ADVANCED WIDE AREA MONITORING SYSTEM TO SECURE TRANSMISSION CORRIDORS DURING PHASES OF HIGH DYNAMIC ACTIVITY

Himadri ENDOW
Alstom Grid – India
himadri.endow@alstom.com

Indranil BANDYO
Alstom Grid - India
indranil.bandyo@alstom.com

ABSTRACT

The Indian Grid is characterised by widely dispersed generation and load points. Because of this there is large amount of power flow in the inter-regional grid in the east-west, east-north and the north-west corridors. Growth of Independent Power Producers and renewable generation are changing the nature of these power flows. Summer peak demand in the north also adds to the already stressed grid conditions. The power corridors are at present being monitored and analysed by SCADA and energy management tools relying on steady-state limits of the network equipment. While these tools are adequate under normal circumstances, it is inadequate in coming to terms with the true state of the grid in situations of high dynamic activity. This was proven during the blackout on two successive days in the end of July 2012 when almost 48 GW of load was impacted.

This paper looks at how the current situation may be mitigated by implementing a Wide area critical care desk. Filtering the low frequency mode of oscillation from the acquired PMU data and subsequent mode analysis, operator is informed of the large and poorly damped group of generators. Analysing the corridor power flow influencing the mode and generators crossing the step, contributors of the oscillations present in the network would be identified.

Once the source and the sink of the oscillations are known, operator will have the means for pro-active re-dispatch action to maintain stability. In addition, wide area phenomenon like load encroachment and situations leading to voltage collapse and network congestion can be brought under critical dashboard monitoring.

INTRODUCTION

The power network in India comprises four synchronised region grids (code named NEW) and a fifth connected asynchronously to NEW. Each region grid consists of several state level transmission systems (STS). These are managed by the various state LDCs (SLDC) while the interstate transmission system (ISTS) is managed by the region LDC (RLDC). From a national perspective, the installed generation capacity (206 GW) seems sufficient to meet the peak demand of ~130 GW [1]. However operational supply shortages do exist. These are due to under utilisation of generation assets on the one hand and the widely dispersed locations of generation and load centres on the other. This causes many load centres like the states and even regions turn into net importers of electricity and hence become critically dependent on the ISTS and the inter-regional transmission system. Probably the worst affected in NEW Grid is the Northern Region which reports a peak demand deficit of 8.5% and energy supply deficit of 11.3% [2].

The supply-demand balance in the synchronous system is not supported by any ancillary services but through the following process,

- Estimation of demand / supply on a monthly basis for each 15 min operational block by each control area (distribution licensee / Bulk consumer / SLDC / RLDC).
- Computation of available transfer capability (ATC) in ISTS & STS.
- Day ahead scheduling of embedded generation, loads as well as net drawals by each control area. This is usually the algebraic summation of drawal from Inter-State Generating Stations (ISGS) and those from contracts (short, medium and long term) through various open access arrangements.
- Intra-day re-scheduling of generation (including renewable) and dispatch based on contingencies.
- Regulation of embedded generation and load by each control area in order to toe the schedule, for frequency above 49.7 Hz. Deviations from schedule are priced according to unscheduled interchange (UI) component under Availability Based Tariff (ABT). Tacit assumption here is, such deviations shall not, cause system parameters to deteriorate beyond permissible limits &/or cause unacceptable line loading.
- Management of load shed for frequency at or below 49.5 Hz. For this the Grid Code defines different categories of interruptible loads (with lower tariffs), such as scheduled rolling load sheds, un-scheduled load sheds, those under ‘under frequency’ &/or ‘df/dt’ relaying and the ones under special protection scheme.

This paper looks at the disturbances leading to the recent blackouts and the findings of the enquiry committee [2], before suggesting a few technology solutions to mitigate some.

WIDE AREA CRITICAL CARE DESK

As already mentioned the stability of the power distribution network is critically dependent on the inter-region and inter-state transmission corridors. While these corridors are being continuously upgraded, the prevailing supply-demand shortages makes it challenging to square up reasonable margin of safety under different contingencies like planned outages, forced outages or tripping. The SCADA/EMS solutions in place are not adequate to manage the dynamic behaviour of major feeder lines leaving enough safety margins. Pilot WAMS projects were initiated in the regions to gain experience on network behaviour. However the scope of work in these pilots did not target specific objectives like assessment of persistent or periodic low frequency modes of oscillation in the pilot area network, analyse impacts on network stability and identifying root cause.

The need of the hour is to establish a critical care desk in each region, and one at the National Load Despatch Centre (NLDC), which will be responsible for monitoring the Wide Area System Disturbances and flag critical dispatching actions ahead in time.

Following is an overview of some advanced analytics [3] based on wide area PMU data, which will help implement the objectives of the Critical Care Desk.

System Disturbance Management

System disturbance management (SDM) enables the system operator to characterise sudden system disturbances and identify their trigger point/s and impact. It relies on the fact that unlike normal conditions, close to a disturbance, the angle changes instantaneously or rapidly depending on the type of issue. To characterise the loss of generation or load (MW gain/loss) before control & load shedding operates, the rate of change of frequency is associated with the change in power in the inertial response of the system.

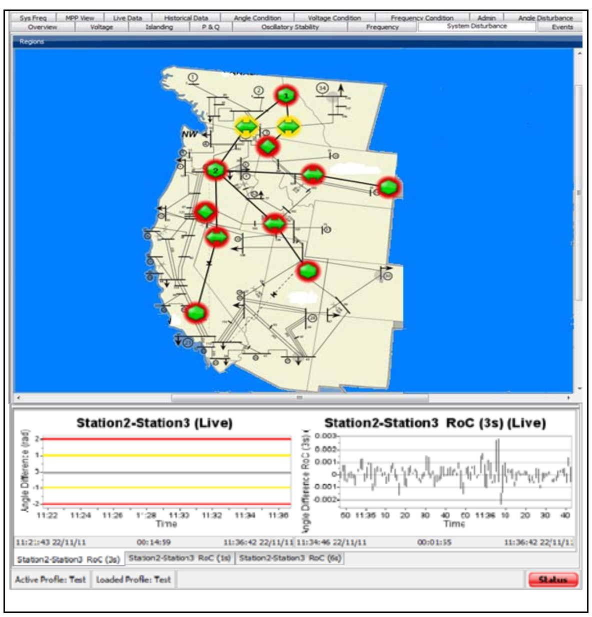

Fig 1: *System Disturbance View*

The real-time event record of the disturbances is made possible through the availability of high speed data streams from system wide PMUs coupled with the performance optimised real-time computation capability and ability to generate complex events from multiple system events within advanced analytics.

SDM works through generating complex event alerts and alarms from rate of change over a period of time of the voltage angle and frequency. Results are presented on a geographic map with location and timing of the sequence of trigger points spread across the interconnection (Fig1). The view shows a number indicating the location of the triggering event. If there are several distinct disturbances, the view will show consecutive numbers indicating where the events were triggered. This may signify a system wide and hence more severe phenomenon. The hexagonal icons represent an aggregated measurement location or hierarchical region with colours representing the dominant alerts and alarms. Operator can drill down on one of these icons to review live data for the relevant measurement. One such live plot is also seen in Fig 1, of selected SD analysed parameters over the most recent 15 min window.

While calculating the ROC of local angles, care is taken to use a smoothed reference that is not strongly influenced by dynamic effects close to the reference location. Recommended values are available for the window length for calculating the ROC, the hysteresis of consecutive analysis results and the alert/alarm thresholds. However these are kept configurable to suit size and inertia of the interconnected system.

Management of Power Corridor

Power transfer capability of major corridors, are revised by RLDCs once every three months based on load and generation forecast and network topology. For a simple corridor comprising of segments A-B, B-C, C-D and D-E the equations for Total Transmission Capacity (TTC) and Available Transfer Capability (ATC) are [4],

$$TTC = Min\,[Cap(A\text{-}B), Cap(B\text{-}C)....Cap(D\text{-}E)] \quad (1)$$

$$ATC = TTC - LTOA - MTOA - RM \quad (2)$$

Where,

Cap(x-y)= Transfer Capacity of segment x-y
RM = Reliability margin set for the corridor
LTOA = Committed through long term open access
MTOA= Committed through medium term open access

The ATC is what remains available for short term open access contracts and, even unscheduled interchanges by virtue of dynamic changes in load and generation. The constraints in calculating the ATC this way are, it only acknowledges the steady state limits of the network with RM being empirically defined. Network congestions or unutilised capacity cannot be accurately estimated and provisioned ahead of time. Also as happened in the recent blackout, frequent forced outages (due to over voltage) will be left out in ATC calculations. In this context periodic assessment of the security and stability of the

inter-connection assumes importance. In this the limitations of the model based technique, is well documented. Instead continuous monitoring of small signal oscillatory modes and damping, of system frequency, power and angle differences, hold out promise. Tools to identify what is aiding the oscillatory instability and what is acting against it and also the security margins available to manoeuvre will become invaluable to the system operator during situations of high dynamic activity.
The Oscillatory Stability Management (OSM) essentially characterise observable modes of oscillation that appear in measured signals in the power system. These tend to occur at frequencies less than 2Hz. As against each frequency measurement, the geographic view will show an arrow representing the relative mode shape. These mode shape arrows are derived from an analysis process that selects the dominant mode in the frequency band from which relative amplitude and shape are determined. Usual form of monitoring oscillatory stability is by trending the mode decay time against a set threshold or by plotting the mode amplitude against the mode decay (Locus plot).
The effectiveness of the OSM is fine tuned by selecting the mode boundaries of interest. This is usually done by initially collecting data over a period of time and assessing them through histogram charts.

Identifying Sources of Instability

Complex dynamic behaviour in power systems leading to poorly damped small signal oscillations is largely due to the interaction between spinning masses interconnected through magnetic linkages over the network. These are influenced by active controllers such as turbine governor controllers, and automatic voltage regulators. It is possible to analyse the magnitude and phase relationship between the power and speed oscillations to trace the path of oscillations through the network and establish the region or plant aiding the oscillation and transmission corridors where power flow is influencing the mode.

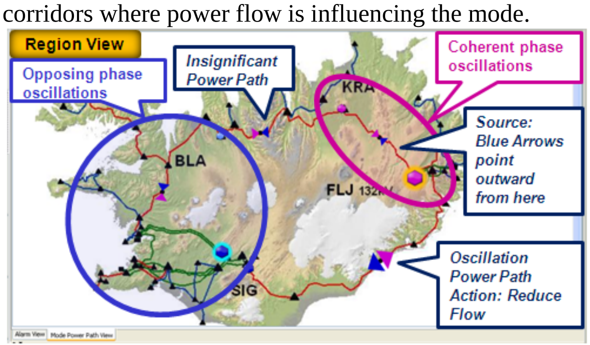

Fig 2: *Tracking coherent & opposing phase oscillations*

In Fig 2, the size of the arrow head is proportional to the amplitude of the largest power signal oscillation from reference with two colours used to depict in-phase (pink) and opposing phase (blue) oscillations. Here contribution from generators, are seen in the southern corridor where the blue arrows are pointing outwards with significant change in size. The region view depicts exchanges and their impacts in power corridors between regions. One step below this, the area exchange indicators are replaced by the individual line indicators. These layered views identifying sources of instability are an excellent way of managing critical power corridors. The given case calls for a dispatching action leading to lowering the flow in the southern corridor. Suitable dash boards may be tailor made to observe the damping of critical parameters locally as well as related phenomenon across interconnected regions.

Approach to detection of Load Encroachment

A calculated data stream may be configured to calculate a single value at each time point in the data source stream, e.g. for a system with a data rate of 50Hz, a value will be calculated 50 times a second from the corresponding data source. The calculated data stream is specified using program fragments written in a dynamic language similar to Groovy programming.
The calculated data function may support other objectives besides SDM. In the present context of grid tripping on zone 3 relaying, this function may be used for detecting load encroachments leading to zone 3 tripping. The approach described in Ref [5], could be implemented by continuously calculating the actual fault resistance for each transmission line segments from data coming from on-site PMUs, and arming the corresponding zone 3 relays only when the calculated fault resistance is within the practical range (0 to few tens of kilo-ohms).

Congestion Management

Real time congestion management today is dependent on comparisons of actual corridor flows against TTC. TTC is calculated offline in advance and is a reflection of the most restrictive component from among thermal limits, voltage limits or stability limits. Further the infinite number of operating contingencies along with ever changing grid complexities makes it difficult to come up with accurate TTCs. Instead in real time one can leverage the improved computations of path flows and path limits using PMU data and the modern analytics. Such real-time calculations of transfer capability will exceed the traditional ATC in most cases, without compromising stability margins. This will lead to reduced congestion and more optimum system dispatch.

Approach to managing Unscheduled Interchange

Another important fact [2] emerging is the lack of restraint on the part of constituents from exceeding scheduled power allocations. The balancing mechanism where UI plays the central role, operate manually and hence is not bankable at the time of emergencies. Moreover the UI penalties are not at par with the wholesale market prices or even cost of embedded generation. This makes it less of a deterrent and more an economically profitable option for the states to deviate from the net drawal schedules from ISGS.

As a mitigation measure, it is a good idea to look at pre-configured and automated demand-response (DR) programmes. These can immediately delink issues connected with operational jurisdiction between State and Regional entities and effectively implement the provisions made in the India Electricity Grid Code 2010 [6]. It will not only instil greater discipline during normal UI fluctuations but also force load sheds during system contingencies.

Demand Curtailment

The day-ahead drawal schedules are aggregated bottom up and formalised at the region level. This means each control layer like distribution licensee, bulk consumers, SLDC up to RLDC will have their own identified drawal schedule to honour and hence reliability DR programmes may be conceived for all control layers. This DR trigger will come from the system frequency (as in the case of UI) and work towards bringing the net drawal of the control area back under schedule limits. The DR at the lower layer 'n' will run a granular reliability programme having a narrower trigger threshold (e.g. 50 +/- 0.1 Hz). DR at the layer 'n+1' will closely monitor the DR execution at the layer 'n'. It will have a wider trigger threshold (e.g. 50 +/- 0.2 Hz) compared to the layer 'n'. When this threshold is crossed, the layer 'n+1' DR may run a more severe rotational shedding of pre-configured loads.

The design of the reliability DR [3] can be manifold, from shifting demand through auto re-scheduling interruptible loads to factoring in peaker generation in the mix or resorting to rolling load sheds if required. The participating entities here shall be contractually obligated to declare a set amount of DR capacity and face penalties for non-performance and also incentives for being available just as it happens with generation capacity charges. Towards this end regulatory changes are necessary but the programme would simply sustain on its own by simply taking the day-ahead scheduling to its logical end. The day-ahead scheduling follows an iterative method between the various control layers. The DR resource, need to form a part of this scheduling mechanism, to eliminate conflicts in real-time operational jurisdiction.

DR Implementation

The DR programmes are closely linked with the demand estimation, scheduling and net drawal in real-time. It has to have interfaces to connect with Enterprise Data Server /AMR /SCADA /DMS /EMS of the designated control area to be able to track the drawal of the target area as the programme executes. Curtail commands from the Auto DR may be routed through the area automation system or directly through gateways or shared between the two. In an interconnected system, the contingency procedures need to be regularly updated as per events not directly related to the control area. Also execution of these procedures and their results, have to be communicated to the n+1 control area for aggregation.

SUMMARY

The challenge in power distribution in India rests on smart management of the complex network flows in the interstate transmission grid. Non homogenous growth in load, pit head generation far removed from load centres, growing penetration of grid connected renewable and increasing trade in electricity due to open access regime is going to complicate these power flows more. This calls for continuous evaluation of the dynamic conditions of the grid, locating the areas under stress and identifying the remedial measures in real time. Modern wide area analytics are designed to achieve this end by providing means to the operator to intuitively focus on the root cause from a sequence of alarms. It also employs powerful computation techniques to generate associative complex alarms to pickup signatures of grid stress and manage network congestion, invaluable in averting failures. The critical care functions could help setup dash boards to focus on major power corridors with features for drilling down to live data. These features have proved their credibility in solving different type of issues in many utilities across the globe. In addition simple demand management tools leveraging the UI based balancing mechanism can be a simple yet elegant way out of the festering problem with rampant violations in unscheduled interchange. Through a process of registering and scheduling the DR resource, reliability demand response programmes can effectively eliminate the uncertainties of the current manual system of demand curtailment.

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