Presented in All India seminar on Smart Grid 15-16 July 2009, Hyderabad
Institution of Engineers

'Smart Power Grid' initiatives at Super Grid level in India

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1.0 Introduction:

Electricity is a service industry. With the objective of "keeping the lights on" as the top priority, more and more emphasis is being attached to make this commodity reliable, economical and environment friendly and available on demand. All these features combined together reflect on the smartness or to say towards the capability of the electricity grid in making it available to the end consumer in an uninterrupted manner at the right cost without any adverse impact on the environment. Smart Power Grid means different to different people and can be defined in many ways. Increase in grid size and harnessing of different type of resources due to increasing dependence of the economy on the Electricity Supply Industry (ESI) has brought the concept of smart grid in focus all around the world.

Recently, the US President soon after assuming charge has made smart electrical grid a key element of his plan to lower energy costs for consumer, achieve energy independence and reduce green house gas emission. [1] A smart grid would employ developments in information technology to allow consumers of electricity to connect directly with power suppliers. At the same time it would make use of communications, computing and power electronics to create a system that is

- Optimized to make best use of resources and equipment;
- Distributed across geographical and organizational boundaries;
- Integrated and merging the functions of monitoring, control, protection, maintenance, EMS, DMS, marketing and IT;
- Interactive with consumers and markets;
- Predictive rather than reactive, to prevent emergencies;
- Self-healing and adaptive;
- More secure from physical or cyber attacks.

The Energy Independence and Security Act (EISA) of 2007 gave the U.S. Department of Commerce, National Institute of Standards and Technology (NIST), the "primary responsibility to co-ordinate development of a frame work that includes protocol and model standards for information management to achieve interoperability of smart grid devices and systems…". [2]

Electric Power Research Institute (EPRI) in its report [3] to NIST on the smart grid interoperability standards roadmap has defined Smart grid based on the descriptions found in EISA of 2007. It says the term "Smart Grid" refers to a modernization of the

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electricity delivery system so it monitors, protects and automatically optimizes the operation of its interconnected elements from the central and distributed generator through the high voltage network and distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances and other household devices.

An automated, widely distributed energy delivery network, the Smart Grid will be characterized by a two-way flow of electricity and information and will be capable of monitoring everything from power plants to customer preferences to individual appliances. It incorporates into the grid the benefits of distributed computing and communications to deliver real-time information and enable the near-instantaneous balance of supply and demand at the device level. [4].

In simple terms smart grid is a combination of the smart transmission system, the smart distribution system and integrating customer systems. Integration of distributed generation from renewable sources like solar photo voltaic cell, wind, biomass, mini and micro hydro into main grid is also an important feature of smart grid development.

Therefore, smartness of grid is to be enhanced in all subsections of the ESI from production to consumption.

i. Integration of new technology/new type of generation at generation level;
ii. Integration of new technology in transmission system;
iii. Smart way of managing the transmission system;
iv. Integration of new & smart technology at distribution level;
v. Smart way of using the Electricity.

2.0 International developments in the area:

Lots of development work in respect of the smart grid is taking place in different part of the world. Some of these developments in this field are as described below.

European Technology Platform: supported by European Commission

Smart Grids is a new concept for electricity network across Europe. The initiative responds to the rising challenges and opportunity, bringing benefits to all users, stakeholders and companies that perform efficiently and effectively. The Smart Grid European Technology Platform for electricity networks of the future began its work in 2005 and it transpired that Europe's electricity networks in 2020 and beyond will be [5]:

- Flexible: fulfilling customers' needs whilst responding to the changes and challenge ahead;
- Accessible: granting connection access to all network users, particularly for renewable power sources and high efficiency local generation with zero or low carbon emissions;
- Reliable: assuring and improving security and quality of supply consistent with the demands of the digital age with resilience to hazards and uncertainties;

- Economic: providing best value through innovation, efficient energy management and ‘level playing field’ competition and regulation.

Italy

Power utility TERENA CESI (Italy), in the presentation made during Very Large Power Grid Operators Conference [6] has identified a number of research areas and tasks in the field of smart grid as described below:
Research Area 1: Smart distribution infrastructure
Research Area 2: Smart operation, energy flows and customer adaptation
Research Area 3: Smart grid asset and asset management (Transmission & Distribution)
Research Area 4: European interoperability of smart grids (Transmission & Distribution)
Research Area 5: Smart grids cross cutting issues and catalysts

For development of Smart grids for transmission some of the research tasks identified under the Research Area 4 are as below:

Research task 4.3: Architectures and tools for operation, restorations and defense plans. Here the main emphasis is in achieving new levels of resilience for smart grids. Use of wide area measurements (WAMS) for enhancement of existing control arrangement and development of novel approaches for defense plans and definition of common rules for data exchange between control zones. It also talks about ensuring the operators to be equipped and trained to respond to the challenges of the new grid paradigm.

Research Task 4.4: Advance operation of the high voltage system, seamless smart grids. Here emphasis is on security and optimization in control room. i.e. innovative solution to the demands of real time security analysis of heavily loaded grids and to the use, in real-time security analysis of heavily loaded grids and to the use, in real-time decisions, of dynamic calculations. Emphasis is also given on better visualization of complex and critical system conditions and adoption of new techniques such as state estimator, WAMS for increasing the security of grids and ensuring that operational stability limits are not exceeded.

China

China's views the Smart Grid as a national, comprehensive concept that no single stakeholder group can achieve single-handedly. China consider that to it the technical challenges are that in China the technologies and pilots for Smart Grid are in early stages.[7] In view of this on November 10, 2008 the Joint US-China Cooperation on Clean Energy (JUCCCE) launched the JUCCCE smart grid cooperative to bring together Smart Grid experts across the world to work closely with China’s two utilities and key influencers to jointly define Smart Grid in a way that makes sense in China.[8]

Constructing a Smart Grid in China as quickly as possible is essential, to avoid unnecessary energy usage and emissions. China has a unique opportunity to apply innovative efficiency measures to its electricity grid, as it is building new electricity infrastructure at an unprecedented pace. As China rapidly builds new power generation, new transmission lines, and sells new appliances to consumers, it is important to improve and enable this extended, integrated electrical grid.

In its endeavor to make a big impact, the JUCCCE Smart Grid Cooperative's initial goals are to stimulate interest in Smart Grid planning, in China, and identify a few key Chinese leaders. Smart Grid will involve bringing in a series of international experts to China, over time. These discussions will help disparate groups begin to define Smart Grid in the context of China—as JUCCCE investigates case studies on return on investment (ROI). Smart Grid will outline a set of necessary early decisions, in China so as not to make later implementation unnecessarily expensive.

The Smart Grid Program's secondary goal is to create a feasibility study of the financial, policy and technical requirements of a Smart Grid in China and the Smart Grid Program's third goal is catalyze a regional pilot for Smart Grid.

The JUCCCE Smart Grid Cooperative brings stakeholders across the energy supply chain together to answer how smart grid rollout in China will be different, and what resources are there to help accelerate the implementation. Hu Xuehao of the China Electric Power Research Institute points out many differences in motives between China and the West. In western countries, the emphasis is on the distribution grid, while in China, the current emphasis is on the transmission grid. In USA, Europe and Japan, solar panels are installed on rooftops, while in China solar farms will mainly be installed in desert areas.

3.0 'Smart Grid' Characteristics and Specific benefits:

For persons associated with service industry Smart Power Grid is the facilities for using and purchasing power similar to that available in other service industry like in the telecom, banking, rail / air ticket booking or in other service industry. For example, a mobile phone user is able to use it anywhere in the world without bothering about how it is being achieved technically and charges for its usage anywhere in the world is reflected in his or her account. Similarly, a person having credit or debit card is able to use it any where in the world without bothering about the technology behind it. With the access of web network a person is able to book ticket for his or her travel from any where in the world. Similar revolution is expected in the power sector.

One should be able to use the electricity anywhere in the power network billable to his or her account without bothering about the technology behind it. In other words Smart Power Grid enables customers to better control the appliances and equipment in their homes and businesses. The grid will interconnect with energy management systems in smart buildings to enable customers to manage their energy use and reduce their energy costs.

On the other hand for persons associated with providing such services Smart Power Grid is its ability to provide reliable supply all the time. In order to achieve this Smart Power Grid should possess the following characteristics:

- Ability to achieve greater throughput, thus lowering power costs. Grid upgrades that increase the throughput of the transmission grid and optimize power flows will reduce waste and maximize use of the lowest-cost generation resources. Better harmonization of the distribution and local load servicing functions with interregional energy flows and transmission traffic will also improve utilization of the existing system assets.

- Ability to enabling the access of right information, at the right time to the right people. Integration of database using Common Information Model (CIM) & Service Oriented Architecture (SOA) Solutions for efficient Management Information System (MIS). Enhancing the Decision Making Operation Tools.

- Ability of Self-Healing i.e. responds to system problems in order to avoid or mitigate power outages and power quality problems.

- Security from physical and cyber threats i.e. technology shall be deployed in such a manner that it will allow better identification and response to manmade or natural disruption.

- Capability of supporting the widespread use of Distributed Generation (DG). Standardized power and communications interfaces will allow customers to interconnect fuel cells, renewable generation, and other distributed generation on a simple ‘plug and play’ basis.

- Capability of the customer to participate in Demand Side Management (DSM) & Demand Response Programs.

Smart Grid has become a wide definition, including for the next future new challenges, driven by environmental concerns and by the need to increase security and technological contents in any sector of the power systems. Smart Grids is therefore meant as a challenge not only for Distribution Networks or Renewable generation but for the large interconnected Transmission Systems as well.

Benefits of smart grid are manifold that can be broadly classified into following five categories [3] & [9]:

i. Reliability and Quality of power: An intelligent, self-healing grid that anticipates and thwarts disruptions and dramatically reduces costly blackouts and power disturbances and provides a reliable power supply through the use of digital information, automated control and autonomous systems.

ii. Safety and Cyber Security: Higher cyber security is built in to all systems and operations including physical plant monitoring, cyber security, and privacy protection of all users and customers.

iii. Energy Efficiency benefits: A more economical grid that has far less need for expensive peak power generators and delivery infrastructure. It has reduced energy losses and ability to induce end-user use reduction instead of new generation.

iv. Environmental benefits: The smart Grid is "green". A cleaner grid that can more rapidly bring on line renewable and cleaner distributed generation. It helps to reduce green house gasses (GHG) and other pollutants by reducing generation from inefficient energy sources, supports renewable energy sources, and enables the replacement of gasoline powered vehicles with plug-in electric vehicles.

v. Direct financial benefits: Operational costs are reduced or avoided. Customers have pricing choices and access to energy information. Entrepreneur accelerated technology gets introduced into the generation, distribution, storage, and coordination of energy.

4.0 Initiatives for Development of 'Smart Grid' in India

Development of Smart Power Grid is not something for which we have to start afresh. It is integration of all the efforts that we are doing since beginning to make the power grid more robust, economical, cleaner and convenient for customer usage. The only difference is its uniform application throughout the system in a time bound manner. Revolution in computation technology, communication system and digital memory cost enables the application of these efforts effectively and economically. On the other hand need of digital quality power requires adoption of new technological development in power sector.

Unlike the smart grid programs emphasis of western countries on distribution grid and Chinese emphasis on transmission grid, Indian smart grid developments are in both the sectors. Indian power system has also adopted technological advancement in the power sector. Few of the Indian initiative in the direction of **Smart Power Grids** are as described below**:**

State of the Art SCADA/EMS system: All the load dispatch centers in the country have been equipped with state of the art SCADA & EMS system.[10] This system had increased the network visualization empowering the load dispatch engineers for real time decision-making. After commissioning of such system instances of major and minor grid disturbances have reduced drastically.

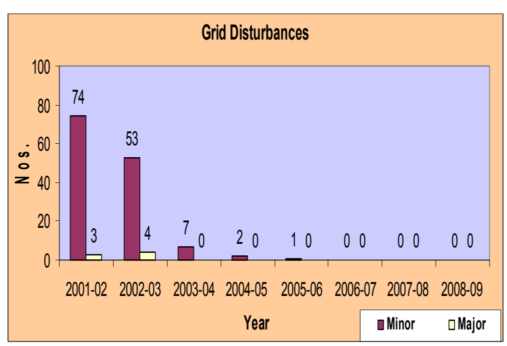

Fig 1: No. of Grid Disturbances in India

ABT Mechanism [11]: Implementation of Availability Based Tariff (ABT) Mechanism at the interstate level for efficiently maintaining real time energy balance and maintaining grid discipline was also in the direction of providing quality power to the consumers.

This mechanism inculcates self-discipline among participants wherein there is a provision of incentive to those who support the grid and disincentive for those who harm the grid. It is a scientific commercial mechanism achieved through a system frequency linked charges for Unscheduled Interchange (UI) viz. overdrawls or underdrawls from the grid with respect to the contracted or scheduled values. This also empowered the consumers at state level to economically utilize the power resources. This mechanism achieves natural merit order in the generation.

Special Energy Meters: In the field of energy metering at super grid level tamper proof Special Energy Meters (SEMs) capable of measuring active and reactive energy time block wise (15 minute duration) in all the four quadrants are being used. These SEMs are also capable of measuring reactive energy under specified conditions for voltage control and reactive power management. Based on these meters reading in an encrypted form from different drawl and injection points in the grid, that is compiled at a central location through electronic mail eliminating the need of joint verification and physical travel. Weekly bills are prepared for Unscheduled Interchange and monthly bills are prepared for regional energy accounting.

State of the art SCADA system and special energy meters (SEMs) enabled in effective implementation of ABT mechanism in the country. Following the implementation of ABT mechanism the fluctuation in system frequency has been significantly narrowed down improving the power quality. (Refer fig 2.) This plot shows gradual improvement in frequency profile from April 2001 i.e. the beginning of ABT mechanism.

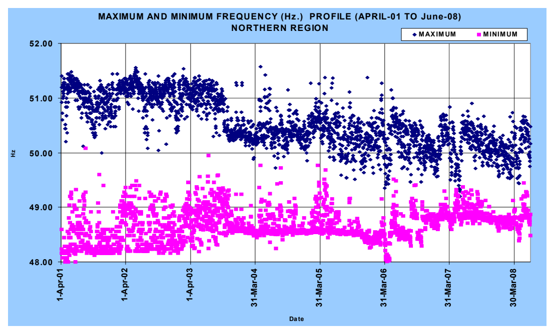

Fig 2: Maximum and minimum frequency in Northern Region

Metering at Retail Level : In many states in the country consumers are billed according to the pattern of usage of electricity in a day i.e. there are different tariffs for peak and off-peak period. For such purpose TOD (Time of the Day) meters are used. Automated Meter Reading (AMR), Advanced Metering Interface (AMI) and prepaid meters are slowly creating revolution at the retail level. These developments can be put to use in creative 'smart grids' of distribution level.

Development of Power System Visualization tools (Real Time as well as Offline): [12]

With the integration of smaller grids into a larger grid, the complexities of real time grid operation have increased significantly. Different power system visualization techniques have been developed to closely monitor the real time grid operation. Some examples of such development are as shown below:

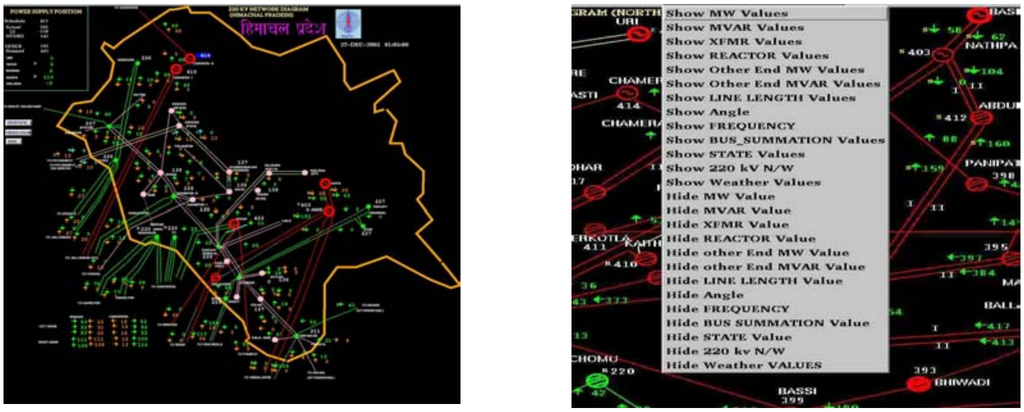

Fig 3: Geographical & Layer Based Visualization

Offline interpretation of huge volume of power system data in a meaningful way also helps in decision-making. For example presenting the hourly daily load data of any city in a two dimensional Load Curve is not as effective as its three dimensional representation as shown below.

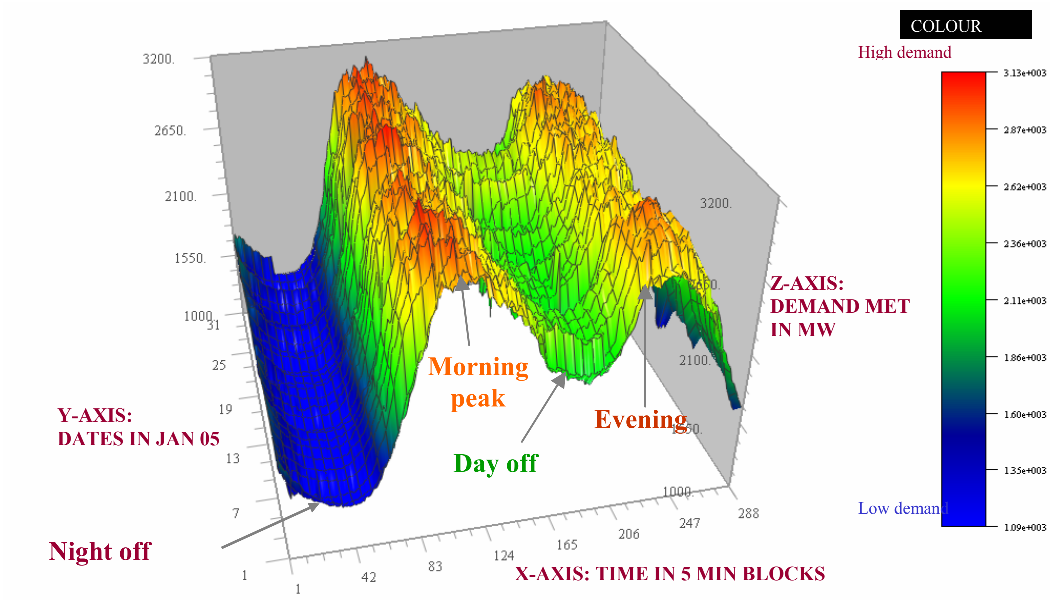

Fig 4: Three dimensional (3D) representation of Delhi City Hourly Load for a month

System Protection Schemes [13]: Power system is considered most stochastic system. In order to make it more reliable during contingency i.e. to make it self-healing numbers of special protection schemes have been implemented in the Indian power system. List of some of important schemes in the country in this respect are as given below:

i. Automatic backing down of generation and load shedding scheme for handling the contingency due to tripping of 2500 MW HVDC bipole Talcher-Kolar between North-East-West (N-E-W) grid and the Southern grid.
ii. Automatic backing down of generation and load shedding scheme for handling the contingency due to tripping of 1500 MW HVDC bipole Rihand Dadri between major load center and Generation hub within the Northern region.
iii. Automatic backing down of generation and load shedding scheme for handling the contingency due to tripping of 400 kV quad Bersimis conductor Muzaffarpur-Gorakhpur D/C link between Eastern region and Northern Region.
iv. Automatic backing down of generation and load shedding scheme for handling the contingency due to tripping of 765 kV Agra-Gwalior D/C (charged at 400 kV).Currently this scheme is in planning stage.

These schemes have avoided number of blackouts and brownouts in the past during contingencies.

Phasor Measurement [14]: Real time monitoring of angular separation between generation hub Rihand and load center Dadri based on network parameters and real time line flow gives a very good idea the status of network between these two nodes and quantum of power flow between these nodes. Analysis of past disturbances shows that likelihood of grid disturbance is more when angular separation between these two nodes is greater than 50 degree. Therefore, grid operator continuously monitors this angle, which is available from state estimator as well as calculation. But, the availability of this angle in real time is limited by state estimator convergence, availability of real time data etc.

Monitoring the network security was a great challenge after the synchronization Northern Region Grid with Central Grid, two large synchronous system with only 400 kV Muzaffarpur –Gorakhpur D/C on 26th August 2006. The regional load dispatch center are having information about the network condition in its own region, whereas with the commissioning of this link the power flow on this tie line was a function of network condition in either of the four region namely east, west north and north east region. Therefore in order to monitor the network condition in any of the four regions an angular separation was monitored between north and west bus of Vindhyachal HVDC back to back station.

Profile of angular Separation, Tie line flow Vs time is shown in the picture during the incident of system separation on 22nd October 2006. Monitoring of angular separation between strategically selected nodes in the grid had have proved to be very effective in real time monitoring of the system condition. However, these measurements have the limitation of 10 sec delay and therefore cannot be relied for monitoring the system stability during transient conditions.

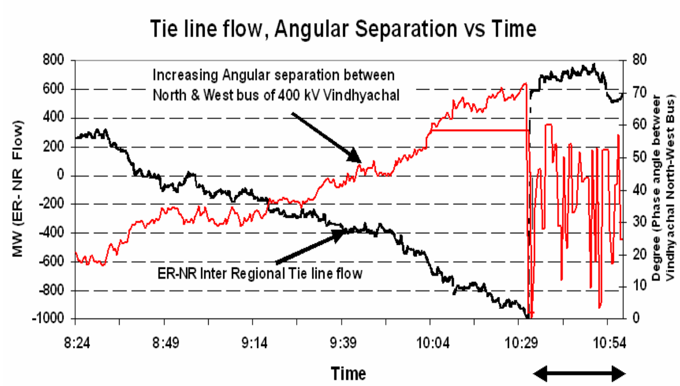

Fig 5: Line Flow, Angular Separation Vs. Time

Grid Strengthening Measures during Fog Conditions: Northern region power system often witnesses contingencies arising due to multiple tripping caused by heavy smog/fog during winter season. These tripping are due to reduction in breakdown strength of insulators because of pollution deposits on it and moisture in the environment. Analyzing the previous incidents of fog related tripping it was observed that whenever temperature is low (below 15 degree Celsius) and humidity is high (RH above 80 %) fog related tripping are reported.[15] Intensity of fog peaked between 0500 hrs -0700 hrs.

In order to forewarn the operator about upcoming contingency provision was made to monitor the trend of temperature and humidity in real time at a large number of locations in the system. Based on these trends advance action was possible through hydro rescheduling, provision of alternate transmission paths, curtailment of open access contracts etc.

For this purpose Short Messaging Service (SMS) utility has been developed in-house to inform all the concerned about upcoming contingency so that preventive actions are taken well in advance rather than responding to the actual contingency. This mechanism proved to be very effective in dealing with contingencies arising out of fog related tripping during the winter of 2008-2009 in Northern Region.

5.0 Ongoing projects at the super grid level in India

Phasor measurement units (PMUs) are power system devices that provide synchronized measurements of real-time phasor of voltages and currents. Synchronization is achieved by same-time sampling of voltage and current waveforms using timing signals from the Global Positioning System Satellite (GPS). Synchronized phasor measurements elevate the standards of power system monitoring, control, and protection to a new level [16]. A number of PMUs are already installed in several utilities around the world for various applications such as post-mortem analysis, adaptive protection, system protection schemes, and state estimation

Monitoring of angular separation in large interconnected grid gives vital information about system status. In this context POWERGRID is going ahead with a pilot project of installing PMUs in the Northern Region network that will be commissioned shortly and data flow to NRLDC would start. Under this project it is envisaged that PMUs would be installed at four strategically selected locations in the network viz. at 400 KV Dadri, Kanpur, Moga and Vindhyachal substations.

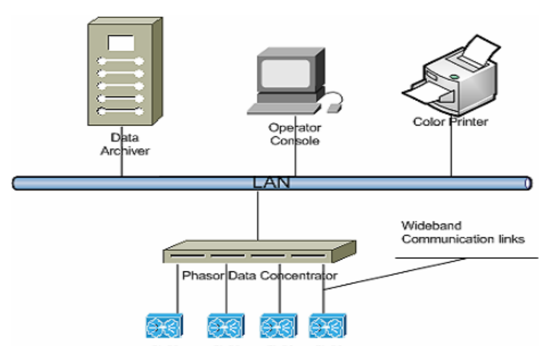

Fig 6: Typical PMU Project Architecture

The pilot project is expected to be a stepping stone to future Wide Area Monitoring & Control schemes making operation of the transmission grid really ‘Smart’.

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