Simple Reformation of Conventional Power Flows to Enhance Resilient Power Grid Analysis

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Objectives

Upon completion of the presentation, the participants will be able to:

1. Identify Renewable Energy Influence to an Evolving Power Grid
2. Recall Conventional Power Flows
3. Introduce a Robust Distributed Slack Bus Method
4. Highlight the Advantages of this Simple Reformation in Power Flows

Emerging Challenges in Power System

- Renewable energy is growing in the upcoming decade, edging out fossil fuels and reducing greenhouse gas emissions, and reducing air pollution.
- Technologies of solar and wind are at the heart of transformations taking place across the global energy system.
- How to ensure efficiently supporting the new mix of generation assets to provide customers with safe and reliable power at the lowest cost possible.
- The high volatility of wind and solar resources makes new challenge in power system operations and analyses.

A New Distributed Slack Bus Power Flow Formulation

- Simple Reformation of Conventional Bus-Oriented Power Flows
- Determine Participation Factors to Allocate Generations
- Enable to Simply Implement in Existing EMS
- Promises to Enhance Resilient Power Grid Analysis.

Conventional Power Flows

The power balance equations of a power system in polar form

$$P_i = \sum_{\substack{j=1 \\ j \varepsilon i}}^{n} \left| V_i V_j Y_{ij} \right| \cos(\delta_i - \delta_j - \theta_{ij})$$

$$Q_i = \sum_{\substack{j=1 \\ j \varepsilon i}}^{n} \left| V_i V_j Y_{ij} \right| \sin(\delta_i - \delta_j - \theta_{ij}) \qquad i = 1, 2, ..., n$$

$$\Delta P_i = P_i^{given} - P_i$$

$$\Delta Q_i = Q_i^{given} - Q_i$$

Newton-Raphson Power Flow(N-R)

$$\begin{bmatrix} \mathbf{\Delta P} \\ \mathbf{\Delta Q} \end{bmatrix} = \begin{bmatrix} \mathbf{H} & \mathbf{N} \\ \mathbf{M} & \mathbf{L} \end{bmatrix} \begin{bmatrix} \mathbf{\Delta \delta} \\ \mathbf{\Delta V} \end{bmatrix}$$

Fast Decoupled Power Flow(FDPF)

$$\Delta P/V = [B']\Delta \delta$$

$$\Delta Q/V = [B'']\Delta V$$

Participation Factors

Minimize $$F_T = \sum_{i=1}^{GN} F_i$$

Subject to

$$\sum_{i=1}^{GN} P_{Gi} = P_{load}^{total} + P_{loss}^{total}$$

$$P_{\min Gi} \le P_{Gi} \le P_{\max Gi}$$

$$P_{\min l} \le P_l \le P_{\max l}$$

Incremental Real Power balance Equation:

$$\sum_{i=1}^{GN} \Delta P_{Gi} = \Delta P_{loss} + \sum_{j=1}^{LDN} \Delta P_{loadj} \Rightarrow \sum_{i=1}^{GN} \Delta P_{Gi} = \Delta P_{loss}$$

Participation factor of each generating unit:

$$k_i = \frac{P_{Gi}}{P_{load}^{total} + P_{loss}^{total}} \Rightarrow k_i = \frac{P_{Gi}}{P_{load}^{total}}$$

Distributed Slack Bus Load Flow Embedded in PFs

Increment Real Power Balance Equation $\Delta DP_{total} = \sum_{i=1}^{GN} \Delta P_{Gi}$

Real Power at Generator Bus i $P_{Gi} = P_{Gi}^{0} + k_i \Delta DP_{total}$, $i=1.2\ldots,N_G$

Generator Bus Participation Factor $\frac{\partial P_i}{\partial DP_{total}} = k_i$

A. New Newton-Raphson Load Flow Formulation Based on Distributed Slack Bus

$$\begin{bmatrix} \mathbf{\Delta P} \\ \mathbf{\Delta Q} \\ --- \\ \Delta P_n \end{bmatrix} = \begin{bmatrix} \mathbf{H} & \mathbf{N} & | & \frac{\partial \mathbf{P}}{\partial DP_{total}} \\ \mathbf{M} & \mathbf{L} & | & \mathbf{0} \\ -- & -- & - & ---- \\ \frac{\partial P_n}{\partial \boldsymbol{\delta}} & \frac{\partial P_n}{\partial \mathbf{V}} & | & \frac{\partial P_n}{\partial DP_{total}} \end{bmatrix} \begin{bmatrix} \mathbf{\Delta \delta} \\ \mathbf{\Delta V} \\ ----- \\ \Delta DP_{total} \end{bmatrix}$$

Distributed Slack Bus Load Flow Embedded in PFs (cont')

B. Distributed Slack Bus Is Embedded in Decoupled Power Flow

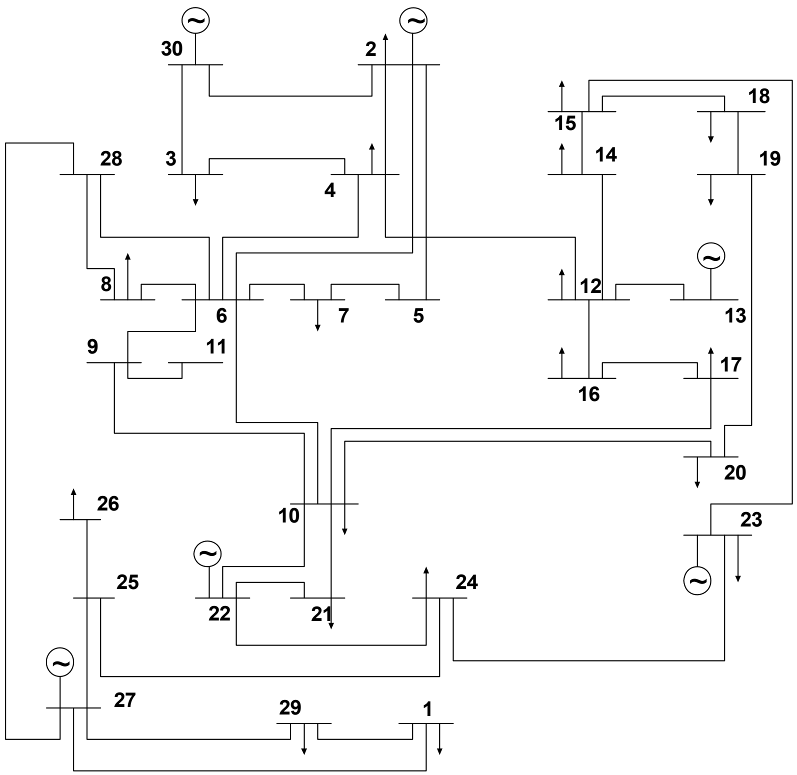
$$\begin{bmatrix} \Delta P_1 \\ \Delta P_2 \\ \vdots \\ \Delta P_n \end{bmatrix} = \begin{bmatrix} \frac{\partial P_1}{\partial \delta_1} & \cdots & \frac{\partial P_1}{\partial \delta_{(n-1)}} & \frac{\partial P_1}{\partial DP_{total}} \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \frac{\partial P_n}{\partial \delta_1} & \cdots & \frac{\partial P_n}{\partial \delta_{(n-1)}} & \frac{\partial P_n}{\partial DP_{total}} \end{bmatrix} \begin{bmatrix} \Delta \delta_1 \\ \vdots \\ \Delta \delta_{n-1} \\ \Delta DP_{total} \end{bmatrix}$$

Further, applying the fast decoupling technique

$$\begin{bmatrix} \frac{\Delta P_1}{V_1} \\ \cdots \\ \frac{\Delta P_{n-1}}{V_{n-1}} \\ --- \\ \frac{\Delta P_n}{V_n} \end{bmatrix} = \begin{bmatrix} & \vdots & \frac{\partial P_1}{V_0 \partial DP_{total}} \\ B'_{(n-1)(n-1)} & & \cdots \\ & \vdots & \frac{\partial P_{n-1}}{V_0 \partial DP_{total}} \\ ----- & & --- \\ B'_{n1} \cdots B'_{n(n-1)} & \vdots & \frac{\partial P_n}{V_0 \partial DP_{total}} \end{bmatrix} \begin{bmatrix} \Delta \delta_1 \\ \cdots \\ \Delta \delta_{n-1} \\ --- \\ \Delta DP_{total} \end{bmatrix}$$

Modified IEEE 30 Bus Test System

THE SYSTEM DESCRIPTION



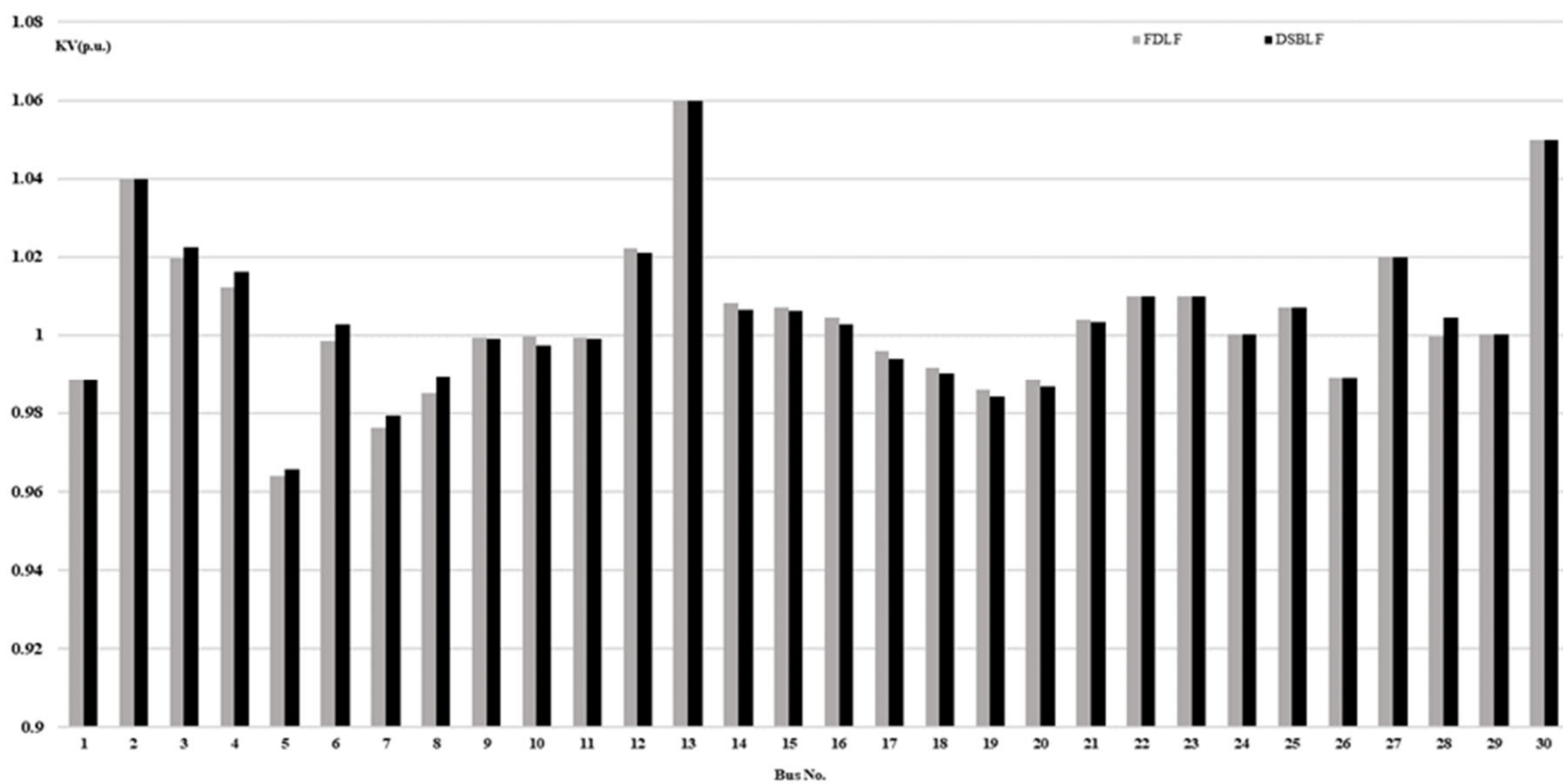
Bus Number	30
Generation Number	6
Branch Number	43
Total Load in MW	283.4
Total Available Units in MW	425

Performance Comparison of FDLF and DSBLF

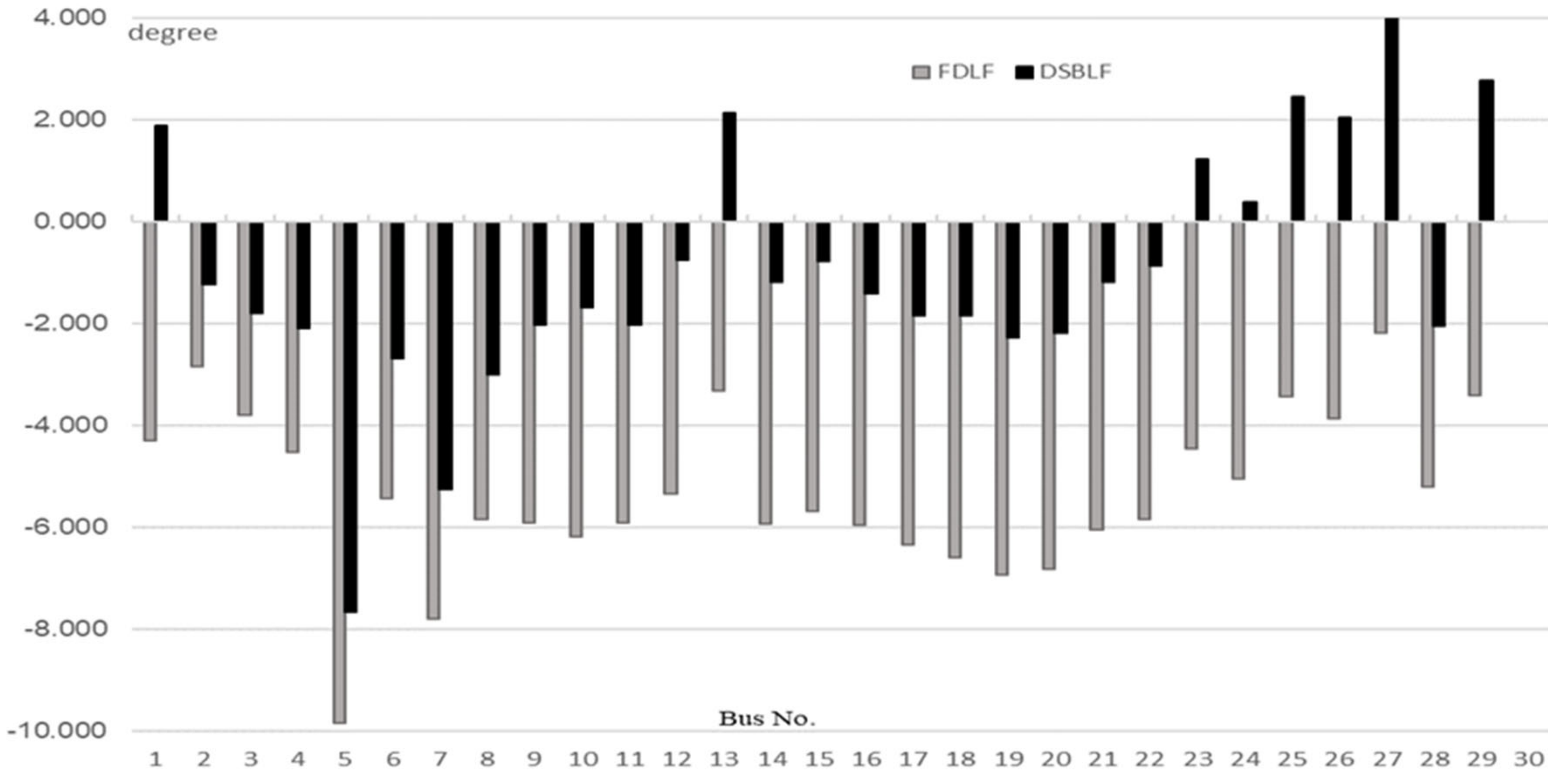
G bus	|V|	P_{max} (MW)	Fast Decoupled LF			Distributed Slack Bus LF			
			Angle	P(MW)	Q(MVR)	k	Angle	P(MW)	Q(MVR)
2	1.04	100	-2.8316	53.50	56.89	0.1833	-1.2245	75.57	40.17
13	1.06	50	-3.3080	27.50	29.17	0.0942	2.1431	38.85	30.50
22	1.01	60	-5.8472	25.00	26.70	0.0856	-0.8676	35.31	26.23
23	1.01	35	-4.4619	17.00	-1.52	0.0582	1.2301	24.01	-4.38
27	1.02	60	-2.1774	38.00	9.57	0.1302	4.0096	53.68	8.46
30	1.05	120	0.0000	130.97	8.09	0.4487	0.0000	62.83	24.50
Total P/Q		425		291.97	128.90			290.25	125.49

FDLF: Fast Decouple Power Flow
DSBLF: Distributed Slack Bus Power Flow

Voltage Magnitudes Comparison of FDLF and DSBLF



Voltage Phasor Angle Comparison of FDLF and DSBLF



Summary

- The Proposed PF Method is No Significant Modifications in the Conventional Load Flow Algorithms
- It Permits EMS Owners Easily Reform Existing PF Algorithms for Real-Time and Planning PF Study in the Resilient Power Gird.
- This Approach Performs Resilient Power System Analysis with Good Accuracy at High Computation Speed
- Test Results Demonstrate the New Method Effectively Allocates Generation Resources, Improves Bus Voltage Profiles and Reduces Line Losses
- This Method Affords Potential in Helping Power Market Analysis and More Comprehensive Testing and Studies are under the Way

What Questions Do You Have