

Power System Economics and Market Modeling



M5: Security-Constrained Optimal Power Flow



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First – More OPF Topics



- A few more OPF Topics will be covered first
 - Interfaces with Contingent elements
 - How interfaces with Line Open/Close elements are handled
 - Area Transactions as OPF Controls
 - DC Power Flow modeling for the OPF
 - Modeling of Losses in a DC power flow. Is this possible?
 - Both dispatch sensitivities
 - Reduction of generation requirement
 - Modeling of VAR flows. Is this possible?
 - Using the “power circle” and assuming unity voltages

Interfaces with Contingent Elements



- Interfaces can have contingent elements
 - Line OPEN and Line CLOSE elements
- You must specify how you would like to treat these special interfaces
 - Choose the **Options** ribbon tab → **Simulator Options**
 - Go to **Power Flow Solution Page** (default)
 - Go to **General Tab**
 - Monitor/Enforce Contingent Interface Elements
 - Never
 - will never calculate the post-contingent flows on the interface
 - Power Flow/OPF, but not CA/SCOPF
 - in the powerflow and OPF we will show the “post-contingent” flow
 - All Applications including CA/SCOPF
 - In the SCOPF and CA we will also show the “post-contingent” flow

Area Transactions as OPF Controls: Why would you do this?



- Situation #1: If the following situation is met
 - One Area/Superarea is on OPF control
 - A second Area/Superarea does not have cost information and is on Participation Factor Control
 - The second area interacts with the first area, and you have a general “cost curve” for how much the first area purchases/sells power from the second area
 - You can then create a MW transaction between the two areas and specify a “cost curve” which applies to the second area
 - The OPF can then be configured to essentially dispatch the second area as though it’s a giant generator available to buy or sell power from
 - The cost curve specified will be used to dispatch the transaction
 - The second area will spread power out using participation factors.

Area Transactions as OPF Controls: Why would you do this?



- Situation #2: If the following situation is met
 - One Area/Superarea is on OPF control
 - A second Area/Superarea is also on OPF Control
 - You want the two areas to be able to freely transfer power between one another, however you want to limit the maximum amount of transfer between the two
 - You might also want to place a “premium” on the transfer so that the two areas will buy/sell only if the price difference is large than some threshold
 - If you wanted two areas to transfer power between one another without any limits, then you would just create a Super Area with both in it.

Area Transactions as OPF Controls



- You may define area-to-area MW transactions that can be dispatched by the OPF
- Choose **Model Explorer** → **Aggregations** → **MW Transactions**
- Go to **List of Transactions** Tab
- Right-Click and Choose **Insert**
 - You must give the transaction a Minimum/Maximum transfer amount
 - Allow OPF to determine the price
 - If both areas are on OPF, then it will just figure out the appropriate amount of transfer and price (within the range specified)
 - Or may enter a Cost Curve for the transaction
 - If one area is on OPF, and the other is on Part. Factor, then this the area on OPF will “dispatch” the area on Part. Factor as though it’s a big “generator”

Area Transactions as OPF Controls



Specify a Min/Max Range for transfer

Specify an Export Cost Curve and Import Cost Curve

Check to allow dispatch

Check to have OPF determine price (cost curves will not be used then)

Transaction Dialog

Transaction ID: 1
Transacting Area: 1 (Top) On OPF control
Transaction to Area: 2 (Left) On OPF control

Transaction MW Amount: 0.00
Transaction Minimum MW: -100.00
Transaction Maximum MW: 100.00
Exports Transmission Charge: 0.00
Imports Transmission Charge: 0.00

Transaction Enabled
 Transaction Dispatchable in OPF
 Determine Price in OPF

Piecwise Linear Transaction Cost Curves for Area 1 (Top)
Note: Costs are only entered for areas that are not on OPF control. Use negative MW values for imports (purchases) and positive MW values for exports (sales). Costs must be monotonically increasing.

Curve for Area 1 (Top)		Curve for Area 2 (Left)	
MW	\$/MWh	MW	\$/MWh
None	Defined	None	Defined

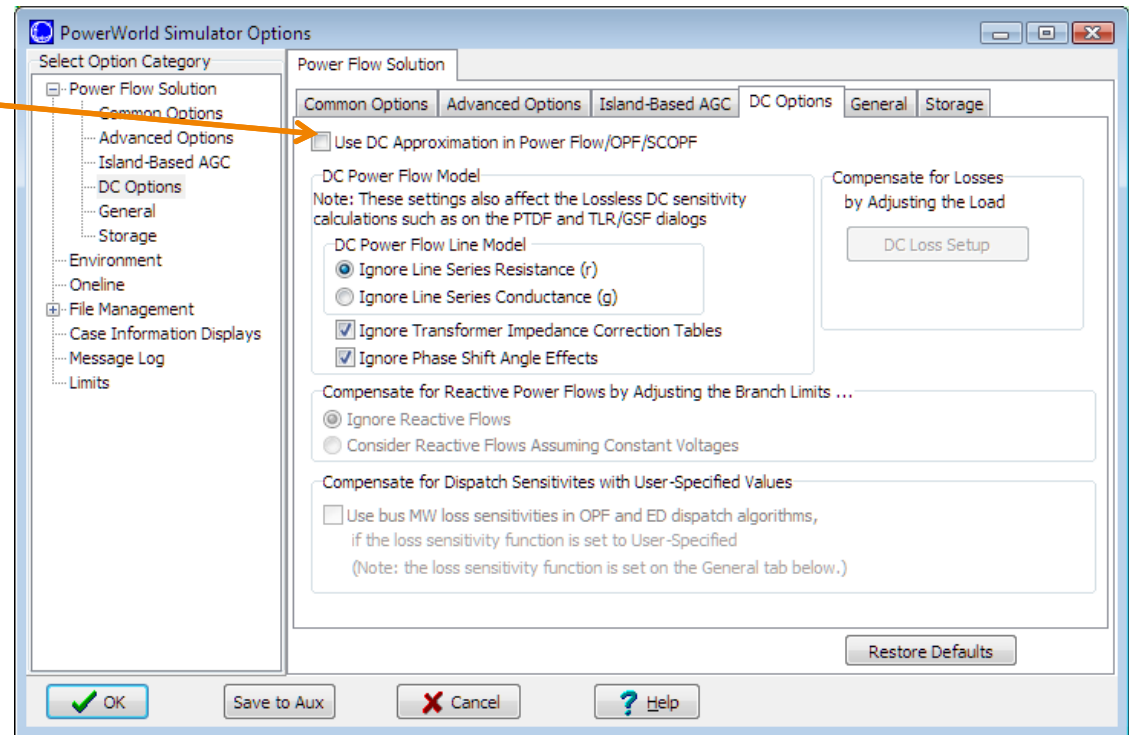
Simulator Options: Power Flow Solution Page



- DC Options Tab
 - Use DC Approximation in Power Flow / OPF / SCOPF

- Check this box to model the system using a DC power flow.

Note: Once you convert a large system to a DC power flow, it is very difficult to get the AC system to resolve.



Simulator Options: Power Flow Solution Page



- DC Options Tab
 - Compensate for Losses by Adjusting Loads
 - Specify a load multiplier at each bus. When solving the DC power, Simulator will artificially increase loads by this multiplier
 - Compensate for Reactive Power Flows by Adjusting the Branch Limits
 - Compensate for Dispatch Sensitivities with User-Specified Values
 - Allows you to make use of loss sensitivities even in the DC power flow

Compensate for Mvar Flows by Adjusting the Branch Limits

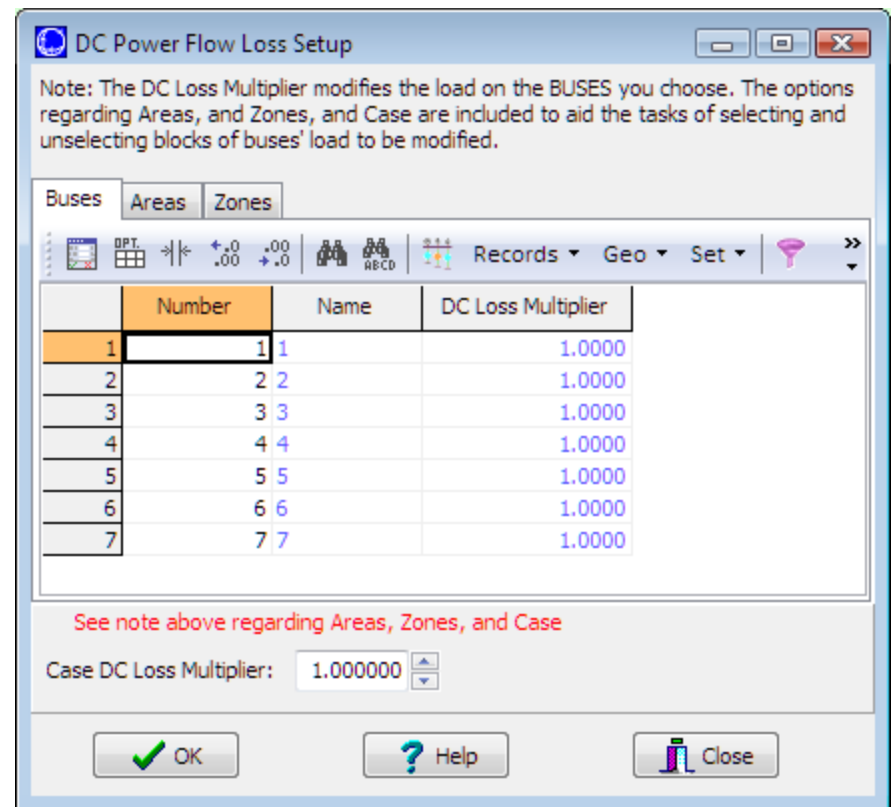


- Normally a DC power flow simply ignores all Mvar flows
- Consider Reactive Flows Assuming Constant Voltages
 - This will modify Simulator so that it approximates Vars flows using a “power circle”
 - If you’re familiar with impedance relay settings, this is similar to those
 - It’s an option to approximate Var flow, but no markets use this right now.

DC Power Flow Loss Setup: Compensate for Losses with Loads



- Click compensate for Losses by Adjusting Loads
- Specify a multiplier at each bus
 - In the DC Power Flow (and thus the OPF/SCOPF), Simulator will artificially increase loads at these buses



Compensate for Dispatch Sensitivities with User-Spec. Values



- Go to the **Tools** ribbon tab → **Sensitivities** → **Loss Sensitivities** and calculate your loss sensitivities
 - Then change the **Loss Function Type** to *User-Specified*
- Now if you choose this check box, the DC power flow will apply a “penalty factor” to each generator according to its loss sensitivity.
 - This approximates how losses would affect the dispatch
 - Some markets do make use of such an approximation.

SCOPF Overview



- Secure power system operation requires that there be no unmanageable base case or contingent violations
- Complete optimization requires considering the base case and contingencies
- Solution of this problem is known as Security Constrained OPF (SCOPF)
- Most of time is spent in contingency analysis
- We will also cover some new features of the OPF which are also helpful in the SCOPF

Contingency Analysis Overview



- Analysis of power system topology resulting from any statistically likely contingency
- Simulator is equipped with tools for analyzing contingencies in an automatic fashion
- Contingencies can be single or multiple element outage

Contingency Analysis



- Contingencies Include:
 - Switching of Lines and Transformers
 - Loss or Recovery of Generating Units
 - Shifting of Load
 - Loss or Recovery of Switched Shunts
- Contingency Analysis tools can be accessed from the **Tools** ribbon tab → **Contingency Analysis**, or from the button on the SCOPF Form

Contingency Analysis Dialog



	Label	Skip	Processed	Solved	Violations	Max Branch %	Min Volt	Max Volt	Max Interface %
1	L_0000011-0000022C1	NO	NO	NO					
2	L_0000011-0000033C1	NO	NO	NO					
3	L_0000022-0000033C1	NO	NO	NO					
4	L_0000022-0000044C1	NO	NO	NO					
5	L_0000022-0000055C1	NO	NO	NO					
6	L_0000022-0000066C1	NO	NO	NO					
7	L_0000033-0000044C1	NO	NO	NO					
8	L_0000044-0000055C1	NO	NO	NO					
9	L_0000077-0000055C1	NO	NO	NO					
10	L_0000066-0000077C1	NO	NO	NO					
11	L_0000066-0000077C2	NO	NO	NO					

Category	Element
None	Defined

Actions
1 OPEN Line 1, 138.0 (1) TO 2, 138.0 (2) CKT 1

Status: **Initialized** Refresh Displays After Each Contingency

Buttons: Load, Auto Insert, Save, Other >, Start Run, Close, Help

The contingency analysis dialog is used to view the contingency analysis process and to edit the contingency set.

SCOPF Solution Process



- SCOPF has three major steps
 - initialization to setup the SCOPF LP tableau and control structures
 - contingency analysis, storing control sensitivities associated with each contingent violation
 - SCOPF iterations, with each iteration enforcing the newest most severe contingent violation
- Open SCOPF dialog from **Add Ons** ribbon tab →
SCOPF
 - The three steps are solved automatically from the button **Run Full Security Constrained OPF**.

SCOPF Solution Process, cont'd



- SCOPF terminates when all of the contingent violations have been processed
- After each violation is processed, all of the unprocessed violations are updated
 - this step is crucial since often resolving the most severe violation resolves numerous other violations
 - example: a single line might be violating in a number of contingencies; fixing the worst contingency fixes the others as well

SCOPF Solution Process, cont'd



- Adjusting controls to relieve some violations may result in new violations that did not previously occur.
- Checking for new violations requires a new contingency solution
 - SCOPF performs this function by iterating the entire process around an Outer Loop
 - Care must be taken since the corrected violations will not be binding in the next Outer Loop Iteration and hence will be excluded from the LP tableau

SCOPF Form: Options



Click to solve an integrated SCOPF

Set maximum number of Outer Loop Iterations

Limiting violations per element can speed up processing

The screenshot shows the 'Options' tab of the 'Security Constrained Optimal Power Flow Form'. The 'SCOPF Specific Options' section contains several controls: a spin box for 'Maximum Number of Outer Loop Iterations' (value: 1), a checked checkbox for 'Consider Binding Contingent Violations from Last SCOPF Solution', an unchecked checkbox for 'Initialize SCOPF with Previously Binding Constraints', and a checked checkbox for 'Set Solution as Contingency Analysis Reference Case'. Below this is another spin box for 'Maximum Number of Contingency Violations Allow Per Element' (value: 12). The 'Basecase Solution Method' section has two radio buttons: 'Solve base case using the power flow' (selected) and 'Solve base case using optimal power flow'. The 'Handling of Contingent Violations Due to Radial Load' section has three radio buttons: 'Flag violations but do not include them in SCOPF' (selected), 'Completely ignore these violations', and 'Include these violations in the SCOPF'. The 'DC SCOPF Options' section includes radio buttons for 'Storage and Reuse of LODFs (when appropriate)': 'None (used and discarded)' (selected), 'Stored in memory only', and 'Stored in memory and case pwb file'. A 'Clear Stored Contingency Analysis LODFs' button is also present. On the right, the 'SCOPF Results Summary' section shows fields for 'Number of Outer Loop Iterations' (0), 'Number of Contingent Violations', 'SCOPF Start Time' (Not started), 'SCOPF End Time', 'Total Solution Time (Seconds)' (0.000), and 'Total LP Iterations' (0). The 'Contingency Analysis Input' section shows 'Number of Active Contingencies' (11) and a 'View Contingency Analysis Form' button. The 'Contingency Analysis Results' section is currently empty.

These fields are updated as contingency analysis solves

SCOPF Form: Options



- Consider Binding Contingent Violations from Last SCOPF Solution
 - Can prevent the SCOPF from hunting between having a constraint binding in one solution, and resolving with it not binding in a later solution because it was previously remedied
 - Leave checked, unless major changes are made to the system since the previous solution
- Initialize SCOPF with Previously Binding Constraints
 - Forces the SCOPF to start with the same LP tableau from the previous solution
 - Helps solution speed when the changes to the system are small
 - Simulator automatically applies this option between multiple outer loops. This option allows the user to solve multiple outer loops by repeatedly solving the SCOPF manually, with outer loop counter = 1.

SCOPF Example: 7-bus Case



- Open case B7SCOPF
- Open **Contingency Analysis** from the **Tools** ribbon tab
- **Auto Insert** all single transmission line or transformer outages (11 total contingencies)

SCOPF Example: 7-bus Case



- Contingency Analysis on the Base Case reveals three violations

The screenshot displays the 'Contingency Analysis' window. The main table lists 10 contingencies with columns for Label, Skip, Processed, Solved, Violations, Max Branch %, Min Volt, Max Volt, and Max Interface %.

	Label	Skip	Processed	Solved	Violations	Max Branch %	Min Volt	Max Volt	Max Interface %
1	L_0000011-0000022C1	NO	YES	YES	1	131.1			
2	L_0000011-0000033C1	NO	YES	YES	1	128.7			
3	L_0000077-0000055C1	NO	YES	YES	1	106.3			
4	L_0000022-0000033C1	NO	YES	YES	0				
5	L_0000022-0000066C1	NO	YES	YES	0				
6	L_0000033-0000044C1	NO	YES	YES	0				
7	L_0000022-0000055C1	NO	YES	YES	0				
8	L_0000044-0000055C1	NO	YES	YES	0				
9	L_0000066-0000077C1	NO	YES	YES	0				
10	L_0000066-0000077C2	NO	YES	YES	0				

Below the main table, there are two smaller tables:

Violations

Category	Element	Value
1 Branch MVA	1 (1) -> 3 (3) CKT 1 at 1	157.31

Contingency Definition

Category	Element	Value
1 OPEN Line 1_138.0 (1) TO 2_138.0		

Status: Finished with 3 Violations and 0 Unsolvable Contingencies. Initial State Restored.

SCOPF Violations



The CTG Violations page lists the results from contingency analysis, which violations were included in SCOPF solution, and the final error for each violation

	Contingency Name	Category	Element	Value	Scaled Limit	New Value	Error	Included	Marginal Cost	Unenforceable	Skip Violation?
1	L_0000011-0000033C1	Branch MVA	1 (1) -> 2 (2) CKT 1 at 2	154.45	120.00	106.87	0.00	NO	0.00	NO	NO
2	L_0000011-0000022C1	Branch MVA	1 (1) -> 3 (3) CKT 1 at 1	157.31	120.00	104.42	0.00	YES	0.00	NO	NO
3	L_0000077-0000055C1	Branch MVA	2 (2) -> 5 (5) CKT 1 at 2	127.56	120.00	120.00	0.00	YES	6.55	NO	NO

Negative errors indicate the violations have been corrected

Tells which violations were used to adjust controls

May be toggled when doing a manual SCOPF solution

SCOPF Solution Details



- LP Basic Variables provide insight to control adjustments and unenforceable constraints

Security Constrained Optimal Power Flow Form

Run Full Security Constrained OPF Close Help Save As Aux Load Aux

SCOPF Status SCOPF Solved Correctly

Options

- Results
 - Contingency Violations
 - Bus Marginal Price Details
 - Bus Marginal Controls
 - LP Solution Details
 - All LP Variables
 - LP Basic Variables
 - LP Basis Matrix

LP Solution Details

All LP Variables LP Basic Variables LP Basis Matrix

	ID	Org. Value	Value	Delta Value	BasicVar	Cost(Up)	Down Range	Up Range
1	Gen 1 #1 MW Control	153.082	102.496	-50.586	1	13.00	82.496	297.504
2	Gen 4 #1 MW Control	50.000	99.655	49.655	4	14.00	49.655	200.345
3	Gen 6 #1 MW Control	250.000	250.000	-0.000	2	17.60	10.000	10.000
4	Gen 7 #1 MW Control	200.274	200.222	-0.052	3	21.80	80.222	39.778
5	Slack-Line 1 TO 3 CKT 1	-37.313	15.584	52.897	5	0.00	15.584	224.416

If a constraint is unenforceable, the Value field associated with its slack variable would be negative.

SCOPF Results



- Note case hourly cost has increased from \$16,011 to \$16,048
- Relieving the contingency violations required increased dispatch of more costly generation

How to handle interfaces with contingent elements in the SCOPF



- Interfaces can have contingent elements
 - Line OPEN and Line CLOSE elements
- Because the SCOPF is already modeling contingencies, you must specify now you would like to treat these special interfaces
 - Choose the **Options** ribbon tab → **Simulator Options**
 - Go to **Power Flow Solution** Page
 - Go to **General** Tab
 - Monitor/Enforce Contingent Interface Elements
 - Never- will never calculate the post-contingent flows on the interface
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