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New and Improved Spatio − Temporal Fault Detection and Integration of ICT on a Large Scale Power Grid

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ABSTRACT
Power grids are the vital life lines of any modern society that can be easily affected by blackouts and outages. These power grids however have remained unchanged over many decades and are collapsing. Automated fault identification and monitoring the smooth operation of the system considered to be one of the key challenges in smart grid development. To add to this, the complex and stochastic nature of environment factors have made fault identification heavily dependent on human experiences and intelligence. This paper thus explores the operating modes of the grid followed by the need of failure identification system. This paper further focuses on modernizing the transmission grid through application of ICT technologies by processing the continuously large amount of data coming into the transmission grid; perform real-time monitoring of grid conditions which in turn can help the control room operator to respond quickly to the grid problems.

General Terms
Fault detection, Emergency management systems, Remedial action schemes.

Keywords
Power grid failures, Failure identification, state of operation, Communication mechanism Information and communication technology (ICT)

1. INTRODUCTION
Power grids are the vital lifelines of any modern society especially the Indian grid. Indian power sector has made remarkable progress since independence with the total installed capacity going up from 1.362MW in 1947 to more than 200,000 MW in 2012 along with the transmission systems increasing from the isolated system concentrated around urban and industrial areas to a country wide National Grid. Inspite of so much progress in the capacity and transmission system, the grid has remained unchanged over many decades and is collapsing. Currently, the demand for electricity is exceeding the supply, triggering a significant risk of system wide failures [1], [2]. This is further causing blackouts and outages which are now becoming inevitable. Thus any fluctuations in the grid parameters can lead to the entire grid becoming unstable and tends to move the grid towards cascading failures and blackout situations. On the basis of observing the occurrence of cascading failures and eventually the blackouts, a mechanism has been proposed to identify the chances of failures to occur at an instant of time and take necessary actions through the application of technology like the Information and Communication Technologies (ICT)[3], [4].The remainder of this paper is organized as follows: - Section 2 identifies the need for an automated failure identification system. Section 3 presents the model utilized in the grid along with the proposed algorithm. This is then followed by the parameters utilized for identification of the failure in Section 4. Section 5 analyses the algorithm developed beginning with the selection of parameters chosen for operation followed by its analysis in section 6. The proposed algorithm is further evaluated based on various parameters in section 7. The conclusion of the paper is presented in section 8.

2. NEED FOR AN AUTOMATED FAILURE IDENTIFICATION SYSTEM
The power grids of different countries differ from each other based on various characteristics such as its topology, size, capacity, interconnectedness and loading levels. Increased complexity and the networks vulnerability further adds to the sensitivity of the grid. All the above mentioned characteristics lead to a considerable delay in identifying and detecting failures. Even though defensive techniques such as Special protection schemes (SPS) and remedial action schemes (RAS) do exist to protect the grid against cascading failures but by the time the problem is detected, it becomes too late to prevent them. Secondly, not all the data that is generated is sent to the control room for analysis. Therefore to enhance the resiliency in the grid, automated fault detection and utilization of modern communication technologies into the transmission domain of the power grid forms the need of the hour [5], [6], [7], [8].

3. THE MODEL
The power grid is modelled as a weighted graph G (N, k) with N nodes and k edges where the nodes represent the substations serving a load while the edges represents a logical connection between the two interconnected nodes. This interconnectedness is further expressed through an N x N adjancy matrix $\{e_{ij}\}$. The matrix so formed is then converted in the form of a graph called the dependency graph. The graph so generated signifies the dependency of the nodes on one another and further represents that any change in the state of operation of the parent node directly affects the other nodes [9], [10]. Based on the dependency graph model and identification of the state of operation of individual node , an algorithm is proposed that focuses on node failures as compared to line failures which is described through Overall Cascade Model (OCM)[11],[12],[13] and randomized graph models[14],[15],[16],[17]

The proposed algorithm is represented as follows: -

1) Determine the area and region under consideration

2) Determine the number of nodes and edges considered in the respective region

3) Determine the N x N adjancy matrix $\{e_{ij}\}$ of the network representing the logical connection between the nodes of the

network. This is further represented as a dependency graph that provides the network structure.

4) Identify the operating parameters in the region of interest at an instant of time t. Let the operating parameters identified be voltage (V), current (I), frequency (F)

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 determined.

7) In order to check the state of operation, change detection logic is further applied to the system under consideration as follows :-

Let x = the last value captured

X_1 = new value

$X_2 = |(x - X_1)|$

If the value of X_2 is between the operating range of 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) The process from step no. 5 is repeated continuously to ensure accurate monitoring of the system state.

4. PARAMETER VALUES FOR THE GRID

The analysis of this research begins with the identification of the values selected for computations. The values selected are based on the standards provided by the Indian Electricity code.For 220 KV , 16A , 50 Hz supply, the values of the voltage , current and frequency parameters considered are as shown below as shown in the table 1 where the normal operating parameters are represented and w represents the working range for the respective parameter.

Parameter Considered	Value
Voltage (V_w)	198 − 245 KV
Current (I_w)	5 − 16 A
Frequency (F_w)	49.7 − 50.2 Hz

Table 1: - Operating parameters

While observing the nodes of the network, if the operating parameters are found to be ± 10 % of the working operating parameter, the node is said to be in the alert state of operation. To add to this further, if the values of operation go beyond ± of the alert state of operation, it is determined that a failure has occurred due to fluctuations in the respective grid parameter. The values considered for threshold low and high values based on the ± 10 % cut off as the threshold are as shown below in the table 2 below.

Value	Voltage (V)	Current (I)	Frequency (F)
Low (L)	178	4.5	49.7
Threshold low (TL)	198	5	49.5
Threshold High (TH)	245	16	50.2
High (H)	270	17.6	50.7

Table 2: - Selection of threshold values

5. ANALYSIS OF THE ALGORITHM DEVELOPED

5.1 Selection of Parameters

The values considered for threshold low and high for alert and failure state are considered to be at ± 10 % of the working state of the operating parameter values as compared to ± 5 %. The reason for selecting these at ± 10 % compared to ± 5 % are as follows:-

5.2 Voltage Selection

Comparing these values with the operating parameters table mentioned above shows that the normal operating values are within the range of198 − 245 KV, and considering alert on low voltage values, for 5 % values compared with normal range, values between 189 − 197 KV are not considered, so 5% does not work for alert on low voltage. Also, the values (235 − 245)KV which are the operating values, come under alert on high voltage in 5%.But these are normal operating values which get intermingled for AHV. So 5% cannot be considered here too.

5.3 Current Selection

Considering 5 % values, the values obtained for alert on low current is identified to be within the range of (4.1 − 4.6 A) while the normal operating range is between (5 − 16 A). Therefore, the values in the range (4.7 − 4.9 A) are found to be missing values in which no action is been determined. Therefore since ALC and AHC give wrong values if considered with 5 % values, 10 % is considered for the current parameter too**.**

5.4 Frequency Parameter Selection

Since the operating values for the current are identified to be between 49.7 − 50.2 Hz, to determine the values for alert and failure scenario on higher and lower side, determining respective values considering 5 % and 10 % cut off were determined. It was further identified that considering 5 % threshold value is not a viable solution for determining the alert and failure thresholds.

5.5 Determination of the Node and the Phase That Is Affected

The node based on the state of operation determined earlier is monitored for the next 50msecs at an interval of 1msec to determine the actual location of failure. For this a function monitor MNC ( ) is triggered. The current date and time are further determined.

5.6 Load Capacity Handling

The visualization of the affected node and its effect on the remaining nodes is determined through the situation awareness screen which represents the initial load on the nodes and the next screen represents the effect of the failure of a single node say N2. This is represented by the tables 3 and 4 respectively.

Node (N1...N4)	**Capacity (KW)**	**Load (KW)**	**Availability (KW)**
N1	1500	900	600
N2	**600**	**500**	**100**
N3	900	700	200
N4	900	500	400

Table 3:- Initial load bearing capacity of the grid

Due to the failure of the node N2, the node N2 gets isolated and therefore, its entire load gets shifted to the remaining nodes that is N1, N3, N4 respectively and is represented in table 4.

Node (N1...N4)	**Capacity (KW)**	**Load (KW)**	**Availability (KW)**
N1	1500	2056.4	556.4
N2	**600**	**-----**	**-----**
N3	900	844.4	55.6
N4	900	500	400

Table 4:- Status of the grid after isolation

6. COMMUNICATION THROUGH ICT

Based on the node on which the failure occurred, utilization of ICT technology was done for dissimilation of information about the area affected the type of fault at an instant of time to the authorities as represented in figure below [18][19][20]

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 1: Utilization of ICT

Further based on the information sent a report is generated that captures the amount of time taken to send the information and receive at the receivers end respectively. This helps to determine the utilization of the ICT in the transmission sector of the grid. A snapshot of the same is represented in the table 5 given below.

Date	**Time**	**Node**	**Phase**	**Email sent**	**Email received**
26/6/15	23:06:07:371	N4	1,3 (Voltage)	23:06:07:421	23.07
18/6/15	14:01:28:962	N3	Frequency	14:01:11:712	14:02
18/6/15	13:52:01:735	N1	1,3 (voltage)	13:52:01:785	13:53

Table 5:- Report of utilization of ICT

The table 5 above indicates that the amount of time taken to pass on the information to the respective authorities for further action is negligible as compared to the uncertainties of the other communication mechanisms.

7. EVALUATION OF THE SYSTEM

Based on the parameters identified and the operating state of the grid, the system was further evaluated through the process 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

3) Severity of the fault is further determined through –

$$\text{\% of load under outage} = \frac{\text{Total load under outage}}{\text{Total load bearing capacity}} * 100$$

4) Operational efficiency η was then determined as represented below as -

$$\text{Operational Efficiency } \eta = \frac{\text{Output power}}{\text{Input power}} * 100$$

Nodes	Phase1	Phase 2	Phase 3
N1	99.9761	100	99.96
N2	100	100	100
N3	99.9747	100	99.9836
N4	100	100	100

Table 6:- Operational efficiency of the nodes

5) ICT technologies are employed to communicate these values further to the authorities as represented in figure above [19], [20]

8. CONCLUSION

The day to day operations of the modern society works on the power and its operations. Focussing on this to be a crucial component for smooth conduction of the overall grid operations, the identification of the fault on any of the nodes of the grid forms an important criteria. Therefore, this paper identifies the need of empowering the grid with introduction of ICT technologies for automated fault detection and identification. Therefore this paper focuses on the need for the automated fault identification and its respective algorithm to be developed. This algorithm forms the essence for fault detection through the communication mechanism of ICT. The developed module further evaluates the systems developed through the various parameters and the operating state of the grid in terms of the various quantitative measures like the operational efficiency, percentage of load affected and the utilization of ICT technologies for handling the failures.The algorithm so developed deals with the network structure which is simple in its operation. The future scope comprises of operating the algorithm with enhancement for the systemic risk failures (black-outs) with increasing network size. More work can be focussed on determining the other communication mechanisms and their respective impact on the fast dissimilation of information. Variance monitoring can further be done and implementation of push notification and the restoration mechanisms can further be incorporated.

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