Biography of Fangxing (Fran) Li

- **B.S. (1994) and M.S. (1997) degrees from Southeast University (China)**
- **Ph.D. (2001) degree from Virginia Tech**

- **Senior Engineer, 02/2001 ~ 03/2005, ABB Consulting, Raleigh, NC**
- **Principal Engineer, 04/2005 ~ 08/2005, ABB Consulting, Raleigh, NC**
- **Assistant Professor, 08/2005 ~ present, The University of Tennessee, Knoxville, TN**

- **Registered Professional Engineer in North Carolina (NC)**
- **IEEE Senior Member, 2005**
- **UT Eta Kappa Nu Outstanding Teacher Award, 2006**

Reactive Power Planning:
(1) A Review
(2) VSCOPF with TSV Approach

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Outlines

- Introduction to Reactive Power Planning
- Review of RPP: Objectives, Constraints, and Algorithms
- Voltage Stability Constrained OPF approach with Two Sets of Variables
- Conclusions

Introduction

Motivation

- Reactive power, or Var, is a critical need for power system operation, and has received greater attention by utilities and researchers since the Great Northeastern Blackout in August 2003.
- The development in Var compensators like SVC and STATCOM makes it more attractive to site Var at appropriate locations with appropriate amount.
- Review of RPP: objectives, constraints, and algorithms
- Present a RPP approach considering voltage stability with two sets of variables

Review of RPP: Objectives, Constraints, and Algorithms

Objective functions

- *Minimize Var cost*
  - $C1 \cdot Qc$ (no fixed cost)
  - $(C0 + C1 \cdot Qc) \cdot x$ (with fixed cost $C0$)
- *Minimize Var cost and real power losses*
- *Minimize Var cost and generator fuel cost*
- *Minimum deviation from a specified point*
  - $\sum(V_i^{max} - V_i)$
- *Voltage stability related objectives*
- *Multi-objective (MO)*

Constraints

- Optimal Power Flow (OPF)
  - *Minimize $f(u,x)$*
  - *Subject to $g(u,x) = 0$*
  - *$h(u,x) \geq 0$*
- Security Constrained OPF (SCOPF)
  - Considers security constraints
- Voltage stability constrained OPF
  - Considers voltage stability constraints

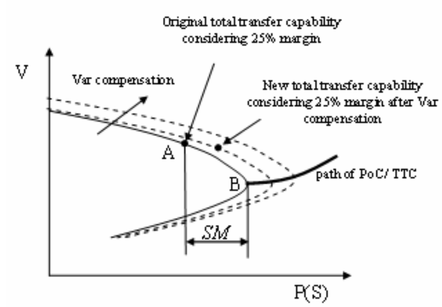
Solution Algorithms

- ***Conventional Approaches***
  - ***Linear programming***
  - ***Nonlinear programming***
  - ***Mixed integer nonlinear programming***
- ***Intelligent Searches***
  - ***Simulated annealing***
  - ***Evolutionary Algorithms***
  - ***Tabu Search***
- ***Fuzzy set theory***
  - ***To address uncertainties in constraints as well as objective functions***

Voltage stability constrained RPP with two sets of variables

Var compensation and stability margin

- **Var compensation increases total transfer capability**



- **Var, TTC and cost**
  - **We may apply an enumerative approach to site Var**

Var compensation Q_c → (Nonlinear OPF) → TTC → (Nonlinear OPF) → fuel cost

A generic approach of two sets of variables

$$Min:\ C(x_o, \rho) \;\Rightarrow\; \sum f_1(P_{Goi}) + \sum f_2(Q_{ci}) \times y_i$$

Subject to:

$$F(x_o, \rho, TTC_o) = 0$$
$$F(x_*, \rho, TTC_*) = 0$$
$$(TTC_* - TTC_o)/TTC_* = SM$$
$$SM \geq SM_{spec}$$
$$x_{o,min} \leq x_o \leq x_{o,max}$$
$$x_{*,min} \leq x_* \leq x_{*,max}$$
$$\rho_{min} \leq \rho \leq \rho_{max}$$

Constraints applicable to both of the normal operating point and PoC

$$\sum y_i = k \quad (\text{Number of Var compensator installations})$$

$$P_{Goi} - P_{Loi} - P(V_o, \theta_o) = 0 \quad (\text{Real power balance})$$

$$P_{G*i} - P_{L*i} - P(V_*, \theta_*) = 0$$

$$Q_{Goi} + Q_{ci} - Q_{Loi} - Q(V_o, \theta_o) = 0 \quad (\text{Reactive power balance})$$

$$Q_{G*i} + Q_{ci} - Q_{L*i} - Q(V_*, \theta_*) = 0$$

$$P_{Gi}^{min} \le P_{Goi} \le P_{Gi}^{max} \quad (\text{Generation real power limits})$$

$$P_{Gi}^{min} \le P_{G*i} \le P_{Gi}^{max}$$

$$Q_{Gi}^{min} \le Q_{Goi} \le Q_{Gi}^{max} \quad (\text{Generation reactive power limits})$$

$$Q_{Gi}^{min} \le Q_{G*i} \le Q_{Gi}^{max}$$

$$V_i^{min} \le V_{oi} \le V_i^{max} \quad (\text{Voltage limits})$$

$$V_i^{min} \le V_{*i} \le V_i^{max}$$

$$|LF_{lo}| \le LF^{max} \quad (\text{Line flow thermal limits})$$

$$|LF_{j*}| \le LF^{max}$$

$$SM = \frac{\sum_{l \in Lt} S_{j*} - \sum_{l \in Lt} S_{lo}}{\sum_{l \in Lt} S_{j*}} \quad (\text{Tie line MVA TTC security margin})$$

$$SM \ge SM_{spect} \quad (\text{Security margin limits})$$

$$Q_{ci}^{min} \le Q_{ci} \le Q_{ci}^{max} \quad (\text{Compensation limits})$$

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Constraints are only applicable to PoC

$$P_{L*i} \ge P_{L*i}^0 \ (i \in Sink) \quad (\text{real load in load center increases})$$

$$Q_{L*i} \ge Q_{L*i}^0 \ (i \in Sink) \quad (\text{reactive load in load center increases})$$

$$P_{G*i} \ge P_{G*i}^0 \ (i \in Source) \quad (\text{real power generation in generation center increases})$$

$$P_{G*i} = P_{G*i}^0 + \frac{\left(\sum_{i \in Source} P_{G*i} - \sum_{i \in Source} P_{G*i}^0\right) \times \left(P_{Gi}^{max} - P_{G*i}^0\right)}{\sum_{i \in Source} \left(P_{Gi}^{max} - P_{G*i}^0\right)} \quad (\text{pattern of generation increase})$$

$$P_{L*i} = P_{L*i}^0 + \frac{\left(\sum_{i \in Sink} P_{L*i} - \sum_{i \in Sink} P_{L*i}^0\right) \times P_{L*i}^0}{\sum_{i \in Sink} P_{L*i}^0} \quad (\text{pattern of load increase})$$

$$P_{L*i} / P_{L*i}^0 = Q_{L*i} / Q_{L*i}^0 \quad (\text{maintaining constant power factor when load increases})$$

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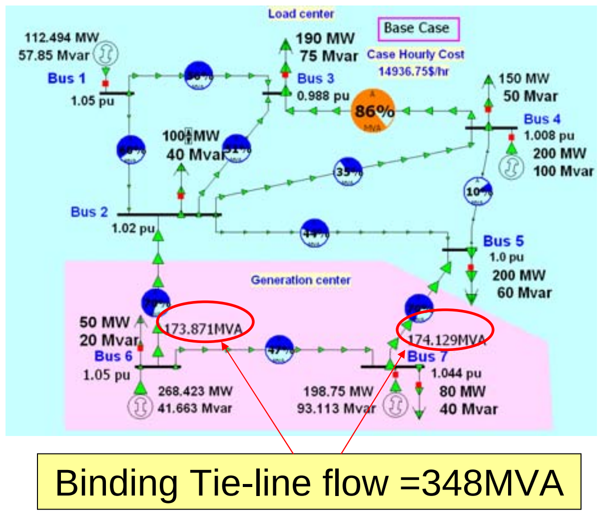
Seven-Bus System Example: Base Case



Results from VSCOPF model with the proposed TSV approach

Objective		
Fuel cost ($/hr)	Var cost ($/hr)	Total cost ($/hr)
15168.98	24.46	15193.44

Variables output							
Bus	1	2	3	4	5	6	7
Q_c (MVar)			14.54				
y (binary)			1				
P_{Go} (MW)	85			200		300	196
Q_{Go} (MVar)	81			100		52	55
P_{Lo} (MW)		100	190	150	200	50	80
Q_{Lo} (MVar)		40	75	50	60	20	40
V_o (V)	1.05	1.01	0.99	1.00	0.97	1.04	1.01
TTC_o (MVA)	369.54						
P_{G*} (MW)	70			200		300	300
Q_{G*} (MVar)	63			100		98	100
P_{L*} (MW)		113	215	170	226	50	80
Q_{L*} (MVar)		47	87	60	73	20	40
V_* (V)	1.02	1.00	0.95	0.97	0.97	1.05	1.03
TTC_* (MVA)	492.73						

Comparison of three models

Table IV. Results comparison of three models: Enumeration, TSV Model I, and TSV Model II.

	Enumeration approach	TSV model to minimize Var cost only **(TSV Model I)**	TSV model to minimize fuel cost + Var cost **(TSV Model II)**
Running time (s)	81	0.156	0.328
Fuel cost ($/hr)	15169.13	15515.86	15168.98
Var cost ($/hr)	25.21	0.00	24.46
Total cost ($/hr)	15194.34	15515.86	15193.44
Var location	Bus 3	None	Bus 3
Var size (MVar)	15	0.00	14.54
TTC_o(MVA)	369.46	304.39	369.54
TTC_*(MVA)	492.61	464.28	492.73
SM	25%	34%	25%

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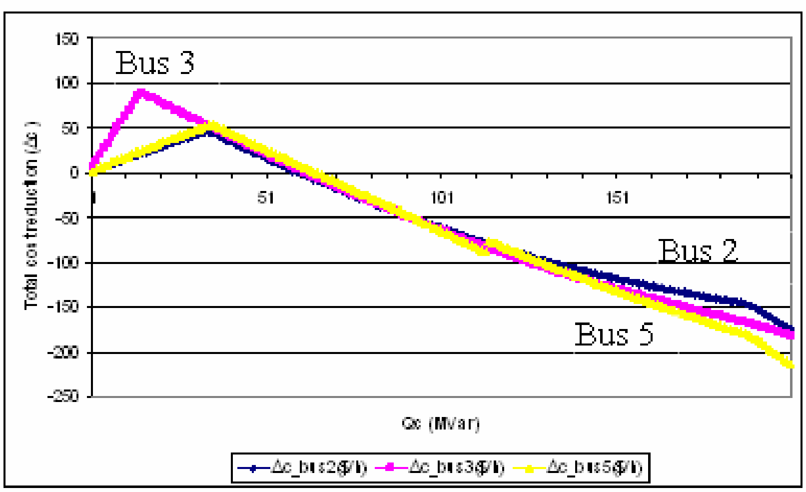
Results from enumeration approach



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Conclusions

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Conclusions

- **A review of RPP is provided.**
- **The results from the enumeration approach and the improved TSV model are very close. This validates the TSV model.**
- **The economic efficiency of Var compensation may not grow as the Var compensation amount grows.**
  - **It may be an economical loss if the Var size is beyond a certain range.**
- **The results show that the new objective function in the improved TSV model (to minimize Var cost and fuel cost) may lead to significantly different results from and is a great improvement over the model to minimize Var cost only.**

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Questions and Answers?

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