Dynamic Monitoring of Information in Large-Scale Power Grids

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Abstract— this document proposes the software model for detection and analysis of cascading faults in the operation of large scale power grids. Using data mining technologies, probable patterns can be detected for faults and proper mitigation measures can be taken. Firstly, the fault is detected by checking the stability of system. Then event sequences are calculated to best approximate the fault node. Then by analyzing the severity of vulnerability and region in which vulnerability would occur, proper ICT Technologies can make operators aware about the faults. Hence, speeding up the existing mechanisms. This model aims to solve problem of detection more efficiently than existing systems.

Key words: power grids, cascading faults, data mining, ICT technologies, event sequences

I. Introduction

A. Power Grid and Its Phases

The power grid can be defined as the network of wires and machines that connect power plants to the end users.

There are three phases involved in the power management system as follows:

1) Production
2) Transmission
3) Distribution

The voltage of electricity generated is amplified by a step-up transformer, for convenient transmission to long distances.

The electricity is transmitted to long distances via wires, i.e. conductors. During this process, some energy is lost. In U.S., typical line transmission losses vary from 6% to 8% Energy loss at higher voltage is comparatively less than losses at lower voltage, i.e. nearly same amount of power can be transmitted to long distances at lower current. This energy loss, is directly proportional to the current. Hence, lower the current, lower the losses.

The high-voltage electricity is carried over transmission lines to local stations, where a step-down transformer brings down the voltage of electricity suitable for customer use.

B. Power Grid operations in Indian Scenario

Grid Management in India is carried out on a regional basis. The country is geographically divided in five regions namely, Northern, Eastern, Western North Eastern and Southern. All the states and union territories in India fall in either of these regions. The first four out these five regional grids are operating in a synchronous mode, which implies that the power across these regions can flow seamlessly as per the relative load generation balance. The Southern Region is interconnected with the rest of India grid through asynchronous links. This implies that quantum and direction of power flow between Southern Grid and rest of India grid can be manually controlled. Load Dispatch Centres-Each of the five regions has a Regional Load Despatch Centre (RLDC), which is the apex body, as per the Electricity Act 2003 (EA 2003), to ensure integrated operation of the power system in the concerned region. The RLDCs for North, East, West, South and Northeast regions are located at Delhi, Kolkata, Mumbai, Bangalore and Shillong respectively.[3] The RLDCs coordinate amongst themselves both offline as well as online for maintaining the security and stability of the integrated pan- India grid. In line with the federal structure of governance in the country, every state has a State Load Despatch Centre (SLDC), which is the apex body to ensure integrated operation of the power system in the state. Role of Load Despatch Centres-As per the Electricity Act 2003, the Regional Load Despatch Centre monitor grid operations, exercise supervision and control over the inter-state transmission system, are responsible for optimum scheduling and despatch of electricity within the region, in accordance with the contracts entered into with the licensees or the generating companies operating in the region and keep accounts of quantity of electricity transmitted through the regional grid. RLDC is responsible for carrying out real time operations of grid control and despatch of electricity within the region through secure and economic operation of the regional grid in accordance with the Grid Standards and Grid Code. The functions of SLDC elaborated in EA 2003 are similar to that of the RLDC except the area of jurisdiction, which in case of SLDC is the state.

C. Limitations in Indian Power Grid

Reliable operation of the large interconnected grids of North America and Europe is founded on established practices of tight frequency control and all control areas sticking to their respective interchange schedules. The grid frequency normally remains within +/- 0.03 Hz of the rated frequency, and any excursion beyond that is considered alarming. Utilities deviations from their schedules are minimal, and have to be made up in kind the next day. They are therefore not priced. Adequacy of generating capacity enables maintenance of requisite spinning and cold reserves at all times, for overcoming contingencies. In a regime with such discipline, all power plants must generate power according to the schedules decided by the concerned load dispatch centres, and pit-head and nuclear power plants can steadily operate at a substantially constant MW as per their respective schedule [2]IN INDIA- The peak-hour consumer demand far exceeds the available generating capacity. Capacity shortage is officially stated as around 15%. Load-shedding is a daily routine except in metropolitan cities and State capitals. Rural supplies are regularly rostered commonly and restricted to 8-12 hours a day in most States. State utilities, in their anxiety or compulsion to minimise load-shedding in their area, tend to overdraw power from the larger grid. Interchange schedules go for a toss, and frequency often plunges below the stipulated lower limits. As per a recent report, the frequency was below 49.2 Hz for about 25 % of the time during August 2009. On the other hand, industries and commercial establishments need back-up diesel generators for continued operation when power supply from the grid is cut-off or is curtailed (for a few hours every day), and domestic consumers have to bank on their own battery-backed "inverters" to get the basic amenities of light and fan round the clock.

Consumers may never know the real reason of the Grid failure but to blame it on the overdrawing State Governments is like accusing gate crashers of spoiling your party when your own security personnel were missing. That comes to the critical point of who ensures Grid compliance, the Power Grid Corporation managing the grid or the State Electric Boards who are being asked to voluntarily play by the rules, but we shall come back to that later.

Frequency variation in the power system exists due to the mismatch between the supply of power and demand for the power. Voltage variations exist in the power grid is due to the mismatch in the reactive power between demand (MVAR) and available.

In spite of all these variations there is certain limit for the operation limits (variations allowed) for voltage and frequency parameters dictated by the Grid Code. Any variations in the parameters (voltage and frequency) below operating limits considered as power grid is unhealthy and restoration steps will be taken to make the power grid healthy. Other failures such as Scheduling and dispatch for nuclear and thermal plants, Grid frequency, Regulation and frequency response,

Grid disturbances, landing and load rejection, Voltage fluctuations, Availability tariff, Renewable energy

D. *Need of Dynamic monitoring of information*

"An automated, widely distributed energy delivery network, the Smart Grid will be characterised 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" [3]

To address broad challenges, it is clear that infrastructural investments are necessary. Indeed, the last decade has seen significant adoption of information technologies as applied to the distribution grid, such as advanced metering, communications equipment, and data analytics. These technologies give utilities the eyes and ears needed to better understand the operational characteristics and performance of their grids. Although these 'grid smarts' are necessary components of a modernised grid, the ability to enact change in response to grid intelligence is the critical ingredient necessary to render a subsidy-free and systemic business case, one whose benefits exceeds associated costs and meets industry-standard cost-effectiveness tests without explicit reliance on societal benefits.

In the context of the distribution system, current examples of the need to enact change in power flows are:

1) Regulating voltage in response to PV-induced voltage rise.
2) Broadly reducing feeder voltage during peak periods for the purposes of demand reduction.
3) actively cancelling harmonics induced by nonlinear and unpredictable loads
4) Dynamically load-balancing distribution transformers.
5) Automatically rerouting power around failures.
6) Efficiently deploying resources to address impending asset failures sequentially.
7) Activating loads upon large-scale outages, among many others.

In each of these cases, a source of monetising value can be realized, whether derived from reliability, power quality, efficiency enhancements, avoided future capital expenses, or reduction in operational expenses.

Unlike the information technologies underlying 'grid smarts,' the technologies required to enact change must necessarily process power in a dynamic and adaptive fashion; that is, have the ability to adapt their regulation response to changing grid conditions and on sufficiently small timescales, providing for 'grid agility.'

II. Domains in which Work Need to be Focussed

1) Fault detection
2) Fault Identification
3) Its classification & analysis
4) Mitigation

III. Faults and their Classification

Generally, the instabilities in system and their aftereffects, are called faults. These faults are classified into three types:

1) Temporary faults
2) Permanent faults
3) Cascading Faults

Temporary faults, are the faults which can be mitigated quickly without affecting the system to a higher extent. These temporary faults can be mitigated by operator itself on its successful detection. Further discussion on temporary faults is out of scope of this document.

Permanent faults, are the faults in the equipment or machinery, which can only be fixed on replacing the defective equipment with a better one. Also, bad logical combination of the efficient equipment can lead to permanent faults. These faults can be handled by the grid designers and equipment vendors.

Cascading faults, are the faults, which occur recursively in nodes similar like a tree. Firstly, a node (i.e any unit which receives or distributes the power) fails, due to certain instability in the system, this increases the chances of other nearby nodes to fail. This, further affects, other nearby nodes, hence causing cascading faults. These faults, are difficult to detect, as chances of predicting the next possible node which would be affected are less accurate. Hence, there is an increasing need of the uniform model, which can predict the affected nodes, with good probability.

Lack of efficient algorithms and resources, make the detection of cascading faults, a major obstacle in the power management. Hence, the model proposed in this paper aims to combine various algorithms at various stages to achieve the following:

A greater accuracy in predicting the failure in a specific node.

Identifying events leading to cascading faults.

Better ICT technologies to mitigate the fault in time

IV. EVENT SEQUENCES LEADING TO CASCADING FAULTS

This document takes into consideration controllable cascades in which the operator has few chances of mitigating the fault. The stages of cascading faults are as follows:

Initiating event: Initiating event may be a fault on transmission line or generator.

Steady state progression: Once the first node fails, the failures in other nodes begins to propagate slowly. This stage ultimately leads to a stage where the failures cannot be controlled.

Dynamic Progression: This stage is the last stage in cascading failures. The nodes begin to fail automatically after the system faces under-voltage.

V. SOFTWARE MODEL PROPOSED

The software model proposed in this paper includes the five components:

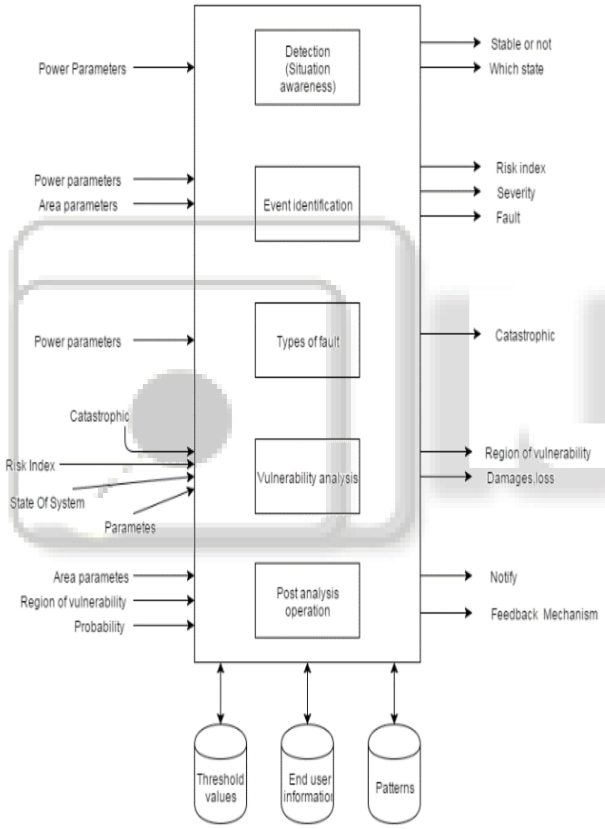

Fig. 1: Software Model Proposed

A. Detecting Failures

This model includes following two stages depending on which the decision is made whether the system is stable or not.

Further, this module also states whether the system is operating in normal state or not. To achieve this, system is classified to be in four stages namely:

1) Normal
2) Alert
3) Emergency
4) Extremis

The system in normal state is desired where the system is stable. System moves to alert state, when a fault is detected, but system is able to operate normally without much changes to the system, system moves to emergency state, if the system faces all-of-a-sudden fault which cannot be mitigated instantly. The system moves to extremis state, when the cascading failures occur and response measures are taken immediately.

B. Event Identification

This module is responsible for identifying the event sequences that lead to cascading faults.

This is achieved by calculating the risk index for each node in the tree and analysing the severity of each risk. Risk is calculated by summing up the probabilities of all the events which lead to cascading fault for a particular node.

C. Classify Faults

This module takes the input of both the previous modules and checks for the type of fault identified depending on risk index of all nodes, and severity analysis. If the fault is cascading then accordingly the overall impact in the form of a severity index is calculated.

D. Analyze Vulnerability

This module further extends the output, by analysing the region of vulnerability, and how probably a fault would occur and by what pattern.

This is the core module, as all the parameters like location of the fault, etc. are considered into picture.

E. Mitigate

This module takes advantage of ICT technologies to actively propagate the probability of fault to corresponding area in charges and operators. Hence, better mitigation measures can be taken in time. Also, a proper feedback loop is ensured so that the communication is acknowledged. This would help in not only to mitigate the risk, but also in increasing efficiency of the current systems.

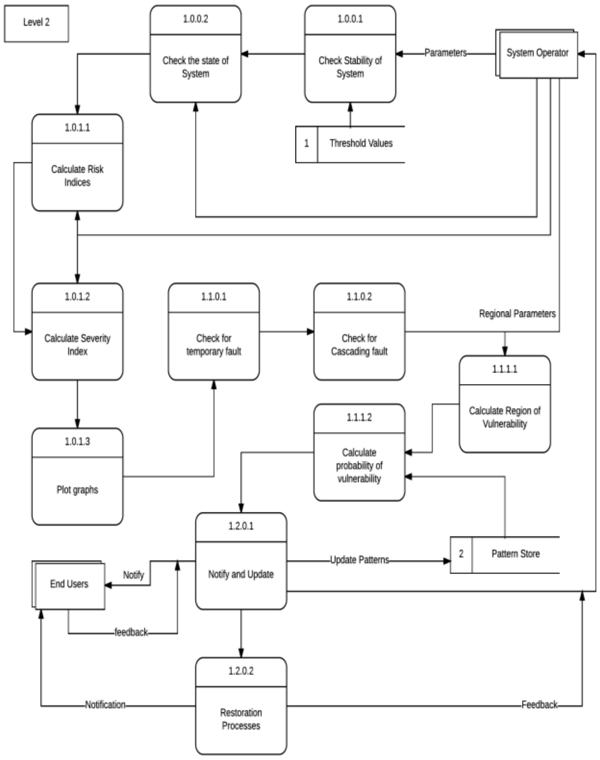

Fig. 2: Mitigate

VI. Conclusion

This paper proposes the software model which would be essential to automate the analysis of faults, using data mining and analytics. This model also takes into consideration, the communication measures currently lacking in our system. This approach can be implemented in any real grid with proper threshold values. Identification of high risk failures can be made convenient than previous approaches.

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