DESIGN AND DEVELOPMENT OF A HVDC CONVERTER STATION SIMULATOR USING A PERSONAL COMPUTER ENVIRONMENT

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Version 1.0

Chapter 6.

Chapter 1

Computer Simulator

1.1 INTRODUCTION

Graphic user interface (GUI) capabilities in personal computer systems are one of the most important developments in computer technology. Using a computer with a GUI to simulate contingencies and unstable conditions in a HVDC converter, allows users to review the problems that can occur in the field. It can also help to identify the best operational strategies for the conditions presented. This approach would result in fewer unit trips, poles with faster starts and stops, and a better understanding of their controls, safety, and clearance procedures. In order to make this program useful, this computer simulator should satisfy the following general requirements:

- The computer simulator should function as close as possible to the actual converter station. The user should be able to see the equipment that he/she is operating, such as the control desk, control board, and alarm panels, enabling the operator to make appropriate responses to each problem that may occur. Through the use of icons, in a windows environment, the computer must visually resemble as closely as possible, the actual control desk.

- The computer simulator should allow actual events that take place on the system to be recreated. This information should be gathered from the control systems, operator reports, read sheets, and oscillographs, AC and DC switchyards status, filter yards, and auxiliary power systems must be available to the user at the computer station.

1.2 Description

After an extensive review of the existing software, LabView software from National Instruments was chosen for this task. LabView (Laboratory Virtual Instrument Engineering Workbench) is a powerful and flexible instrumentation and analysis software system for personal computers running under Microsoft Windows. Its main feature is a graphical programming environment and all the necessary tools for analysis and presentation. LabView programs are called virtual instruments (VI's) and they consist of a *front panel* and a *block diagram* (**Fig. 1.1**). The front panel specifies the inputs *controls,* knobs and switches (**Fig. 1.2**) and outputs *indicators,* graphs and meters (**Fig. 1.3**). The block diagram runs in the background, where icons "wired" together form the graphical code, an equivalent to the source code of text based programming languages.

On this simulator there are three different types of controls; Switches, Dials and Digital Controls. These devices are used for the input of data from the user, by pointing and clicking on its icon. There are also two types of indicators; graphs and meters. Graphs will display all data developing in the circuit in two forms; chart and scope mode. Meters are very simple, they resemble a common analog meter. They have a needle pointing at the current value and a digital display showing a more accurate reading.

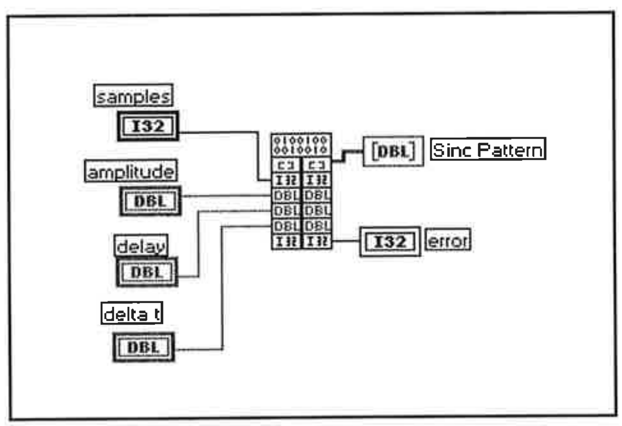


***Figure 1.1** LabView Code.* This is actual code taken from a synchrony generator.

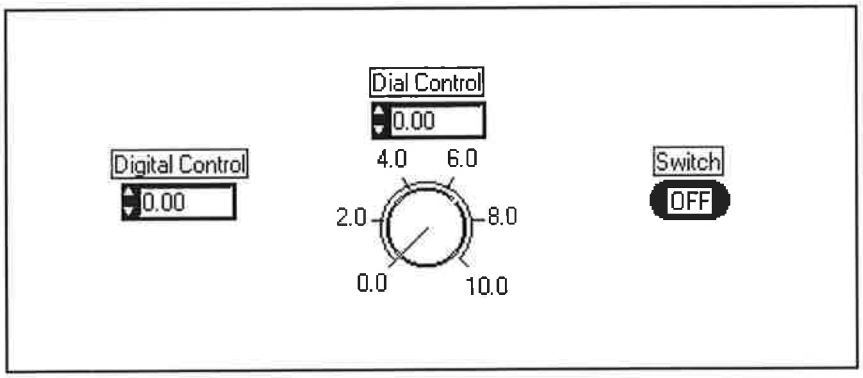


Figure 1.2 *Front Panel Controls.* These controls are used as input devices.

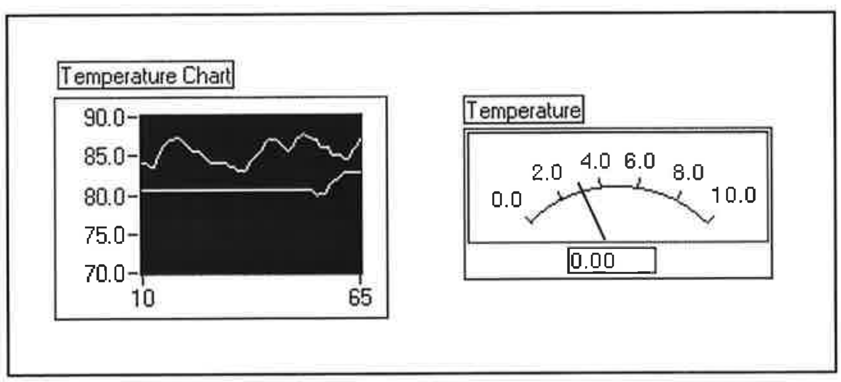


Figure 1.3 *Front Panel Indicators.* These indicators display events as they occur during simulation.

Chapter 2

Bipole Console

2.1 Introduction

The Bipole Console screen is divided into three different sections; Bipole Setup Control, Bipole, and Bipole Monitor.

2.1.1. *Bipole Setup Control*: This Section emulates the Master Controller from the original design. The Bipole Setup Control section consists of:

- Power Switch.
- Lamp Test switch.
- Control Location:
    1. Local/ECC LED.
    2. Master Station Adelanto/Intermountain LED.

- Deviation Control.
- Amplitude Control.
- Electronic Current Null Control.

2.1.2. *Bipole*: This section along with the bipole monitor will be the two main sections the user will interact with during a simulator session. Here the user will be able to follow changes as they develop within the poles. The Bipole section consists of:

- Sequence Control:
    1. Control Location Local/ECC switch.
    2. Master Station Adelanto/Intermountain switch.
    3. Constant Frequency Control switch.
    4. Insulated Start Up switch.

- Power Control switch:
    1. Power Order switch.
    2. Power Ramp switch.
    3. Power Limit switch.
    4. Reached LED.

- Frequency Control
- Electronic Current null
- Desk Enable/Disable switch.
- Lamp Test.

2.1.3. *Bipole Monitor*: This section will display any changes developing on the poles. The Bipole monitor console consists of:

- Frequency Monitor scope and Deviation Meter
- Power Monitor Chart Recorder
- Electronic Current Null Meter.

2.2. *Operation*

2.2.1. The *Bipole Setup Control* section is used for setting the parameters that the user will work with during the session. The *Bipole* section will be used to rectify any problems preseted by the Bipole Setup Control section. Also, the *Bipole Monitor* is used to view events produced by either the Setup Control, or by the Bipole console. The instructor may change the initial setup through the use of the Bipole Setup Controls (**Fig. 2.1**). The Bipole Setup Controls and their use consists of:

- Control Location: These two LED's display the location controlling the station, Local or ECC.
- Power: This On/Off switch sets the program ready for execution.
- Master Station: These two LED's display the station being controlled, Adelanto or Intermountain.
- Deviation: This control is used to change the shift of frequency in Hertz between the reference sine wave, and the sine wave on the circuit.
- Amplitude: This control is used to set the amplitude of the sine wave on the scope chart.
- Electric Null Master: This control is used to set the unbalanced current between the poles.

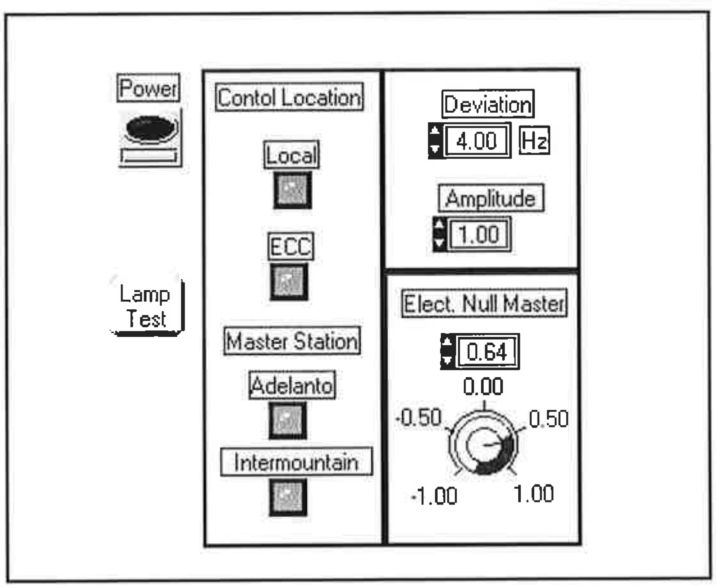


Figure 2.1. Bipole Setup Control. This front panel is temporary and will be replace in later revisions.

2.2.2. *Bipole*: Once the controls on this section are preseted, the user by means of the Bipole controls, can rectify any problems caused by the Bipole Setup Control section (**Fig. 2.2**). The Bipole controls and their use consists of:

- Sequence Control:
  1. Control Location: This switch is used to set the screen to remote, Local, or ECC.
  2. Master Station: This switch is used to set the master station default to Adelanto or Intermountain.
  3. Constant Frequency Control: This switch is used to enable or disable the frequency control feature.
  4. Insolation Start Up: This switch has not yet been programmed.

- Power controls:
  1. Power order: This control is used to set the output power to the desired value.
  2. Power Ramp: This control is used to set the time in minutes, for the current power output to reach new order value.
  3. Power Limit: This control is used to set the output power's maximum value.
  4. Reached: This indicator is an LED that is used to make the user aware that the output power has reached the Order value.

- Frequency Control: This dial is used to compensate for the shift of frequency, produced by the *Bipole Setup Control* deviation control.

- Electronic Current Null: This dial is used to compensate for the shift of current produced by the Elect. Null Master control that is on the Bipole Setup Control section.

- Desk Enable/Disable: This switch is used to turn on or off the Bipole Desk screen.

- Lamp Test: This switch is used to test all lights within the given section.

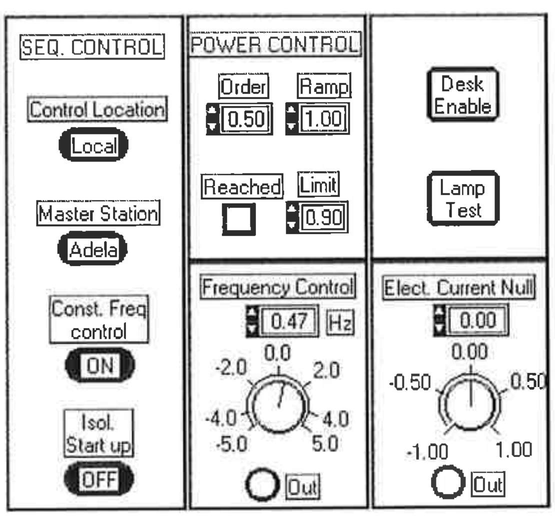


Figure 2.2 *Bipole*. This front panel will be used to rectify any events that develop in the Bipole.

2.2.3. *Bipole Monitor*: This section is used for the display of events affecting the circuit (**Fig. 2.3**). The Bipole Monitor section consists of :

- Frequency Monitor: This is a scope type graph and is used for the display of the reference 60 Hz sine wave and the sine wave in the circuit. Attached to this monitor there is a frequency deviation meter that measures the difference between the two sine waves. This meter shows a more accurate reading.

- Power Monitor: This is a strip type graph and is used for the display of three plots; output power, order power, and limit power. Also attached to this chart, there is an output power meter, measuring the total output power.

- Elect. Current Null Monitor: This meter is used for the display of the shift of current between the poles.

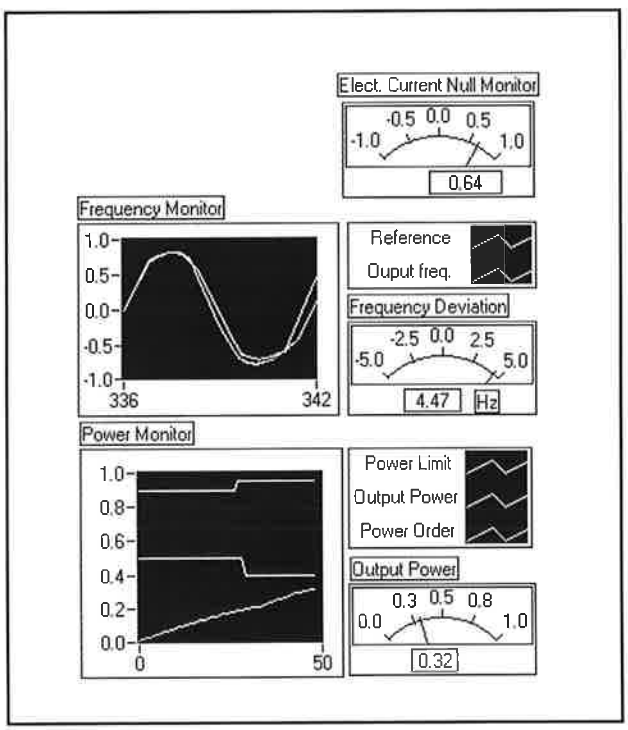


Figure 2.3. *Bipole Control.* This section displays all events related to the poles.

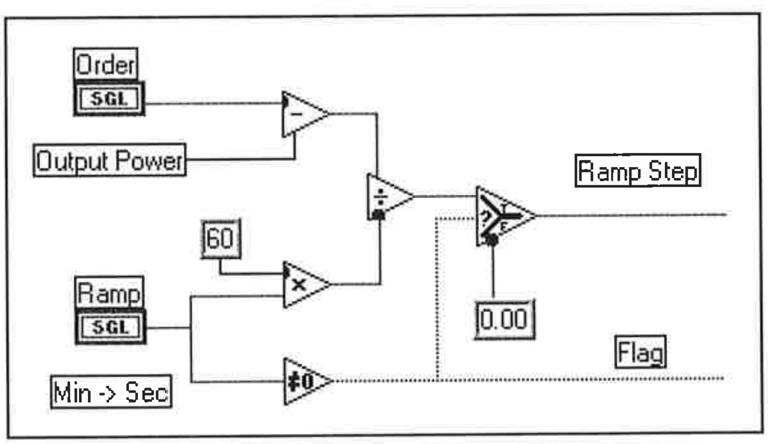
2.3 Logic

2.3.1. There are two main loops and eight sections in the block diagram of this program. The main loop is a ***Do While*** loop containing seven sections and a ***For Do*** loop, which in turn contains the last section of the program.

Do While Loop

1. Step Ramp Generator
2. Power Order-Limit
3. Lamp Testing
4. Null Current Monitor
5. Location LED's
6. Time Intervals
7. Power On/Off
8. For Loop
    a) 60 Hz Sine Wave Generator and comparator

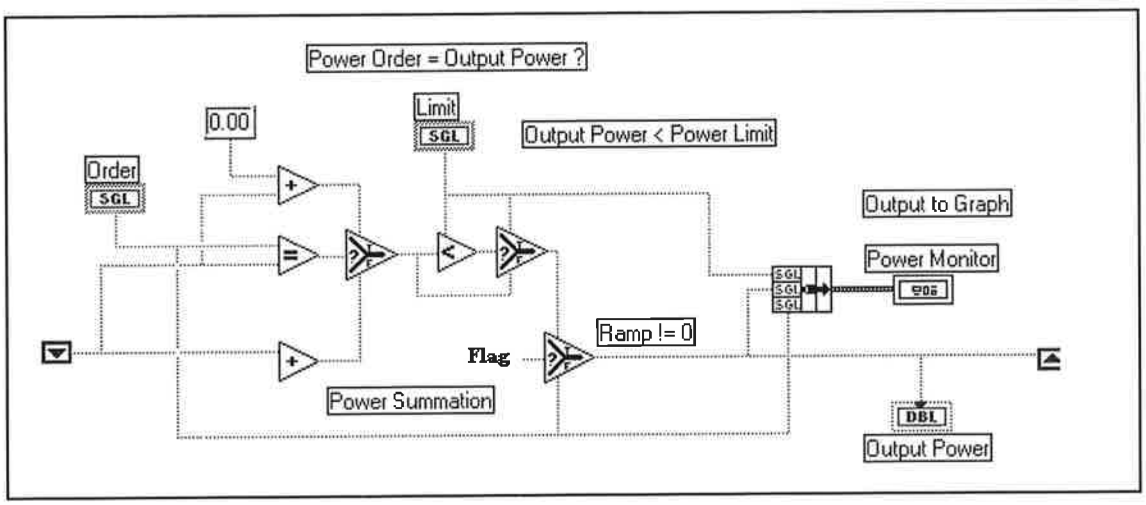
2.3.1.1. *Step Ramp Generator*: This section inputs the number of minutes through the Ramp control, and then the value is converted to seconds, and divided by the difference between the order and the power output. If the ramp is equal to zero, the output power is set to the order power (**Fig. 2.4**).




```
IF ramp{
    step = (order_power/(ramp*60));
    flag = 1;}
ELSE{
    step=0;
    flag =0;}
```

Figure 2.4 *Step Ramp Generator.* The step ramp generator will calculate a new step value whenever the power order is change, independently from the power order's initial value.

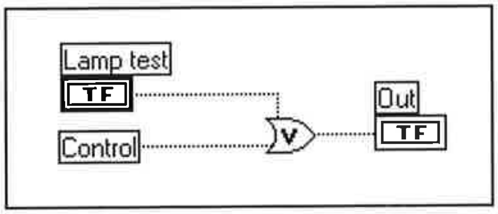
2.3.1.2. *Power Order-Limit*: This section is used to increase or decrease the output power with respect of the order and the ramp factors, without going above the power limit. If the order is equal to the output power, then the program adds zero to the output power, otherwise the program adds the corresponding ramp step from the prior section to the output power. Thereafter, the program will test for the limit power. If this limit is reached, the output power will stay at the power limit value. If not, it will decrease if the power order is decreased. After all calculations are finished, Order power, Limit power and Output power are *bundle*d and transferred to a chart recorder (the *bundle* function is equivalent to the *structure* function in C), to the Power Monitor and the Output Power meter (**Fig. 2.5**).




```
IF limit < power_output
    power_output = limit;
ELSE {
    IF order = = power_output
        power_output + = 0;
        turn on reached LED;
    }
    ELSE
        power_output+ =step;
}
```

***Figure 2.5** Power-Order-Limit diagram and C code.* This diagram shows how the output power value will not go above the power limit.

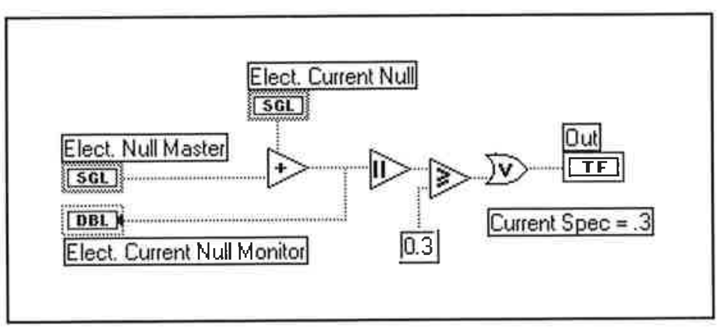
2.3.1.3. *Lamp Testing*: This section is very simple, every LED and light is connected directly through a OR gate to the Lamp Test switch (**Fig. 2.6**).




```
IF (lamp_test || other_switch)
    turn on LED/Light;
```

Figure 2.6 *Lamp Testing.* LabView and C code.

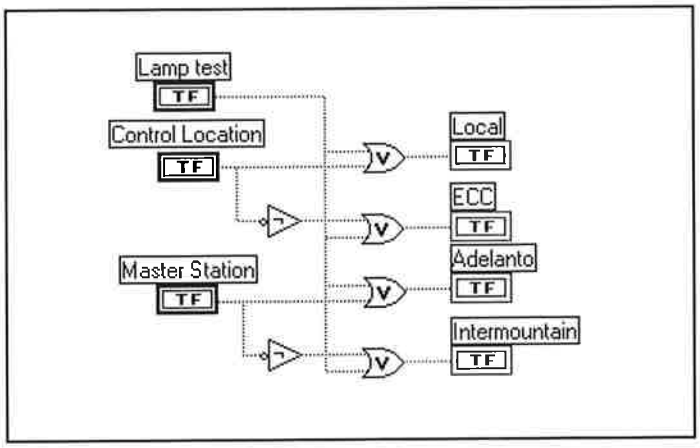
2.3.1.4. *Null Current Monitor*. The Elect. Current Null Master control input value from the Bipole Setup Control and the Elect. Current Null from the Bipole section input values are summed, and their absolute value calculated. Thereafter, the result is compared to the specification (30 %) and transferred to the Lamp Test section to be displayed if out of specification (**Fig. 2.7**).




```
IF  0.3 < ABS(null_master + current_null)
    turn on LED/Light;
```

Figure 2.7 *Null Current Monitor.* The specification on the error value for the bipole current is 30%, this may change in future revisions.

2.3.1.5. *Control Location and Master Station LED's*: In this diagram the indicators are connected to their respective On/Off control and "wired" to the Lamp Test switch through an Or gate (**Fig. 2.8**).




```
IF (lamp_test || any_switch)
    turn on LED/Light;
```

Figure 2.8 *Control Location & Master Station indicators.*

2.3.1.6. *Time Interval*: This section is formed by two items; a constant number and a *Wait Until* function. The constant number dictates the time every interation should take. This was necessary in order to produce a evenly timed ramp during the invocation of the simulator (**Fig. 2.9**).

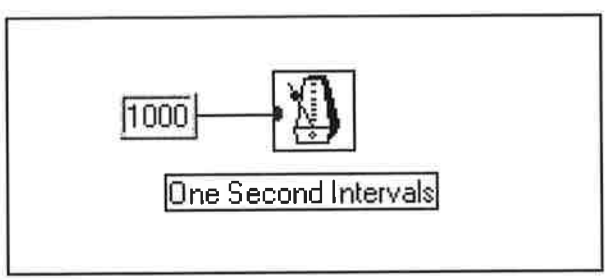
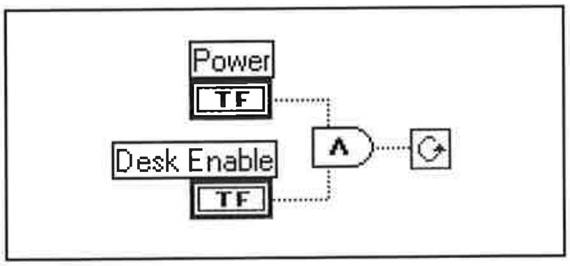


Figure 2.9 *Time Interval.*

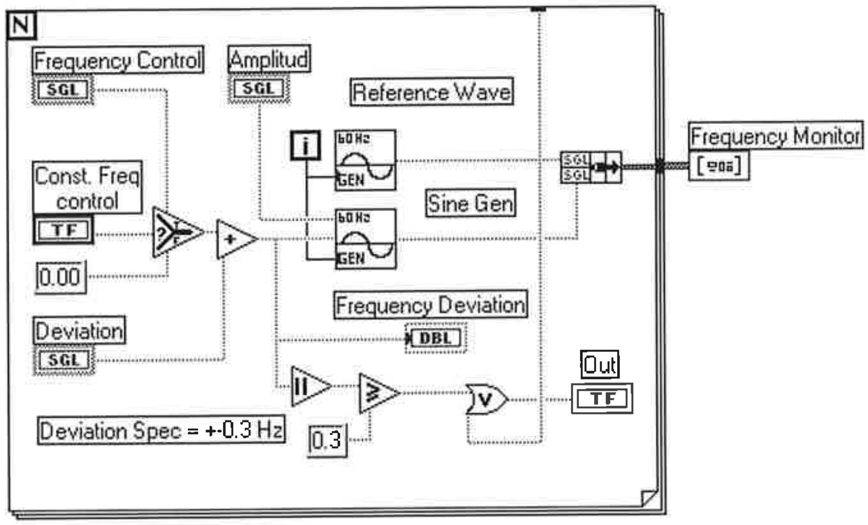
2.3.1.7. *Power On/Off*: This section consist of two items, Power switch and Desk Enable. Both switches must be true in order for the loop to execute (**Fig. 2.10**).



IF (power_switch && desk_enable)
run application;

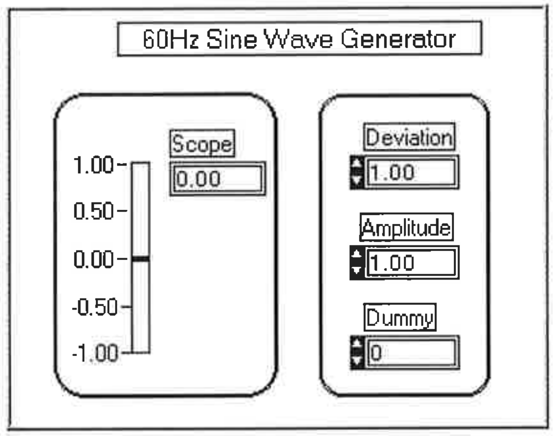
Figure 2.10 *Power switch & Desk Enable.*

2.3.2. *For Do loop*: This section contains the reference *sine wave generator* subprogram. This subprogram generates a sine wave by using the equation $y= a^* \sin(w^*x)$ where a is the amplitude, w is the index variable, and x is the frequency (**Fig. 2.11**). There are three display controls in this subprogram; a deviation, an amplitude (a), and a dummy (w) control. To produce a 60 Hz sine wave, the deviation is added to a constant, in this case 60, then the value is converted to radians and fed to the prior equation as the given frequency (**Fig. 2.12**). There is also an scalar indicator, which is used to show the output frequency in a faster way, rather than using a graph. If the Const. Frequency control switch is on, the values from the frequency control plus the value of the deviation control at the Bipole setup Control, will be added and transferred to the sine wave generator, which in turn will output 60 Hz plus their sum. If the result from these two values is greater than the specification (0.3), then the Out LED will be turned on through the Lamp Test section. If the *Const. frequency* control is off, the deviation control at the Bipole setup Control will dictate the shift of frequency on the generator. Only one generator has variable frequency, and both are *bundle*d and transferred to a graph in scope mode.




```
If const_freq_control
   output_freq=frequency_control+deviation;
ELSE
   output_freq=deviation;
generator(output_freq);
   If ABS(output_freq>=0.3
      turn OUT LED;
```

Figure 2.11 *For Do Loop.* On this section two sine waves are produced and their frequency compared.



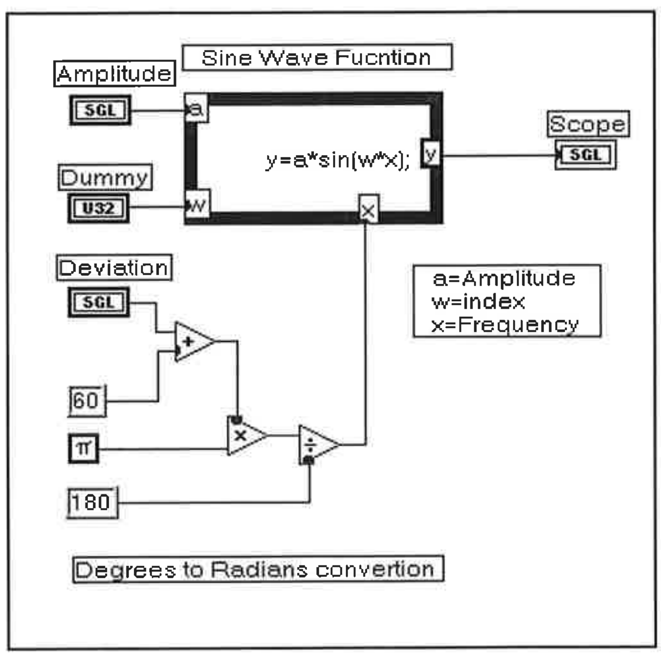


Figure 2.12. *60 Hz Sine Wave Generator.* This subVI will be running in the background during the execution on the Bipole VI.

Chapter 3

MAIN DC-CIRCUIT

3.1 Introduction

The *Main DC-Circuit* console screen is divided into two different sections; *Master Control* and *Main DC-Circuit.*

3.1.1. *Master DC-Circuit* .- This section emulates the Master Controller from the original design. The Master DC-Circuit section consists of the following parts:

- Ready for Operation bipole switches array.
- Converter Energized switches.
- Over Load switches.
- Communication Fail switch.
- Return bipole switch array.
- Current, Voltage and Power set Controls.

3.1.2. *Main DC-Circuit*.- This section shows the status of the DC-Circuit, and is divided into three different parts:

- Digital Displays.
    1. Current.
    2. Voltage.
    3. Power.

- Pole 1 & Pole 2 Controls.
    1. Ready for Operation.
    2. Converter Energized.
    3. Overload.
    4. Local, Ground, Metallic Return.

- Pole 1 & Pole 2 Indicators.
    1. Start/Stop.
    2. Block/Deblock.

3.2 Operation

In order to run this simulation, the Power switch must be turned on and the Run command executed (**Fig. 3.1**). Once the program is running, the user has the choice to change any of the default settings on the Master DC-Circuit section (**Fig. 3.2**). The operator monitoring the Main DC-Circuit will experience an event that is as close as possible to a real life situation.

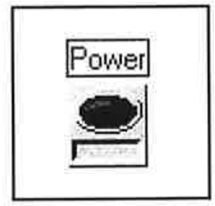


Figure 3.1 *Power Switch.* The power switch controls the execution of the simulator.

3.2.1. The Master DC-Circuit section consists of th following elements (**Fig. 3.2**):

- Ready For Operation: This switch array contains four vertical toggle switches that control the status of the four *Ready* LED's on the Main DC-Circuit .
- Converter Energized: These two switches control the two *Converter Energized* LED's on the Main DC-Circuit Console, but their use has not been defined yet.
- Overload: These switches control the *Overload* LED's on the Main DC-Circuit.
- Pole Return: This switch array contains six toggle switches that control the Local, Ground and Metallic return.
- Control Section: This section contains the display controls necessary to change; Current, Voltage and Power.
- Communication Fail: This control simulates the failure of telecommunication between stations.

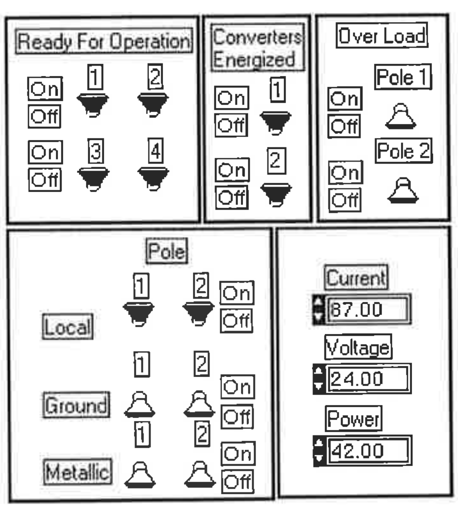


Figure 3.3 *Communication Fail.* Simulates the interruption of telecommunications.

Figure 3.2 *Master DC sectios.* The Master Control is a partial emulation of the Instructor's control.

3.2.2. The Main DC-Circuit sections are (**Fig. 3.4**):

- Digital Displays:

1. Current Display: This indicator shows the current set by the *current control* on the Master Control.
2. Voltage Display: This indicator shows the voltage set by the *voltage control* on the *Master Control*.
3. Power Display: This indicator shows the power set by the *power control* on the *Master Control*. The voltage on Pole 1 is normally positive and the voltage on Pole 2 is normally negative. The DC-Power digital display shows the summation of the power on the two poles.

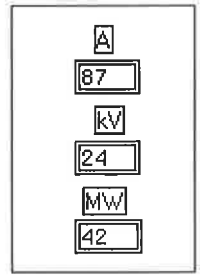


Figure 3.4 *Digital Displays.* Main DC-Circuit Indicators.

- Pole 1 & Pole 2 Indicators:

1. Ready for Operation: These four indicators show the status of the diodes (**Fig. 3.5**).
2. Converter Energized: These two indicators show the status of the converter (**Fig. 3.5**).
3. Overload: These two indicators show the overload status of the poles.
4. Return: These six indicators show the return being used; Local, Ground or Metallic (**Fig. 3.6**).

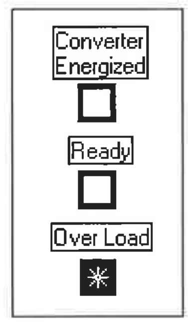


Figure 3.5 *Poles Indicators.* Converter Energized, Ready, and Overload Indicator.

- Pole 1 & Pole 2 Controls (**Fig. 3.7**):

1. Start/Stop: These two switches start and stop the bipoles.
2. Block/Deblock: These two switches block and deblock the bipoles.

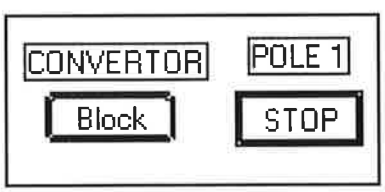
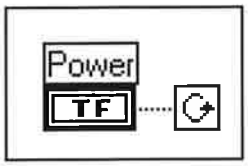


Figure 3.7 *Convertor and Pole switches.* Push buttons controls.

Figure 3.6 *Pole Return.* There are three indicators Local, Ground, and Metallic.

3.3 Logic

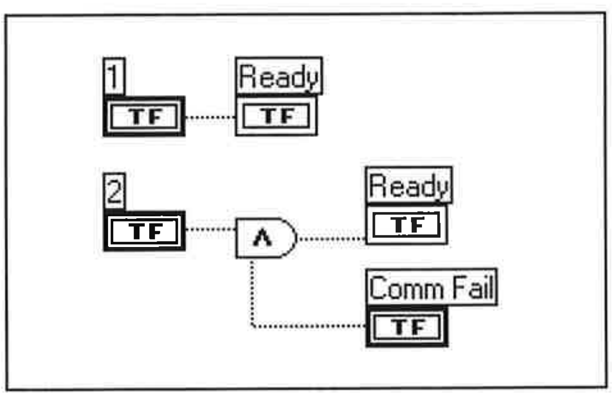
3.3.1. The power switch controls the test of the main Do While loop (**Fig. 3.8**).




```
Do{
        program_simulator;
}While(Power_switch);
```

Figure 3.8 *Power Switch.* LabView and C code.

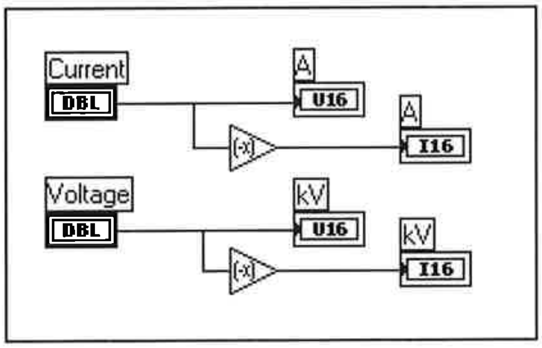
3.3.2. The Ready for operation toggle switch controls in the Master DC-Circuit section operate the *Ready* LED's on the Main DC-Circuit section. All indicators will be turned off, if the telecommunication fails on both pole 1 and pole 2 (**Fig. 3.9**).




```
If (switch)
        turn_on_LED;
If (communication_fail && switch)
        disable_LEDs;
```

Figure 3.9 *Ready and Telecommunications Fail Indicators.* LabView and C code.

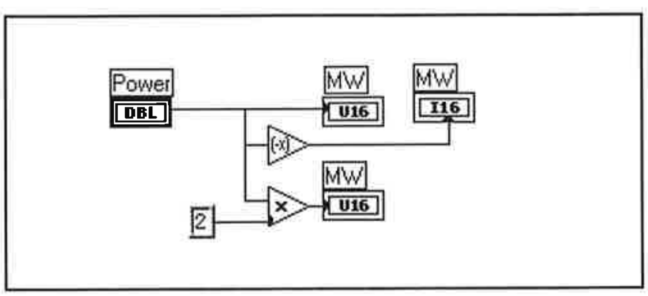
3.3.3. The controls on the Master DC-Circuit section; *Current*, *Voltage*, and *Power*, command the *Current*, *Voltage*, and *Power* indicators on the Main DC-Circuit section (**Fig. 3.10**). Pole 2's indicators such as, current and voltage will normally display negative numbers.




```
pole1_indicator = control;
pole2_indicator = (- control );
```

Figure 3.10 *Current, Voltage and Power Indicators.* LabView and C code (power indicator not shown).

3.3.4. The DC-Power indicator on the Main DC-Circuit displays twice the power on any of the bipoles (**Fig. 3.11**).




```
pole1_indicator = control;
pole2_indicator = (- control );
Dc_power = 2 * pole1_indicator;
```

Figure 3.11 *DC-Power Indicator.* LabView and C code.

3.3.5. Pole returns, Overload, and Converter Energizer controls are directly connected to the indicators on the Main DC-Circuit section with no other logic (**Fig. 3.12**).

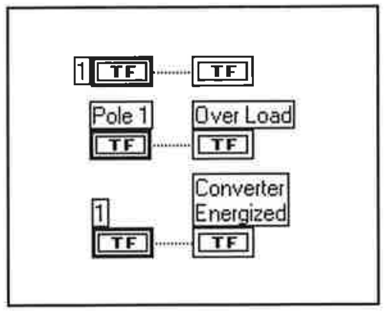


Figure 3.12 *Pole returns, Overload, and Converter Energizer controls.*

3.3.6. Pole Start/Stop and Convertor switches (**Fig. 3.13**).

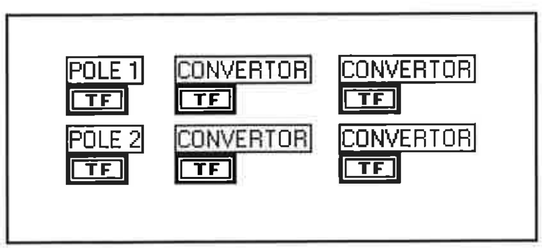


Figure 3.13 *Pole Start/Stop and Convertor switches.*

Chapter 4

REACTIVE POWER

4.1 Introduction

The *Reactive Power* screen is divided into three different sections; Generator Status Control, Reactive Power and Reactive Power Monitor.

4.1.1. *Generator Status Control*: This section emulates the Master Controller from the original design. The Generator Status Control section consists of two toggle switches; **A** and **B**.

4.1.2. *Reactive Power*: This section shows the Generator's status of the DC-Circuit, and is divided into four different sections:

- Mode selection.
    1. RPC Switch.
    2. RPC Control mode.
    3. Filter switching Control.
    4. Generator Status LED's.
    5. Automatic Trip Replace Switch.

- Voltage Control.
    1. Bus Voltage indicator.
    2. Reference Control.

- Reactive Power Flow Control (REA PWR FLOW CONT).
    1. Reactive Power Export Indicator.
    2. Reference Control.

- Filter Switching .
    1. Reactor Filter Connect/disconnect Indicator.
    2. 3-5-7 Filter Connect/disconnect Indicator.
    3. 11-13 Filter Connect/disconnect Indicator.
    4. HP1 Filter Connect/disconnect Indicator.
    5. HP2 Filter Connect/disconnect Indicator.
    6. Switching limits, PDC.
        - Lower Indicator.
        - Upper Indicator.

4.2. Operation

In order to run this simulation, the RPC switch must be turned on, and the Run command executed. Once the program is running, the user has the choice of changing any of the default settings on the Master Control

4.2.1. *Master Generator Status* section consists of:

- A set of two toggle switches (**Fig. 4.1**). This set of switches control the status of the two generators according to the following table:

A	B	Gen Status
0	0	No Generators in Line
0	1	One Generator in Line
1	0	Two Generators in Line
1	1	No Generators in Line

Generator Control truth table.

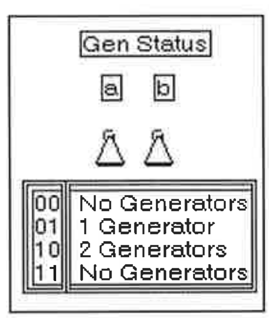


Figure 4.1 *Master Generator Status.* This is a portion of the original Master screen.

4.2.2. *Reactive Power*: This section consists of:

- Mode Selection (**Fig. 4.2**).

1. RPC power : This is the power switch that controls the execution of any control in the entire screen.
2. Generator Status: These Indicators (LED's) display the current status of the generators.
3. RPC Control Mode: This control switches the RPC console from Reactive power setup or Voltage setup to the Off position.
4. Filter Switching: This control switches the line filters from automatic or manual to the Off position.
5. Automatic Trip Replace: This switch has not been included in this program's code yet.

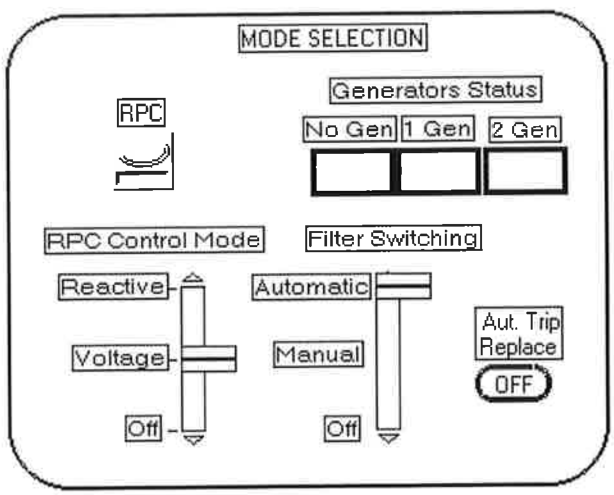


Figure 4.2 *Reactive Power.* This is the Mode selection section of the reactive power screen.

- Voltage Control **(Fig. 4.3)**.

    1. Bus Volts meter: This Meter displays the actual output voltage on the line.
    2. Voltage Reference: This control dictates the target voltage desired.

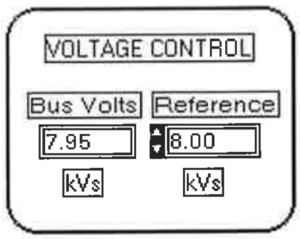


Figure 4.3 *Voltage Control.* This section displays the actual output voltage and the target voltage output.

- REA Power Flow control **(Fig. 4.4)**.

    1. REA Export meter: This Meter displays the actual reactive power on the line.
    2. Reactive Power Reference: This control dictates the target reactive power desired.

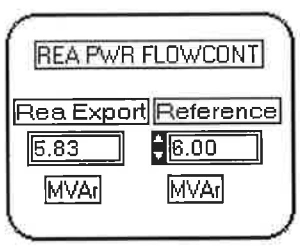


Figure 4.4 *REA Power Flow Control.* This section displays the actual reactive power on the line, and the reactive power target value.

- Filter Switching Indicators **(Fig. 4.5)**.

1. Filter Connect/Disconnect: These series of indicator display the filters that are connected or disconnected.
2. Switching limit, PDC.

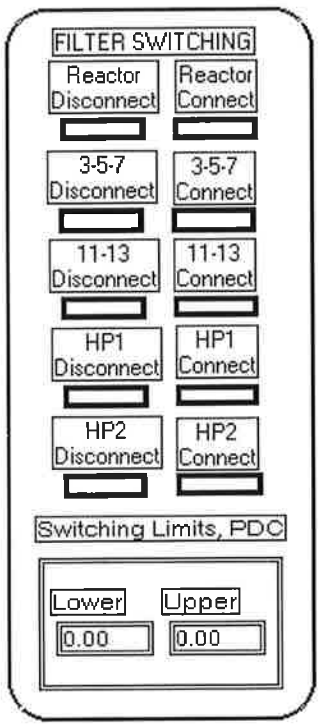


Figure 4.5 *Filter Switching.* This displays the filters that are connected.

4.2.3. *Reactive Power Monitor*: This section consists of **(Fig. 4.6)** :

- Reactive Power Export History Graph:
  This graph records the history of all points of the reactive power throughout the session.
- Bus Voltage History Graph:
  This graph records the history of all points of the output voltage throughout the session

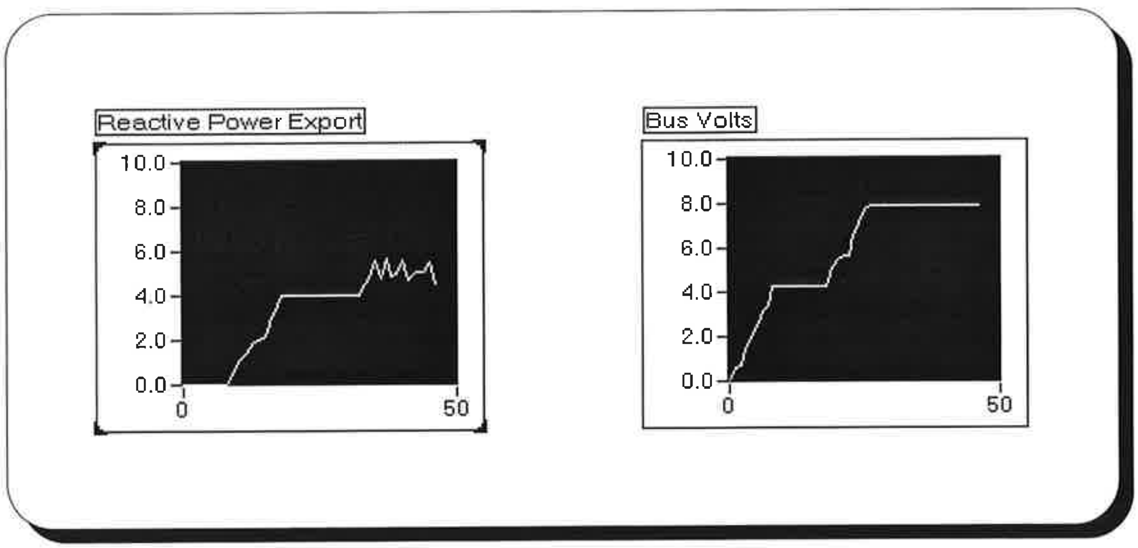
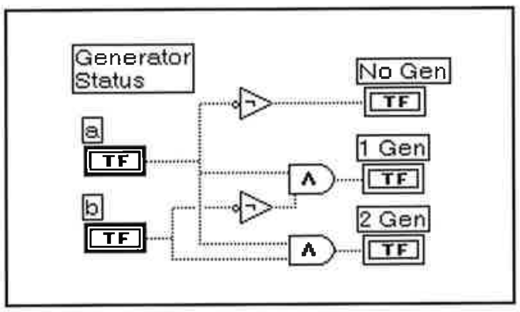


Figure 4.6 *Reactive Power Monitor. These* two graph are setup in the scope mode.

4.3. Logic

The Reactive Power screen has been divided into four sections; filter switching, generator status control, mode selection, and various controls.

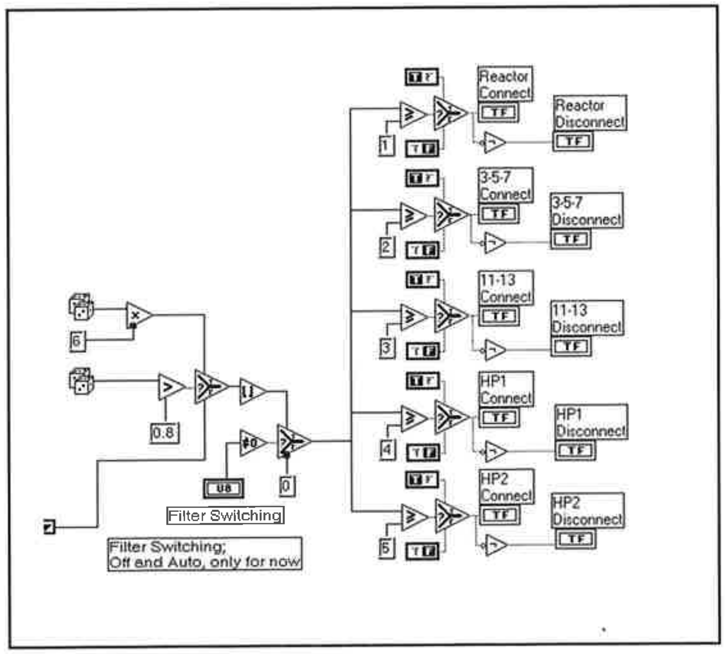
4.3.1. *Generator Status*: This section is most simple of the three sections. The two toggle switches are setup by the below equations, and the voltage and reactive power controls will work when there are no generators on line (**Fig. 4.7**).



no_gen = a̲
1_gen = a * b̲
2_gen = a * b

Figure 4.7 Generator Status. The LabView diagram and pseudo code.

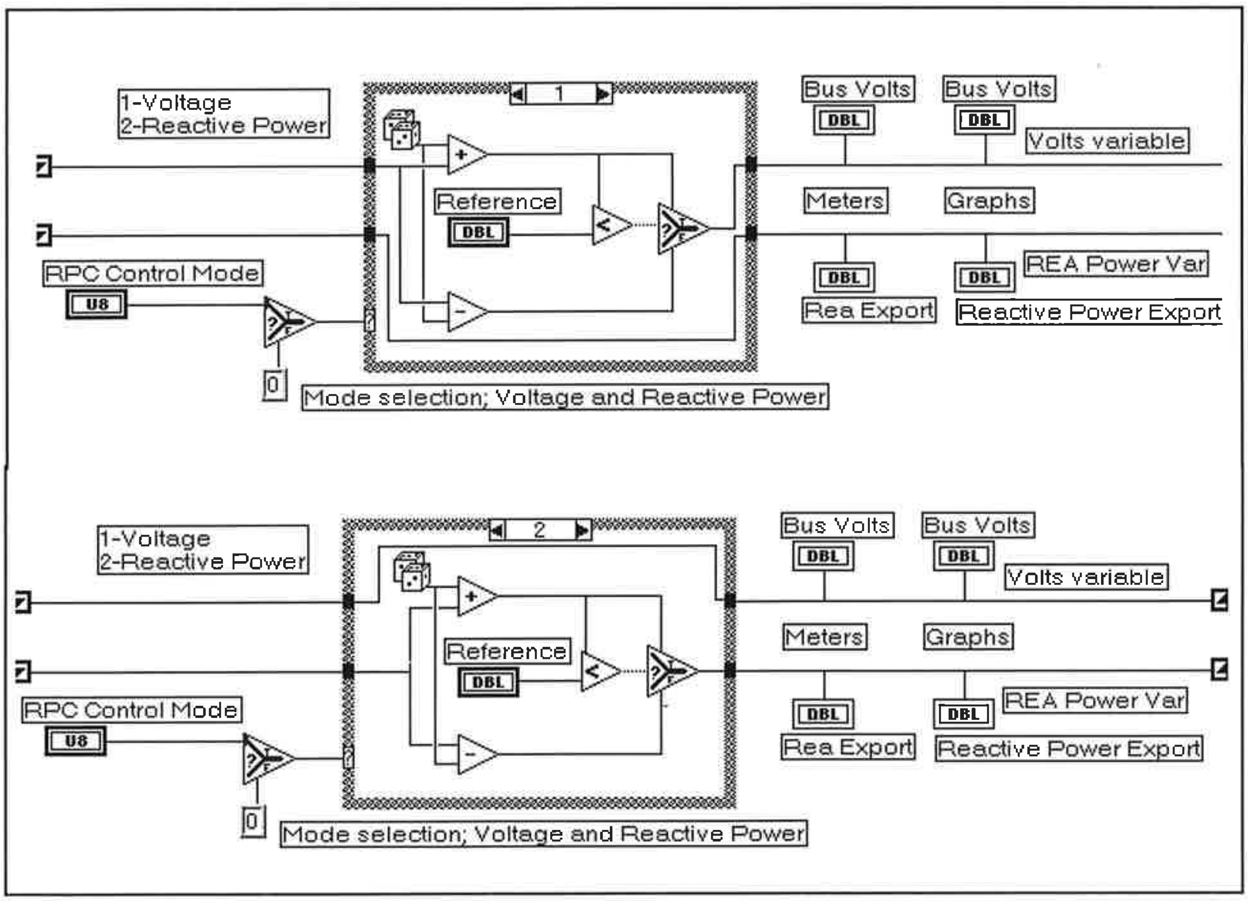
4.3.2. *Filter switching*: This section is programmed to work on automatic mode only. This section contains two random number generators, the first one controls the number of filters that will be connected at one point. The second generator controls the delay between changes of filters, as it is only 20 % of the numbers that are being generated will affect the number of filters connected. The connect/disconnect LED's are complements of each other (**Fig. 4.8**).




```
If filter_on{
num_filters_on = random * 6;
If (random > 0.8){
    If num_filter_on = = 1{
        turn_on_connect;
        turn_off_diconnect;
    }
    If num_filter_on = = 2{
        turn_on_connect;
        turn_off_diconnect;
    .
    .   and so on.
```

Figure 4.8. *Filter Switching.* The logic is on this diagram equivalent to a common bar graph display.

4.3.3. *Output Voltage and Reactive Power*: These two do not work together, when one of them is on, the other one stays at its previous value and vice versa. If the RPC Control mode switch is on, and the generators are off line, either the output voltage, or the reactive power would be selected depending on the case statement. Whichever one is chosen, it will increase or decrease by a random number generator (0-1) depending on its previous value (**Fig. 4.9**).




```
case mode{
   If (Reference < Previous_reference + random_number)
      Reference += random_number
   else
      Reference -= random_number
}
```

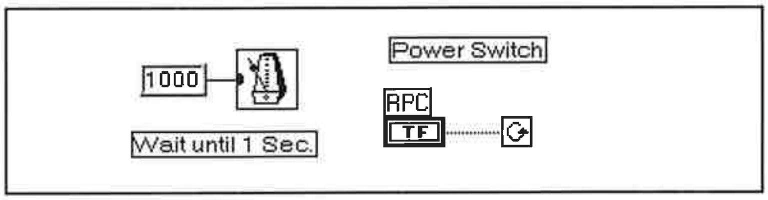


Figure 4.10 Wait Statement & Power switch.

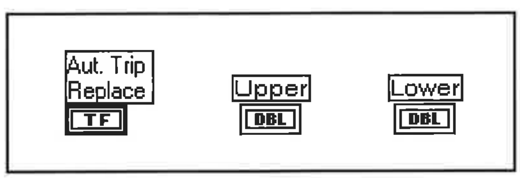


Figure 4.11 Auto Trip Replace & Upper and Lower Switching Limits.

4.3.4. *Power switch*: This switch controls the main While loop (**Fig. 4.10**).

4.3.5. *Wait Statement:* This code controls the duration of each interation to an accuracy of 55 msec (**Fig. 4.10**).

4.3.6. *Auto Trip Replace & Upper and Lower Switching Limits* (**Fig. 4.11**).

Chapter 5

BIPOLE CONTROL DESK

5.1 Introduction

The *Bipole Control Desk* screen is divided into three different sections; Bipole Control Desk Master, Bipole Control Desk and Bipole Control Desk Monitor.

5.1.1. *Bipole Control Desk Master*: This section emulates the Master Controller from the original design. The bipole control desk master consist of :

- Toggle Failure Switches.
    1. Communication Switch.
    2. Short Time Overload.
    3. Pole Overload.

- Power Controls.
    1. Output Power.
    2. Generator Power.
    3. Switchyard used Power.
    4. K-DCPSC Adelanto and Intermountain.
    5. SIP Order Adelanto and Intermountain.

- Status Indicators.
    1. Local control.
    2. ECC control.

- Number of Generator Available Control.

- Power Switch.

5.1.2. *Bipole Control Desk*: This section along with the *Bipole Control Desk Monitor* will be the two main sections the user will interact with during a simulator session. Here the user will be able to follow changes as they develop within the poles. The Bipole Control Desk consists of:

- Generator Station Runback Control (GSRC).
  1. GSRC On/Off switch.
  2. Generators 1&2 Available/In progress indicators.

- Direct Current Power Schedule Calculator (DCPSC).
  1. Local/ECC Control Location switch.
  2. On/Off Control & Inhibit indicator.
  3. Telecommunications indicator.
  4. K-DCPSC Value control.
  5. SIP Value control.
  6. Generation indicator.
  7. Measuring Point.

5.1.3. *Bipole Control Desk Monitor*: This section will display any changes developing on the poles. The Bipole Control Desk Monitor consists of:

- Output Power Scope recorder.
- Measuring Point analog meter.

5.2. Operation

In order to run this simulation, the Power switch must be turned on, and the Run command executed. Once the program is running, the user has the choice of changing any of the default settings on the Bipole Control Desk Master.

5.2.1. *Bipole Control Desk Master* section consists of: **(Fig. 5.1)**

- Toggle Failure Switches **(Fig. 5.2)**.
  1. Communications Failure switch : This switch when turned on will simulate the failure of communications on the bipole and the control will be transferred to the local station.
  2. Short time Overload switch : This switch when turned on will simulate short time overload on the bipole.
  3. Pole Overload switch : This switch will enable the ramp down of the generators when only one is available.

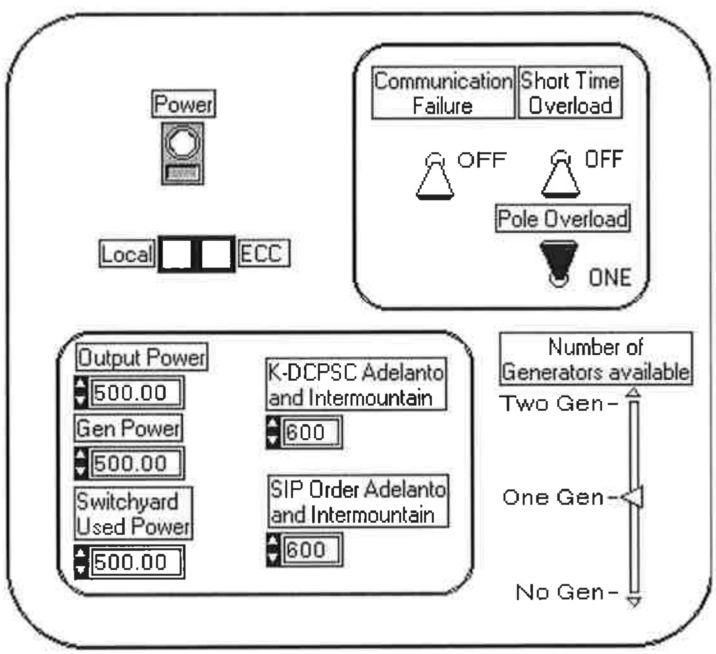


***Figure 5.1** Bipole Control Desk Master.* This is the section that the instructor will be working with.

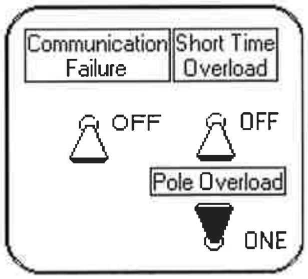


Figure 5.2 *Toggle Failure Switches.* This set of switches allows the simulation of different events on the Bipole Control Desk.

- Power Controls. (**Fig. 5.3**)
    1. Output Power: This control sets the total output power on the bipole.
    2. Gen Power: This control simulates the power produced by the Generators.
    3. Switchyard used Power: This control simulates the power being consumed by the station.
    4. K-DCPSC Adelanto and Intermountain: This control simulates the power Order from the ECC RTU in Adelanto or Intermountain.
    5. SIP Order Adelanto and Intermountain: This control simulates the SIP Order from the ECC RTU in Adelanto or Intermountain.

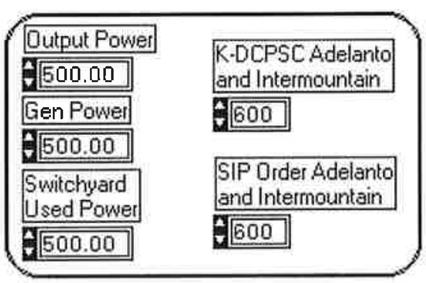


Figure 5.3 *Power Controls.* This set of controls allows the simulation of different events on the bipole control desk.

- Status Indicators. (**Fig. 5.4**).
    1. Local indicator: This indicator turns on whenever the Local control is set.
    2. ECC indicator: This indicator turns on whenever the ECC control is set.

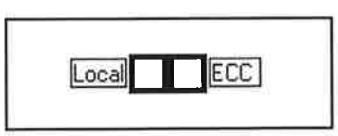
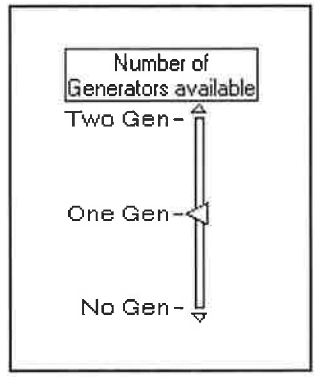


Figure 5.4 *Status indicators.* These indicators display the status of control on the bipole.

- Number of Generators Available Control.

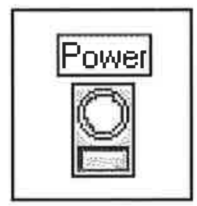
Figure 5.5 Number of Generators Available. This is a slide control very popular with LabView users.



This control sets the number of generators available to the user (**Fig. 5.5**).

- Power Switch.

Figure 5.6 Power switch. This control turns on the bipole control desk simulator.



This control turns on and off the Bipole Control Desk simulator (**Fig. 5.6**).

5.2.2. *Bipole Control Desk* section consists of:

- Direct Current Power Schedule Calculator.
  1. Local/ECC control: This switch sets the status control of the simulator, local or remot.
  2. SIP Comfail: This indicator comes on when telecommunications are inoperative between stations (**Fig. 5.8**).
  3. On/Off switch : This switch turns on and off the Bipole Control Desk .
  4. K-DCPSC section: This section is divided into two controls;**K-Fraction** and **K-Min** . The K-Fraction sets the percentage of generator power to be sent down the bipole. The

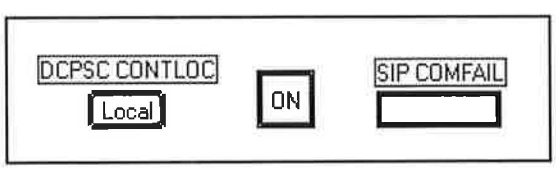


Figure 5.7 Remote, SIP Comfail and On/Off switch. These are controls located on the upper part of the Bipole Control Desk.

K-Min control sets the ramp time for the desired level to be reached in minutes **(Fig. 5.8)**.

5. SIP section: This section is divided into two components; **Fraction** and **Min** controls. The Fraction sets the power ordered from the AC ties. The Min control sets the ramp time, from a minimum of 0.5 to a maximum of 30 minutes **(Fig. 5.9)**.
6. Generation Section: This section is divided into two components; **Gross** and **Net** indicators. The Gross indicator displays the power from the generators into the

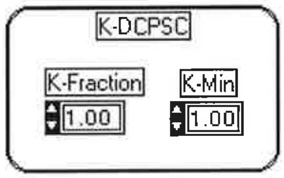


Figure 5.8 *K-DCPSC Section.* This set of controls is found within the DCPSC.

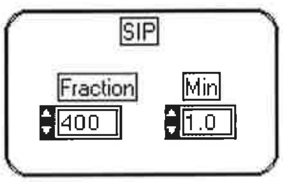


Figure 5.9 *SIP Section.* This set of controls is found within the DCPSC.

switchyard. The Net indicator displays the result of the substraction of the power used by the switchyard for internal use **(Fig. 5.10)**.

7. Measuring Point : These indicators and controls display the following values: **(Fig. 5.11)**.

- 00 Bipole Power Order from the DCPSC
- 01 Ramp time Remaining for SIP
- 02 Ramp time Remaining for K-DCPSC
- 03 K-DCPSC Order from the ECC RTU in Adelanto
- 04 K-DCPSC Order from the ECC RTU in Intermountain
- 05 SIP Order from the ECC RTU in Adelanto
- 06 SIP Order from the ECC RTU in Intermountain

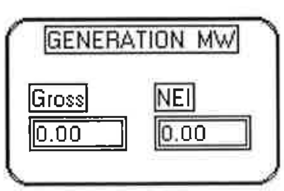


Figure 5.10 *Generation Section.* This set of controls is found within the DCPSC.

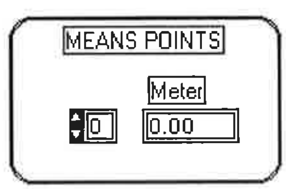


Figure 5.11 *Measurement Point.* This set of controls is used to review several parameters not obvious at first glance.

- Miscellaneous Control Desk Buttons **(Fig. 5.12)**.
  1. Acknowledge Button: This indicator acknowledges the panels.

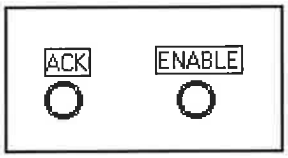


***Figure 5.12** Miscellaneous Control Desk Buttons.* These two switches are push button switches.

  2. Desk Disable: This switch disables all functions on the Bipole Control desk.

- Bipole Control Monitor.
  1. Output Power Meter: This indicator displays the history of the power flow **(Fig. 5.13)**.
  2. Means Meter: This indicator simulates a Simpson's analog meter, displaying the values of the Means Point indicator (Fig. 5.14).

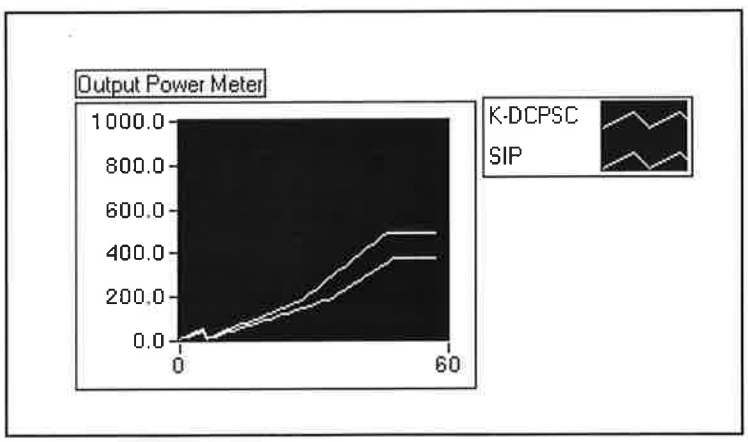


***Figure 5.13** Output Power monitor.* This graph will help the user to visualize a wider picture.

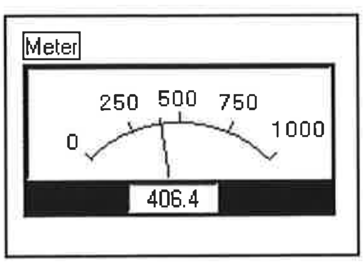


***Figure 5.14** Analog meter.* This Simpson look alike meter will display in an analog manner the current value on the measurement indicator.

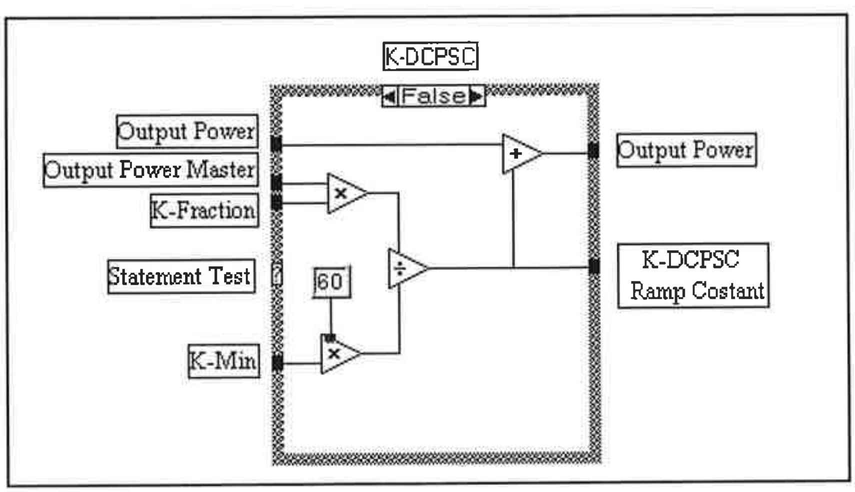


Figure 5.15 *K-DCPSC section.* This IF ELSE statement calculates the ramp value for the output power.

5.3. Logic

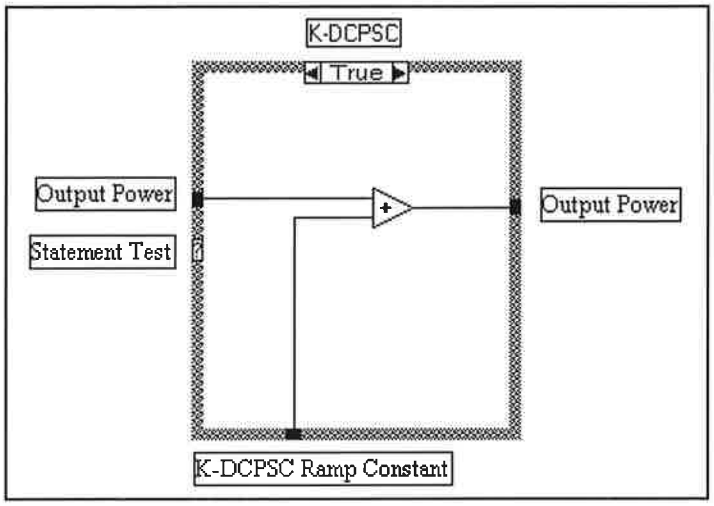


Figure 5.16 *K-DCPSC section.* This the TRUE section of the IF ELSE statement.

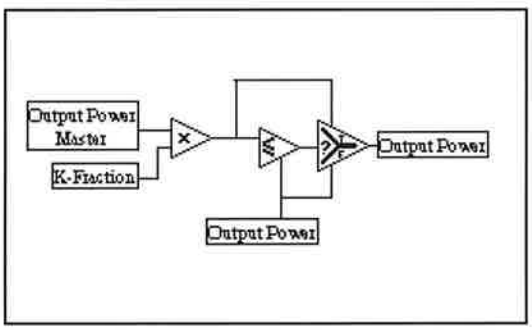


Figure 5.17 *K-DCPSC section.* This is another type of IF ELSE statement.

5.3.1. The Bipole control desk screen has been divided in a main Do while Loop and a main IF ELSE statement. Within the IF ELSE statement there are four other sections composed of a series of smaller IF ELSE statements. These smaller IF ELSE sections are

```
IF (k_dcpsc_output = = k_fraction) && (k_dcpsc_ramp = = k_min)
    output_power + = k_dcpsc_ramp_constant;
ELSE {
    k_dcpsc_ramp_constant = (output_power_master*K_Fraction)/(k_min*60);
    IF (output_power_master*k_fraction< =k_dcpsc + output_power)
        output_power = output_power_master * k_fraction;
    ELSE
        output_power + = k_dcpsc_ramp;
    }
```

Figure 5.18 *K-DCPSC section.* C code equivalent to LabView.

called: Ramp Generator, K-DCPSC, Generator Station Runback Control, Scheduled Interchange of Power (SIP), Measuring Point, and Miscellaneous.

Do While Loop

IF ELSE
1. K-DCPSC
2. Generator Station Runback Control
3. Scheduled Interchange of Power (SIP)
4. Measuring Point
5. Miscellaneous

5.3.1.1. *K-DCPSC*: This section takes a number of inputs (K-Min, K-Fraction and Output Power Master), and outputs (Output Power, K-DCPSC output, K-DCPSC Ramp Constant and K-DCPSC Ramp). The *K-DCPSC Ramp* value is initialize to the product of *K-DCPSC* and *Output Power Master* values. On the first interation the *Ramp Constant* is calculated by taking the number of minutes entered by the *Ramp control* (*K-Min*) and converting this value to seconds, then dividing the result by the value of *K-DCPSC Ramp* (**Fig. 5.15**). On the next N interations the *K-DCPSC Ramp Constant* will keep adding to the *Output Power* until the values of either the *K-Fraction* or *K-Min* are changed (**Fig. 5.16**). If the values of *K-Fraction* or *K-Min* are changed then the value of the *Ramp Constant* will be recalculated. If the *Output Power* reaches the *K-DCPSC* value the *Ramp Constant* will

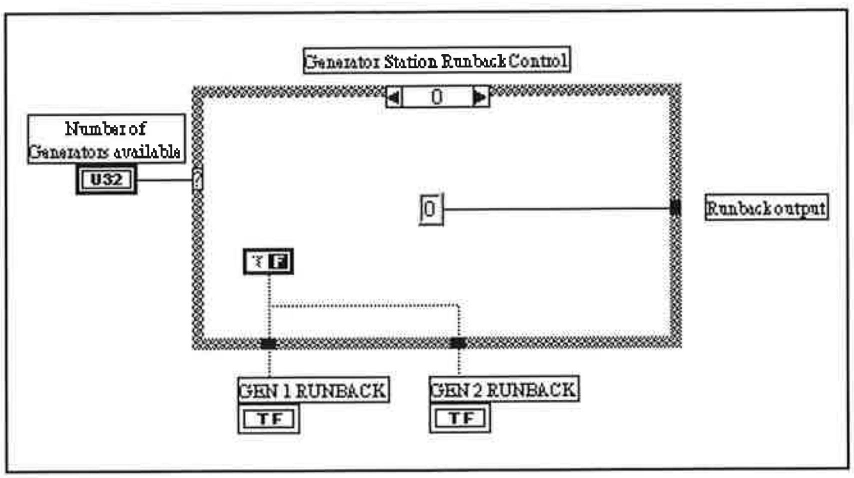


***Figure 5.19** Generator Station Runback Control section.* The true/false boolean constant is used for the turning on/off of the generator's indicators.

stop adding to the *Output Power* (**Fig. 5.17**).

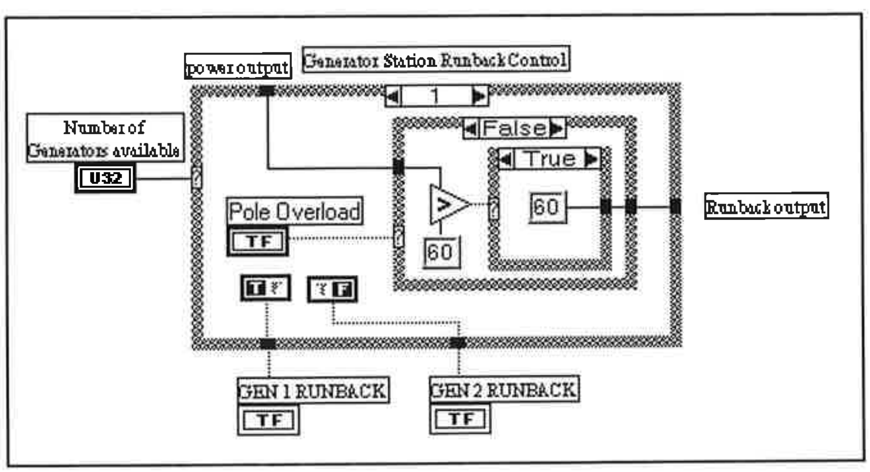


***Figure 5.20** Generator Station Runback Control section.* The numbers enclosed in the squares are constants.

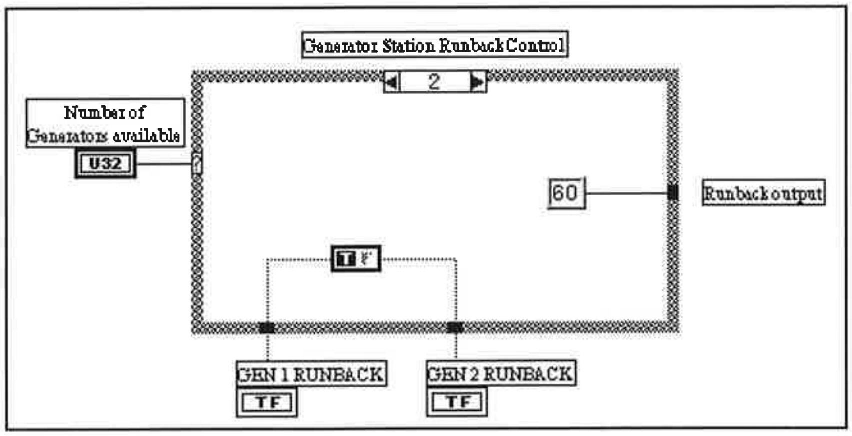


Figure 5.21 *Generator Station Runback Control section.* Another type of IF ELSE statement that is equivalent to a case statement in C.

```
IF (short_time_overload)
    turn on gsrc_indicator;
    select(number_generators_available)
        case 0:
                turn off generator_1_runback_indicator;
                turn on generator_2_runback_indicator;
                runback = 0;
                break;
        case 1:
                turn on generator_1_runback_indicator;
                turn off generator_2_runback_indicator;
                IF(pole_overload)
                        IF(output_power>30)
                              runback = 30;
                        ELSE
                              runback = 0;
                ELSE
                        runback = 0;
                break;
        case 2:
                turn on generator_1_runback_indicator;
                turn on generator_2_runback_indicator;
                runback = 60;
                break;
ELSE
    runback = 0;
output_power -= runback;
```

Figure 5.21 *Generator Station Runback Control section.* C Code equivalent to this section.

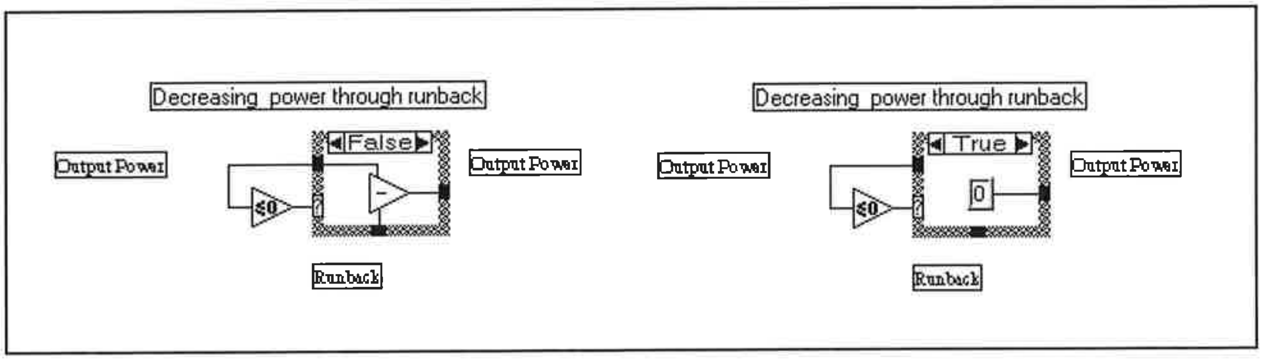


Figure 5.22 *Generator Station Runback Control section.* This implementation was done to protect the output power from going below zero, a task which was not implemented in earlier stages, but will be implemented in the next version.

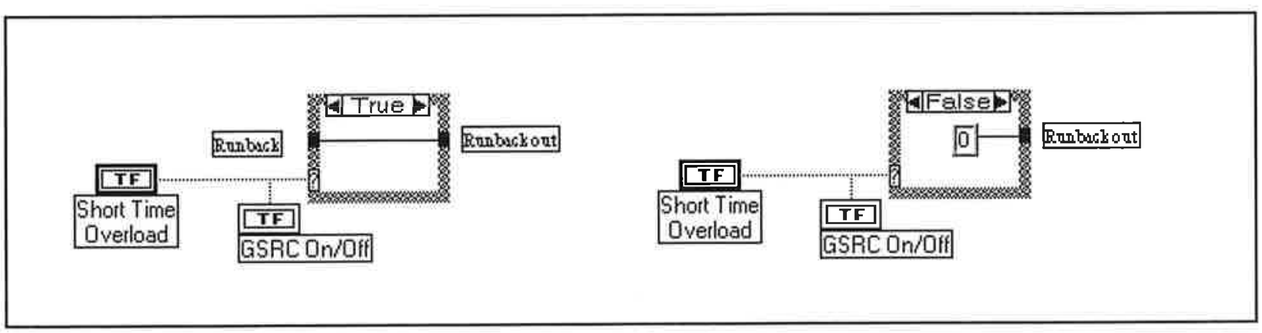


Figure 5.23 *Generator Station Runback Control section.* Runback IF ELSE statement.

5.3.1.2. *Generator Station Runback Control*: This section takes in two inputs (Output Power and Number of Generators Available), and produces three outputs (Gen 1 Runback, Gen 2 Runback and Output Runback). This section is divided in three parallel IF ELSE statements; Generator Station runback, Decrease of power, and short time overload enable. The Generator station runback IF ELSE statement calculates the amount of runback to send out, depending on the number of generators available. If there are no generators available, both *generator available indicator*s will be turned off and the runback output will be set to zero (**Fig. 5.19**). In the case of only one generator available, the indicator for *generator one available* will turn on and the second generator's indicator will turn off. If the pole Overload control from the *Bipole Control Master* is also activated and if the *Output Power* is greater than zero, then the runback output will be set to 30, otherwise the runback output will be set to zero (**Fig. 5.20**). If there are two generators available for use, then both of the

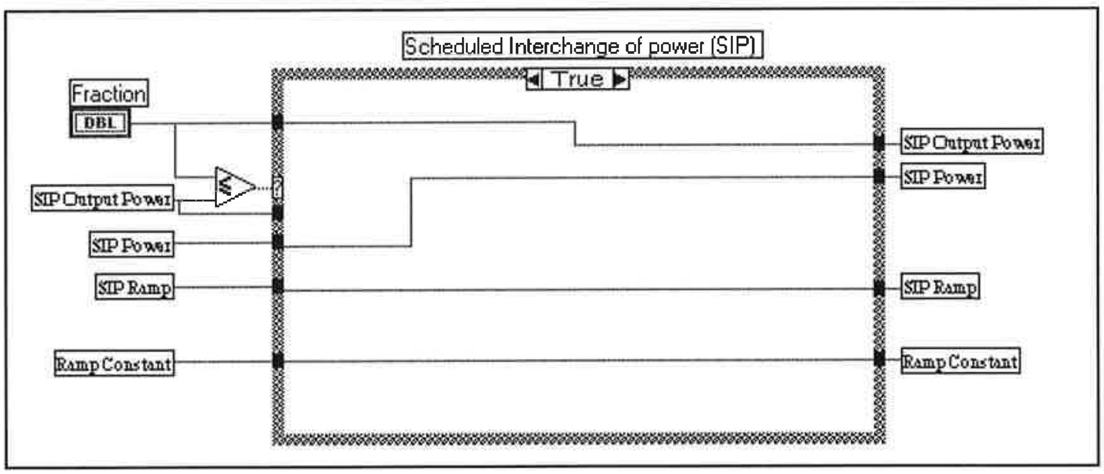


Figure 5.24 *Scheduled Interchange of Power (SIP).* In order to carry out the previous and current values of a variable such as SIP Ramp, a shift register must be implemented.

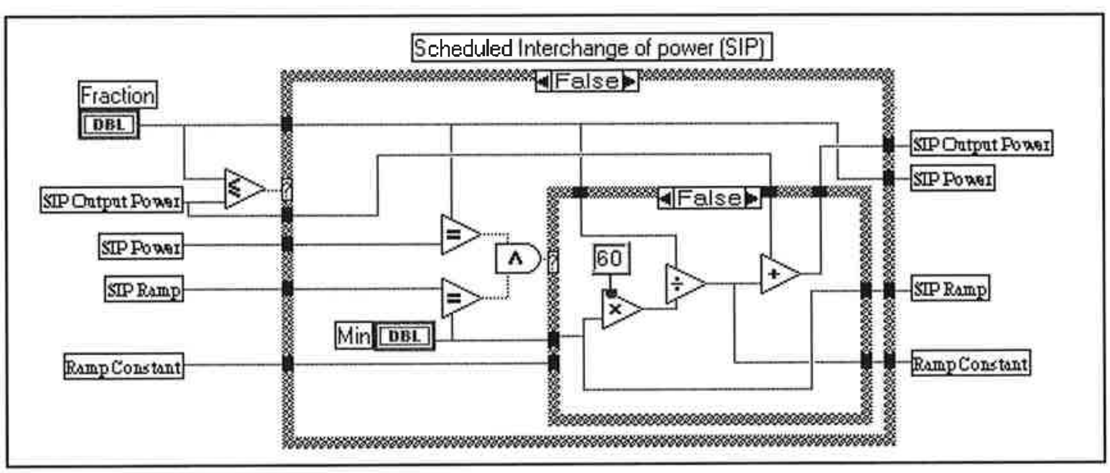


Figure 5.25 *Scheduled Interchange of Power (SIP).* Notice how the first IF ELSE statement containes another statement within it.

```
IF (fraction <= sip_output_power)
    sip_output_power = fraction;
ELSE
    IF (fraction == sip_power && sip_ramp == min){
        sip_output_power += ramp_constant;
        sip_ramp = min;
    }
    ELSE{
        ramp_constant = fraction/(min*60);
        sip_output_power += ramp_constant;
        sip_ramp = min;
    }
```

***Figure 5.26** Scheduled Interchange of Power (SIP).* C Code equivalent to SIP LabView code.

generators indicators will be turned on and the runback output will be set to 60 (**Fig. 5.21**).

The purpose of the Decrease Power section is to decrease the *Output Power* by the amount of runback calculated in the *Generator Station Runback Control*. If the *Power Output* is equal to zero the output will be set to zero also (**Fig. 5.22**).

Short time overload: In order for the generators to be used there should be a short overload. This overload is simulated by activating the *Short Time Overload* switch on the bipole control master. Once this switch is activated, the *GSRC on/off* indicator will be lit and the calculated runback value is transmitted to be subtracted from the *Output Power*, otherwise its output is set to zero (**Fig. 5.23**).

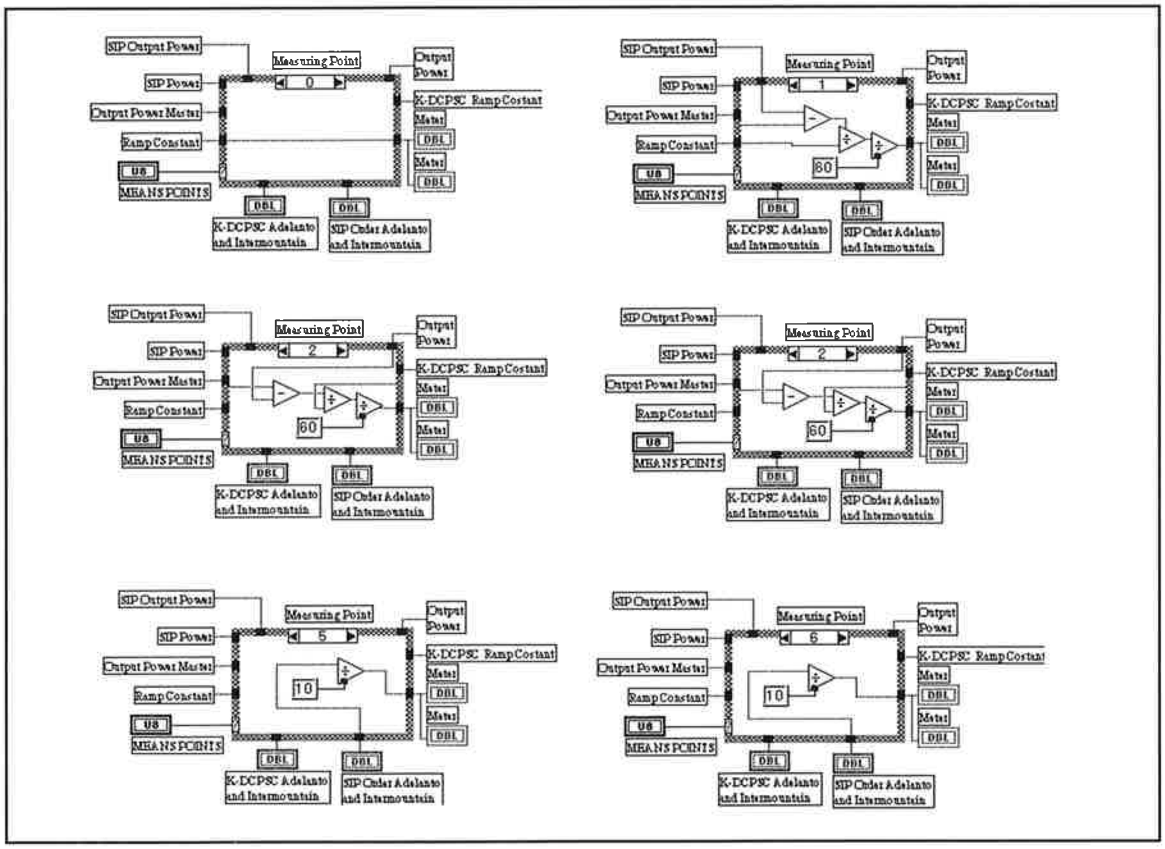


Figure 5.27 *Measuring Point.* Measuring point case statement.

5.3.1.3. *Schedule Interchange of Power*: The scheduled interchange of power (SIP) is the

```
SELECT (means_points)
    case 0:
        meter = output_master_power;
        break;
    case 1:
        meter = (sip_output_power-sip_power)/ramp_constant/60;
        break;
    case 2:
        meter = (output_power_master-output_power)/k_dcpsc_ramp_constant/60;
        break;
    case 3:
    case 4:
        meter = k_dcpsc_ade_inter / 10;
        break;
    case 5:
    case 6:
        meter = sip_order_adel_inter /10;
        break;
```

Figure 5.28 *Measuring Point.* C code equivalent to the case statement in LabView.

power ordered from the AC ties (Mona and Gonder). This is generally considered to come from the two Mona a.c. lines. This stage is simulated by two IF ELSE statements. The first IF ELSE statement is controlled by the *SIP Fraction* and the *SIP Output Power*. If the *SIP Fraction* is greater than the *SIP Output Power*, then the *SIP Output Power* will be set to the *SIP Fraction* (**Fig. 5.24**). If this comparison is less than the *SIP Output Power*, then the second IF ELSE statement comes in, in order for this statement to be true, the *SIP Fraction* must be equal to the *SIP Power* and the *SIP Min* must be equal to the *SIP Ramp* (**Fig. 5.25**). When the statement is true, the *Ramp Constant* value is added to the *SIP Output Power* value. If the statement is false the *Ramp Constant* is recalculated to the *SIP Fraction* value divided by 60 and by *SIP Minutes*. The *Ramp Constant* is added to the *SIP Output Power* value, and the *SIP Ramp* value is set equal to the *SIP Minutes* (**Fig. 5.26**).

5.3.1.4. *Measuring Point*: The Measuring Point is used to display several other values, power, ramp time, etc. To simulate this, a case statement has been implemented (**Fig. 5.27**). This case statement selects from the following list:

00 Bipole Power Order from the DCPSC

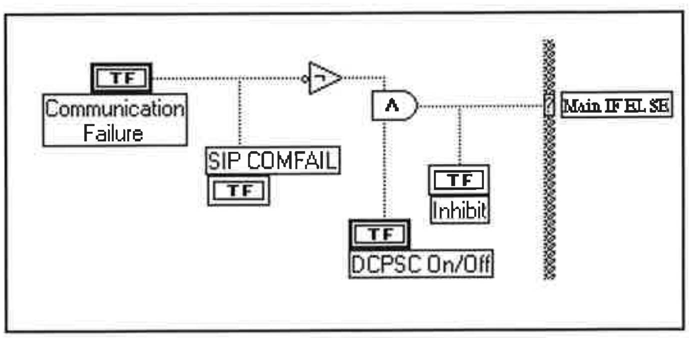
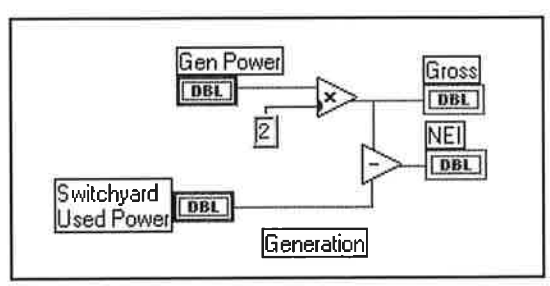


***Figure 5.29** Desk enable/disable.* This section is setup to enable and disable the Desk Control, not to be confused by the Overall switch which if activated will terminate the program.

01 Ramp time Remaining for SIP
02 Ramp time Remaining for K-DCPSC
03 K-DCPSC Order from the ECC RTU in Adelanto
04 K-DCPSC Order from the ECC RTU in Intermountain
05 SIP Order from the ECC RTU in Adelanto
06 SIP Order from the ECC RTU in Intermountain

***Figure 5.30** Generation.* This section calculated the Gross and NEI power.



The Bipole Power Order from the DCPSC reading is taken directly from the *Output Power Master*. The *Ramp Time Remaining* for SIP reading is taken from the substraction of the

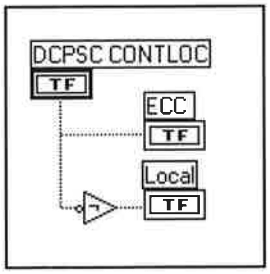


Figure 5.31 *GDCPSC Control Location.* This section is formed of a control and two indicators.

SIP Output Power, minus the *SIP Power*, and then its division by the *Ramp Constant* and the constant 60 (seconds). The *Ramp Time Remaining* for *K-DCPSC* reading is taken from the substraction of the *Output Power Master*, minus the *Output Power* divided by the *K-DCPSC Ramp Constant* and the constant 60 (seconds). The *K-DCPSC Order* from the ECC RTU in Adelanto and Intermountain readings are taken in the same manner; the division of the *K-DCPSC* Adelanto Intermountain by the constant 10. The SIP Order from the ECC RTU in Adelanto and Intermountain readings are also taken in the same manner; the division of the *SIP Order* Adelanto Intermountain by the constant 10 (**Fig. 5.28**).

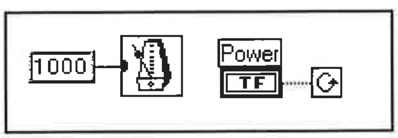


Figure 5.32 *Timer and Overall Control Desk.* These two sections are essential for the accurate and proper execution of the program.

5.3.1.5. *Miscellaneous*: This section has a collection of small functions on the bipole desk control. These functions are: Desk enable/disable, Generation, DCPSC control location, timer, and overall desk control switch.

The Desk enable/disable section has the following controls; communication failure and DCPSC on/off, and the indicators; SIP comfail and Inhibit (**Fig. 5.29**). This section turns off and on the entire desk control except the *Timer* and the *Overall Desk Control* switch. The logic is set by the following table:

Controls:		**Indicators:**		
Communication Failure	DCPSC on/off	SIP Comfail	Inhibit	Bipole Desk Control
Off	Off	Off	Off	Off
On	Off	On	Off	Off
Off	On	Off	On	On
On	On	On	Off	Off

The Generation section displays the gross and the power left after subtracting the power used at the switch yard. This is simulated by multiplying the *Gen Power* by two, displaying the *Gross Power*, subtracting the Switch yard power used, and displaying its result (**Fig. 5.30**).

The DCPSC Control Location displays the controlling location (ECC or Local) (**Fig. 5.31**).

The Timer is set up so that every interation of the main Do While loop takes one second, otherwise the ramp timing will not be accurate (**Fig. 5.32**).

The Overall Desk Control switch is used to terminate the program (**Fig. 5.32**).

Chapter 6

POLE 1 & 2

6.1 Introduction

The *Pole 1* and *Pole 2* are identical therefore the discussion this chapter applies to both poles. The Pole screen handles all of the functions for itself and interfaces with the other pole. The Pole (1 or 2) screen is divided into four different sections; Master Switch Control, Master Indicator Panel, Pole, and Current & Voltage Monitor.

6.1.1. *Master Switch Control*: This section partially emulates the Master Controller from the original design. The master switch control consist of :

1. Grd Neutral Bus Inter Station Switch.
2. Pole (1 or 2) Power/Current Control switch.
3. Metallic Neutral Bus Inter Station switch.
4. Communications Control switch.
5. Telecommunications.
6. Frequency Discriminator.
7. Poles Blocked.

6.1.2. *Master Indicator Panel*: This section displays events that are occurring in the poles using LED's. The master indicator panel consist of :

1. Overload Lower/Raise (OL).
2. Overload On/Off (OL).
3. Recovery On/Off (Recov).
4. Stability On/Off.
5. Control Current/Power.
6. Backup On (B-Up).
7. Frequency Control On.
8. Power Flow (W->E, E->W).
9. Return metallic/ground.
10. Control Sep/Joint.

6.1.3. *Pole* : This section along with the *Current & Voltage Monitor* will be the two main sections the user will interact with during a simulation session.The user will be able to follow changes as they develop within the poles. The Pole panel consist of :

- Sequence Control.
    1. Cont & Ind Mode.
    2. Joint Set Point Control.
    3. Current Return.
    4. Frequency Control.
    5. C&I and SP commfail.
    6. Joint sp Backup Control.
    7. Stability Control.
    8. Power Direction.
    9. Current Memory.
    10. DC Voltage.
    11. Overload Recovery Control.

- Current Control.
    1. Order.
    2. Ramp.
    3. Limit.

- Current Memory.
    1. Calculated.
    2. Memory.
    3. Lower & Rise.

- Open Line Test.
    1. On/Off.
    2. Lower & Rise.

- Emergency Stop.

- Means Points.

6.1.4. *Current Voltage Monitor*: This section displays any changes developing on the poles. The current voltage monitor consists of:

- Current Monitor recorder.
- Voltage meter.

6.2 Operation

In order to run this simulation the Run command must be executed. Once the program is running, the user has the choice of changing any of the default settings on the Master Control.

6.2.1. *Master Control* section consists of (**Fig. 6.1**):

- Toggle Switches.
  1. Ground Neutral Bus Inter Station: This switch simulates the Intermountain Converter station ground return neutral bus disconnect switch.
  2. Pole (1 or 2) Power/Current control: Simulates the status of the other pole; power or current control mode.
  3. Metallic Neutral Bus Inter Station: Simulates the metallic return neutral bus disconnect switch.
  4. Comm Control: Simulates synchronous and asynchronous communications.

- Miscellaneous Switches.
  1. Telecommunications: Simulates C & I and SP communication failures.
  2. Frequency Discriminator Working Properly Box: Simulates the status of the frequency discriminator.
  3. Poles Blocked Box: Simulates the blockage of the poles.

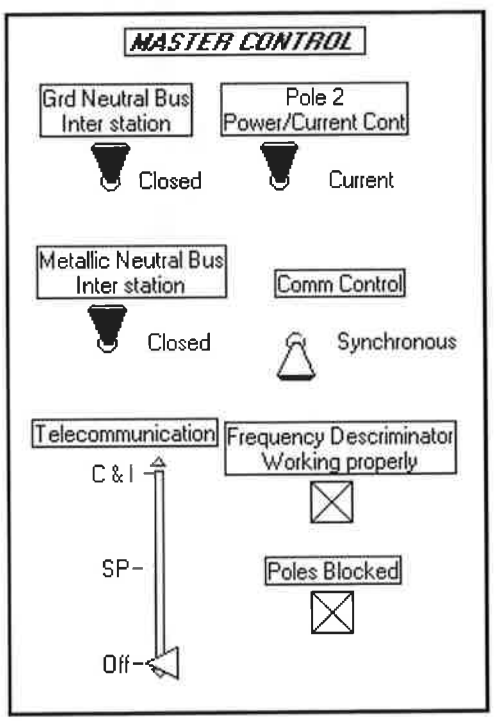


Figure 6.1 *Master Control.* This section is consists of a set of different types of LabView Controls.

- Open Line Test (**Fig. 6.6**).

    1. Off/On switch: This switch simulates the open line test.
    2. Lower Rise Control: This switch will allow the user to increase or decrease the voltage on the DC line.

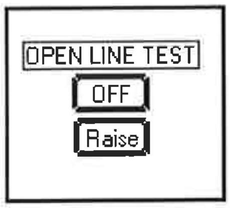


Figure 6.6 *open Line Test.* This section is located on the bottom left of the screen.

- Emergency Trip: This switch will stop the execution of the simulator and will work regardless of any other function or event (**Fig. 6.7**).

Figure 6.7 *Emergency Trip.* This section is rather noticeable due to its red color.

- Means Points (**Fig. 6.8**).

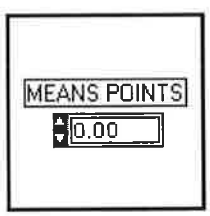


Figure 6.8 *Means Points.* Means points numeric control.

6.3.2. *Power Direction*: This section will display a Power Direction from East to West as a default, but in order for this to occur the telecommunications procedures must be working, the Poles Blocked, the Frequency Control On, and the Power Direction E->W. Otherwise a direction West to East will be displayed (**Fig. 6.12**).

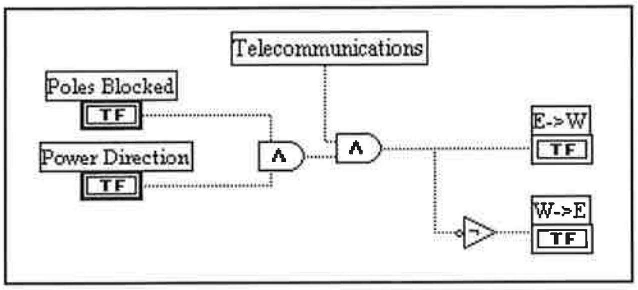


Figure 6.12 *Power Direction.* Power Direction simulator.

6.3.3. *Frequency Control*: This section will indicate when the frequency control mode is on. This mode will only be on if the Frequency Discriminator is working properly (**Fig. 6.13**).

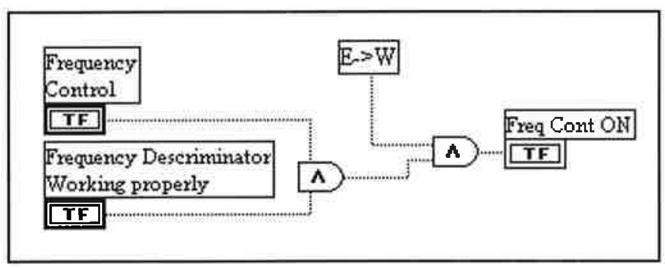


Figure 6.13 *Frequency Control.* Frequency Control LabView code.

6.3.4. *Telecommunications*: This section will indicate when communications fail (**Fig. 6.14**).

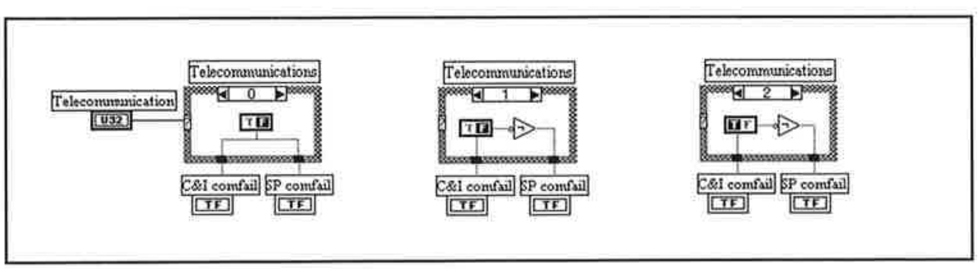


Figure 6.14 *Telecommunications.* Telecommunications CASE statement.

6.3.5. *Back-Up and Location Mode*: This section will simulate the location that is in control as well as the display of the Back-Up On Mode. This Back-Up mode can only be on if the telecommunications are working, the Joint mode is on, the Poles are blocked and the Power direction is from East to West (**Fig. 6.15**).

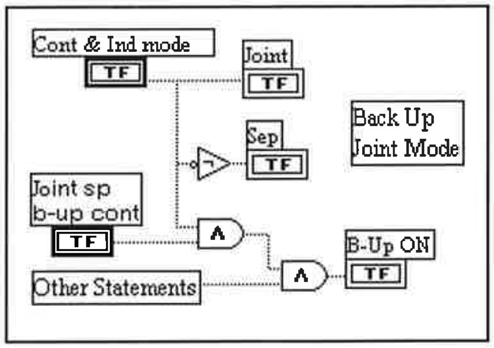


Figure 6.15 *Back-Up & Location mode.* Simple code composed of three gates.

6.3.6. *Stability & Recovery*: This section will display the status of the stability and recovery controls (**Fig. 6.16**).

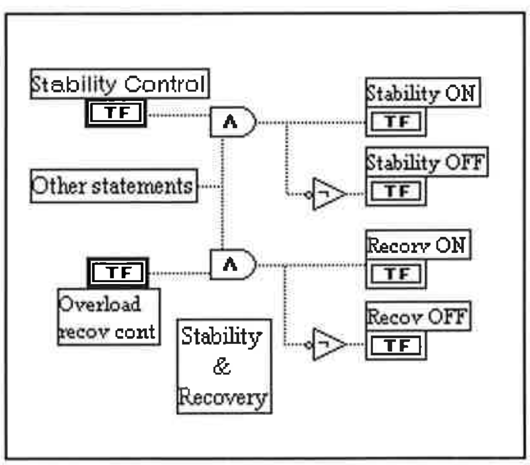
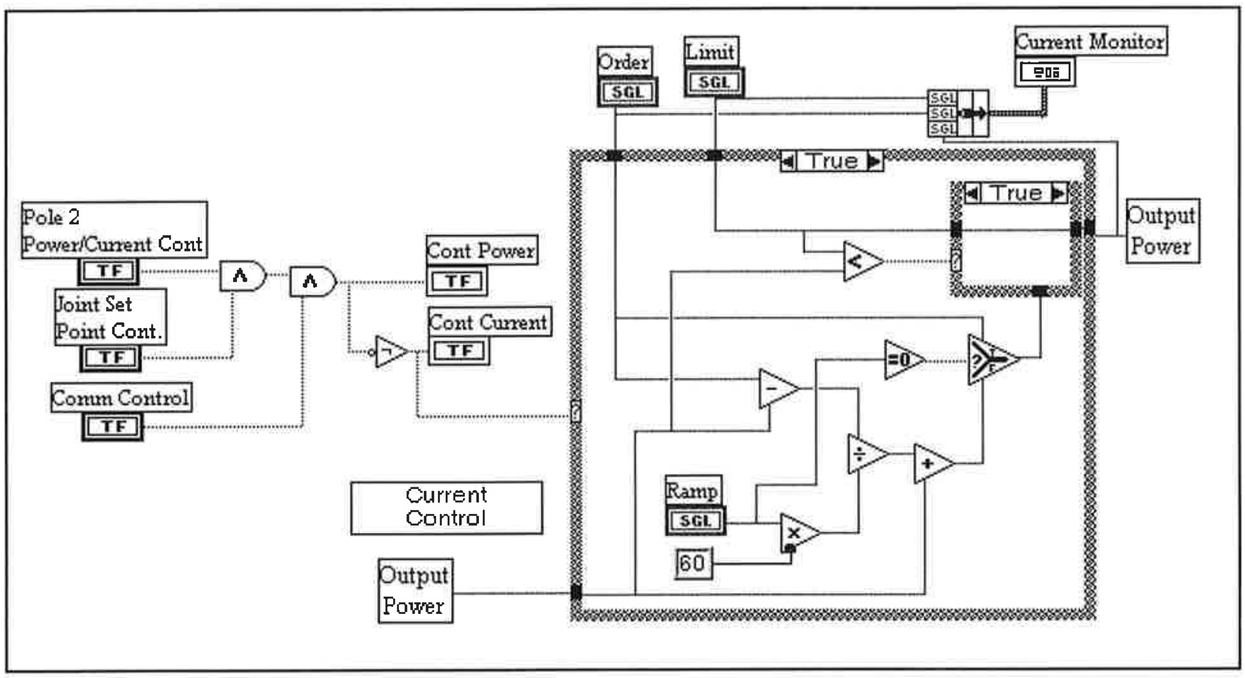


Figure 6.16 *Stability & recovery.* Simple code composed of four gates.

6.3.7. *Current Control*: This section calculates the amount of time the output power will take to reach the order power. The calculations will be done only if the other pole is set to current, the joint set Point control is set to current and the telecommunications are working properly. The rate of increment is calculated through the conversion of the Ramp control's value into seconds and divided by the substraction of the order power minus the output power. If the output power is equal to the limit control, then the summation of the power plus the rate of increment will stop (**Fig. 6.17**).




```
if !(pole_current_power_control&&joint_set_poit&& comm_control)
        Cont Current ON;
        Cont Power OFF;
        if(output_power<limit)
            if !(ramp)
                output_power=order;
            else
                output_power+=order-output_power/(Ramp*60);
        else
            output_power=limit;
else
    output_power=output_power;
```

Figure 6.17 *Current Control.* The most important part of this section is the calculation of the rate of power increment.

6.3.8. *Normal/Reduced Voltage*: This section simulates the option of running the poles on a reduced voltage (**Fig. 6.18**).

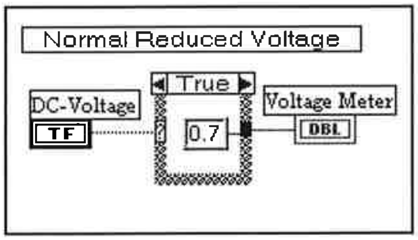


Figure 6.18 *Normal/Reduced Voltage.* This is another type of IF ELSE statement commonly used in LabView.

6.3.9. *Overload*: This section simulates the option turning of On or Off and lowering or raising the overload setting (**Fig. 6.19**).

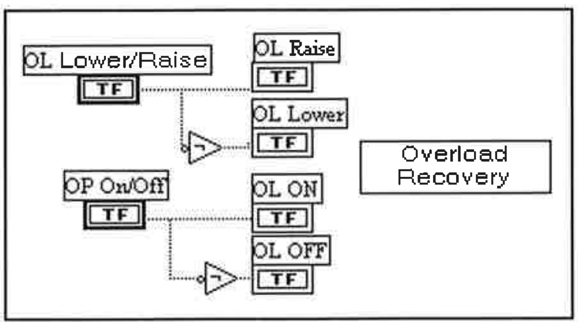


Figure 6.19 *Overload.* Notice the simplicity of this section.

6.3.10. *Timer*: This section helps to time every interation to a regular pace, necessary for accurate increments of power through out the simulation (**Fig. 6.20**).

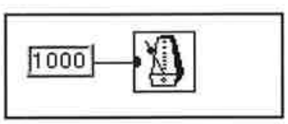


Figure 6.20 *Timer.* Time setting is one second per interation.

6.3.11. *Emergency Trip*: This section stops the execution of the simulation immediately after activation (**Fig. 6.21**).

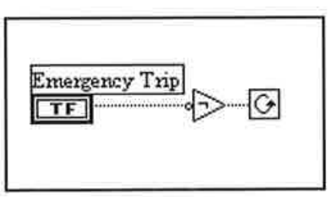


Figure 6.21 *Emergency Trip.* Do While test.

6.3.12. *Others* (**Fig. 6.22**).

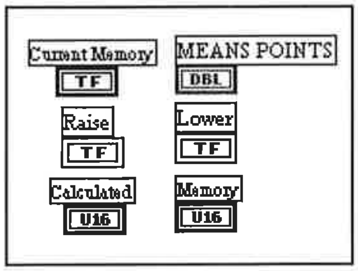


Figure 6.22 *Others.* Controls implemented on the version of this simulator.

PANELS & DIAGRAMS