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Application of neural network and Levenberg–Marquardt algorithm for electrical grid planning

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Abstract: In the present scenario of industrial growth, technological advancement and population growth, the single most inseparable commodity is electrical energy. This paper presents a novel way to use Neural Networks to forecast long-term electricity load and use the result for proper grid planning in terms of expansion and maintenance. Uninterrupted, reliable and cheap electricity can only be available if there is a proper planned and stable grid, which can be achieved only through proper futuristic grid planning models. In this paper, focus is centered to form the cluster of areas based on the forecasted energy needs in India. Priority ranking also allocated to decide the level of expansion for forthcoming decades.

1. Introduction

The delivery electricity from suppliers to consumers is well maintained by an interconnected network called as electrical grid, which consists of generating stations that produce electrical power and high voltage transmission lines. The transmission lines carry power from distant sources to demand hubs, and distribution lines that connect individual customers. Apart from just generation and transmission infrastructure the electric grid is an ecosystem of manufacturers, service providers and government officials at state and local levels. Reliable Electrical distribution is vital to any nation's wellbeing. With increasing power demands, it is necessary to not only add additional power generation capability but to also improve ageing power grids and add additional transport capacity. Grid planning is a necessity when any new grid is being constructed or when existing grids are improved. This ensures the efficiency of the grid in the long term.

2. Literature

2.1 The Indian Scenario

India is the fourth biggest customer of energy next to United States, China and Russia in the world. Power cuts are fundamental problems in India and the resulting framework inability to fulfill the interest for power has affected Indian financial development. Indian power segment experiences high transmission and conveyance misfortunes, power deficiencies, poor money related soundness of the State Electricity Boards, AT&C (non-specialized) misfortunes and enormous request and supply hole in power influence. Power cuts are the principle concern in India and the subsequent inability to fulfill the interest for power has badly affected Indian economic development. Hence, efficient grid planning is found to be necessary to meet out the demands of the forthcoming decades.

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Table 1. Electrical Peak Demand Data for NN training

Fiscal year	Peak Demand in MW			
	Demand	Met	Shortage	%
2002-03	81,492	71,547	9,945	12.2
2003-04	84,574	75,066	9,508	11.2
2004-05	87,906	77,652	10,254	11.7
2005-06	93,214	81,792	11,422	12.3
2006-07	100,715	86,818	13,897	13.8
2007-08	108,866	90,793	18,073	16.6
2008-09	109,809	96,785	13,024	11.9
2009-10	118,472	102,725	15,747	13.3
2010-11	122,287	110,256	12,031	9.83
2011-12	130,006	116,191	13,815	10.6
2012-13	135,453	123,294	12159	8.98
2013-14	135,561	129,815	5746	4.24

From table 1[10], it can be observed that the shortage percentage gradually increases over the year, then decreases and become surplus. The availability increases rapidly, which would have required separate generation infrastructure to in-crease in just one year.

2.2 Existing solutions and approaches

Long term forecasting of electrical loads is important for planning and development of generation, transmission and distribution system. Artificial neural networks can solve various power problems, such as design, planning, control protection, security analysis, fault diagnosis and load forecasting. Neural systems are well known in load gauging due to their capacity in mapping complex non-straight connections. In most of the cases, ANN's are used in short-term load forecasting. [1] In order to further improve the flexibility of the load forecasting methodology, an architecture based on Long Short Term Memory (LSTM), called sequence to sequence (S2S), can be used. [2] The Back-Propagation Network (BP) network can be used for short term load forecasting. The generally used BP network structure for short-term load forecasting is a three-layer network with transfer function as nonlinear Sigmoid function. [3] Use of support Vector regression is another effective method for use of load forecasting. In order to predict the peak load of a particular day, we can roughly consider Peak Demand as a non-linear combination of a number of at-tributes from different source. [4]

Feed-forward Deep Neural Networks (FFDNN) and Recurrent Deep Neural Networks (R-DNN) can be used to predict short-term electricity load. Data is analyzed on the time and frequency domain independently and subsequently frequency domain components are transformed back to the time domain. The resulted time-frequency (TF) features capture dominant effects i.e. weather, time, working and non-working days, lagged load and data distribution effects. Then the FFDNN is trained using the above data and then can be used for providing load forecast. [5] Electrical load allocation problems and maintenance management were assumed as critical aspects for realizing good grid stability. Neural modeling coupled with optimization techniques can lead to time saving and allows fast solution. [6] The optimal routes of power suppliers can be obtained by considering load-forecasting error with an objective of minimization of total investment and operational costs subject to topological constraints. On the way to overcome dynamic behavior of the planning parameters, multistage expansion planning in mid and long-term planning cases is implemented with imperial competitive algorithm. [7]

Demand side management (DSM) improves energy efficiency and reduces general electricity consumption. The good energy management system can help in real-time monitoring of the power

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grid, which can be used to monitor success and failure in the grid. This information can be used to plan future grid expansion. [8] A two-stage optimization model can be used to get the planning characteristics of an electricity grid and then the results can be applied to any grid. Transmission engineers primarily commit to certain options to which the network reacts. Later a decision is made followed by a market response, but a set of alternatives must be existing, constrained to previous decisions. [9]

3. Methodology

The first step in the process of grid planning starts by the long-term electricity load forecasting. Generally Bayesian Probabilistic model to forecast the electrical load using previous 10 years data. This can also be projected using Levenberg-Marquardt algorithm with an advantage of more compliance. The Pseudo Code for the Levenberg-Marquardt algorithm:

i. Initialize weights
ii. While (non-stop criterion) do
  Calculate $C^P(W)$ for each pattern
    $e1 = \sum e^P (W)^T e^P(W)$
  Calculates $J^P(W)$ for each pattern
  Repeat
  Calculate Δw
    $e2 = \sum e^P(w+\Delta w)Te^P(w+\Delta w)$
  If $e1 \leq e2$
    $\mu = \mu * \beta$
  End if
  Until $e1 \leq e2$
iii. $\mu = \mu / \beta$
iv. $W = w + \Delta w$

The parameters considered while doing the forecast are Dry Bulb Temperature, Holidays, Dew Point. 70 % of the data were used for training and 15 % were used for both validation and testing. The process was repeated for all the zones of a country. The zone can be divided based on the number of connected users and the mean peak demand for past 10 years. After successful forecasting for all the zones, a clustering algorithm is used to cluster the zones with respect to their electricity load consumption for the next 10 years. Clustering is an integral part of Machine Learning, which is used to group different objects, which vary on certain parameters. A specific algorithm cannot achieve cluster analysis itself. Widespread notions of clusters include groups of small distances among cluster members, dense areas of data space, intervals or specific statistical distributions. Hence clustering can be formulated as a multi-objective optimization problem.

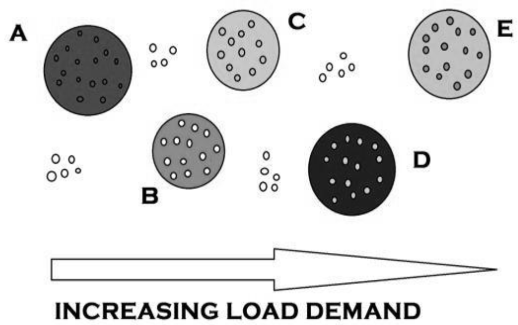


Figure 1. *Forecasted demand clustering of zones*

As depicted in figure 1, A, B, C, D and E are the different clusters formed by the clustering algorithm. As, moving from left towards right the peak forecasted electricity demand increases. Therefore, when grid planning will be done the preference of expansion should be E > D > C > B > A. The proposed clustering can be done using higher order logistic regression with suitable regularization.

4. Results and discussions

4.1 Neural Network

This work contributes an innovative approach to load forecasting using neural networks by the application of Levenberg-Marquardt Algorithm. The algorithm tries to account for seasonal changes and holidays without using traditional smoothing algorithms, which were necessary in earlier models. Furthermore, with the applications of Project management principle alongside the load forecasting data we can create a robust and efficient grid planning approach.

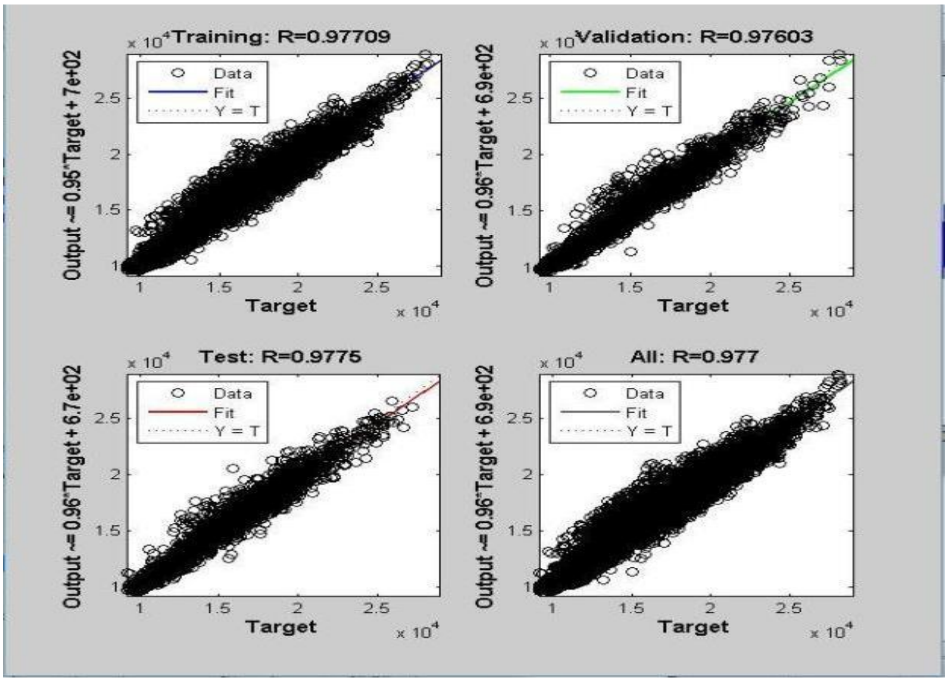


Figure 2. Regression Plot for the ANN training and results

The figure 2, depicts the regression plot for the training, validation and testing sets. From the result, it is evident that all the data are very well fitted by the regression curve. The value of R is 0.9755 which is a very good approximation. While considering individual day results, we find few abnormalities over the course of three years used for testing with most of the results satisfying an error of less than 5%, which is understood from figure 3 and figure 4. The irregularities generally occur due to the holidays. Thus, the proposed neural network algorithm is a viable alternative for load forecasting and more research on hybrid models using Levenberg-Marquardt algorithm can be suggested for greater industrial use.

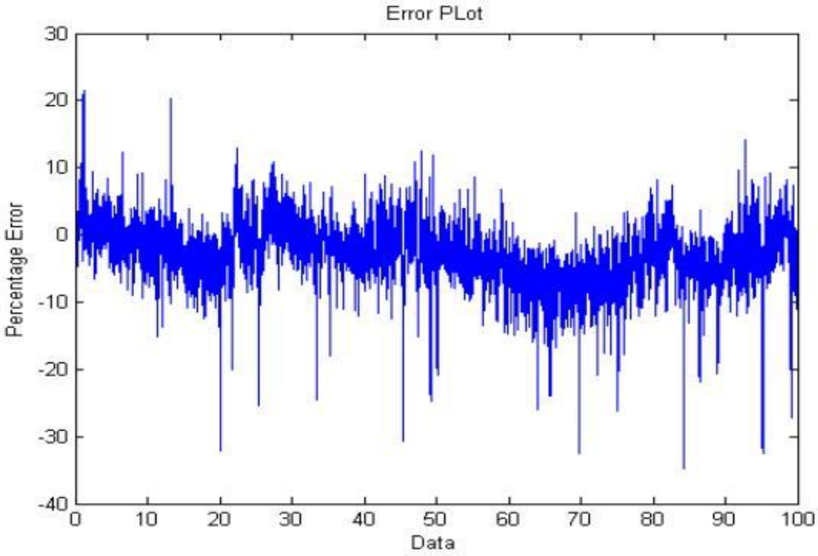


Figure 3. Individual error plot

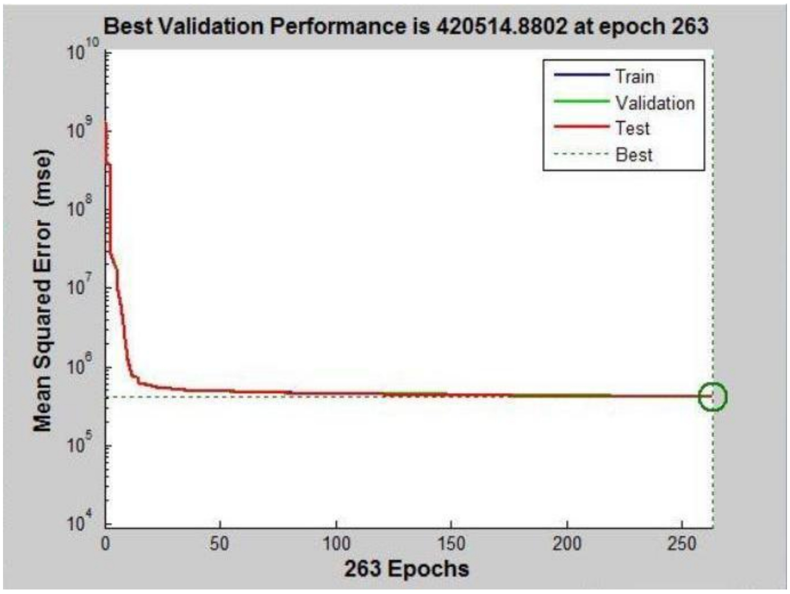


Figure 4. Performance Characteristics Curve

4.2 Clustering of Zones.

By dividing the region into clusters based on load forecasting approach, the areas with high demand can be determined. This can help to design a grid in such a way that it can be scaled up in specific areas. This can lead to less costs in the long run and ensure the grid does not fall apart due to unforeseen spike in demand. As per projected demand, the infrastructure development can be planned. This can help engineers in setting more realistic and achievable project scope, costs and quality standards. Demand side management can be used to adjust the day-to-day operation of the grid. Forecasting must balance the demand and supply requirements, resource schedules and overloading of the existing power plants.

4.3. Validating NN model and future demand/met forecast

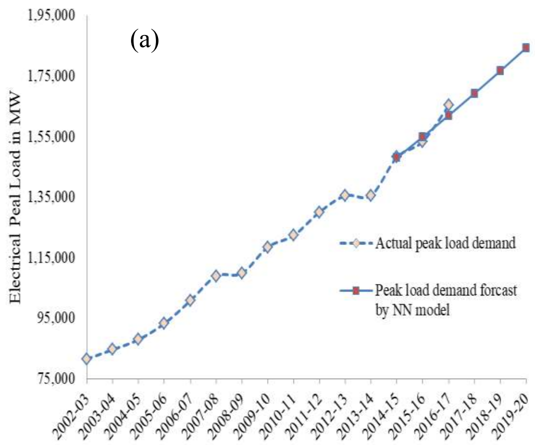
From the electrical peak data up to 2013-14 has been taken for the training of NN model and it is being validated [table 2] by the actual data available in 2014-15 to 2016-17. It shows a very minimum error between the actual and forecasted one. Based on the trained model, the forecasting has been done for next three years as shown in table 3.

Table 2. Electrical Peak Demand Data for NN model Validation

Fiscal year	Forecasted Peak Demand in MW				Actual Peak Demand in MW			
	Demand	Met	Shortage	%	Demand	Met	Shortage	%
2014-15	1,48,035	1,40,440	7,594	5.13	148,166	141,160	7006	4.73
2015-16	1,54,907	1,50,210	4,697	3.03	153,366	148,463	4903	3.20
2016-17	1,61,971	1,60,618	1,353	0.84	165,253	169,503	-4250	-2.57

Table 3. Predicted Electrical Peak Demand Data from NN model

Fiscal year	Peak Demand in MW			
	Demand	Met	Shortage	%
2017-18	1,69,226	1,71,662	-2,436	-1.44
2018-19	1,76,674	1,83,344	-6,671	-3.78
2019-20	1,84,313	1,95,664	-11,351	-6.16



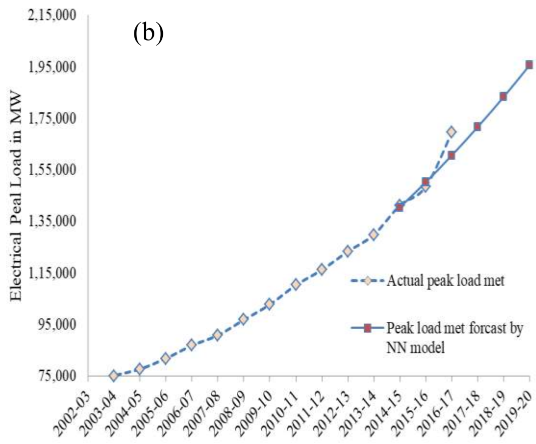


Figure 5. **(a)** NN forecast for peak load demand **(b)** NN forecast for peak load met

Figure 5 (a) and (b) discuss about the forecasting of peak load demand and met up to 2019-20. The gap between real and forecasted one is minimal and the graph data can be taken for the planning purposes.

5. Conclusion

Grid management is a vital part of the modern electricity distribution mechanism. It is important to plan the future network more robust by load forecasting methods. This paper discussed a possible way to enhance grid planning via load forecasting for Indian scenario. Dividing regions into clusters based on load demand also allows greater degree of success in planning long-term grid designs. By use of neural networks and Levenberg–Marquardt Algorithm, accurate forecast was made for a period of 2014-2020 with a variation of 0.17~1.73%. It was found that the algorithm is robust and viable for long-term load forecasting. In the long term forecasting, an additional costs benefit such as maintenance requirements are reduced and the grid operates at greater efficiency. The methodology could be extended to short term load forecasting like day-to-day load forecasts, which allow grid operators to get a general idea of demand and spikes in demand can be avoided, which can enhance equipment. Further, by adjusting infrastructure requirements based on demand such as tailored equipment for the electrical grid, can reduce costs in short term.

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Comments on the above paper**:**
Technical criteria:
Scientific merit: notably scientific rigour, accuracy and correctness:

1. As far as research content is concerned, scope of work is there but not sufficiently backed up by data beyond 2010 say at least up to 2020 (even if data is not there is it possible to extrapolate). Secondly, the output graphs show regression plots but can it be made a bit more clearer. Assumption is that load increases from Cluster A to Cluster E but randomness in occurrence of peak loads can also be considered (if possible).

1. Grammar to be checked and a few abstract sentences. Any claims should be backed up by past or present data.
2. Content is there but justification should be there. Example ANN can be used for both short term and long term

Quality criteria:

1. **Originality** is there but how any researcher can use the techniques mentioned in future is not clear.
2. **Motivation**: It is a good effort but more efforts in terms of recent data and projected cost savings in Rs can be highlighted for the future years..
3. Similar work has been done but how different and how more accurate this is has to be highlighted.
4. Content length is okay.

Presentation Criteria
1**.Title**: Can be changed to convey more technical meaning and can be briefer.

2**.Abstrac**t: Any abstract should be supported nore by technical details rather than plain English which is more abstrac**t.**There are some sentences which are abstract.I have highlighted them in red.

3**.Diagrams, figures, tables**: More clarity and results and conclusions should match the graphs in more detail.

4.**Text and mathematics**: Mathematics of the ANN techniques used is not clear.Maybe a couple of sentences to highlight the same may be helpful without increasing the length of the paper.

5.Conclusion: Lot of abstract sentences.More technical data supported effort might be needed.

Note:
Many of the grammatical and abstract sentences have been highlighted in red. On the whole the paper is okay but more clarity, more technical data more technical inputs especially of peak demands up to 2020(if not available to be extrapolated)