CSIRO Flagship 2012 – Project 2: Grid Planning and Co-optimisation

- M3 update

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Project Plan - Milestone 1

- **MS 1a: Detailed Project Plan finalised and signed-off by the Cluster Management Committee.**

- **MS 1b: Develop electricity and natural gas network models covering both system and economic aspects.**
- ✓ Power system models (generators, power flow equations, line flow limits, etc);
- ✓ Natural gas models (gas flow equations, compressors, underground storage, etc);

Project Plan - Milestone 2

- **MS 2a: Test run the models with benchmark systems or baseline scenario, as well as other multiple scenarios in coordination with other project teams, and identify improvements.**

✓ Both benchmark power systems and natural gas networks will be developed for testing purpose;

✓ Scenarios concerning the penetration of natural gas generation will also be formulated;

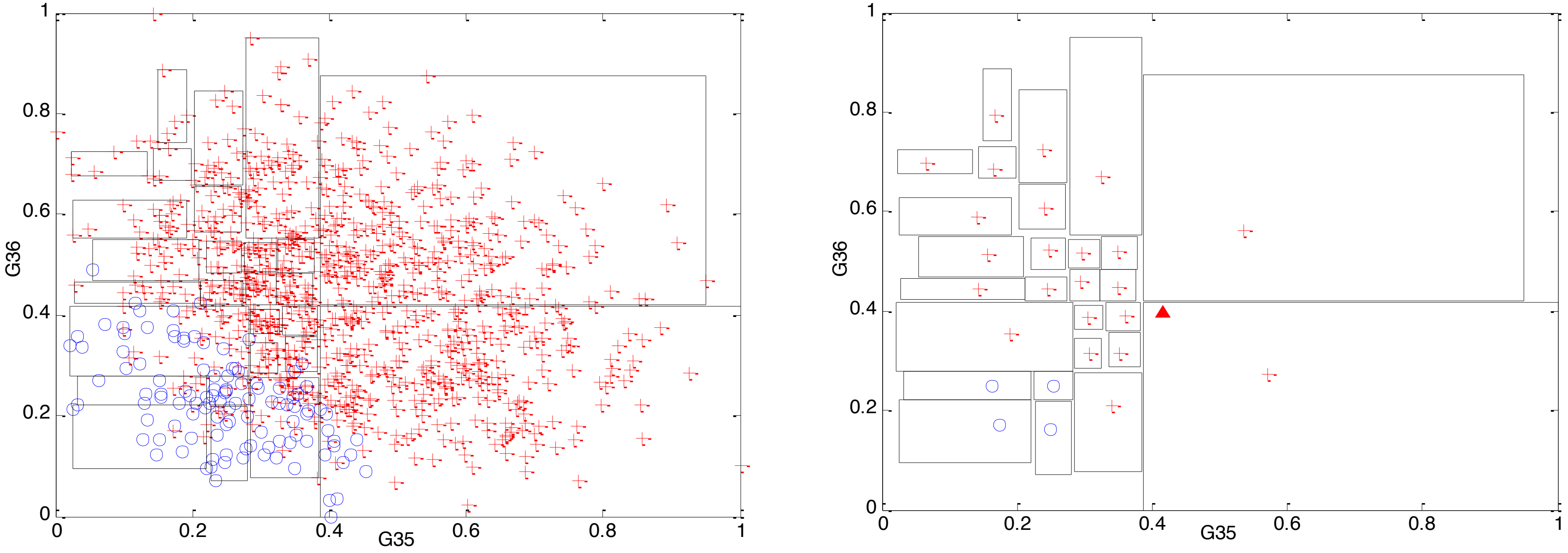
- **MS 2b: Report for Financial Year 2012 - 2013.**

Project Plan - Milestone 3

- **Develop network model constraints**

✓ Develop data mining based methods for network model simplification and constraints formulation;

Developed pattern discovery approach to form security constraints



Y. Xu, Z.Y. Dong, L. Guan, R. Zhang, K.P. Wong, and F. Luo, “Preventive dynamic security control of power systems based on pattern discovery technique,” *IEEE Trans. Power Systems*, DOI: 10.1109/TPWRS.2012.2183898.

Project Plan - Milestone 4

- **MS 4a: Formulation of the co-optimization problem (Due: 01/09/2014)**

- ✓ Investigate model simplification in a number of special situations;
- ✓ Develop advanced optimization techniques based on simplified models and mathematical programming techniques (calculus of variations, global descent, robust optimization, etc);
- ✓ Cloud computing based optimization techniques for handling large-scale systems;

- **MS 4b: Report for Financial Year 2013 - 2014.**

Project Plan - Milestone 5

- **Develop demand side model which provides spatial and temporal aggregation of the demand side in a form suitable for utilisation by the framework (Due: 01/03/2015)**

✓ Develop aggregation models of demand response, and investigate its impacts on power system planning;

✓ Investigate driving behaviours of electric vehicles, develop its aggregation models;

✓ Co-planning of power system and electric vehicle charging facilities;

Project Plan - Milestone 6

- **MS 6a: Develop the overall network co - optimization framework with advanced optimization methods**

✓ Formulate co-optimization models considering power system, gas network, demand response and EV charging facility;

✓ Develop advanced optimization techniques for solving the co-optimization models;

- **MS 6b: Report for financial year 2014-2015**

- **MS 6c: Complete final end of cluster report detailing the research findings**

Progress

- NEM Model for electricity market simulation
- National Gas Network model for gas market simulations
- NEM grid model for power system analysis
- Scenarios following NTNDP 2012 planning for 25 years, & incorporating scenarios from P3
- Generic constraint development using NEM grid system simulation data in collaboration with P1
- Co-planning model development

II Our research

1) multi-stage flexible co-planning

- Flexibility criterion (adaptation costs) to handle uncertainties;
- Sequential importance sampling to speed up simulations;
- Maximizing social welfare of the overall energy infrastructures;
- Enhancing the economic efficiency of assets.

Our research

2) new reliability criterion:

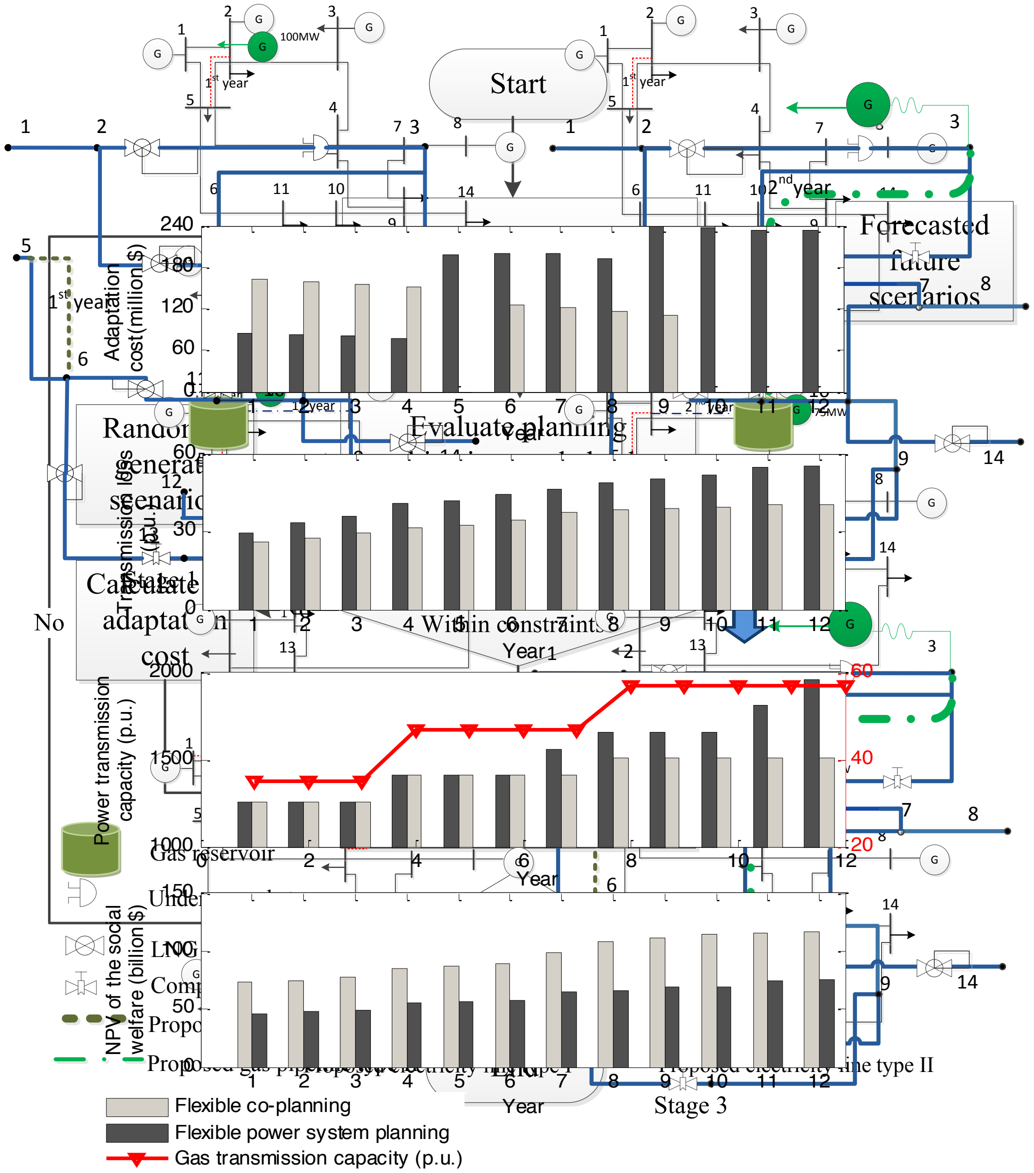
- Integrating gas security issues (e.g. pipeline contingencies, pressure losses);
- Proposed a generalized EENS calculation method for the overall energy network;
- Considered the working states by homogeneous Markov Chain model for gas storage facilities.

Our research

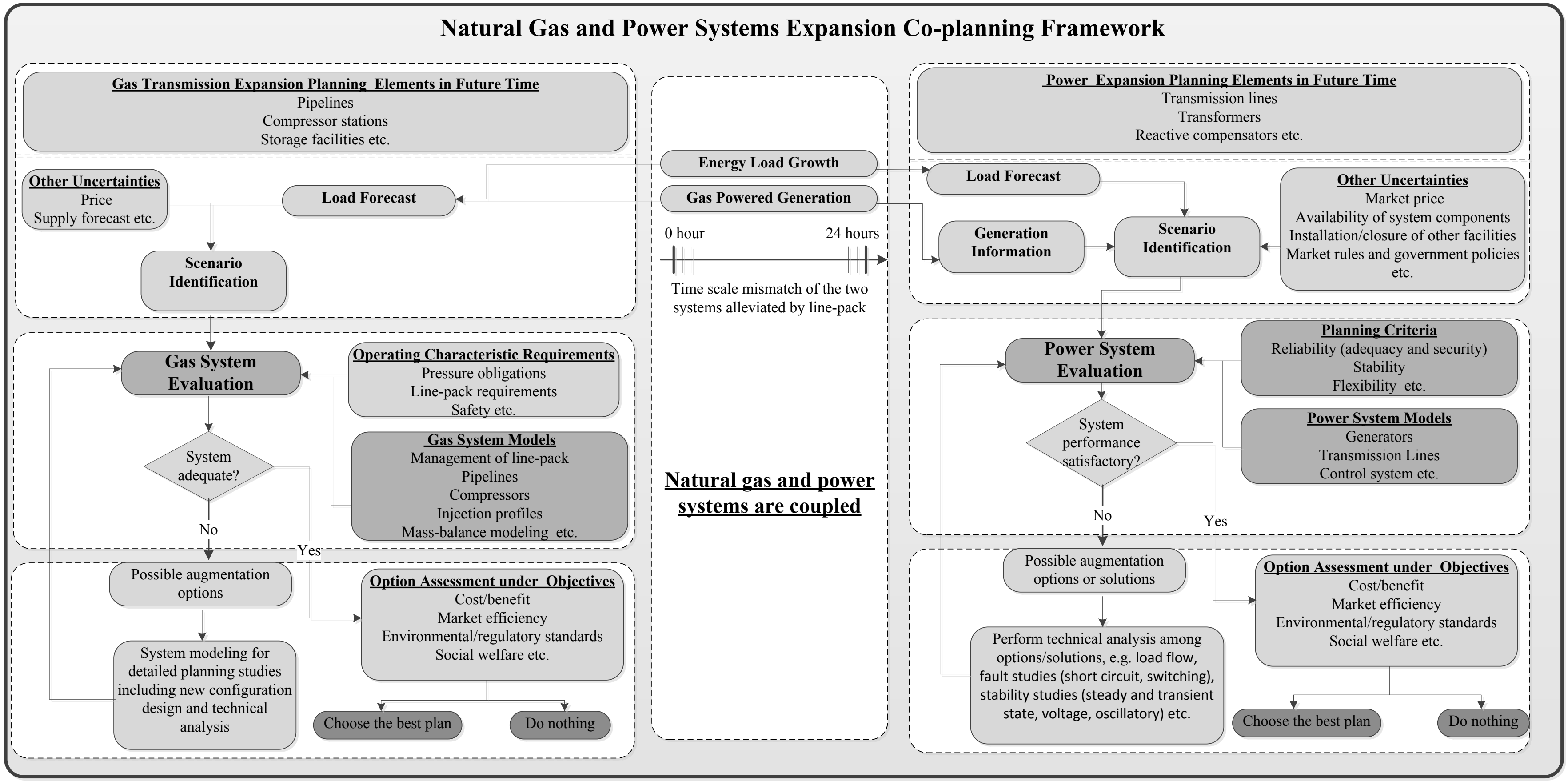
3) Co-planning using *decision analysis* :

- Planning robustness is evaluated by *decision analysis*;
- Analysed market timeline mismatch for gas and electricity;
- Modelled the variations of gas linepack;
- Considered the working states of compressor stations.

1) Multi-stage flexible co-planning



Proposed co-planning framework



Natural Gas and Power Systems Expansion Co-planning Framework

Gas Transmission Expansion Planning Elements in Future Time
Pipelines
Compressor stations
Storage facilities etc.

Other Uncertainties
Price
Supply forecast etc.

Load Forecast

Scenario Identification

Gas System Evaluation

Operating Characteristic Requirements
Pressure obligations
Line-pack requirements
Safety etc.

Gas System Models
Management of line-pack
Pipelines
Compressors
Injection profiles
Mass-balance modeling etc.

System adequate?

No

Yes

Possible augmentation options

System modeling for detailed planning studies including new configuration design and technical analysis

Option Assessment under Objectives
Cost/benefit
Market efficiency
Environmental/regulatory standards
Social welfare etc.

Choose the best plan

Do nothing

Energy Load Growth

Gas Powered Generation

0 hour

24 hours

Time scale mismatch of the two systems alleviated by line-pack

Natural gas and power systems are coupled

Power Expansion Planning Elements in Future Time
Transmission lines
Transformers
Reactive compensators etc.

Load Forecast

Generation Information

Scenario Identification

Other Uncertainties
Market price
Availability of system components
Installation/closure of other facilities
Market rules and government policies etc.

Power System Evaluation

Planning Criteria
Reliability (adequacy and security)
Stability
Flexibility etc.

Power System Models
Generators
Transmission Lines
Control system etc.

System performance satisfactory?

No

Yes

Possible augmentation options or solutions

Perform technical analysis among options/solutions, e.g. load flow, fault studies (short circuit, switching), stability studies (steady and transient state, voltage, oscillatory) etc.

Option Assessment under Objectives
Cost/benefit
Market efficiency
Environmental/regulatory standards
Social welfare etc.

Choose the best plan

Do nothing

M3 - Deriving Constraints based on Pattern Discovery Technology

Stability Constraints

- The operations of a power system are limited to many constraints, including static thermal constraints and dynamic security (stability) constraints subject to credible contingencies.
- The stability constraints, once violated, could trigger protective actions, such as generator tripping, load shedding, etc., in a very short time frame, leading to cascading failures and/or blackouts.
- To protect the power system against instabilities, the stability constraints should be invoked and incorporated into the dispatching procedure.

Mathematical Formulation of Stability Constraints

- The modeling of power system stability is a large set of differential-algebraic equations (DAEs), normally up to thousands order, thus the stability constraints are difficult to be explicitly formulated.
- $$\begin{cases} M_i \dot{\omega}_i = P_{mi} - P_{ei} \\ \dot{\delta}_i = \omega_i \end{cases}, \ (i \in NG)$$

  where M_i is the inertia constant of i-th machine in the synchronous generator set NG, δ_i and ω_i stand for its angle and angular speed respectively, and P_{mi} and P_{ei} are its mechanical input and electrical output powers respectively.

Stability Constraints from Off-Line Simulations

- In order to consider the stability issues in the dispatching procedure, there is a need for explicit stability constraints which can be interpretably and transparently invoked when necessary, e.g., include a item of stability constraint into a market dispatch / OPF model.
- Conventionally, AEMO derives the stability constraints based on extensive off-line contingency simulations.

Stability Constraints from Off-Line Simulations

- The process consists of linear fitting, regression analysis, etc., and the constraints are formulated as a linear combination of some parameters:

$$a \times P_{G1} + b \times P_{G2} + c \times V_1 + \ldots + e \times P_{34} > T_1$$

- When needed, such constraint can be invoked and incorporated into the dispatching model, e.g., NEMDE.

Drawbacks of Linear Stability Constraints

- The method can be inaccurate, which can result in conservative constraints for use, leading to high operating cost.
- The constraints are very difficult to interpret by operators.
- The constraints are sensitive to the contingency simulations.
- The constraints provide very limited information on operational rules against instability.
- The constraints could result in un-converged NEMDE/OPF solutions in practice.

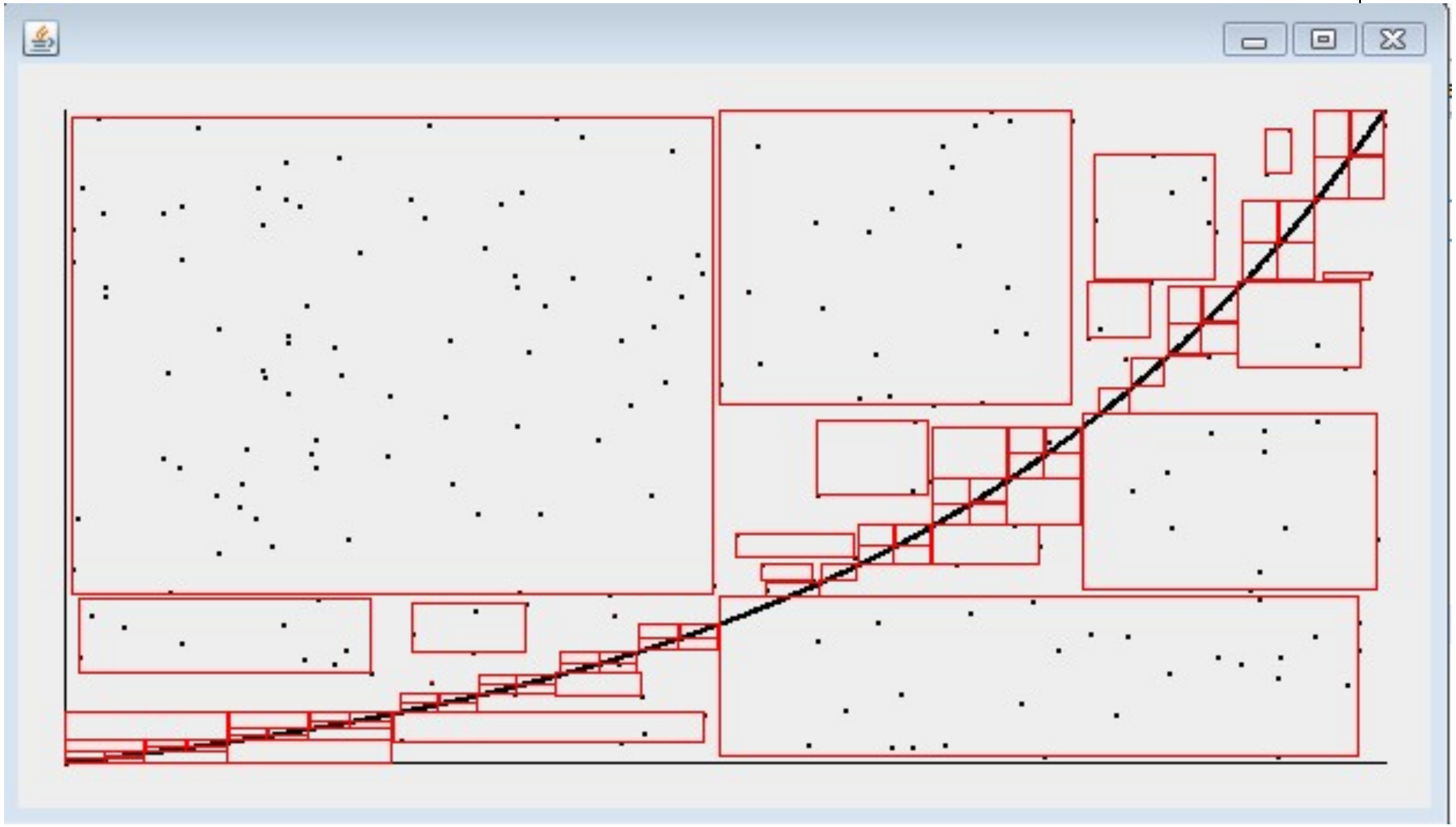
Deriving Explicit Stability Constraints

- This milestone aims at deriving more explicit stability constraints for practical use.
- Pattern Discovery (PD) technology is featured by its strong ability in discovering nonlinear and multimodal patterns of high order with high speed; and be able to rank them according to their statistical significance for interpretation, comparison, and assessment so that greater understanding of the data can be achieved and thereby better decisions can be made.

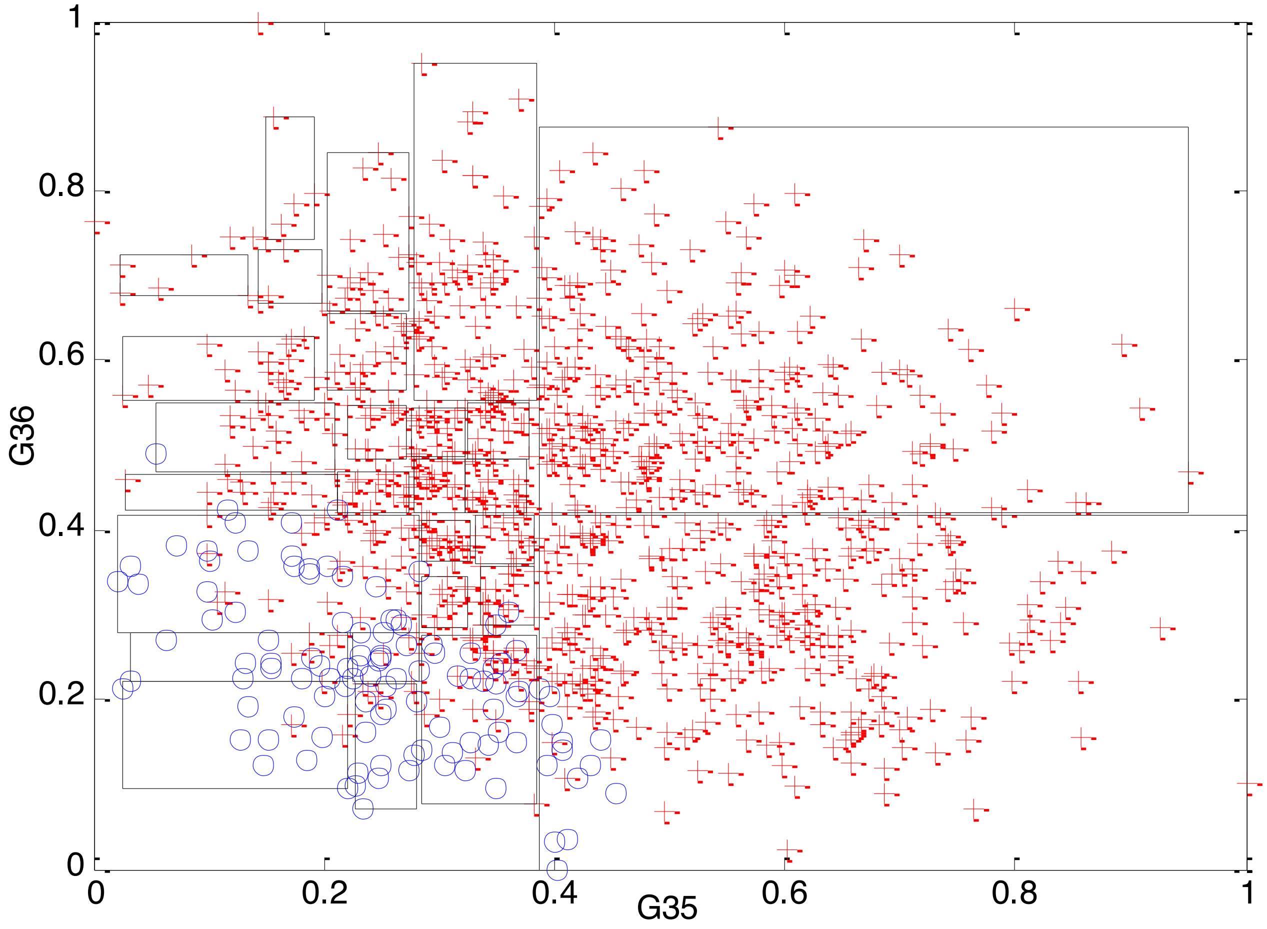
Pattern Discovery (PD)

- PD has been used for power system transient stability assessment
- Generally, PD can extract unbiased and comprehensive knowledge (i.e. patterns) from a database.
- The patterns are a set of non-overlapped hyper-rectangles in the parameter space, easy to present and interpret. When the database is 2 or 3-D, the patterns can be visualized by users.

Illustration of PD



PD in Power System Stability Database



PD in Power System Stability Database

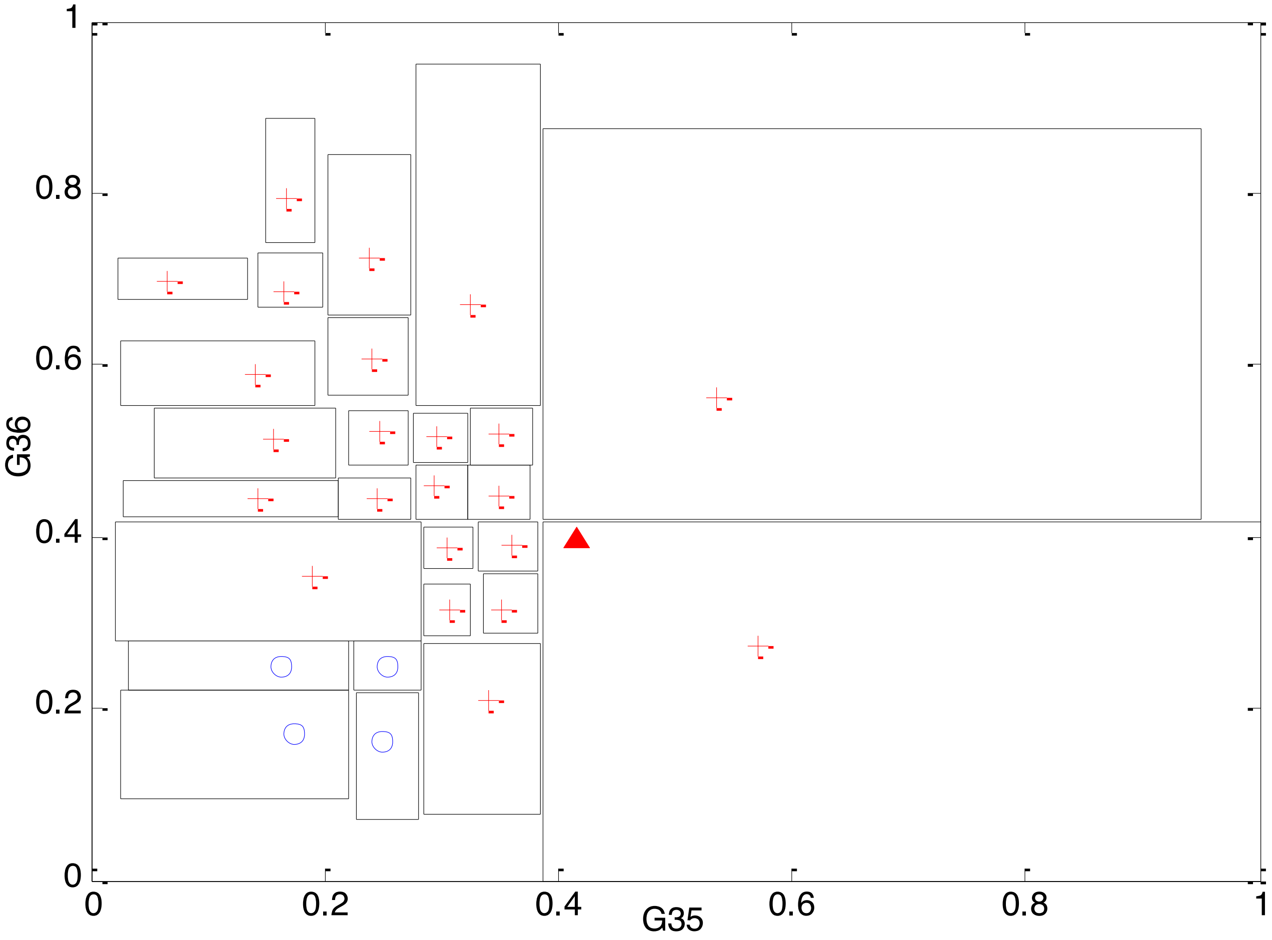


Illustration of PD

- The patterns are discrete, mathematically, they can be formulated as a set of independent inequalities:

0.22<Pg35<0.28 & 0.22<Pg36<0.27 **-->** stable

- These patterns are pure algebraic inequalities, can be directly used as operational rules for stability constraints.

Advantages

- The patterns are obtained through a robust and unbiased procedure, they are not sensitive to the change of the database, and thus can be updated anytime.
- The patterns are interpretable and easily presented to operators (for 2 or 3-D space, they are visualized); they are compatible with practical software for evoking.
- The invoking of a constraint can thus be transparent: an operating point should be located in stable region.
- The patterns can be directly incorporated into the dispatching process, e.g., a OPF without adding any difficulties for the OPF solution.
- The patterns can also represent the stability region, providing decision support for stability monitoring and situational awareness for enhancing the security of the power system.

Publications providing inputs to the project:

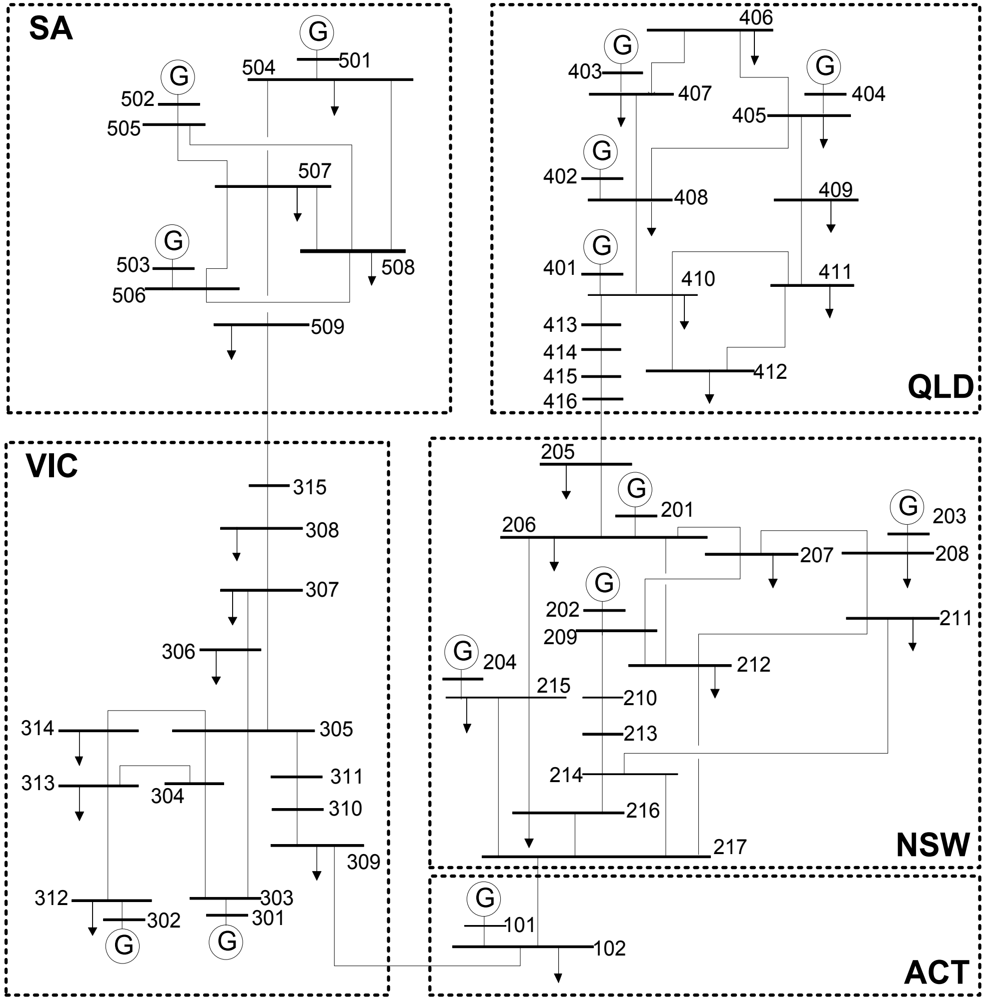
- FJ Luo, JH Zhao, J. Qiu, J. Foster, Y Peng and ZY Dong, “Assessing the Transmission Expansion Cost with Distributed Generation: an Australian Case Study”, IEEE Transactions on Smart Grid, Vol. 5, No. 4, pp. 1892 – 1904, July 2014
- Yan Xu, Zhao Yang Dong, Rui Zhang & Kit Po Wong, “A decision tree-based on-line preventive control strategy for power system transient instability prevention”, International Journal of Systems Science, Vol 45, Issue 2, 2014 DOI:10.1080/00207721.2011.626906 <http://dx.doi.org/10.1080/00207721.2011.626906>
- Y. Zheng, ZY Dong, Y Xu, K Meng, J Zhao, J Qiu, “Electric Vehicle Battery Charging/ Swap Stations in Distribution Systems: Comparison Study and Optimal Planning”, IEEE Trans on Power Systems, Vol. 29, No. 1, Jan 2014, pp 221-229
- Y. Dai, G. Chen, ZY Dong, Y Xue, DJ Hill and Y. Zhao, “An improved framework for power grid vulnerability analysis considering critical system features”, Physica A 395 (2014) 405-415
- K. Meng, Z. Y. Dong, Y. Zheng, J. Qiu, and K. P. Wong, “Optimal Allocation of ESS in Distribution Systems Considering Wind Power Uncertainties”. *APSCOM 2012*, Hongkong.
- J. Qiu, Z. Y. Dong, J. H. Zhao, Y. Xu and Y. Zheng, “Multi-stage Flexible Expansion Co-planning with Uncertainties in a Combined Electricity and Gas Market**,”** ***IEEE Trans. Power Syst***. Under review
- J. Qiu, Z. Y. Dong, K. Meng, F. J. Luo and K. P. Wong “Coordination of Transmission and Generation Capacity Planning in a Coupled Energy Market,” ***IEEE Trans. Power Syst***. Under review

Publications providing inputs to the project:

- J. Qiu, Z. Y. Dong, J. H. Zhao, K. Meng, Y. Zheng and K. P. Wong "Expansion Co-planning Considering Gas Impacts on Electricity Markets," ***IEEE Trans. Power Syst***. underreview
- J. Qiu, Z. Y. Dong, J. H. Zhao, K. Meng, Y. Zheng and K. P. Wong "Expansion Co-planning in a Coupled Electricity and Gas Market with Uncertainties**,"** ***IEEE Trans. Power Syst.*** Under review
- J. Qiu, Z. Y. Dong, K. Meng, Y. Zheng, Y. Y. Chen and H. Q. Tian "Risk Sharing Strategy for Minimizing Imbalance Costs of Wind Power Forecast Errors", *IEEE PES 2013 General Meeting*, Vancouver.
- J. Qiu, Z. Y. Dong, J. H. Zhao, K. Meng, Y. Zheng and H. Q. Tian "Insurance Strategy for Minimizing Imbalance Costs of Wind Power in Real-time Markets**,"** ***IEEE Trans. Power Syst***. (submitted)
- Y. Zheng, Z. Y. Dong, Y. Xu, K. Meng, J. H. Zhao and J. Qiu, "Electric Vehicle Battery Charging/Swap Stations in Distribution Systems: Comparison Study and Optimal Planning," ***IEEE Trans. Power Syst***. 2014
- Y. Zheng, Z. Y. Dong, F. J. Luo, K. Meng, J. Qiu and K. P. Wong, "Optimal Allocation of Energy Storage System for Risk Mitigation of DISCOs with High Renewable Penetrations," ***IEEE Trans. Power Syst***. (accepted)
- W. F. Yao, J.H. Zhao, F.S. Wen, Y.S. Xue, G. Ledwich, "A Hierarchical Decomposition Approach for Coordinated Dispatch of Plug-in Electric Vehicles", ***IEEE Trans. Power Systems***, 2013. (Accepted, Apr 2013
- H. M. Yang, D. Yi, J.H. Zhao, Z.Y. Dong, "Distributed Optimal Dispatch of Virtual Power Plant via Limited Communication**",** ***IEEE Trans. Power Systems***, 28(3): 3511 – 3512, 2013.
- H. M. Yang, C.Y. Chuang, J.H. Zhao, "Application of Plug-in Electric Vehicles to Frequency Regulation Based on Distributed Signal Acquisition via Limited Communication", ***IEEE Trans. Power Systems*****,** 28(2): 1017 – 1026, 2012.
- J. H. Zhao, F.S. Wen, Z.Y. Dong, Y. S. Xue, K.P. Wong, "Optimal Dispatch of Electric Vehicles and Wind Power Using Enhanced Particle Swarm Optimization**",** ***IEEE Trans. Industrial Informatics***, 8(4): 889 – 899, 2012.

Thanks

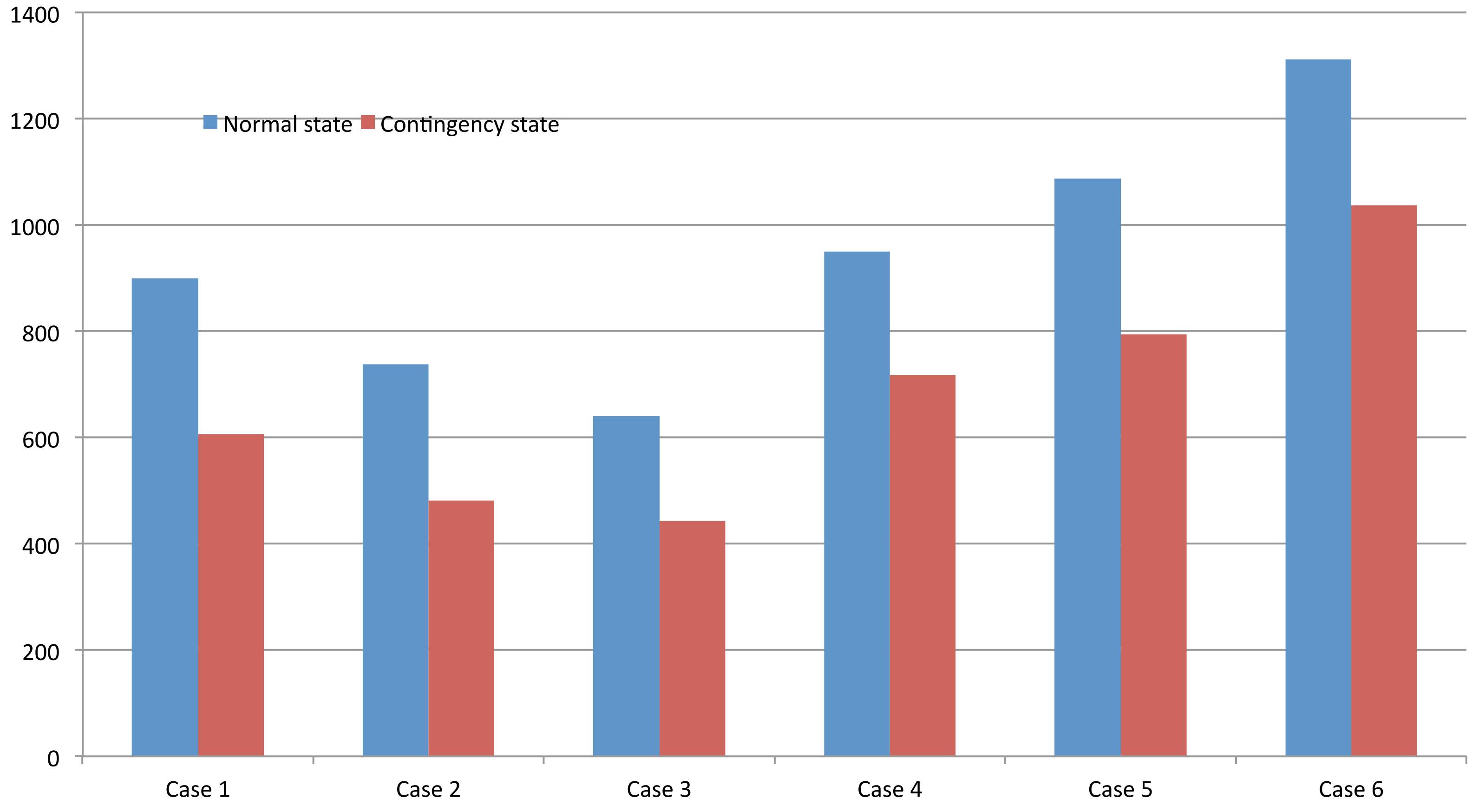
Some Results



Normal steady-state operating conditions

Name	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Load condition	Heavy	Medium-heavy	Peak	Light	Medium	Light
Total generation	23030	21590	25430	15050	19060	14840
Total load	22300	21000	24800	14810	18600	14630
Inter-area flows	North to south	South to north	Hydro to N&S	NSW to N&S	N&S to pumping	Zero transfers
QLD to NSW	500	-500	-500	-200	300	0
NSW to ACT	1134	-1120	-1525	470	740	270
ACT to VIC	1000	-1000	1000	200	-200	0
VIC to SA	500	-500	250	200	250	0

Steady-state voltage stability limits QLD-NSW



Transient stability limit QLD-NSW simulation results