# **PowerWorld Tutorial**

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## Introduction

- PowerWorld is one of the most popular power system simulation tools.
- Evaluation version can be downloaded at: <u>http://www.powerworld.com/download-purchase/demo-software</u>
- Evaluation version can handle up to 12 buses.

## Outline

- > In this tutorial, we will cover:
  - Editing a power system model
  - Running power flow
  - Solving optimal power flow (OPF)
  - Showing locational marginal prices (LMP)
  - Extracting Lagrange multipliers from OPF
  - Showing contours of LMP
  - Solving security-constrained OPF
  - Extracting shift factors

## Editing a Power System Model

- Open "Model Explorer" under "Case Information". All system specifications can be edited here.
- For example, to change the line impedance, change the "R" and "X" column under "Branches Input".
- We can also modify an object by right-clicking it on the one-line diagram.

### Example: editing line parameters

Case: 13bus.PWB Status: Initialized   Simulator 15 Evaluation									
Case Information Draw Onelines	Тоо	ls Opti	ons Add Ons	Window					
	Ne	twork 🝷	l → l		Case	Description	Power Flow List.		
	Ag	gregation -	$\Delta X$		Case	Summary	Quick Power Flo	w List	
Run Mode Model Area/Zone Limit Explorer Filters Monitoring	So	lution Detail	S T Flows T	e <u>S</u> imulator Options	Custo	om Case Info	AUX Export For	nat Desc	
Mode Case Information						Case Data			
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		: Filter A	ovanceo 🖌 Branc	_n	-		_		
Branches Input			To Number	To Name	Circuit	% of MVA Limit (Max)	R	X	
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		2	6 F		1	41.378	0.00000	0.03000	
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Generators		4	5 E		1	8.704	0.00000	0.02500	
Impedance Correction Tables	Ξ	5	2 B		1	25.841	0.00000	0.01800	
🛗 Line Shunts		6	4 D		1	6.209	0.00000	0.02500	
🗉 🚟 Loads		7	3 C		1	88.991	0.00000	0.01500	
🌐 Mismatches		8	4 D		1	1.762	0.00000	0.01500	
🗉 🔡 Multi-Terminal DC		9	9 I		1	5.336	0.00000	0.01500	
III Switched Shunts		10	6 F		1	41.272	0.00000	0.01000	
Three-Winding Transformers		11	7 G		1	45.664	0.00000	0.01000	
Transformer Controls		12	8 H		1	55.336	0.00000	0.01200	
		13	8 H		1	100.000	0.00000	0.00800	
		14	11 K		1	47.668	0.00000	0.01000	
		15	10 J		1	73,333	0.00000	0.01200	
🖃 🎬 Injection Groups		15	11 K		1	52,332	0.00000	0.01000	
Interfaces		17	12 L		1	34,455	0.00000	0.01100	

## Example: Adding and Removing Columns

Not all data is displayed in the table by default.

- To Add/Remove a data column, select "Fields" tab in the Explore Pane.
- Select the data column to add/remove, then click "add->" or "remove <-".</p>

Note that some columns are editable, some are read-only.

### Example: Adding the LMP column

				Mod	lel Explorer: B	uses - C	ase: 13bus.PV	VB Status: Ru	nnir
Case Information Draw Onelin	nes	Tools Opti	ons Ad	d Ons	Window				
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Available Fields             Geography              Island              Island             Island             Island             Island             Island             Island             Island             Island             Island             Island             Island             Island             Island             Island             Island             Island             Island            Island             Island             Neighbors            Net Injection             OPF             Binding Contraint             Marginal Mvar Cost             Marginal Mvar Cost of Congestion	1 2 3 4 5 6 7 7 8 9 10 11 11 12 13	1 / 2 / 3 ( 4 / 5 / 6 / 7 ( 8 / 9 / 10 / 11 / 12 / 13 /	A 3 2 5 5 4 1 4	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1		100.00 100.00 100.00 100.00 100.00 100.00 100.00 100.00 100.00 100.00 100.00	1.00000 0.99995 1.00000 1.00000 0.99989 0.99987 1.00000 0.99991 0.99988 0.99979 1.00000 0.99996 1.00000	100.000 99,995 100.000 99,989 99,987 100.000 99,991 99,988 99,979 100.000 99,996 100.000	
<ul> <li>Marginal MW. Cost</li> <li>Marginal MW Cost of Congestion</li> <li>Marginal MW Cost of Energy</li> <li>Marginal MW Cost of Losses</li> <li>Marginal Voltage Cost</li> <li>Unenforceable Voltage Limit (not used</li> <li>Image: Cost</li> <li>Owners</li> </ul>									

## **Running Power Flow**

- To run an AC power flow, simply click the "Single Solution-Full Newton" under "Tools" tab.
- To run DC power flow, click "Simulator Options", and check "Use DC Approximation ..." under the "DC options" tab.
- With DC power flow, there should be no reactive power generated.
- Click the "Play" button to show the animation of power flow.

## Running power flow



# **Optimal Power Flow**

Optimal power flow (OPF) determines the least cost dispatch of generators considering transmission constraints.

- If we check the option "Use DC Approximation ..." described earlier, DC OPF will be used. Otherwise, AC OPF is used.
- Click "OPF Options and Results ..." under "Add Ons" tab to bring up the "LP OPF Dialog".
- Select "Solution Summary" under "Results". Then click "Initialize LP OPF".

# Solving OPF

Click "Solve LP OPF" to run OPF, the total costs is shown in "Final Cost Function Value".



# Showing LMP

- Select "Buses" in the "Model Explorer."
- > Add the field "Marginal MW Cost" under "OPF." (As shown on slide 7.)
- The value indicates the marginal cost of serving one additional unit of demand at a given bus, which is the locational marginal price:
  - See rest of course for details on definition.

# Showing Lagrange Multiplier of **Power Balance Constraint**

We can show the Lagrange multiplier that represents the "shadow price" of each constraint:

See slides on optimization for definitions.

- > For the power balance constraint, select "Area" in the "Model Explorer".
- > Add the field "MW Marg. Cost for ACE Constraint in OPF", which is the Lagrange multiplier of the power balance constraint.

### Lagrange Multiplier for Power Balance Constraint

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Showing Lagrange Multipliers of Transmission Constraints

Select the "Branches Input" in the "Model Explorer".

> Add the field "MVA Marg. Cost" under OPF, which is the Lagrange multiplier of the binding transmission constraint.

### Lagrange Multipliers for Transmission Constraints

💽 Model Explorer: Branches Input									
Fields	џ (	X Line	and Transformer	Records 🗶 /	Areas × Buse	es			
Explore Fields			ä ** :0 ;0	🐴 🏘 👯	Records •	Geo 🔹 Set 🝷	Columns	• 📴 • 📲 •	👺 - 😤 🛗
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🗄 📄 Island	^	1	1	A	2	2 B	1	69.374	
Labels		2	1	Α	6	5 F	1	41.378	
🕀 🚞 Limit Monitoring		3	2	В	3	3 C	1	54.448	
🗄 🚞 Line Drop/Reac Current Comp		4	2	В	5	5 E	1	8.704	
🕀 🚞 Line Shunts		5	13	M	2	2 B	1	25.841	
표 🚞 Multi-Section Line		6	3	С	4	1 D	1	6.209	
🕀 🧰 MVA		7	12	L	3	3 C	1	88.991	
🕀 🧰 Mvar		8	5	E	4	1 D	1	1.762	
MW		9	4	5	9	) I	1	5.336	
		10	5	E E	-		1	41.272	
Binding Constraint		12	5				1	55 226	
Constraint Status		13	7	G		х н	1	100.000	11 689
Control Phase Shifters in Area of From Pus		14	8	H	11	I K	1	47.668	11.005
A Marrian Mark Cost		15	9	I	10	3	1	73.333	
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Marginal MW Cost at From Bus		17	13	M	12	2 L	1	34.455	
Marginal MW Cost at To Bus									
MVA Limit is Unenforceable									
Phase Shifter Delta Degrees	-								
Phase Shifter Initial Degrees									
Regulation Limit Binding									
Regulation Limit Marginal Cost									
Regulation Limit Unenforceable									
Transformer is Control Variable									
🕀 🚞 OPF Input									

# Extracting Lagrange Multipliers from LP Solution Details

> Another way to extract Lagrange multipliers.

- Click "OPF Options and Results ..." under "Add Ons" tab to call the LP OPF Dialog.
- Select "LP Basis Matrix" under "LP Solution Detail".

The data column "Lambda" represents the Lagrange multiplier of each constraint.

### Extracting Lagrange Multipliers from LP Solution Details

💽 LP OPF Dialog		•
	LP Solution Details	
Common Options	All LP Variables LP Basic Variables LP Basis Matrix Inverse of LP Basis Trace Solution	
Control Options	「 町 小 *** ···· ···· ·····················	
Advanced Options		
- Results	Constraint ID Contingency ID RHS b value Lambda Slack Pos Gen 1 #1 MW Gen Control	n 7 #1 MW Control
Bus MW Marginal Price Details	SuperArea DefaultSA1 MW Constra         Base Case         0.000         35.000         7         1.000	1.0
Bus Mvar Marginal Price Details	2 Line from 7 to 8 ckt. 1 Base Case 0.000 11.689 8	0.4
Bus Marginal Controls		
I P. Basic Variables		
LP Basis Matrix		
Trace Solution		
		+
✓ OK Solve LP	LP OPF Single Outer Loop Initialize LP OPF Save As Aux Load Aux Print ? Help X Cancel	

## Showing Contours of LMPs

> The "Contouring" function can visualize various numerical data, such as voltages, angles, prices, and etc, as color contours. Click "Contouring" in "Onelines" tab. Select "Bus" in "Object", and then select "OPF\Marginal MW Cost" in "Value". > Press "OK" to plot contour.

# Plotting LMP Contours

- Contour map can be customized by adjustments in "Contour Type Options" and "Custom Color Map".
- The color contour map can be saved as image file by right-click on the onelines, then choose "Export Image to File".



### Exporting Image to File



## Solving Security-Constrained OPF

- Security-Constrained OPF (SCOPF) runs iteratively between solving an OPF and running a contingency analysis (CA).
- > To solve SCOPF, a contingency list must be defined in advance.
- Select "Contingency Analysis" under "Tools" tab.

## Define CA List

- Click "Insert" under "Records".
- Click "Insert New Element" to bring up the "Contingency Element Dialog"
- Choose the element and the action type, then press "OK".
- We could also use Auto Insert to insert multiple contingencies at a time.



### Manually Define CA List

Contingency Analysis	Dialog		
Contingency Label New	Contingency Element	Dialog	
Definition Custom Moni	Element Type Branch Generator	Choose the Element  Sort by Name  Number	
Insert New Element	© Load Simoled Shant © Bus © Interface	Search For Near Bus	Select Far Bus, CKT 2 (B) [100 kV] CKT 1 6 (F) [100 kV] CKT 1
	<ul> <li>Injection Group</li> <li>Series Capacitor</li> <li>DC Line</li> <li>Phase Shifter</li> <li>3-Winding Transformer</li> <li>Solve Power Flow</li> <li>Contingency Block</li> </ul>	4 (D) [100 kV] 5 (E) [100 kV] 6 (F) [100 kV] 7 (G) [100 kV] 8 (H) [100 kV] 9 (I) [100 kV] 10 (J) [100 kV] 11 (K) [100 kV] 12 (L) [100 kV]	
Viola Sł Use specific solution of Define Solution Option Ignore ALL contingenc specific solution option	Action Type Open Close Move Set To Change By Open Breakers	Amount 0 Constant * Find Make-up Power Sources	in MW (const pf) Percent MW Mwar Setpoint Voltage
	Status: CHECK Model Criteria: Add Comment:	•]	
•	🗸 ок	Cancel ? Help	2

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## Automatically Define CA List

 $\succ$  For example, generating a contingency list with each contingency composed of a single line/ transformer outage.

Auto Insertion of Contingencie:	5						
Automatically generate contingency involving a         Single transmission line         Single transmission line or transformer         Single generating unit         Single generating unit         Single bus         Image: Single generating unit         Single generating unit         Single bus         Image: Single generating unit         Single generating unit outages         Image: Single generating unit outages		Action Type to Create Open  Open  Open Breakers					
		Options  Delete Existing Contingencies  Use Area/Zone Filters  Only include branches meeting  Only include generators meeting  Only include buses meeting  Only include elements within	Edit Area/Zone Filter Define Branch Filter Define Generator Filte Define Bus Filter				
		X Cancel	Help				

# Solving SCOPF

Click "SCOPF" under "Add Ons" tab.

- Enter a value in the "Maximum Number of Outer Loop Iterations". For small systems, 10 is usually sufficient.
- Press "Run Full Security Constrained OPF".
- Similar to solving an OPF, we can check the Lagrange Multipliers for both pre- and postcontingency constraints at LP solution details.

Again, if we check the option "Use DC Approximation ..." described earlier, DC SCOPF will be used. Otherwise, AC SCOPF is used.

## Solving SCOPF



Extracting Shift Factors (Power Transfer Distribution Factors)

- Shift Factors represent the sensitivity of power flow on a given line with respect to power injection at a given bus/zone and withdrawal at another bus/zone.
- Click the "Sensitivities" in "Tools" tab. Select "TLR Sensitivities / Generation Shift Factors".
- Choose "Multiple Element" in "Device Type". Select the line or transformer we are interested in the dialog brought up by clicking "Select Lines/XFMR".
- Transactor type "Seller"/"Buyer" calculates the sensitivities with respect to injecting/withdrawing power.
- Press "Calculate TLR Sensitivities."

Power transfer distribution factors represent the sensitivity of power flow for injection at a given bus and withdrawal at the slack bus.

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## **Extracting Shift Factors**

C TLR Sensitivities / Generatio	n Shift Factors				
Select Device		T	ransactor		
Device Type Lines/	XFMRs or Interfaces		Type	Sort by Name ONumber	
○ Line/XEMR	es and Transformers		Buyer	Sort by O Name O Number	
			Seller		
	ienales		Transactor Object	None Defined	
Multiple Elements	th				
Which	Devices		Area		
<ul> <li>Se</li> </ul>	lected Devices				
() Ov	verloaded Devices		Super Area		
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2 2 8	1	0.7772	0.7772	0.7772	
4 4 0	1	0.5918	0.5918	0.7318	
5 5 E	1	0.5457	0.5457	0.5457	
6 6 F	1	0.4456	0.4456	0.4456	
7 7 G	1	0.5224	0.5224	0.5224	e 📗
8 8 H	1	0.5037	0.5037	0.5037 Shift Factors o	t line
<u>9</u> 91	1	0.5541	0.5541	0.5541	
10 10 1	1	0.5541	0.5541		
11 11 K	1	0.5289	0.5289	0.5289	
12 12 L	1	0.74/2	0.7472		5 Z 📗
15 13 1	1	0.7586	0.7586	0.7500	

## Saving Data into Excel/CSV

Data shown in a table can be saved into a Excel or csv file.

Right-click on any table, move cursor on "Copy/Paste/Send", and select "Send All to Excel". A Excel spread sheet will be brought up.

Or, Right-click on the table, move cursor on "Save As", and select the desired format.

# Summary

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- Running power flow
- Solving optimal power flow (OPF)
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- Extracting Lagrange multipliers from OPF
- Showing contours of LMP
- Solving security-constrained OPF
- Extracting shift factors