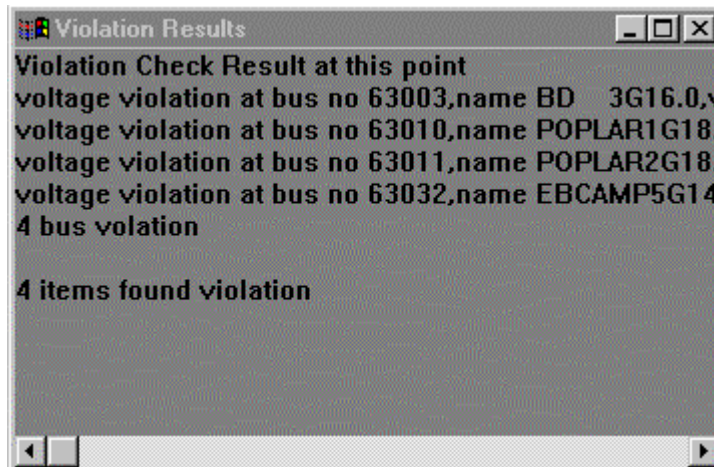


Figure 3.9 List of buses with violations

4. Double-clicking on an area other than the sign "x" opens a window that displays the ATC determined by the nose point and the ATC limited by the voltage violation.

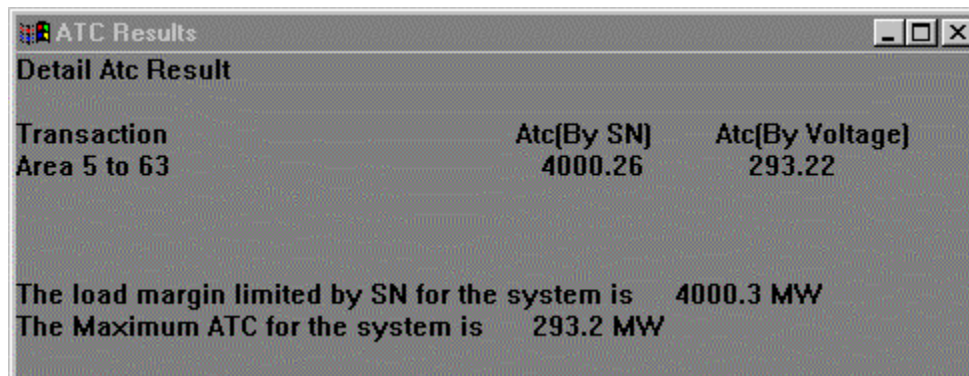


Figure 3.10 ATC information

3.4.2 ZIP Load

Load models are known to have a profound impact on power system behavior. The nonlinear load model, a ZIP-model is a combination of constant current, constant power, and constant impedance. This version of the CPFLOW program can generate ZIP-V curves to quantify the impacts of a particular load model on the overall loadability. ZIP-V curves represent power system quasi-steady-state behaviors as all the values of constant Z, I, P-Q (ZIP) vary and their variations are uniform. The ZIP-V curve can become an I-V, Z-V, IP-V, ZP-V or IZ-V curve when the values of the corresponding component are kept constant.

Under the same test power system and using the same transaction proposed in the above, we have computed loadabilities for the following three different load models: CI, CZ, and ZIP load of 20% constant PQ, 20% constant current, and 60% constant impedance. Here the short form

CP stands for constant PQ load, CI stands for constant current load, CZ stands for constant impedance load and ZIP stands for a load combination of the above three load models. Three extra ZIP-V curves, along with a table summarizing the impact of the load model, are obtained and are given as follows.

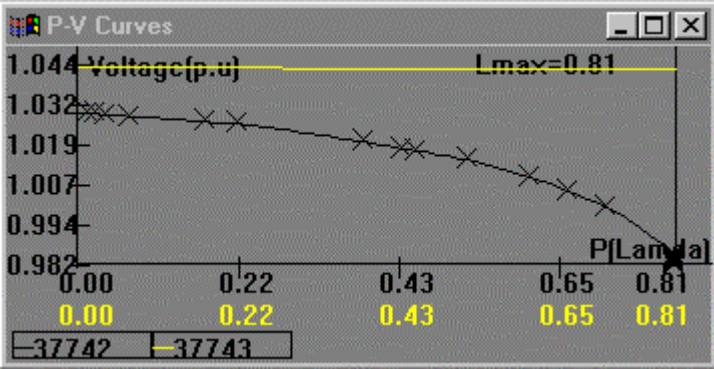


Figure 3.11 I-V Curve for CI load

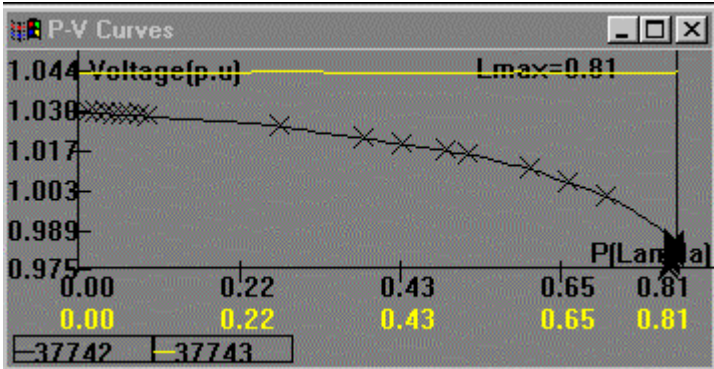


Figure 3.12 Z-V Curve for CZ load

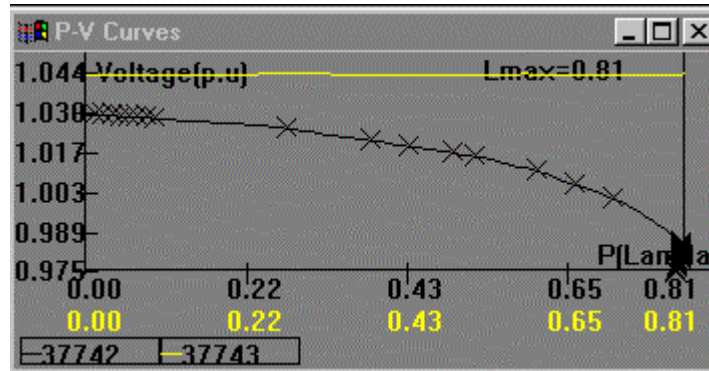


Figure 3.13 ZIP-V curve for ZIP load

Table 1: Load Model Impact

	CP	CI	CZ	ZIP
ATC by nose point	4005 MW	4020 MW	4037 MW	4027 MW

3.5 Miscellaneous Usage Information

This section contains basic information about the appearance of the CPFLOW program screen and using the CPFLOW program.

3.5.1 Tips for Operating the GUI

1. The commands to enable or disable several information windows are under the Window menu. These information windows include the Message Window, Curve Window, Transaction Window, Monitor Window, and other windows.
2. The commands to show or hide different types of components of the one-line diagram are under the Component menu.
3. The commands to verify the one-line diagram of a power system are under the Verify menu.
4. The commands to display the power flow results on the GUI are under the Result menu.
5. Short-cut buttons have been created to ease operations. The "Bus" Button activates a quick search dialog box that is used to search branch, generator, load nodes, shunt capacitor, and text, on the one-line diagram or in the power flow data file. The "PF", "BuV", "LiF", "LoF" and "BuN" Buttons display the power flow information on the GUI, where PF stands for power flow, BuV stands for bus voltage, LiF stands for line flow, LoF stands for load flow, and BuN stands for bus number.

3.5.2 Starting the CPFLOW Program

The first screen is the introductory screen, giving the program title and copyright information. To enter the program, click “OK”. To exit the program, click “EXIT”.

The maps used are internal company copies of maps depicting all relevant information within a geographical section of territory. The maps may be modified through the use of the menu bar and the control bar.

3.5.3 Menu Bar

The Menu Bar runs across the top of the CPFLOW window and contains the menus and sub-menus from which you can choose commands.

3.5.4 File Menu

Basic commands for opening, saving, printing, importing material into, and closing CPFLOW documents are located under the File menu.

3.5.5 Opening a CPFLOW File

Before a document is opened, the program screen will be completely blank, with the Menu Bar and Control Bar buttons at the top. To open a CPFLOW file, select “Open” from the File menu. The shortcut key F6 (“Open”) may also be used.

Once “Open” has been selected, the Open dialog box will appear. This box is a standard Windows box, allowing the user to specify the file location, name and type. Once the correct file has been selected, click on the “Open” button.

3.5.6 Creating a CPFLOW File

To create a CPFLOW, select “New” from the File menu. The shortcut key F5 (“New”) may also be used.

3.5.7 Saving a CPFLOW File

There are two options for saving a file. The first, “Save”, is used when there are no changes to the name or location of the document. The shortcut key F2 (“Save”) may also be used. The “Save As” command is used to name and save a new file or to save an existing file under a new name or at a different location. The “Save As” command also allows the user to maintain a copy of the original file without the changes. The shortcut key F3 (“Save As”) may also be used.

3.5.8 Closing a CPFLOW File

Chose the command “DB Close” under the “File” menu. The shortcut key F4 (“DB Close”) may also be used. If changes have been made, the program will ask if the user wishes to save the changes or close the program without saving any changes. Any unsaved changes will be lost.

3.5.9 Importing a Graphic

The Graphic Import command is used for bringing graphic information into a CPFLOW document. From this menu item, a sub-menu listing the available formats opens. Clicking on a

format will bring up a window with the import setting specifications. Currently, only the exported file from our digitalization program can be imported.

Example: Selecting the Gra Format submenu from the Graphic Import command opens a window with the heading “Import Setting”. Within this window, the user can select the specific settings desired. Under the sub-heading “File Path,” the user may type in a File Path and a Symbol File, or may click on the “Browse” button to browse available options. Under the sub-heading “Transfer Convention,” the categories “Layer” and “Symbol” are set at a default of “Restall,” but may be modified if the user desires. The third option under this sub-heading is “Available Symbol”. The user may open the list of possible symbols by using the arrow on the right-hand side of the category. Available symbols are:

- Arrow
- Both_Arrow
- Bus
- Dc-converter
- Dc-line
- Distribution
- End_Arrow
- Fix_shunt
- Fix-series-capacitor
- Generation
- Generator
- Graphic-line
- Line
- Load
- Off-switch
- On-switch
- Service
- Stp
- Substation
- Switched-series-capacitor
- Switched-shunt
- Text
- Transformer
- Ultc-transformer

3.5.10 Importing Data

The Import Data command is used for bringing existing power flow data into a CPFLOW document. From this menu item, a sub-menu listing the available formats opens. These formats are:

- PSF Format
- PTI Format (Under the PTI Format, there are two options: “under 23” or “24 and up”)
- IEEE Format
- EPRI Raw
- EPRI His
- BPA Format
- PECO Format

3.5.11 Printing a CPFLOW File

The “Print” command prints the current CPFLOW file. The shortcut key sequence “Ctrl + p” may also be used.

NOTE: At the present time, this feature does not function.

3.5.12 Adjusting the Printer Settings

The “Set Print” command brings up a dialog box containing the printer settings, including the printer chosen, the format for printing, and the number of copies. The shortcut key sequence “Ctrl + s” may also be used to open this dialog box.

3.5.13 Exiting CPFLOW

Choosing this menu item exits the program. If changes have been made, the program asks if the user wishes to save before exiting. Any unsaved changes will be lost

3.6 Menus and Control Bar

3.6.1 Edit Menu

NOTE: At the present time, the Edit Menu features do not function.

The commands under the “Edit” menu are used to modify a graphic object in the window. Some of them are the same as the commands in the buttons across the Control Bar, and the Control Bar buttons will register as activated when the commands are activated using the edit menu. Commands may also be deactivated by clicking on the Control Bar buttons rather than through the use of the edit menu items.

3.6.1.1 Deleting a Device

To delete a device, select “Del” from the edit menu or use the “Delete” button from the Control Bar and then click on the device to delete. The cursor will change from an arrow to a cross when the cursor is on a device. After clicking on the device, the program will ask whether or not the user actually wants to delete the device. Click “Yes” to delete and “No” to leave the device where it is. The “Del” feature remains active even if the answer is “No.” To deactivate this feature, click on “Del” again. Devices may also be deleted using commands on the Control Bar.

3.6.1.2 Moving a Device

In order to move a device, select “Move” from the edit menu or use the “Move” command button from the Control Bar and then click on the device to move. The cursor will change from an arrow to a cross when the cursor is on a device. After clicking on the device, the device and all connecting lines will be shown in yellow. The user may then drag the device, with its attached lines, to its new position and click again to set it in place. The colors will then return to normal. To deactivate this feature, click on “Move” again. Devices may also be moved using commands on the Control Bar.

3.6.1.3 Copying a Device

In order to copy a device, select “Copy” from the edit menu and then click on the device to copy. The cursor will change from an arrow to a cross when the cursor is on a device. The device chosen and its copy will turn yellow to indicate their location. The user may then drag the copied device to its new location and click again to set it in place. The original device remains yellow, indicating that the “Copy” feature remains active. Clicking again on the original or its copy will produce another copy of the original device. To deactivate this feature, click on “Copy” again. Devices may also be copied using commands on the toolbar.

3.6.1.4 Replacing a Device

At present this feature is not available.

3.6.1.5 Restoring Settings to Normal

This feature resets the current editing state.

3.6.1.6 Redrawing

This feature refreshes the screen.

3.6.1.7 Removing a Point

This feature removes a point from a line of multiple points.

3.6.1.8 Removing a Link

This feature detaches a graphic object from its underlying power flow record.

3.6.1.9 The Color Palette

This command is used to display or remove a color palette window. Selecting this command brings up a palette display in the lower left-hand screen, with a selection of colors. The palette remains in place until removed through the use of the edit menu command or the shortcut key F8.

3.6.2 Analysis Menu

The commands under the “Analysis” button indicate the various types of action-related analysis that may be carried out.

3.6.2.1 Power Flow Settings

Power Flow Settings: Clicking on this menu item produces a window containing the information for the System Analysis Settings. These settings may be modified. This feature may also be accessed through the use of the shortcut key F9.

CPFLOW Initial

- Set Transaction:
 - Graphic: This feature may also be accessed through the use of the shortcut command Alt + F2

- Dialog Box: This feature may also be accessed through the use of the shortcut command Alt + F3
- Set Monitor:
 - From GUI: This feature may also be accessed through the use of the shortcut command Alt + F5
 - From Dialog Box:
- Unselect All: This feature closes the analysis menu and its submenus.

3.6.2.2 Run Analysis

This feature may also be accessed through the use of the shortcut key F10.

3.6.3 Verify Menu

The verify menu is used to confirm results.

3.6.3.1 Verifying Connectivity

Clicking on this sub-menu will call up the Verify Result window, listing the number, the component status, and the reason. To run the verification, click on the “Start” button at the bottom of the window. To close the window, click on the “X” in the upper right-hand corner.

3.6.3.2 Verifying Linkage

Clicking on this sub-menu will call up a “Select Element” window, listing the possible elements for this feature. The elements are: Bus, Fix Shunt, Fix Series Capacitor, Generation, Generator, Line, Load, STP, Substation, Switched Series Capacitor, Switched Shunt, Transformer, and ULTC Transformer. Click on the desired element and then click “OK.” The search result window will list the component, the starting bus, the end bus, and the ID. The search may be run to locate graphics or data; the choice may be made by selecting “Graphic Locate” or “Data Locate” from the bottom of the search result window. To remove the Search Result window, click on the X at the upper right-hand corner of the window.

3.6.3.3 Returning to the Original Position

The “New Scope” command returns the view shown in the larger portion of the screen to the top left of the map (blank). The “Panorama” view, if present, remains the same. The view may be changed by clicking within the panorama box and moving the rectangle or by using the scroll bars on the side and bottom of the screen.

3.6.4 Window Menu

The Window Menu is used to make modifications to the display window of the CPFLOW Program. Features that are activated, such as the Panorama Map and the Control Bar, are marked with a check.

3.6.4.1 Adding or Removing the Control Bar

The Control Bar is the selection of buttons located at the top of the map. Many of the buttons represent shortcuts to features found under the Edit menu. The control bar may be added or removed by clicking on the “Control Bar” command under the Window menu.

3.6.4.2 Adding or Removing the Panorama Map

The Panorama map is a small box in the lower right-hand corner of screen, which provides an overview of the entire map area. The red rectangle in the panorama display surrounds the area currently displayed on the larger portion of the screen; it may be moved by placing the arrow within the red rectangle, holding down the left mouse key and “dragging” the rectangle to the desired position. The panorama can be removed or brought back by clicking on the “Panorama” command under the Window menu. For faster access, there is also a “Map” button on the Control Bar that may be clicked to add or remove the panorama feature.

3.6.4.3 Adding or Removing the Active Layer

The Active Layer feature may be added or removed by clicking on the “Active Layer” command under the Window menu.

3.6.4.4 Viewing the Cursor Position

Activating the “Cursor Position” feature pulls up a numerical representation of the exact cursor position on the map, located to the right of the Control Bar. As the cursor is moved within the map, the numerical position representation changes. This feature may be added or removed by clicking on the “Cursor Position” command under the Window menu or by using the shortcut command Alt + c.

3.6.4.5 Adding or Removing the Message Window

The “Message Window” command brings up a small PFlow Result Message window within the map. This feature may be added or removed by clicking on the “Message Window” command under the Window menu or by clicking to close the PFLOW Result Message window itself.

3.6.4.6 Adding or Removing the Curve Window

The “Curve Window” command brings up a small P-V Curves graph window within the map. The x-axis of the graph represents the P(Lambda) value and the y-axis represents the Voltage (p.u.), expressed in values ranging from 0.000 to 1.818. This range will be adaptively adjusted to fit real curves once they are drawn. An example is shown above in Figure 3.8. Double-clicking on the graph itself brings up another window displaying ATC Results that shows the maximum ATC and the load margin limited by SN for the system. To close the ATC Results window, click on the X at the top right-hand corner of the window. To close the P-V Curves graph, click on the Curve Window command under the Window menu or on the X at the top right-hand corner of the P-V Curves graph window.

3.6.4.7 Adding or Removing the Transaction Window

Clicking on the “Transction Wnd” command brings up a small Proposed Power Transaction window within the map. To close the Proposed Power Transaction window, click on the Transaction Window command under the Window menu or on the X at the top right-hand corner of the P-V Curves graph window.

3.6.4.8 Adding or Removing the Monitor Window

Clicking on the “Monitor Wnd” command brings up a small Monitored Components window within the map. To close the Monitored Components window, click on the “Monitor Wnd” command under the Window menu or on the X at the top right-hand corner of the Monitored Components window.

3.6.4.9 Performing Bus Searches

In order to perform a bus search, click on the “Search Bus” command under the Window menu or use the shortcut command Alt + b. The “Search Bus” feature is also available through a command button on the Control Bar. Activating this feature brings up a “Quick Search” window within the map. The Quick Search window contains a list of features within which a search can be made. These features include: branch, generator, load, nodes, shunt, and text. To select a feature, click on it so that it is highlighted. Once a feature has been highlighted, the right side of the window displays a list of search mode criteria that can be adjusted. These criteria vary according to the feature that has been highlighted:

- Branch: The search mode can be either “Graphic” or “All Data.” There is a space for inputting the first bus (“From Bus”) and the last bus (“To Bus”). Both buses can be adjusted to run with “Auto,” “Name,” or “Number” as the determining factor.
- Generator: The search mode can be either “Graphic” or “All Data.” There is a space for the bus name, and the bus selected can be adjusted to run with “Auto,” “Name,” or “Number” as the determining factor.
- Load: The search mode can be either “Graphic” or “All Data.” There is a space for the bus name, and the bus selected can be adjusted to run with “Auto,” “Name,” or “Number” as the determining factor.
- Nodes: The search mode can be either “Graphic” or “All Data.” There is a space for the bus name and for the voltage involved. The bus selected can be adjusted to run with “Auto,” “Name,” or “Number” as the determining factor.
- Shunt: The search mode can be either “Graphic” or “All Data.” There is a space for the bus name, and the bus selected can be adjusted to run with “Auto,” “Name,” or “Number” as the determining factor.
- Text: The “Text” search mode provides a space to type the text that is being searched for.

Once the search features have been properly set, the search results will be displayed in a “Verify Results” window. Information will be displayed for several categories, including Component, From/End Bus or Bus Name, and ID. The “Verify Results” window can be closed by clicking on the X in the upper right-hand corner. To turn off “Search Bus,” either click on “Search Bus” within the Window menu, use the short-cut command Alt + b, or click on the “Search Bus” command button on the Control Bar. To run another search, the “Search Bus” feature must be turned off and then turned back on again.

3.6.4.10 Obtaining Information

Information can be obtained about the following components: Bus, Fix Shunt, Fix Series Capacitor, Generator, Graphic Line, Line, Load, STP, Switched Series Capacitor, Switched Shunt, Text, Transformer, and ULTC Transformer. To access information concerning these

components, choose “Information” from the Window menu. Each component displays a different set of informational criteria:

- Bus:
- Fix Shunt: (Not Available)
- Fix Series Capacitor: (Not Available)
- Generator: (Not Available)
- Graphic Line: (Not Available)
- Line:
- Load: (Not Available)
- STP: (Not Available)
- Switched Series Capacitor: (Not Available)
- Switched Shunt: (Not Available)
- Text: (Not Available)
- Transformer: (Not Available)
- ULTC Transformer: (Not Available)

3.6.4.11 Returning to Previous Status (not available)

3.6.4.12 Adding or Removing the Zoom Box (not available)

3.6.5 Results Menu

Before any of the items within this menu can be run, a regular power flow must be run first.

3.6.5.1 Power Flows

This feature can also be accessed through the use of the “PF” command button on the Control Bar. It displays the power flow result on the screen if it is a one-line drawing. It contains diagram of the system with linkages to the underlying power flow data.

3.6.5.2 Bus Voltages

This feature can also be accessed through the use of the “BuV” command button on the Control Bar. It contains a diagram of the system with linkages to the bus voltages in the underlying power flow data.

3.6.5.3 Line Flows

This feature can also be accessed through the use of the “LiF” command button on the Control Bar. It contains diagram of the system with linkages to the line flow information in the underlying power flow data. The arrow over the data represents the direction of the real power flow.

3.6.5.4 Load Flows

This feature can also be accessed through the use of the “LoF” command button on the Control Bar. It contains diagram of the system with linkages to the underlying power flow data and displays the power flow injected into or from a bus from a generation or load.

3.6.5.5 Power Flow Summary

This feature may also be accessed through the use of the shortcut keys.

3.6.6 Query Menu

3.6.6.1 Query Elements

This feature may also be accessed through the use of the shortcut command Ctrl + e.

3.6.6.2 Query Results

Results can only be queried after a simulation has been run. This feature may also be accessed through the use of the shortcut command Ctrl + r.

3.6.7 Component Menu

The component menu contains a list of all of the components present within the map display. Each component currently shown on the screen is marked with a check. To add or remove components, click on the component name within the list or use a shortcut command. Any configuration of components may be displayed.

3.6.7.1 Bus

Buses are represented on the map by empty circles or squares with solid center circles. Buses may also be added or removed through the use of the shortcut command Shift + b.

3.6.7.2 Line

Lines are represented on the map by colored lines. Lines may also be added or removed through the use of the shortcut command Shift + l.

3.6.7.3 Switch

Switches may also be added or removed through the use of the shortcut command Shift + s.

3.6.7.4 Generator

Generators are represented on the map by circles with solid center circles. Generators may also be added or removed through the use of the shortcut command Shift + r.

3.6.7.5 Shunt

Shunts may also be added or removed through the use of the shortcut command Shift + v.

3.6.7.6 Transformer

Transformers may also be added or removed through the use of the shortcut command Shift + t.

3.6.7.7 Map

The use of the “Map” command adds or removes all geographic references, shown in white, from the screen. Geographic references may also be added or removed through the use of the shortcut command Shift + m.

3.6.8 Option Menu

The option menu provides an opportunity to adjust map display options.

3.6.8.1 View

Clicking on the “View” command under the Option menu brings up the “View Option” window. This window contains the controls for adjusting color and margins within the CPFLOW display. Options whose color can be adjusted include: Select Color, Highlighted Color, Background Color, Flash Color, Outage Color, Label Color, and View Frame, Options whose measurements can be adjusted include Margin and Fuzzy Dis. Clicking on any of the colors shown for the categories brings up the palette of colors available to select from.

3.6.8.2 Layer

Clicking on the “Layer” command under the Option menu brings up the “Layer Control” window. The list of layers represents every component present in the CPFLOW map displayed. At the top of the window, the number of the current component selected is displayed. To select a component, click on it within the list. Once a component has been selected, it can be modified. If the component is currently on, it can be turned off by clicking the “Off” button on the right side of the window. Once the “Off” button has been clicked, it becomes an “On” button and may be used to reactivate the component. The display color of the component selected can be changed by clicking on the “Color” button on the right side of the window. Clicking the “Color” button brings up the color palette selection. Clicking on a color selects that color. As a shortcut to turn all components on or off simultaneously, there are “All On” and “All Off” buttons. At the bottom of the “Layer Control” window are buttons for creating a new layer or renaming an existing layer, along with a text input window to type the new name. Once the settings have been changed, click “OK” to close the window and accept the new settings or “Cancel” to close the window without any changes having been made.

3.6.9 Help Menu

The “Help” menu is designed to provide assistance and information to CPFLOW users.

3.6.9.1 About DSA/G 1.0...

Selecting this item brings up a window containing basic information about the program. This feature may also be accessed through the use of the shortcut command Alt + a

3.6.9.2 Help Index

Note: This feature is not currently available.

This feature may also be accessed through the use of the shortcut key F1.

3.6.10 The Control Bar

The Control Bar runs across the top of the map. This feature is listed under the “Window” menu in the main menu bar. When it is present, it is marked with a check to the left of the menu item. It can be removed or brought back by clicking on the name “Control Bar.” The Control Bar contains buttons controlling various features relating to map display. These include:

3.6.10.1 Search Bus

The “Search Bus” button brings up the “Quick Search” window, which offers the user a variety of search options. Searches can be made within the functions of Branch, Generator, Load, Nodes, Shunt, or Text. To select a feature, click on it so that it is highlighted. Once a feature has been highlighted, the right side of the window displays a list of search mode criteria that can be adjusted. These criteria vary according to the feature that has been highlighted:

- Branch: The search mode can be either “Graphic” or “All Data.” There is a space for inputting the first bus (“From Bus”) and the last bus (“To Bus”). Both buses can be adjusted to run with “Auto,” “Name,” or “Number” as the determining factor.
- Generator: The search mode can be either “Graphic” or “All Data.” There is a space for the bus name, and the bus selected can be adjusted to run with “Auto,” “Name,” or “Number” as the determining factor.
- Load: The search mode can be either “Graphic” or “All Data.” There is a space for the bus name, and the bus selected can be adjusted to run with “Auto,” “Name,” or “Number” as the determining factor.
- Nodes: The search mode can be either “Graphic” or “All Data.” There is a space for the bus name and for the voltage involved. The bus selected can be adjusted to run with “Auto,” “Name,” or “Number” as the determining factor.
- Shunt: The search mode can be either “Graphic” or “All Data.” There is a space for the bus name, and the bus selected can be adjusted to run with “Auto,” “Name,” or “Number” as the determining factor.
- Text: The “Text” search mode provides a space to type the text that is being searched for.

Once the search features have been properly set, the search results will be displayed in a “Verify Results” window. Information will be displayed for several categories, including Component, From/End Bus or Bus Name, and ID. The “Verify Results” window can be closed by clicking on the X in the upper right-hand corner. To turn off “Search Bus,” click on the “Search Bus” command button, “Search Bus” within the Window menu, or use the short-cut command Alt + b. To run another search, the “Search Bus” feature must be turned off and then turned back on again.

3.6.10.2 Selecting an area

The “Selecting” button allows the user to mark an area of the screen for modification. Setting the arrow key at one corner of the desired location and clicking the left mouse button will result in the creation of a box, defined by yellow lines. Surround the feature that needs to be selected and click the left mouse button. The selected feature(s) and the connecting lines will be highlighted in yellow. The size of the box will change as the cursor is moved. Click again to remove the highlighting and start a new box. Clicking on the left mouse button when no features are in the box will eliminate the box appearing on the screen and establish the cursor as the point of origin for a new box. Clicking on the right mouse button will eliminate the box and disengage the “Selecting” feature. To turn off the “Selecting” function, click on the Control Bar button.

3.6.10.3 Moving a Device

Once an area has been selected, it may be moved. Select the “Move Device” command button from the Control Bar. Move the cursor to the selected device and click once with the left mouse button. When the cursor is on the device, the arrow will change to a cross. Next, drag the item to the desired position and click the left mouse button again. The attached lines will move along with the device selected. To turn the “Move Device” function off, click on the Control Bar button or click “Move” from the Window menu.

3.6.10.4 Copying a Device

Once a device has been selected, it may be copied. When the cursor is on the device, the arrow will change to a cross. Move the cursor to the selected item and click once with the left mouse button. A duplicate of the item will appear and may be moved to any point in the diagram. When it is in the desired position, simply click the left mouse button again to position it. The device will remain highlighted and other copies can be made. To remove the highlighting, click on the “Selecting” button.

3.6.10.5 Delete Device

Once a device has been selected, it may be deleted. Simply click on the “DEL” button on the toolbar. A screen will appear, asking if you are certain that you wish to delete the device. If “No” is clicked, nothing will happen. If “Yes” is clicked, then the device will be deleted.

3.6.10.6 Replace Color

Note: This feature is not currently available.

This feature replaces the color of a selected line when that line is clicked on. Click on the “REP” button to activate this feature.

3.6.10.7 Remove Point

This feature removes a point when it is selected and clicked on. Click on the button with the Remove Point symbol (to the right of the “REP” button) to activate this feature.

3.6.10.8 Remove Link

This feature is used to remove a selected link from the map. Click on the button with the Remove Link symbol (to the right of the Remove Point button) to activate this feature. Once a link has been selected and clicked on, the program will ask if you are certain that you wish to remove this link. If “No” is clicked, nothing will happen. If “Yes” is clicked, then the link will be removed.

3.6.10.9 Panorama

The panorama is a small box in the lower right-hand corner of screen, which provides an overview of the entire map area. Clicking on the “MAP” command button will open or close the panorama option. The red rectangle in the panorama display surrounds the area currently displayed on the larger portion of the screen; it may be moved by placing the arrow within the red rectangle, holding down the left mouse key and “dragging” the rectangle to the desired position. The panorama feature is also listed under “Window” in the main toolbar.

3.6.11 Normal System

3.6.11.1 Update View

(Note: in order to use the following features, a regular power flow must be run first)

3.6.11.2 Power Flow

This feature can also be accessed by clicking on “Power Flows” under the Results menu.

3.6.11.3 Bus Voltage

This feature can also be accessed by clicking on “Bus Voltages” under the Results menu.

3.6.11.4 Line Flow

This feature can also be accessed by clicking on “Line Flows” under the Results menu.

3.6.11.5 Load Flow

This feature can also be accessed by clicking on “Load Flows” under the Results menu.

3.6.11.6 Bus Name

When a one-line diagram containing buses is displayed on the screen, clicking on this feature will cause the bus names to appear on the screen or be removed from the display.

Chapter 4

Future Research and Software Development

CPFLOW can be used in a variety of applications such as:

- monitoring voltage behaviors due to load and generation variations to detect such problems as voltage dip and collapse
- evaluating maximum interchange capability
- evaluating maximum available transfer capability
- tracing of power system behaviors due to load and/ generation variations with/without control devices
- conducting coordination studies of control devices for steady-state security enhancements
- evaluating the effects of different load models on voltage stability, transfer capability among other system condition variables of interest.

It is imperative in these applications to take into account all credible contingencies. At present, CPFLOW can be ineffective in doing so for all credible contingencies. The strategy of using effective schemes to rank all credible contingencies and of applying detailed analysis programs only to critical contingencies is widely accepted. In order to identify critical contingencies which will severely violate security constraints, we suggest the development of look-ahead ranking schemes and the incorporation of these schemes into CPFLOW.

We consider the following situation given (i) the current operating condition (obtained from the state estimator and the topological analyzer), (ii) a set of proposed power transactions, and (iii) a list of credible contingencies. For each credible contingency, we suggest the development of three look-ahead schemes for estimating the load margins between the current operating point (in the load-generation space), along the proposed power transaction vector b , to the following three limiting operating points respectively: the steady-state stability limit (nose-point load margin), the bus voltage limit point, and the line flow thermal limit point of the power system with the proposed power transactions. In other words, the three look-ahead schemes estimate the following:

- the nose-point load margin for each contingency to measure the distance (in MW and/or MVAR) between the current operating condition and the nose point of the parameterized power system subject to the contingency;
- the voltage-limit load margin for each contingency to measure the distance (in MW and/or MVAR) between the current operating condition and the state vector, at which the voltage constraint at some bus is violated of the parameterized power system subject to the contingency; and
- the thermal-limit load margin for each contingency to measure the distance (in MW and/or MVAR) between the current operating condition and the state vector, at which the thermal limit constraint of some transmission line is violated of the parameterized power system.

Bibliography

1. H.D. Chiang, C.S. Wang and A.J. Flueck, "Look-ahead Voltage and Load Margin Contingency Selection Functions for Large-Scale Power Systems," 96 WM 208-9 PWRS, IEEE PES Winter Meeting 1996.
2. S. Greene, I. Dobson and F.L. Alvarado, "Contingency analysis for voltage collapse via sensitivities from a single nose curve," to appear in *IEEE Trans. on Power Systems*.
3. H.D. Chiang, A.J. Flueck, K.S. Shah and N. Balu, "CPFLOW: A Practical Tool for Tracing Power System Steady-State Stationary Behavior Due to Load and Generation Variations," *IEEE Trans. on Power Systems*, Vol. 10, No. 2, May 1995, pp. 623-634.
4. G. C. Ejebe, G. D. Irisarri, S. Mokhtari, O. Obadina, P. Ristanovic, J. Tong, "Methods for contingency screening and ranking for voltage stability analysis of power systems," *IEEE Trans. on Power Systems*, Vol. 11, No. 1, Feb. 1996, pp. 350-356.
5. S. Greene, I. Dobson, F. L. Alvarado, "Sensitivity of the loading margin to voltage collapse with respect to arbitrary parameters," *IEEE Trans. on Power Systems*, Vol. 12, No. 1.