The Future of Power System Monitoring and Control

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Abstract: This paper will present a few potential software applications for power system monitoring and control, the required sensor and sensor network technology, and their relationships with existing applications.

Introduction

In this 21st century, electric power engineering goes green and intelligent. Green means environment friendly: wind power, solar power, fuel cell, etc. Intelligent means agent, self-organizing, and automated reasoning. What does this mean to the control room applications? Two examples can help demonstrate the concept.

Real-Time Transmission Capacity Monitoring and Optimal Load Flow Control Thereof

One of the many green thoughts is to push more electricity through the existing transmission network, thus avoiding the addition of new transmission lines and substations. To do this without endangering the reliability of the system, the real-time capacity information of the transmission lines and transformers must be available, and the system load flows must be controlled accordingly.

Real-Time Transmission Capacity Monitoring

Real-time capacity monitoring systems exist for power transformer and transmission lines. The transformer monitoring systems use embedded fiber optic sensors to get the winding hot-spot temperature, or calculate the hot-spot temperature based on the ambient temperature, top and bottom oil temperature. A transformer thermal model can then be used to estimate the temperature rise for a given load and weather condition. The transmission line monitoring systems use voltage/current measurement, or vibration/video capturing devices to get the information on conductor tension, temperature and sags.

Real-Time Transmission Capacity Monitoring Based Load Flow Control

Conventionally, load flow was controlled through system operator's generator dispatch orders. The control functionality has been enriched by the usage of phase-shifters, FACTS devices (TCSC, TCPR, UPFC, SVC, etc.) and HVDC Light®. Emerging devices include SmartWire devices, which are Distributed Static Series Compensator (DSSC) modules that clip on to existing conductors. These new breeds of devices have made feasible the load flow control that is based on real-time transmission capacity monitoring.

Potential Applications

Application wise, the existing real-time transmission capacity monitoring systems have not often been integrated with existing EMS/SCADA, and there is a need to do so, for at least two reasons:

1) From an operator's view point it may be cumbersome to interact with multiple applications;
2) From the perspective of IT support, data consistency is always an issue with multiple software applications.

Therefore a reasonable approach is to develop add-on modules for the transmission capacity monitoring systems and integrate them with the EMS/SCADA. These add-on modules would gather the most important information (e.g. total transfer capacity) from the monitoring systems, combine them with other power system information, run an optimal power flow simulation, and present the operator with a power flow control strategy in real time.

Complications

The adoption of the aforementioned EMS/SCADA add-on modules may involve many legal arrangements between system operators and the transmission asset owners, as well as considerations on the transmission line protection settings. For example, from the asset owner's perspective, the asset should be used to its maximum capacity minus a safety margin to avoid excessive aging or catastrophic failure; from the system operator's perspective, system stability and reliability are more important than the asset owner's profitability. The modules have to consider many technical, legal, economical, and political aspects of the application.

Wide Area Monitoring, Protection and Control

After the recent blackouts around the world, the idea of a self-healing electric grid seems more appealing. The Special Protection Schemes (SPSs), implemented in significant number in the WECC after the 1996 blackouts, are in some sense supporting a self-healing grid. However, because SPSs are predefined protection schemes based on system studies, they cannot adapt to ever-changing system conditions. There is still a need to integrate new technologies with the SPSs to prevent power system disturbance propagation under any system conditions.

Wide Area Monitoring (WAM) Technologies

Phasor Measurement

Phasor Measurement Units (PMUs) can report the precise phasor value of the monitored buses, synchronized to GPS satellite time base. They are the basis of advanced wide area monitoring applications (below), and they can be valuable in many other new applications[1]. For example, PMUs can be used to help improve the accuracy and speed of state estimation, and help characterize load behaviors after power system disturbances[2].

Power Oscillation (Swing) Monitoring

The PMU based power oscillation monitoring can identify

- The most important oscillation frequency
- Amplitude of the most important kind of oscillation
- Damping of the most important kind of oscillation

The monitoring can also issue warnings, emergency alerts, and recommendation for load shedding for the provided remedial action scheme with a data repetition rate of one second[3].

Voltage Instability Monitoring and Prediction

Long-term voltage instability is the root cause of cascading outages, and it is determined by the dynamic system behaviors after the disturbance (line trip).

One prediction algorithm is based on a full dynamic system model. After model reduction (neglecting all short-term transients in the model), the algorithm tries to determine the steady state equilibrium point of the system. If the equilibrium point cannot be found, the system is said to be in danger of collapse, and stabilizing actions can be determined for the supervised area of the system[2].

A simpler alternative is based on local apparent impedance measurements only and is suitable to be implemented using agent technology[4]. Coordination of the agents, however, needs to be considered at the system level.

Wide Area Protection and Control

To prevent or contain large-scale cascade outages, protection and control actions must be taken based on wide area monitoring. The SPSs are certainly the most important piece of the puzzle, but SPSs only (at its current implementation) are short of adaptability. They must be combined with the control of Power System Stabilizer (PSS), automated voltage regulation of generators (AVR), secondary voltage regulation (SVR), shunt capacitors, shunt reactors, static var compensators (SVCs), STATECOM, OLTC, and dynamic load shedding.

Implementation Scenarios

There are two ways of realizing a wide area monitoring, protection and control system. One way is revolutionary and the other is evolutionary.

The revolutionary way is completely based on PMUs, with loose integration with the existing power system protection and control infrastructure. This scenario requires the system wide installation of PMUs. The monitoring and control application is standalone but it exchanges some information with the EMS/SCADA system. System operators view a dedicated console to monitor the system instability indexes, and issue control commands based on the recommendations. The advantages of this scenario include the easiness to install and upgrade the system, and the possibility of adopting new protection and control schemes.

The evolutionary way is to enhance the SPSs with PMU based advanced wide area monitoring and Fast Simulation and Modeling (FSM). This requires a relatively tight integration of WAM and EMS/SCADA. With PMUs at strategically selected buses, the FSM can improve the necessary accuracy of state estimation for system studies in the control room. The FSM can help operators to cost-effectively optimize operations by integrating market, policy, and risk analysis. It also performs "what if" analysis to provide anticipation capabilities to operators. The advantage of this scenario is that the implementation can be incremental to reduce the impact of culture shock to the operators.

Control Room Visualization

Whatever the implementation scenario is, the control room application will have some kinds of user interface for the operators. It has been realized that the visual presentation of control room applications is very important for convey critical information to the operators. Tabular forms used to dominate the console display of control room applications, and they are no longer sufficient for the prevention of cascading outages. P-V, V-Q and P-V-Q graphs, together with geographical information system background, are more straightforward to interpret.

Visualization is not only important for the wide area monitoring, protection and control applications. It is important for any control room applications. R&D is needed in both the academia and the industry.

Conclusions

The future of power system monitoring and control is smart and green, and significant brain power is needed to make it happen.

References

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