

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**



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1



Reactive Power Planning:

- (1) A Review
- (2) VSCOPF with TSV Approach

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2

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*

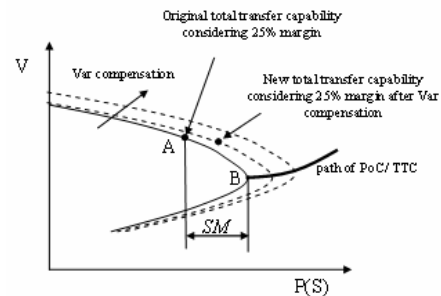


Voltage stability constrained
RPP with two sets of variables

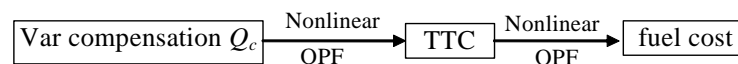


Var compensation and stability margin

- **Var compensation increases total transfer capability**



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



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11

A generic approach of two sets of variables

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

Subject to:

$$F(x_o, \rho, TTC_o) = 0$$

$$F(x_*, \rho, TTC_*) = 0$$

$$(TTC_* - TTC_o) / TTC_* = SM$$

$$SM \geq SM_{spec}$$

$$x_{o,min} \leq x_o \leq x_{o,max}$$

$$x_{*,min} \leq x_* \leq x_{*,max}$$

$$\rho_{min} \leq \rho \leq \rho_{max}$$



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12

Constraints applicable to both of the normal operating point and PoC

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

$$P_{G_{oi}} - P_{L_{oi}} - P(V, \theta) = 0 \quad (\text{Real power balance})$$

$$P_{G_{si}} - P_{L_{si}} - P(V, \theta) = 0$$

$$Q_{G_{oi}} + Q_c - Q_{L_{oi}} - Q(V, \theta) = 0 \quad (\text{Reactive power balance})$$

$$Q_{G_{si}} + Q_c - Q_{L_{si}} - Q(V, \theta) = 0$$

$$P_{G_i}^{\min} \leq P_{G_{oi}} \leq P_{G_i}^{\max} \quad (\text{Generation real power limits})$$

$$P_{G_i}^{\min} \leq P_{G_{si}} \leq P_{G_i}^{\max}$$

$$Q_{G_i}^{\min} \leq Q_{G_{oi}} \leq Q_{G_i}^{\max} \quad (\text{Generation reactive power limits})$$

$$Q_{G_i}^{\min} \leq Q_{G_{si}} \leq Q_{G_i}^{\max}$$

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

$$V_i^{\min} \leq V_{si} \leq V_i^{\max}$$

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

$$|LF_{si}| \leq LF^{\max}$$

$$SM = \frac{\sum_{i \in S_s} S_i - \sum_{i \in S_r} S_i}{\sum_{i \in S_s} S_i} \quad (\text{Tie line MVA TTC security margin})$$

$$SM \geq SM_{\text{spec}} \quad (\text{Security margin limits})$$

$$Q_{c_i}^{\min} \leq Q_{c_i} \leq Q_{c_i}^{\max} \quad (\text{Compensation limits})$$

13

Constraints are only applicable to PoC

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

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

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

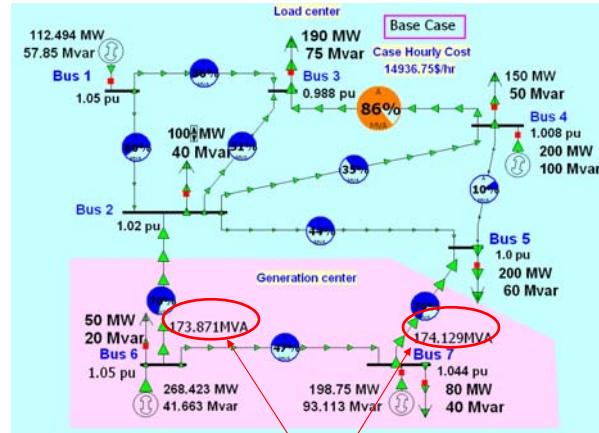
$$P_{G_{i^*}} = P_{G_{i^*}}^0 + \frac{\left(\sum_{i \in \text{Source}} P_{G_{i^*}} - \sum_{i \in \text{Source}} P_{G_{i^*}}^0 \right) \times (P_{G_{i^*}}^{\max} - P_{G_{i^*}}^0)}{\sum_{i \in \text{Source}} (P_{G_{i^*}}^{\max} - P_{G_{i^*}}^0)} \quad (\text{pattern of generation increase})$$

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

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

14

Seven-Bus System Example: Base Case



Binding Tie-line flow = 348MVA

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15

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_{Gc} (MW)	85			200		300	196
Q_{Gc} (MVar)	81			100		52	55
P_{Lc} (MW)		100	190	150	200	50	80
Q_{Lc} (MVar)		40	75	50	60	20	40
V_c (V)	1.05	1.01	0.99	1.00	0.97	1.04	1.01
TTC_c (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						

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16

Comparison of three models

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

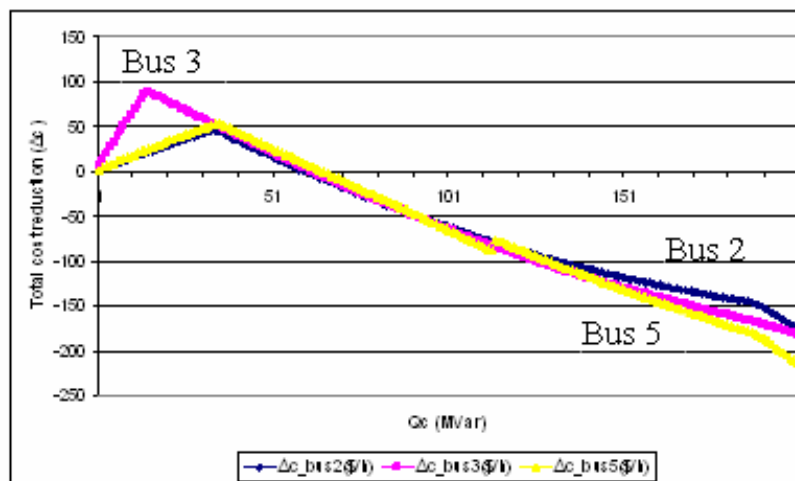
	Enumeration approach	TSV model to minimize Var cost only (TSV Model I)	TSV model to minimize fuel cost + Var cost (TSV Model II)
Running time (s)	81	0.156	0.328
Fuel cost (\$/hr)	15169.13	15515.86	15168.98
Var cost (\$/hr)	25.21	0.00	24.46
Total cost (\$/hr)	15194.34	15515.86	15193.44
Var location	Bus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



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17

Results from enumeration approach



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18

Conclusions



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.**



Questions and Answers?



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21