SPATIO – Temporal Fault Detection and Integration of ICTON a Large Scale Power Grid

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ABSTRACT

Power grid is the vital life line of modern society that can be easily get affected by blackouts and outages. Therefore it is important to diagnose the faults and restore the service in a timely manner in order to minimize the fault induced losses. To add to this, the complex and stochastic nature of environment factors makes automated fault identification, its diagnosis and its restoration is a big challenge. Thus , this paper determines the blackout scenarios around the world .It further explores the Overload Cascade model (OCM) algorithm and then proposes a modification into the OCM with a focus on modernizing the transmission grid through application of ICT technologies

Keywords

Power grid, cascading failures, Information and communication technology (ICT), OCM

1. INTRODUCTION

Power grids are the vital lifelines of modern society. Indian power sector has made remarkable progress since independence with a total installed capacity going up from 1.362MW in 1947 to more than 200,000 MW in 2012 while the transmission network increasing from an single isolated system concentrated around urban and industrial area to a country wide National Grid. However, this grid has remained unchanged over many decades and is collapsing. Blackouts, outages are becoming inevitable and the demand for electricity has been exceeding the supply implying a significant risk of system wide failures.[1][2]Researchers around the world have put in considerable efforts in deriving models for cascading failures in power grids, with the ultimate goal of designing a reliable power outage management system by converting the present power grids into robust smart grids. However, since the grids are large and complex, these cascading failure models are intractable. [3]On the basis of observing the occurrence of cascading failures and eventually the blackouts, this paper proposes a mechanism to identify the chances of failure occurring at an instant of time and take necessary actions through the application of Information and Communication Technologies (ICT). The remainder of this paper is organized as follows: - In section 2, we describe the blackout scenarios around the world is specified. Section 3 identifies the need for an automated failure identification system. Section 4 represents the Overload CASCADE Model. Section 5 discusses the model developed for handling cascading failures. Section 6 further evaluates the system and further determines the results obtained from the simulation.Section 7 concludes the work followed by the references mentioned in section 8.

2. BLACK OUT SCENARIOS AROUND THE WORLD

A number of examples given below exemplify the need for automation of failure identification process and integration of the ICT technologies in the existing energy management system.

1) Statistical data of the year 2012 reveal the number of interruptions in the Indian power grid as follows :-

Year	No. of interruptions	Duration in hrs.
2008-09	4007	14979
2009-10	3034	10021
2010-11	2045	6766
2011-12	1591	4426

Table 1:- Number of Interruptions

2) Mumbai was hit by big power cuts after a technical glitch at Tata Power Unit in September 2014.

3) July 30^{th} and 31^{st} 2012, saw collapse of Northern and Eastern grid in which half of India was without electricity supply, affecting more than 600 million people in and around New Delhi and Kolkata.

4) In September 2012, Sipat generation plant with a capacity of 2980 MW along with ACBIL plant having a capacity of 270 MW tripped due to various oscillations which significantly modified the characteristics of the grid causing higher risk in stability Transmission depletion, lack of immediate frequency response and lack of situational awareness are some of the major reasons identified for low frequency operation of the grid [5][6]

5) On 1^{st} November 2014, 100 million people in Bangladesh were affected due to a nationwide blackout that occurred after a transmission line that brought 445 MW of power from India tripped, knocking out about 400 kV. This technical glitch forced the entire country's power plants to shutdown leading to cascading failure. This required at least 12 hours for normalcy to be restored in the grid.[7]

6) On 25^{th} January 2015, 80 % of Pakistan plunged into darkness after a short circuit breakdown of 500kva power transmission line carrying electricity from the private sector Hubco power plant to the national grid tripped.[8]

Thus, this reveals that there needs to be augmentation of ICT and smart grid for effective control to avoid overloading and reduce the number of interruptions [4].

3. NEED FOR AN AUTOMATED FAILURE IDENTIFICATION SYSTEM

Power grid of different countries is identified to be different from one another based on their topology, size, capacity, interconnectedness and their loading levels. Due to its complex nature, grids are becoming increasing vulnerable, leading to delays in detecting and handling failures. Even though defensive techniques against the cascading failures such as Special protection schemes (SPS) and remedial action schemes (RAS) exist but by the time the problem is detected, it becomes too late to prevent them and not all the generated data is sent to the control room for analysis. To enhance the resilience of the grid, gives rise to employing modern communication technologies, automated fault detection, classification and restoration strategies into the power grid to make it smarter and enhance resilience. This would thus aid in safeguarding and self-healing the grid. [9][10].

4. OVERLOAD CASCADE MODEL

The features that mainly contribute to the formidable complexities of large blackouts are the components that fail when their loads exceeds a threshold. This is represented by the CASCADE model. This Overload CASCADE model (OCM) works on the DC power flow model with the sources of inputs representing the stress imposed on the power grid where in the following steps are incorporated –

1) The initial power flow is calculated.

2) If the load on a line goes beyond its capacity the line trips or disconnects and the power flow are recalculated on the new topology by subtracting (eliminating) the tripped lines.

3) This process is repeated until there are no further trips as shown in figure 1 [11]. This incorporates the CASCADE algorithm which identifies the component failure when their load exceeds Lfail. The normalized modified initial disturbance and the normalized load increase when a component fails are then given by ,

$$d = \frac{D + L_{max} - L_{fail}}{L_{max} - L_{min}}$$

$$P = \frac{P}{L_{max} - L_{min}}$$

Where P is the positive and fixed amount of load transferred to other components in case of failure

L_{min} is the minimum initial load for each component. L_{max} is the maximum initial load and D is the additional amount of load added to components at the beginning of the cascade. [12][13]

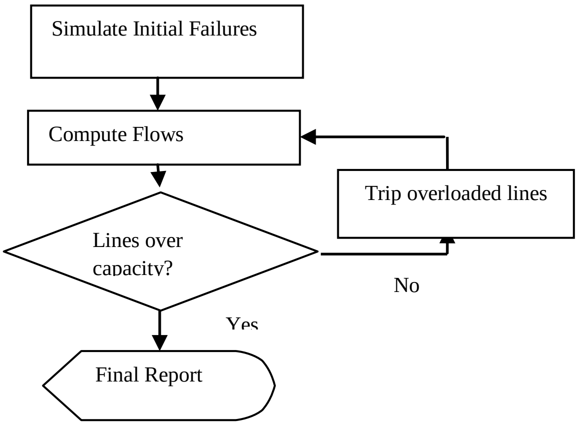

Figure 1: Overload Cascade Model (OCM)

5. THE MODEL

Based on the concept utilized in the OCM, the proposed model of the power grid is represented as a weighted graph G (N, k) with N nodes and k edges. The nodes represent the substations serving a load while the edges between two nodes represents a logical connection between the nodes and are expressed by a N x N adjancy matrix $\{e_{ij}\}$.For example, consider a network consisting of 4 nodes N = (N1, N2, N3, N4) and (N – 1 = 4 -1 = 3 edges) and represented through the matrix as shown in figure 2[16][17]

Adj {eij} =

	N1	N2	N3	N4
N1	0	1	1	0
N2	0	0	0	0
N3	0	0	0	1
N4	0	0	0	0

i.e. adj{eij} =[0,1,1,0;0,0,0,0;0,0,0,1;0,0,0,0]

Figure 2: Adjancy matrix

e_{ij} = 1 ,if there is an edge between node i and node j
= 0,if there is no edge between node i and node j

The graph so generated, often known as the dependency graph signifies the dependency of the nodes on one another and also represents that any change in the state of operation of the parent node directly affects the other nodes. [14][15]

The OCM model and other models such as Randomized graphs focus mainly on the transmission line failure or component/equipment failure. However, the proposed algorithm focuses on node failures where the operating parameters on the 3 phases vary. These variations are identified via the change detection logic to determine the occurrence of failure as follows:-

1) Let the area within a region to be monitored be identified as R = R1, R2…….Rn and A= A1, A2…An Where, A and R represent the area and the regions to be monitored respectively.

2) For this region determine the state of operation of the grid at an instant of time.

3) Determine the parent child relationship through the model and the adjancy matrix

4) Identify the operating parameters in the region of interest at an instant of time t. Let i = no. of nodes, j= the number of parameters identified as:-

j= 1, 2, 3 representing 3 φ voltage

= 4, 5, 6 representing 3 φ current

=7 representing the frequency

5) For every node determine the current state of operation where N = Normal operating state, A = Alert state , F = Failure state where Alert state is further bifurcated into AL and AH and the failure state is further divided into FL ,FH representing low and high for alert and failure state respectively.

6) Based on the value of the normal operating parameter , the values of AL, AH, FL, FH are calculated as follows :-

If, value = TL <value > TH, the grid is operating within the operating limits else

If, value = (TL – 1)<value > (AL + 1), there is a disturbance observed in the grid with the value of the parameter decreasing else

If, value = value <AL, the grid has moved into the failure state else

If, value = (TH + 1)<value > (AH – 1), the grid has encountered disturbance by crossing its operating else

If, value = >AH, the grid has moved to the failure state.

7) In order to check the state of operation, logic for change detection is further applied to the system under consideration.

Let x = the last value captured

X1 = new value,X2= | (x – X1)|

X2 <> step 6,

If the value of X2 is within the operating range, the system is said to be in stable working range else an alert or failure state is detected and the entire process is continuously repeated to determine the state of operation of the grid and the type of fault occurrence.

8) If state = "A" or "F", the frequency of monitoring the specific node is increased to 50msecs with a step size of 1msec to accurately identify the type of fault.

9) Utilization of ICT technology needs to be done for dissimilation of information about the area affected the type of fault at that instant of time as shown in figure 3.

Date : 17/6/15 At time – 20:00:01.730		
Node	Phase	State
1	1	ALV
1	3	FHV
After monitoring for 50msecs, the current status of the system is At time – 20:00:01.780		
1	1	ALV
1	3	FHV
The suggested order of restoration in descending order of priority is		
Node	Load under outage	Failure % Damage
1	400	44.44

Figure 3: Utilization of ICT

10) The process from step no. 4 is repeated continuously to ensure accurate monitoring of the system state.

6. EVALUATION OF THE SYSTEM

Based on the node on which the failure has occurred and considering four nodes of operation and initial operating state being normal, the system can be evaluated with a failure occurring on node N_4 with phase 1 and phase 3 going down due to failure on low voltage (FLV) and Failure on low current (FLC) respectively and phase 2 facing alert on high current (AHC). The evaluation process comprised of:-

1) Determining the load bearing capacity C_i as$C_i = \alpha L_i$

Where α = tolerance factor and L_i is the loading factor.

2) Determining the phase affected –

If cap2load2 > = phase_cap then,Load 2 = load2+ phase_cap.

Else check if phase 3 can further handle the load after restructuring the grid as shown in figure 4.

Characteristics	**Value**
Overall Operation Efficiency	83.32 %
Overall losses	16.67 %
Cascading Operational Efficiency	0.99895 %

Node	**Phase 1**	**Phase 2**	**Phase 3**
Node 1	99.9761	100	99.9609
Node 2	100	100	100
Node 3	99.9747	100	99.9836
Node 4	100	100	100

Figure 4: Analysis of the system

3) Severity of the fault can be determined through –

% of load = Total load under outage * 100
under outage Total load bearing capacity

Total load under outage = load_phase 1+ load _phase 2
if fault has occurred on phase 1 and 2. For the scenario mentioned above the total losses obtained was = 16.6754 %

Operational = Output power * 100
Efficiency η Input power

The Operational efficiency η was obtained to be = 83.32 %while Cascading efficiency that is given by the average operational efficiency of all phases of all nodes at an instant of time = $\eta_1 * \eta_2 * \eta_3 * \eta_4$ and was obtained to be 0.99895 %.

5) ICT technologies are employed to communicate these values further to the authorities as represented in figure 3[18][19]

7. CONCLUSION

Power grid is considered to be one of the most critical infrastructures existing today that drive the industry, government, economy and the society at large. Transmission grid that forms a crucial link between the generation and distribution of power has to be up and running all the time. Failures and blackouts have a devasting effect on the entire nation. Due to the complexity in the grid operations, infrastructure deficiencies, catastrophic power system blackout events have occurred across the globe making the grid vulnerable and risky. One of the mechanisms to handle failures is the Overload Cascade failure that focuses on the transmission line failures. The proposed model deals with node failures through graph based approach and based on a set of rule based change detection logic, these failures, are categorized in different orders and magnitudes of impact. The ICT based technology is further utilized for communication of the same to the authorities for necessary actions. . The system is further evaluated in terms of the cascading and operational efficiency. These types of failures at the micro level can help the control center operators in risk assessment, strategy planning and recovery procedures.

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