FAILURE ANALYSIS AND PHASE DETERMINATION OF SMART GRID

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Abstract:
The purpose of the study is to analyse the failures of smart grid and to start with, phase determination is important to know. If some lines are tripped due to overload, natural disaster, intentional attack, any error etc load is shifted to another phase and another phase got overloaded, its overall capacity decreases, so all lines are failed which is situation of blackout. So reliability of overall smart grid decreases. Study is conducted to determine the phase of failed lines and then impact of load shifted to another phase/lines is studied and plotted using MATPLOT. Also CPLEX tool is used to study linear optimization problem of phase determination.

Keywords*: failures, smart grid, probability, MATPLOT, CPLEX*

1. INTRODUCTION

THE flow of electricity from generation to consumption is currently through legacy electricity grid which will be completely transformed to smart grid soon. In legacy electrical grid, the generation, transmission, distribution and consumption of electricity is not smart enough to adapt to current changes and manual interruption is required. Smart grid enhances energy efficiency, reduce burden on layman's pocket through cost reduction as well as accommodate the various generation options likes' solar, wind and multiple renewable resources [1]. Till now, our legacy systems are using fossil fuels which will deplete soon and emits carbon emissions. After implementation of smart grid, the smart infrastructure from smart meters to smart generation includes smart substations and smart distribution which has capability of self-healing as well as self-monitoring, will improve the quality of life. By using two-way communication in smart grid enhances the intervention of consumer and consumer will be more satisfy for being a participant in this process. The issues with black and brown outs will also be solved through smart grid as smart grid is smart enough to resist attacks and theft of electricity too. Smart grid has optimized resources and it enables the electricity market. The quality of service gets improved in smart grid which improves the quality of experience. Smart grid improves if any of below parameters like the overall system parameters as energy efficiency, reliability, flexibility, security, sustainability and quality of service improves.

Smart grid can be divided based on multiple parameters like if we divide as power system then it has four areas i.e generation, distribution, transmission and consumption. Similarly, it has multiple divisions based on communication layers as wide area networks, neighbourhood area networks, home area network. Smart appliances are used in home area network or at consumption area such as smart meters, Iot devices etc [2]. These are some high research areas in smart grid now a day: smart assets, demand-supply management, storage, smart sensors as well as smart generators etc. Further going down, information structures are divided into two parts as first part from the electrical appliances to smart meter using wireless communication technologies such as GSM, GPRS,3G, WiMAX, PLC, zigbee, Low PAN etc and another is flow of data from smart meters and the utility data centers using cellular technologies.

Smart grid deployment is of great concerns to researchers that include communication deployment as well as infrastructure deployment. After deployment, smart grid can operate in islanding mode as well grid connected mode that can also be dependent on various situations, so system is adaptable also as per the need of hour. So self-alignment, self-healing as well as self-monitoring are also great achievements of smart grid. The optimization of flow of energy can be solved by linear optimization tools like cplex by choosing resources optimally. The key points when concerning about smart grid are: the demand should be fulfilled; the resources should be available always so that there is no blackout occurs, cost should be minimized, and business goals should be met as well as lesser operational constraints. Also, the objective should be to forecast demand as well revenue optimization. The goal can be like specific resource alignment or routing should be optimal or sequencing, best possible timing of activities etc. When working on optimization, decision variables are important then create objective function and constraints should be defined properly [3]. We still have some area in the existing systems that can be improved like whenever there is any power cut, the first step is to know the phase of that area or house and then determine the reason of failure before rectify it manually. All these processes are done manually and time consuming and also it is know that manual intervention can cause errors. There are three phases at transformer level and it should distribute properly so that every phase will get electricity as desired. The number of transformers should fulfill the energy requirement of limited customers only as there are multiple constraints i.e dependent of input received, distance of house from transformer etc.

Also there are multiple languages are used to resolve the issues associated with smart grid like python, java, matlab, OPL, css etc so researchers are working in different languages to resolve issues or implementation of smart grid.

2. PURPOSE OF THE STUDY

When there is a loss of electricity in an area or house, first investigation done is to determine the phase of that house or area which is done manually and then manually rectify the cause of failure, which took time as well as manual effort. So some action has been done to reduce the manual effort and quickly identify the phase of the house/houses. Also, to reduce the effect of loss of electricity on smart grid is studied and work related to this is done. The cause of Blackout and ramification of that is studied.

3. METHODOLOGY

There are three phases are used to transmit the electricity i.e phase A, phase B, and phase C. To determine the phase of individual house is difficult to maintain in records but it is needed to have a balance of magnitude of voltages and currents in all the three phases. If the feeders are imbalanced, then losses are increased and overload happens which reduces the efficiency of smart grid. So, it is important that transformers serve houses according to its capacity only and there is no overload which causes failures. The load capacity of a transformer should be equal to demands of the houses connected to it. The calculations are done in every 10 mins. The power transmitted by a transformer for phase A is 10, phase B is

5 and phase C is 15 as shown below. Also, D1, D2, D3....Dn are the houses consumes power as shown below as D1 consumes 5.5 Wh in 10 mins, D2 4.5 and D3 5. So using linear optimization algorithms, this can be solved by CPLEX. From the table shown below, the phase can be determined as sum of power consumed by houses i.e the sum of power consumed by D1 and D2 is same as Phase A, total is 10 so it means D1 and D2 house is served by Phase A. Similarly, Phase B is completed served by D3 house similarly others can be easily find out.

Time calculated	Phase A (in Wh)	Phase B (in Wh)	Phase C (in Wh)	D1	D2	D3....
$T_{1\text{-}10mins}$	10	5	15	5.5	4.5	5

If k is either phase A or B or C and C_{jk} is j house is served by phase k.
Then,
$Z_{jA} + Z_{jB} + Z_{jC} = 1$ (equ. 1)
where j is number of houses and A,B,C are the phases.
Z_{jk} is 1 or 0 if connection is establish then 1 otherwise 0.

But this equation 1 has issues as there can be error in measurement at j house at time t.
So, we can write this as
$H_{jt}Z_{jk} + E_{kt} <= P_{jt}$

where H is a matrix of home measurement, Z is connection, E is error in measurement and P is phase measurements.
H = [0 0 1;
0 1 0;
1 0 0]

3a. Assumptions:

1. Each house is connected to at least one phase.
2. Each transformer should have specific capacity and server that much number of houses so that there is no overloading and failure occurred.
3. The voltage and current is limited in a phase and demand should be less than total voltage and current at transformer.

3b. Errors: The error in measurement can be Gaussian error, dynamic error, time synchronization error etc. By vary the values of m*n matrix for number of houses, we get multiple error estimations as shown below in the table.

Case 2: The failures caused due to overload in a phase B after failure in houses connected to phase A. These types of failures are studied and if failure causes blackout situation is also studied below. There are five transformers of different Wh capacity are considered. Stochastic state estimation method is used. States are estimated and failures are calculated. States are function of these variables: number of failed lines, capacity of failed lines and stability of power grid.

4. ANALYSIS OF DATA

Case 1. Phase detection in Smart grid:

The blue lines on the figure shows that each house is evenly distributed for 3 phases with probability of one-third whereas red lines shows uneven distribution. When the number of measurement are less than half the number of houses, the success shows are fractional solutions and success shown as low. If measurements are more than half the number of houses, the linear problem shows high success rate. The linear problem is solved with data of 50 houses to 250 houses and meter readings are randomly calculated. The duration varies from 15 mins to 30 mins. Conclusion is as the numbers of houses are increased, measurement gives accurate results.

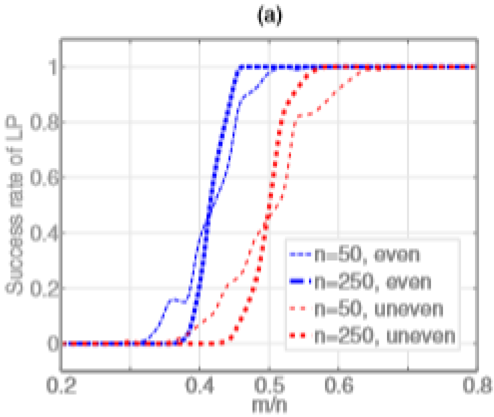

Figure-1: When there is no error.

Case 2: Failure analysis in case of overload problem results to blackout:

In case of failure due to overload in phase A then all the houses in phase A are connected to Phase B and then failure of Phase B is also occurred due to overload. Failure probability corresponds to the amount of overload. The initial demand should be multiplied by load. First calculate the total demand and generation capacity of the grid. Then count the number of possible states. Whenever failure occurs, we save this as first state of the grid. Dynamics of multiple failures is studied based upon markov chains [10].

The number of failed lines of capacity j at next time step following failure of line of capacity i is plotted below. The data is collected with multiple iterations.

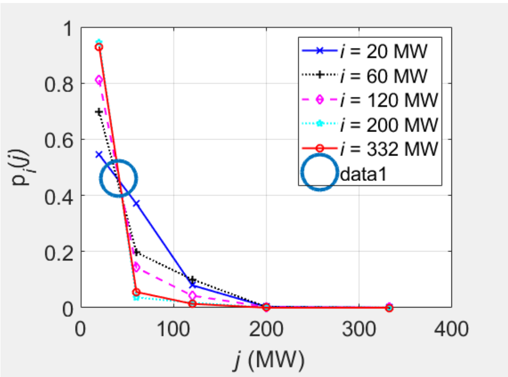

Figure-2: failure probability

From the above graph it shows there is high correlation between the total number of failed lines and total capacity of failed lines.

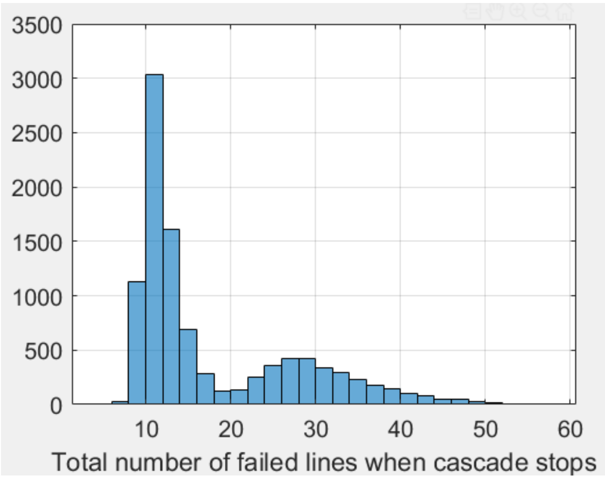

Figure-3: Number of failed lines

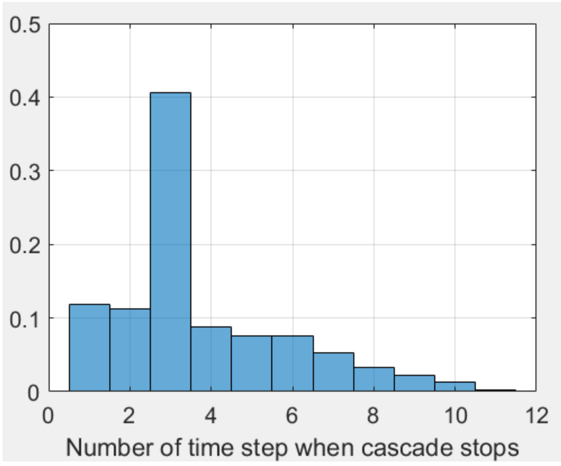

Figure-4: Number of time steps

Fig 3 and Fig 4 shows the number of steps needed and cumulative number of lines in steady state.

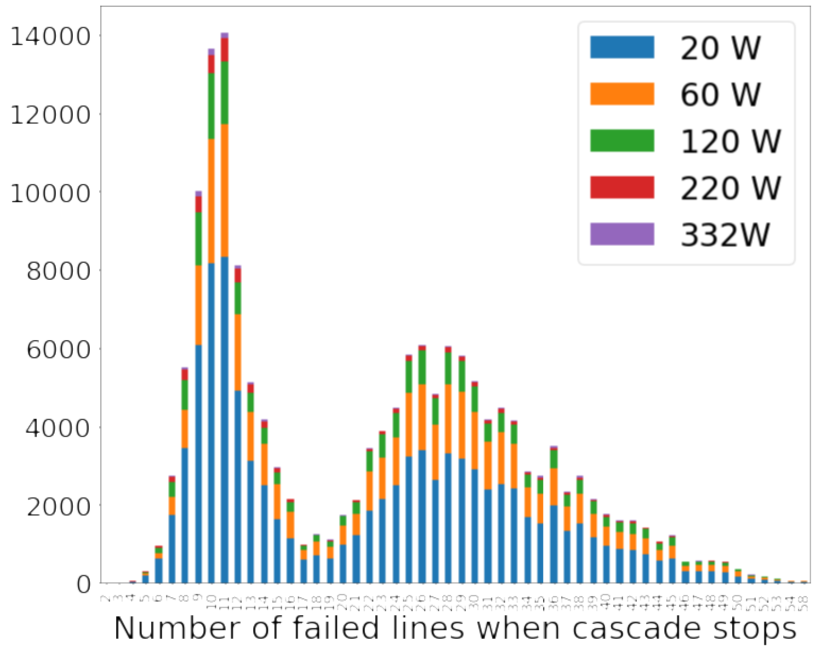

Figure-5: Number of failed lines in each category at steady state

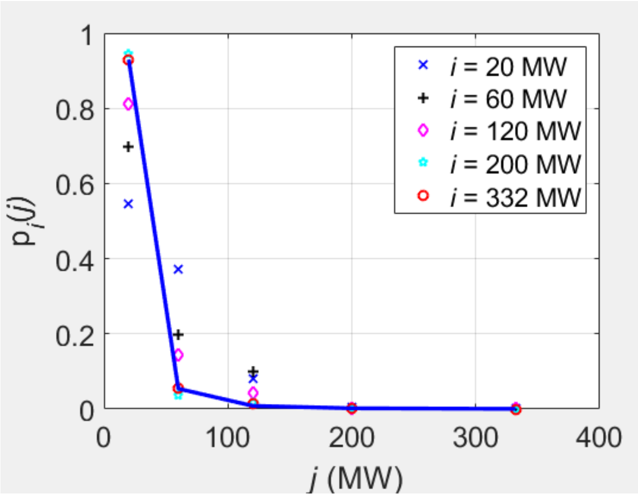

Figure-6: Plot with power law function

Lsqnonlin function is used for power law function [12].

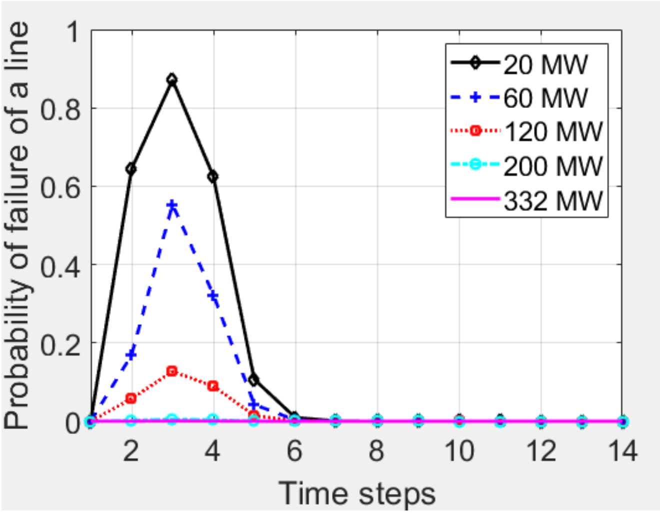

Figure-7: Probability of failure of a line with time step

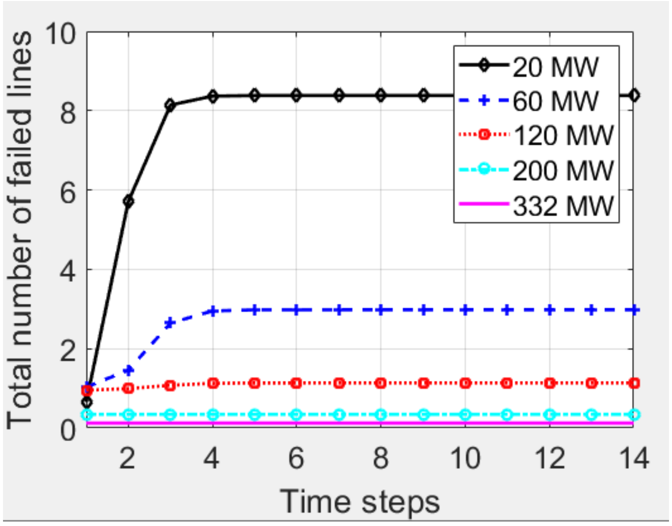

Figure-8: Total number of failed lines with time step

5. DISCUSSION ON FINDINGS

To study the impact of failures can cause blackout situation that is recently happened in Nigeria. To reduce the situation of blackout, failure study of smart grid is very important. To start the analysis, it is important to know the failure phase and if failures increases. The first failure and reason of failure is known to us, then ramification/reduction in failure can also be done. The failure study is conducted based on multiple simulation parameters like power grid loading level, capacity estimation error, load shedding constraint levels, number of failed lines, proability, capacity of lines and stability of smart grid etc.

Also, agreed with the findings of these studies of Abreu, Hardy, Pereira & Zeifman , (2016) [10], Naeini ,Wang &Mammoli, (2014) [11], Naeini, Hayat (2016) [12], Bessani ,Fanucchi, Delbem & Maciel C. D. (2016) [13], R. A. Shuvro(2017) [14], Wang & Khanna (2011) [14], Wang & Khanna (2011) [15].

6. CONCLUSIONS

If there is any failure in power connection is determined and if that failure impacted the other phases also due to overload or any naturally occurred phenomena. If there is large impact occurred then it will cause blackout or brownout. So to reduce the scenarios of blackout or brownout, it is important to study the failure analysis of smart grid which is worked upon with time as well as different transformer of different capacities. Phase determination in case of failure in smart grid quickly and efficiently. If the capacity is increased and supply is not met as per demand then there will be failures in the smart grid which increases with time if not controlled over time. So if the capacity of number of lines are increased and controlled then failures can be reduced. The failures analysis is done to estimate the number of failures and probability to increase the reliability of the smart grid.

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