Looking ahead

The future of power system control

Petr Korba, Mats Larsson, Alexandre Oudalov and Otto Preiss

As economies and populations grow, the need to enhance the security, capacity and flexibility of power transmission systems also grows. A reliable electrical grid is one of the main infrastructures supporting a developed economy and one of the key premises for a developing economy. The reliable delivery of electricity at an acceptable price depends on the electrical transmission and distribution networks which link power generation with power consumption.

Because of changing market conditions, power utilities have been forced to look at ways of utilizing old transmission lines more efficiently, at cross-border co-operation and the issue of power quality. This situation has inevitably led to an increased interest in state-of-the-art solutions.

All solutions, whether based on traditional methods or new technologies, must be capable of controlling the flow of power from the producer to the consumer and the stability of the grid must be maintained.

ABB is currently working on the next generation of control and automation products for power systems and in doing so has employed the help and expertise of two renowned universities: Imperial College London and the ETH in Zürich.

One of ABB's many goals is to provide technology for secure and long-term reliable power systems. Security refers to the ability of the power system to survive disturbances without interrupting service to the customer, and power system security is mainly affected by the characteristics of the physical system.

A number of developments are now taking place and these are changing many of the crucial physical parameters in the power system:

- *Interconnecting electrical grids* – In recent years, the general trend has been to open European grids to the east. This means electrical networks, which in the past were poorly interconnected, must now be properly synchronized. Because of this, angular network stability has been affected thus leading to undesired (or even unstable) power oscillations which in turn directly affect network security.
- *Deregulated power market* – Transmission lines are now required to transport greater quantities of power over longer distances as a part of the power trading business. In fact, electricity no longer needs to be produced in the country where it is consumed. The downside of this is that weak lines constructed in the past are now becoming major corridors and the risk of undesirable power flows and oscillations occurring has increased significantly.
- *Growing concern for environmental issues* – The public attitude towards environmental issues means there is increased opposition to overhead lines, greater awareness of the current CO_2 problem or a push to phase out nuclear power in some countries. This leads to more distributed as well as renewable-based power generation. Consequently, more generation is produced at lower voltage levels with lower power output.
- *Distributed generation* – The greater the distance between a renewable power source and the intended area of consumption, the greater the chance of intermittent generation patterns. Hydro, solar or wind power generation plants may be built up in locations with weak connections to the transmission or distribution grids. Because the production of power depends heavily on weather conditions, some form of compensation (energy storage) is necessary to secure a stable and reliable power supply. This leads to changes in current power generation and power flow patterns in the electrical grids.
- *Aging grid infrastructure* – New power system components are used to replace old ones. They are typically based on different technologies (power electronics) and therefore have a different impact on the physical characteristics of the network. The need to manage grid security and power flow leads to an increase in the number of powerful controllers required. This in turn can have negative mutual effects which significantly degrade overall performance.

1 Future trends in power system control: voltage stability, angle stability, frequency stability and power flow.

The original electrical grids were planned and built without taking the above considerations into account. The evolution of many electrical grids requires innovative ideas and technologies to cope with changing conditions. The basic objective, however, remains: control the flow of power from the supplier to the consumer and maintain a stable grid. For this to happen, voltage and frequency stability needs to be maintained. All generators connected to the same AC network will have to be synchronized (angular stability) while the power flow follows a specific "contract path" to the consumer.

The above phenomena have been addressed by ABB using analysis, modelling and control techniques. This research is supported by collaborations with renowned universities in London (Imperial College) and Zürich (ETH).

Future trends

The future trends in power system control with regard to power flow control, and frequency, voltage and angular stability are subject to the same pattern changes: from *local measurement based control* to *local and remote measurement based coordinated control* **1**.

To reach the control objectives in power flow so that stable power system operation is maintained, conventional actuators such as Automatic Voltage Regulators (AVR), Power System Stabilizers (PSS) and transformers, and Flexible AC Transmission devices (FACTS) must be considered in the control algorithms. These algorithms are then used in solutions characterized by a combination of the following advanced control techniques:

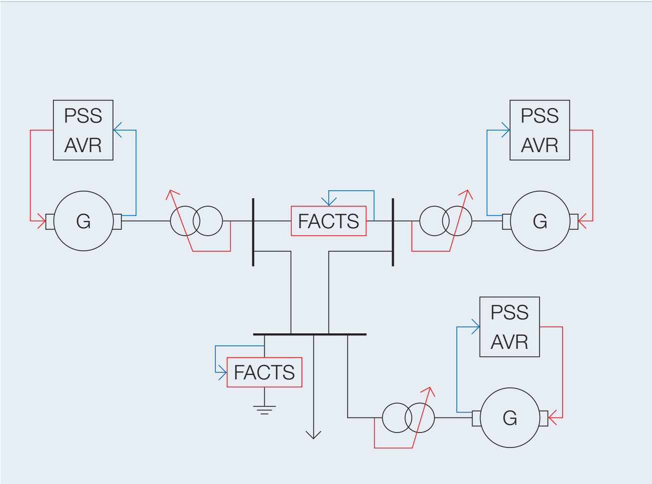
- *Multi-variable control* – Control actions, which have been typically based on one local feedback signal **2**, will now be based on local and remote measurements. The decision must be made, however, as to which measurements among the many available are most relevant **3**.
- *Hierarchical control* – Controlling a particular phenomenon, such as power oscillations, is co-ordinated by a set of devices so that the control objective, eg, required damping of oscillations, can be reached under any circumstances **3**.
- *Multi-objective control* – Control laws reflect the impact of one phenomenon on another, eg, changes in power flow that lead to poorly damped oscillations.
- *Adaptive Control* – Controllers detect and take into account the real-time status, behaviour and changes in the structure and physical parameters of the power system.

Prerequisites and opportunities

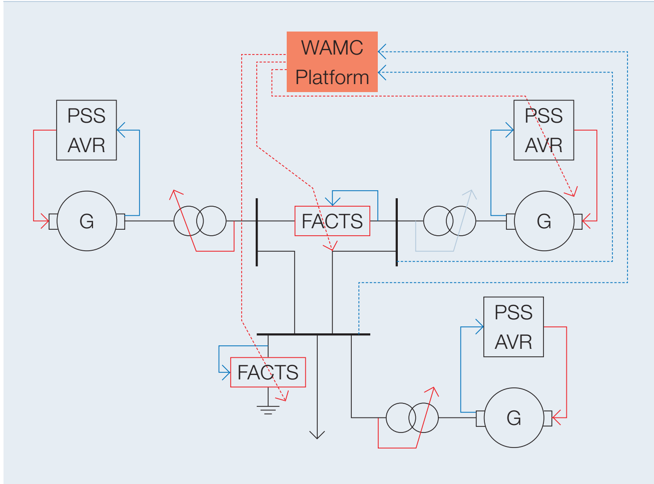
To realise such control techniques, the existence of a wide-area monitoring and control (WAMC) platform is required to pre-process all signals measured throughout the entire power system.

By applying advanced algorithms to remote signal measurements, power system stability can be characterized in real-time [1, 2] because phenomena such as the frequency and damping of electromechanical oscillations, thermal line overloading or voltage instability in corridors are dynamically monitored.

2 Conventional control of power systems is based on single independent local control loops.



3 Future trends in control of power systems go towards multi-variable adaptive control wiith additional feedback information from remote measurements.



The first WAMC platform is now on the market but because it is currently available for monitoring purposes only, decisions made when irregularities occur fall to an operator or to whomever is in charge. Future developments aim at feeding all additional information directly to the fast-acting power system controllers which in turn should open new opportunities for the advanced control of power systems.

ABB in Switzerland is credited with the pioneering work on the WAMC platform. Because the initial internal results have proved very promising, several university projects are currently underway to strengthen ABB's competence in the field of advanced power system control: Imperial College London and the Swiss Federal Institute of Technology (ETH) in Zürich are investigating new approaches in the control of single and multiple FACTS devices.

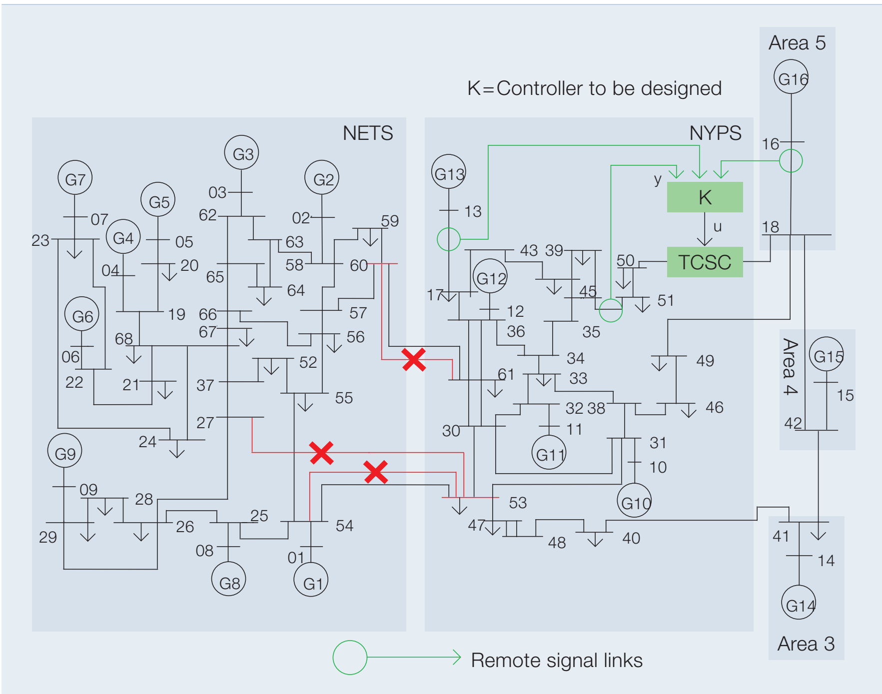
Collaboration with Imperial College London

ABB and Imperial College London are working to improve the angular stability of power systems. An earlier collaboration on robust FACTS control[1)] was successfully completed at the end of 2004 resulting in the development of a powerful tool for multivariable FACTS controller design. This tool is designed to help dampen undesired electromechanical oscillations in the electrical power networks. The methodology is based on convex optimisation techniques employing linear matrix inequalities and it includes methods for dynamic model reduction. The solution has been tested in numerous simulations where several different types of FACTS devices and many power system benchmark models were considered 4, 5.

A relatively accurate dynamic model of the power system under consideration is required for the controller design procedure and these are not always available. To ensure the accuracy of the required model parameters, ABB and Imperial College are now developing a procedure which identifies the parameters of the required dynamic model directly from on-line measurements. This procedure will become part of the controller and will result in an indirect adaptive control scheme. Thus the performance of this controller over a broad range of different operating conditions is guaranteed. Even without such corrective action, the proposed solution is superior to those already available on the market [3].

Footnote:
1) "Advanced FACTS control", ABB Review 4/2003 pp 21–26.

4 Developed multi-variable FACTS control based on remote signals applied to a benchmark model of the New England power system including the testing of typical faults.



University collaboration with ETHZ

The goal of this cooperation, launched in September 2004, is to find a way of improving the power flow control in power systems. In recent years, the total transmission circuit capacity added annually is trending downwards while overall consumption continues to grow. This means transmission networks are operating close to their limit 6a. To reduce this stress, power flow control can be used to utilize existing transmission network capacity more effectively [4].

However, a fundamental drawback of an AC electric power system is the difficulty in controlling power flow along a specific contract path. So called "loop flows" can take power away from the most direct route between a generator and a load centre, affecting all interconnected nodes not included in the transaction 6b.

To overcome this, a variety of power flow control devices produced by ABB, such as PSS, HVDC and FACTS, can be used to redirect and uniformly redistribute power flow in the transmission system without having to reschedule generation or implement topological changes. Until recently though, standard power management practice meant this problem was solved by the addition of isolated and individually controlled devices to existing networks. The mutual effect, however, of adding multiple power flow control devices to a transmission system remains relatively unknown [5].

The ETH collaboration focuses on the design of controllers capable of governing multiple power flow control devices so that congestions in transmission networks can be removed. Multiple controllers in the same electrical area working in close coordination must avoid all possible negative effects from individual control actions.

Fruitful collaborations

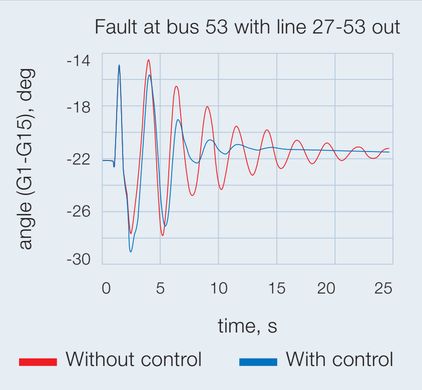
Research collaboration is a means by which scientists in academia and industry can advance their own research, and companies can move new products more quickly into the marketplace serving the interests of both sides, the pursuit of new knowledge and society at large. Working with outside experts can greatly improve the quality and comprehensiveness of the research.

This is the idea behind ABB's collaboration with two renowned universities. ETH and Imperial College are playing an important role in the development of ABB's next generation of control and automation products for power systems. These products are based on wide-area phasor measurement technology in which ABB is a market leader.

ABB realizes the importance of university relations in helping to strengthen its market position. University scientists' curiosity-driven basic research frequently opens lines of inquiry that help develop new and valuable technologies.

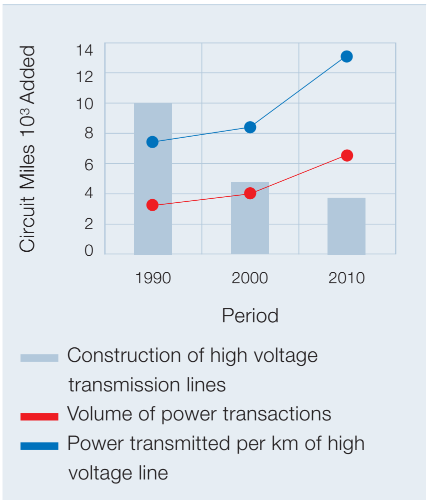
Dr. Petr Korba
Dr. Mats Larsson
Dr. Alexandre Oudalov
Dr. Otto Preiss
ABB Switzerland, Corporate Research
Baden-Dättwil
petr.korba@ch.abb.com

5 Improved transient stability with advanced FACTS control.

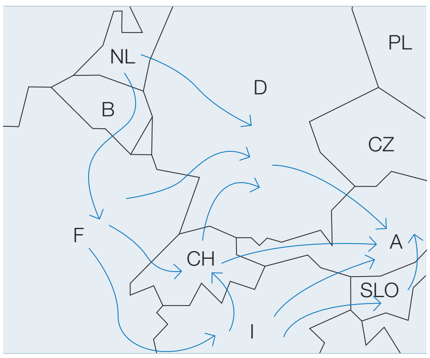


6 Effective utilization of existing transmission network capacity.

a) Increased stress on the transmission grid



b) Power transaction from the Netherlands to Austria within the UCTE network



References:

[1a] **P. Korba, M. Larsson, C. Rehtanz,** "Detection of oscillations in power systems using Kalman filtering techniques", In Proc. of IEEE Conference on Control Applications, pp.183–188, Vol.1, 23 – 25 June, 2003.

[1b] **P. Korba, M. Larsson, C. Rehtanz,** "Detection of Power System Oscillations based on adaptive Kalman Filter." European Patent EP 1 489 714, US Patent Appl. Nr 10/871,685.

[2] **Larsson, M., Rehtanz, C., Westermann, D.,** Improvement of Cross-border Trading Capabilities through Wide-area Control of FACTS, In Proc. of Bulk Power System Dynamics and Control VI, 22 – 27 August, Cortina D'Ampezzo, Italy, 2004.

[3] **B. Chaudhuri, P. Korba, B. C. Pal,** "Damping controller design through simultaneous stabilization technique", In Proc. of World Automation Congress, Seville, Spain, 28 June – 1 July, 2004.

[4] **R. Sadikovic, G. Andersson, P. Korba,** "Power Flow Control Strategy for FACTS Devices", In Proc. of World Automation Congress, Seville, Spain, 28 June – 1 July, 2004.

[5] **A. Oudalov, P. Korba,** "Coordinated Power Flow Control using FACTS", In Proc. of IFAC World Congress, Prague, Czech Republic, 4 – 8 July, 2005.

[6] **M. Zima, M. Larsson, P. Korba, C. Rehtanz, G. Andersson,** "Design Aspects for Wide Area Monitoring and Control Systems", Proceedings of the IEEE, Special Issue on Energy Infrastructure Defence Systems, May 2005.