

A Survey of Data Mining Techniques for Smart Grid Systems

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Abstract - Electricity generated through steam and hydro – turbines have been serving us since ages. It has reached its limits. Outages, blackouts are becoming inevitable. So, there is a need to develop a system that is able to identify the links right from the source of electricity generation to the consumers that are vulnerable to failures, automatically switch over to other network load if need be, be prepared prior to such a situation and hence take corrective measures to restore the electricity transparently. All this can be done by applying machine learning and data mining algorithms to the existing infrastructure. This leads to development of a system that is smart, intelligent and works transparently towards its goal i.e. preventing power failures.

The aim of this paper is to focus on the existing electricity generation infrastructure, the factors that affect the current system and the need for Smart Grid. The various methods that have been concentrated on are that of machine learning and data mining techniques that can be mapped to these smart grid environments. For each of these techniques namely - data mining, ranking, visualization and testing, we have highlighted the key points of every technique stating their advantages, features of each. In this paper we have also tried to analyze the evaluation framework that would aid in monitoring grid activities depending on the type of data, anticipate and respond to system disturbances proactively based on the method applied to minimize the impact of power failure on consumers and thereby improve the overall performance of the system.

Keywords - Data mining, Electrical infrastructure, evaluation framework, Smart grid.

I. INTRODUCTION

Generation of electricity and its power grid is a complex task lot of uncertainties at various levels. In today's environment, the infrastructure is collapsing. There is a shortage of electricity, blackouts and outages are becoming inevitable. The entire infrastructure is crumbling so its efficient, reliable and safe operation and control is becoming a challenge today. To overcome the challenges brought about by this complexity, the power system needs intelligence at all levels, right from electricity generation through transmission to distribution level [1]. Therefore, the traditional way of modelling, controlling and optimization of the power grid needs to be elevated into a smart grid that is capable of rapid adaptation, having dynamic foresight, being fault-tolerant and robust to disturbances and randomness.

This paper describes the various data mining and machine learning techniques that can be applied for providing computational intelligence of prediction of failures at component or equipment level [1]. Other surveys on SG were done in [28, 29, 30, 31, 32]. Hassan and Radman [33] briefly reviewed the basic concepts of smart grid and some technologies that could be used in them. Akyol *et al.* [28] analyzed how, where, and what

types of wireless communications are used. Brown and Suryanarayanan [30] determined an industry perspective for the smart distribution system and identified those technologies which could be applied in the future research in the smart distribution system. Baumeister [29] presented a review of the work related to smart grid cyber security. Our survey checks out the data mining techniques. This survey is structured as follows. In Section II, we present a background of generation of electricity. In Section III and IV we identify the factors that issues for failure. We then describe the need and give an overview of the smart grid system along with few of its properties in Sections V-VI respectively. We next describe the various data mining and machine learning techniques that can be utilized in a smart environment to make the system resilient in section VII. Section VIII gives an insight into the various data mining, ranking, visualization and testing techniques. Section IX provides an evaluation framework for the various data parameters, the techniques employed and measurement of the improvement in the system performance. Section X, we conclude this survey and present some lessons learned.

II. BACKGROUND

Generation of electricity [3] [5] can be divided into various parts:

- 1. Generation:** Large amount electrical current is generated by applying force of water, steam, or hot gasses on a turbine that spins an electromagnet. This activity is done at the generating station.
- 2. Transmission:** This current and hence the power is ramped up to a high voltage for long distance transmission via feeder cables and power grids to substations closer to the customers
- 3. Primary Distribution:** Power or electricity generated is distributed further at mid-level voltage from substations to local transformers.
- 4. Secondary Distribution:** Electricity is then passed through a number of distribution lines via switches to local low voltage networks to the individual customers.

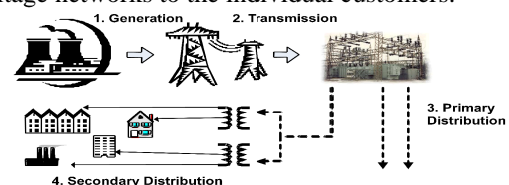


Fig.1. Electricity Distribution

III. ISSUES THAT NEED TO BE HANDLED

The distribution grid is organized into networks, each composed of a substation, its attached primary feeders,

and a secondary grid. Failure in any one of them can have a cascading effect. So, the networks have to be electrically isolated from each other. The feeders (power lines) of the primary grid are critical and have a significant failure rate. Therefore, much of the daily work would require continuous monitoring, maintenance and speedy repair on failure.

IV. REASONS FOR FAILURE

Every link in the infrastructure is susceptible to various failures – natural calamity, deliberate sabotage, human errors etc of which equipment or component failure forms a major vulnerable part. [34, 35, 36]

1) Equipments, feeders (line) are susceptible to different types of failures namely:-

- Ageing
- Power quality events (spikes)
- Overloads (seasonal variations)
- Known weak components
- At-risk topologies

2) Some feeders may fail multiple times within a short time span (infant mortality) or can last more than a few years.

Fluctuations in survival times can result in very unbalanced dataset.

3) Emergency isolations caused by automatic substation relays.

Other factors that also need to be considered apart from failures include:-

- Initial quality
- History of exposure to moisture
- Current load on feeder
- Impulse/mechanical stress
- Data size
- Security Loss of electricity generated
- Blackouts and outages
- Interconnection mismatches etc

V. NEED FOR SMART GRID

Looking at the factors that affect the electricity infrastructure there is a need to develop a system that would automatically perform emergency identification, construct models to determine the time between failures (TBF), rank the equipments according to their failure rates, evaluates and tests the system in terms of its performance measures.

This leads to the development of a smart grid system for generation of electricity.

VI. OVERVIEW OF SMART GRID SYSTEM

The traditional system however is a centralized one way communication network leading to failures and blackouts. This leads to the use of smart grids. The smart grid also referred to as Intelligent

Grid/*Intelligrid* and *FutureGrid* [1][17] can be said to be a digital upgrade of the existing electricity infrastructure,

providing two way flows of electricity and information. This leads to a distributed network that is intelligent, smart, adopting various strategies for safe, reliable, effective, resilient network. These smart grids themselves have the following properties:

- Self-healing capability.
- Fault-tolerant.
- Allow integration of all energy generation
- Dynamic optimization of grid operation and resources
- Clients can provide timely information
- Improves reliability, power quality, security and efficiency of the electricity infrastructure etc

In this paper, we surveyed the need for advanced monitoring, forecasting and prediction techniques that could help in developing algorithms which would assist in better resilient system.

VII. MODELLING AND TESTING TECHNIQUES EMPLOYED

Ganesh K. Venayagamoorthy of [1] describes the potentials and promises of the computational intelligence for smart grid operation and control enable or facilitates intelligent behaviour in the smart grid. Since the smart grid needs to identify failure beforehand to avoid widespread network failure due to cascading and interactive effects, various techniques need to be identified. This paper identifies various data mining, ranking, visualization and testing techniques that can aid in preventive maintenance of the smart grid as shown in the table1 below. This table has been based considering parameters of time, mean time of failure and ranking within components

Modelling with respect to	Techniques Used		
Time Between Failures (TBF)	Support Vector machine	CART	Ensemble based
Time	Short term survivors	One year survivors	Long term survivors
Ranking	MartiRank	Ensemble based wrapper	Martinge boosting
Visualization	Receivers Operator characteristics (ROC)	Area under curve (AUC)	Duane Plot
Testing	Wilcoxon	ANOVA	Duncans Multiple range test

Table 1:- Techniques used for modelling the smart grid environment

VIII. COMPARISON OF THE MODELLING AND TESTING TECHNIQUES

A number of data mining techniques can be used in the smart grid environment to predict beforehand the chances of equipment or component failure. In [7] the authors

propose an ensemble approach for Feature Ranking, selecting the relevant features in order to focus the learning search. In [20] the authors the various data mining techniques are represented in brief to show how this can be applied to the grid environment. The linear classifiers and the key parameters of high margin along with the quadratic classifiers are represented in [21]. Lior Rokach in [23] gives the idea of ensemble methodology to build a predictive model by integrating multiple models for improving prediction performance. The types of ensembles are further explored in [23] [24]. CART technique is defined in [13]. An integrated view of the same is shown in table 2. This section of the paper is further subdivided into integration of techniques for mining, ranking, visualization and testing respectively into tables for each.

1) Data Mining Techniques :-

Characteristics	SVM	CART	Ensemble
Uses	linear models to implement nonlinear class boundaries	uses a sample of training data for which the correct classification is known	the task of searching through a hypothesis space
Converts	Input space to feature space	By building a tree, pruning sub trees and selecting an optimal tree.	A set of classifier from training data into predicted class labels of previously unseen records.
Involves	maximum margin principle	Identification and construction of a binary decision tree	Training set, Base inducer , Diversity generator, combiner
Advantages:	1. Produces very accurate classifiers. 2. Less over fitting, robust to noise.	1. Used for feature selection	1.reduces variance 2. reduce bias 3 Improves predictive accuracy and hence performance
Disadvantage	1) Binary classifier. 2) Computationally expensive, 3) runs slow	1)may have unstable decision trees 2) splits only by one variable	Tends to increase the error of each individual base classifier 2 . Produces output that is hard to analyse.
Methods / Types employed	1) least squares 2) Kernel logistic regression 3) weighted least squares	1) Classification trees 2) Regression trees	1) Bayes optimal classifier 2) Bootstrap aggregating (bagging) 3) Boosting 4) Bayesian model averaging 5) Random Forests
Can be extended to	Multi class	Using multiple splits	Building different experts

Table 2 :- Comparison of the data mining techniques for smart grid system.

2) Ranking techniques:-

In [4] the authors give an overview of the electricity generation followed by the problem statement. An algorithm for MartiRank is discussed further followed by the use of AI techniques. This is then followed by the future work in this direction. [10] gives the fundamentals behind machine learning techniques, information about SVM and MartiRank followed by software testing approach for the problem domain defined. , In [7] the authors give an overview of how feature selection can be a major bottleneck for supervised machine learning An relaxed approach for feature selection i.e. feature ranking with respect to its relevance is elaborated. This is then followed by an experimental setup for the same. In [8] the authors Hoi and discuss about the semi supervised ensemble ranking systems followed by performance

evaluation and comparison methods. Hwanjo Yu and Sungchul Kim [6] elaborate on the two special properties of SVMs that SVMs achieve (1) *high generalization* by maximizing the *margin* and (2) support an efficient learning of nonlinear functions by *kernel trick*. [8] gives an introduction to linear SVM and features of ranking strategies followed by experimental setup. Our survey combines these techniques and represents them in the tabular format as shown in the table 3 below.

Characteristics	MartiRank	SVM	Ensemble
Features	Adapted to ranking and is a Batch algorithm	developed for classification and extended for regression and preference (or rank) learning	Predictive models that selects and then ranks the relevant features according to their relevance
Advantage	1Fast, easy to implement 2Interpretable 3 Only one tuning parameter	1. High generalization 2.Maximizing the margin 3. Efficient learning of nonlinear functions by Kernel trick	1. Improve the retrieval performance 2. increased accuracy 3. improves interpretability and generalization
Disadvantage	1.Only one tuning parameter, 2. making quantitative predictions about the time to failure of each feeder and relevant component in the network.	causal importance is not considered and, thus, they do not enhance our knowledge of the underlying causal relationships between features	learned weights for ranking algorithms are query independent.
Uses	Applies the segmentation and the sorting rules from the model to the testing data set to produce the ranking	Global ordering of data	training data to combine the ranking results output from multiple ranking Algorithms.
Types	Using experts	Ranking vector machine	RankBoost, Ranking SVM, ListNet, AdaRank, MHR-BC, SER, SSER, tree-based ensembles (Random Forest)
Strategies / Algorithms	Provides algorithm with the device failure application in mind	F-score for Feature Ranking, Linear SVM Weight, Change of AUC with/without Removing Each Feature, Change of Accuracy with/without Removing Each Feature	ROGER

Table 3:- Comparison of the ranking techniques employed

3) Visualization techniques:-

[26] Elaborates on the statistical principles and the various comparisons that can be made with respect to continuous, categorical, survival, specialised and pre processing data. In [27] the authors Matt Culver, Deng Kun, and Stephen Scott elaborate on how active learning affects AUC after examining two existing algorithms from

the literature and present their own active learning algorithms to maximize the AUC of the hypothesis and also provides ROC information. Our survey combines the information in a tabular format as represented in the table 4 below.

Characteristics	AUC	ROC	Duane Plot
Measures	Classifier accuracy	Skewed class distribution and unequal classification error cost.	Cumulative number of failures vs. time
Calculation of variability done	1) Confidence 2)Standard error of Wilcoxon 3) Cross validation	1)Confusion matrix 2)Contingency matrix	1) R2 value 2)Monte Carlo simulation
Highlight	Not dependent on decision threshold chosen	2-D depiction of classifier performance	Log-log plot
Useful for	Determining sensitivity	Determining relative trade off between benefits and costs	Graphical analysis of reliability growth , parameter estimation, reliability distortion
Disadvantage	Deals with two classes	Deals with two classes	It may become awkward to compare visual acuity values,

Table 4:- Comparison of the visualization techniques

4) Testing techniques :-

Paper [13] gives an overview of Wilcoxon testing, assumptions underlying a Wilcoxon test with an example. Misconceptions namely (1) false statement, (2) true premise, but false conclusion, and (3) true statement irrespective of the test chosen are expressed in [14]. [12] gives us an overview of ANOVA in terms of background, terminology used, assumptions made, its models, logic applied and associated analysis. Table 5 summarizes the testing techniques.

Property	Wilcoxon	ANOVA
Purpose	Developed to analyze data from studies with repeated-measures and matched-subjects designs.	ANOVA provides a statistical test of whether or not the means of several groups are all equal.
Works on	an individual is assessed on a measure on two occasions or under two conditions	making decisions using data
Categorized into	1. Repeated-measures designs with an intervention 2. Repeated-measures designs without an intervention 3. Matched-subjects designs with an intervention 4. Matched-subjects designs without an intervention	three classes of models used in the analysis of variance:- 1.Fixed-effects models 2.Random-effects models 3. Mixed-effects models (Model 3)
Logic used	Rank sum and signed rank test	1. Partitioning of the sum of squares 2. The F-test

Table 5:- Comparison of the testing techniques used

IX. EVALUATION FRAMEWORK

[3] gives an overview of the smart grid system, dividing it into protection, infrastructure and management system , comparing it with the traditional systems and identifying the challenges for the new systems. [17] elaborates the fact that the control of electric power systems relies on the availability, quality of sensor measurements and the various techniques used and each of them is subjected to faults caused by broken or bad connections, bad communication, sensor failure, or malfunction of some hardware or software. So the entire system needs to be evaluated and tested automatically, continuously and transparently. This leads to development of the evaluation framework. Our paper represents the evaluation framework considering the input data quality, machine learning and data mining techniques and then identifying the improvements in system performance.

The evaluation framework comprises of:-

- 1) Evaluation of the input data quality
 This phase comprises of checking the inputs to the system namely – number of joints, cables, voltage, peak load etc. This can result in accurate feature selection, feature derivation and identify the potentially vulnerable component or equipment.
- 2) Evaluation of machine learning and data mining techniques
 Out of the various techniques discussed i the paper above, the suitable technique is identified and applied to the ranked components, its effect seen on the ROC curve and AUC
- 3) Evaluation of improvement of the smart power grid.
 The output thus obtained from the earlier step can be compared with the previous reading to determine the system improvements, fewer outages and longer time between failures through the Duane plot.

X. CONCLUSION

The electric power grid is rapidly growing and demanding new technologies for fault tolerant systems. Advanced intelligent techniques are required to handle the smart grid operation in an efficient and economical manner. Various techniques need to be combined so as to identify the failed component, rectify it automatically and transparently. The entire process can be done by applying the data mining, machine learning, visualization and testing techniques.

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