

# A Fuzzy-Neural Approach to Electricity Load and Spot-price Forecasting in a Deregulated Electricity Market

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*Abstract*— Accurate short term load forecasting is crucial to the efficient and economic operation of modern electrical power systems. With the recent effort by many governments in the development of open and deregulated power markets, research in forecasting methods is getting renewed attention. Although long term and short term electric load forecasting has been of interest to the practicing engineers and researchers for many years, spot-price prediction is a relatively new research area. This paper examines the use of a neural-fuzzy inference method for the prediction of 24 hourly load and spot price for the next day. Publicly available data of the electricity market of the state of New South Wales, Australia is used in a case study.

## 1. INTRODUCTION

Modern societies have become completely dependant on electricity power to function and operate. Reliable and efficient electricity production and supply are essential to the maintenance of a country's economy and stability. For many years, the electricity industry has been operating as monopoly with or without government intervention in most countries. However, it has argued by economists and governments that such model does not necessarily bring forth efficiency and productivity in a free and open market environment. Over the past decade, many countries have begun major deregulation and restructuring processes. This has resulted in the replacement of "vertically integrated" local monopolized utility companies with different degrees of liberation of the wholesale electricity market. In most cases, the generation and distribution utilities are independent entities. It is also expected that multiple players are involved in each sector of the market. A common practice is that each player will bid to sell or buy electricity or supply of electricity through some form of regulating body.

In Australia, utility industries at the eastern states such as New South Wales and Victoria have already started this restructuring process from 1998. The state of Western

Australia is also expected to follow in the near future. This restructuring is expected to benefit the end-consumers by giving them choices. It also introduces competition at each stage of supply and demand chain. While there are many models being implemented in other countries, most of them follow a new structure where a central management body operates a wholesale market for trading electricity between generators and electricity retailers. This body is responsible for the day-to-day operation and administration of the system. All the electricity is traded through what is known as a "spot market". Spot market is the mechanism through which prices are set and then settled. The central body is responsible for continually matching supply and demand. The generator operators compete by providing generation bids and their corresponding prices to the central body. The electricity retailers do the same with the consuming bids. From all the offers submitted, the central body selects the generators required to produce power at different times throughout the day. Dispatch instructions are sent to each generator at fixed intervals of, say 5 to 15 minutes. The spot price is the clearing price to match supply with demand. In such system, the retailers pay for the electricity they use from the electricity pool and distribute it to the consumer. This restructuring is expected to introduce competition at each stage of supply and demand chain whereby bringing forth more efficient allocation of resources. In the restructured competitive electricity market as shown in Fig. 1, the participants in the wholesale market, such as the generators and retailers require not only the load forecast information but also the spot price forecast information to develop a beneficial bidding strategy.

This area of spot price forecasting is a newly opened field of study [1, 4, 6, 7]. A neural-network forecasting tool is used by Sansom et al [4] to predict the spot price of the NSW electricity market. Francisco et al [1] presented a time series method based on dynamic regression approach and transfer function approach, which produces less accurate forecasts in periods of high demand. Some of the work on price

forecasting of the previous years based on time series method, neural networks and fuzzy modeling method is considered by Songhuai et al [6] when a new method based on grey system theory is considered. All this shows that more work needs to be done in spot price forecasting. This paper proposes a method that forecasts next-day electricity prices, based on fuzzy logic and neural networks.

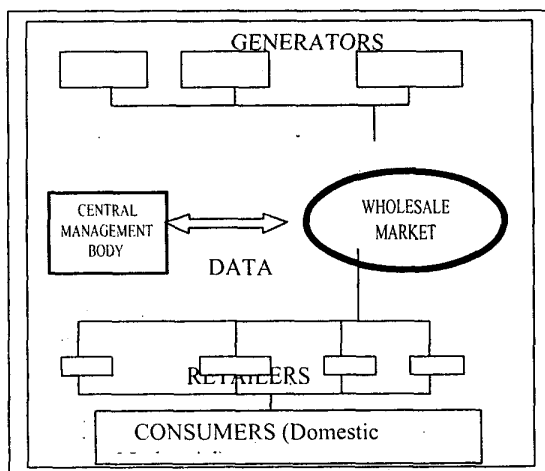


Fig. 1. Structure of a deregulated electricity market

### 2. FORECASTING PROBLEM

The problem considered is the determination of next day's hourly spot price forecast. Half hourly load data during the past few years from the NSW electricity market are used. On examination of the data, it is evident that the daily load curve shows a definite pattern based on the season of the year, day of the week and temperature as shown in Fig. 2 and Fig. 3. Within any day and depending on the time of the day, the load also follows a set pattern.

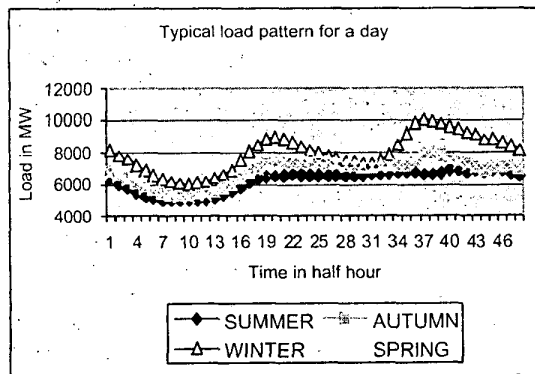


Fig. 2. Typical daily load pattern in different seasons

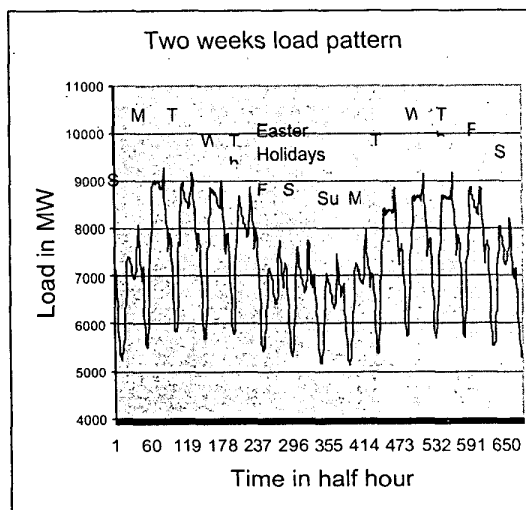


Fig. 3. Typical Load pattern during a fortnight

The spot price also varies with the load demand as shown in Fig. 4 during a typical day.

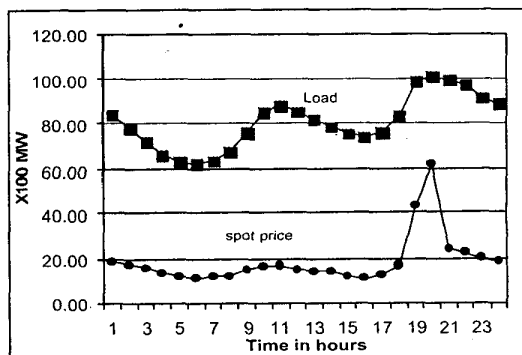


Fig. 4. Load vs. spot price pattern for a typical day

### 3. FORECASTING METHOD

The proposed spot price forecast system is based on two components as shown in Fig. 5. The first component is the load forecasting component based on the fuzzy inference method and the second component is the spot price predicting component based on an artificial neural network.

A fuzzy inference system for each season namely summer, winter, spring and autumn is developed separately based on the concept of 'fuzzy set theory'. The inputs to the system are forecast temperature, day of the week and time of the day. This is illustrated in Fig. 5.

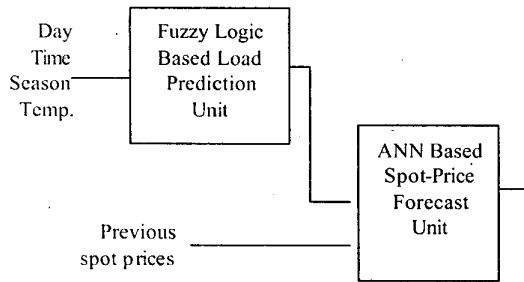


Fig. 5. Fuzzy-neural system for the spot price prediction

The fuzzy term set associated with each variable is:

- Forecast temperature (lo, med, hi)
- Day of the week (WkDay, SunDay and SatDay)
- Time of the Day (earlymorn, morn, noon, eve, night)

In general, the load consumption patterns for public holidays are similar to that of Sundays and they are therefore treated as the same. The knowledge base consists of the fuzzy rule base and data base. The data base provides the necessary definitions of the fuzzy parameters as fuzzy sets with membership functions defined on the universe of discourse for each variable. The rule-base consists of rules in the form:

*If the Temperature of the Day is lo AND Day of the week is Sunday AND Time of the day is earlymorn THEN the load is lo.*

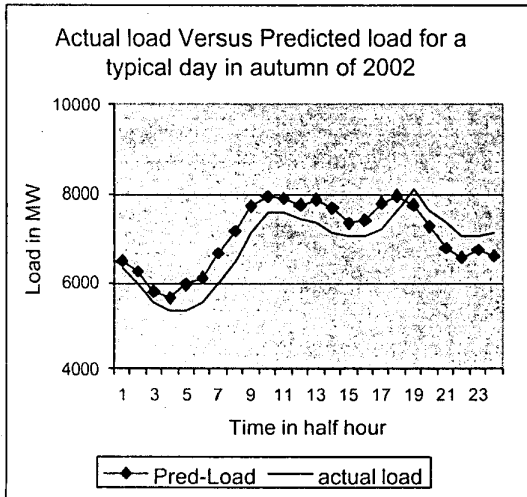


Fig. 6 Comparison of Predicted and Actual Load

An example of a predicted load pattern for a day in autumn in 2002 is compared with the actual load pattern is shown in Fig. 6.

The initial results of the application of fuzzy inference method have shown that the approach is promising in predicting the trend of the load consumption. During the first three quarters from 00 to 18 Hours, the prediction has exceeded the actual load while the prediction for the remaining six hours has under estimated the actual consumption. Prediction above the actual consumption will lead to extra power being generated. This actually increases the security of supply. On the other hand, an underestimation may lead to possible shortage. In terms of spot-price prediction, the former may lead to a higher bidding price because of expected higher demands while the latter will lead to submission of a lower price. However, in a pool system where there will be more than one generator, the shortfall will be supplement by other generators. Supply continuity is therefore ensured. The proposed system requires further work in the tuning and optimization of a number of parameters. This forecasted load consumption data would be used in predicting the next day spot-price prediction.

The spot price prediction component is based on an artificial neural network. In this study, a modular General Regression Neural Network (GRNN) is used to predict the next day's 24-hour spot price. GRNN are memory-based feed-forward networks based on nonlinear regression theory for function approximation. GRNN was originally developed in statistics literature as Nadaraya-Watson kernel regression and was reinvented by Donal Specht [5]. GRNN is a 3-layer network that has an input layer, hidden layer consisting of at least one node for each pattern it is presented and an output layer. The transfer function for this paradigm consists of a parameter called a smoothing factor, instead of a learning rate and momentum. This smoothing factor provides the same service as the learning rate and momentum in determining how tightly the data will match the predictions or fit the curve.

The neural network model used in this study has four modular networks each predicting the spot price for eight hours out of the 24 hours. Each network has 24 inputs consisting of

- predicted load data of the eight hours for spot price prediction;
- spot price for the same eight hours of the previous day, and
- spot price for the same eight hours of the previous week.

The modular network is shown in Fig. 7. The figure shows a network for the first eight hours of the day with the output being the predicted spot price. Similar arrangement is used for the remaining 16 hours.

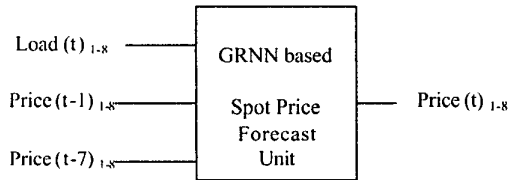


Fig. 7: Modular Price Prediction network

Table 1 shows the results for 3 days in comparison with the NEMMCO results. NEMMCO is being the central body governing the settlement of the bids and the final spot price. It also provides predictions for the next 24 hours and this study has used the data as a bench mark to compare the results of system.

Table 1 Comparing RMS and MAX error values between the two methods

Date	NEMMCO		GRNN	
	RMS	Max	RMS	Max
Jun10th 2003	7.07	29.5	1.83	13.2
Jun11th 2003	3.39	16.9	5.80	14.27
Jun15th 2003	4.85	59.4	1.83	24.7

In the above results, two measures have been used to compare the performance. The RMS is the root-mean-square error between the predicted values and the actual values. This is averaged over the 24 hours period. In the reported result, GRNN has outperformed NEMMCO's prediction with the exception of 11<sup>th</sup> June 2003. The MAX error is the maximum error observed during the 24 hours period. Again, in the example cases, the proposed method outperformed NEMMCO. However, one should note that there have been big differences in the maximum values predicted. This is normally occurring at the peak hour at the evening.

#### 4. CONCLUSIONS

The initial results of the application of fuzzy-neural method for the spot price prediction have shown that results are promising. However, there remains much work to be done. Since the price prediction unit requires inputs from the load prediction unit, the accuracy of such unit is therefore important. The fuzzy rules could be fine tuned in order to produce more accurate results. As the electricity is also supplied interstate on the same grid, there are also other factors that could have affected the spot price, besides the load demand and historical spot price data. Further work is now in progress to further improve the system.

#### References

- [1] Francisco, N. J., C. Javier, et al. (2002). "Forecasting Next-Day Electricity Prices by Time Series Models." *IEEE Transactions on Power Systems* 17(2): 342-348.
- [2] Hippert, H. B., C. E. Pedreira, et al. (2001). "Neural networks for short-term load forecasting: a review and evaluation." *IEEE Transactions on Power Systems* 16: 44-55.
- [3] Outhred, H. (2000). "The competitive market for electricity in Australia: Why it works so well." *Proceedings of the 33rd Hawaii International Conference on System Sciences-2000*, Hawaii.
- [4] Sansom, D. C. and T. K. Saha (1999). "Neural Networks for forecasting electricity pool price in a deregulated electricity supply industry." *AUPEC/EECON'99*, Darwin, Australia.
- [5] Specht, D.F., "A General Regression Neural Network." (1991) *IEEE transactions on Neural Networks*, 2(6): p. 568-576
- [6] Sonhuai, D., H. Zhijian, et al. (2002). Design On Spot Price Forecasting and Mutation Alarm System In Electricity Market. Power Systems and Communications Infrastructures for the Future, Beijing.
- [7] Torre, S. d. I., J. M. Arroyo, et al. (2002). "Price Marker Self-Scheduling in a Pool-Based Electricity Market: A Mixed-Integer LP Approach." *IEEE Transactions on Power Systems* 17(4):1037-1042