

Electrical and Computer Engineering

<Title>

A proposal in partial fulfilment of the MScE

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Updated: 2020-Dec-14 by <Author>

**BE SURE TO INCLUDE MANY REFERENCES TO SUPPORT YOU IDEAS/EXPLANATIONS**

# Focus (Example of Heading 1)

<Pose the research problem here – aim for 2 pages. Provide enough background information for the reader to understand why the problem exists, and why it is useful to solve – make sure you back up all your information with literature references. Conclude this section with a brief explanation about the approach you are researching to solve the problem.>

* ~~Explain what load forecasting is and why it is useful to do.~~
* ~~Provide a general overview of the different approaches to load forecasting. Be sure to include many different approaches;~~ ~~Explain terms like Horizon, and differentiate between single-step and multistep~~.
* ~~Explain what multistep load forecasting is in a bit of detail. Provide some commentary on the current state of art.~~
* ~~Explain what you intend to do, and why you think it needs to be done (don’t provide any details about how here…they will fall into the next part).~~

## General Overview of Load Forecasting

* ~~Explain what load forecasting is and why its useful to do.~~

Electricity is one of the driving forces of economic development and is essential to our daily life and wellbeing. Load forecasting is an integral part of the process of the planning and operation of electric utilities; it has played a vital role in the power industry for over a century. In terms of power supply and demand; for the stable supply of electricity, the reserve power must be prepared to serve consumers e.g., in case of high demand or failure in the current grid supply. Businesses' needs for load forecasting include power systems planning/operations, revenue projection, rate design, energy trading, and so on. Load forecasting is needed by many business entities other than electric utilities, such as load aggregators, power marketers, independent system operators, regulatory commissions, industrial/commercial companies, banks, trading firms, and insurance companies (Hong and Fan 2016a)(Saurabh, Shoeb, and Mohammad 2017).

Electric load forecasting still receives attention from researchers today, because the need for more accurate forecasts arises, particularly with the advent of new smart grid technologies. The demand pattern is very complex due to the deregulation of energy markets and the number of the different random variables that need to be taken into consideration to predict human behaviour; therefore finding an appropriate forecasting model for a specific electricity network is not a trivial task (Nti et al. 2020)(Zhang et al. 2018)(Kuster, Rezgui, and Mourshed 2017).

Electricity demand is assessed by accumulating the demand periodically; it can be considered for hourly, daily, weekly, monthly, and yearly periods. The forecasting processes can be grouped into four categories based on their horizons namely: very short-term load forecasting (VSTLF), short-term load forecasting (STLF), medium-term load forecasting (MTLF), and long-term load forecasting (LTLF). The cut-off for these categories are 1 day, 2 weeks, and 3 years respectively (Deng et al. 2019a). A rougher classification would consider only two categories: STLF and LTLF, with a cut-off at two weeks. Short-term load forecasting has been the major point of focus in most literature; the main focus has been on horizons of less than 2 weeks (Hong, Wilson, and Xie 2014)(Deng et al. 2019a)(Hong and Fan 2016b).

Different factors can affect load forecasting such as; the location of the area, the type of customers in the region, weather factors (temperature, etc.), a trend in the time series dataset, the time of the day, day of the week, and other unpredictable factors (coronavirus outbreak, etc.).

## Load Forecasting Techniques

* ~~Provide a general overview of the different approaches to load forecasting. Be sure to include many different approaches;~~ ~~Explain terms like Horizon, and differentiate between single-step and multistep~~.

Different techniques have been used for load forecasting; these techniques can be categorized into two major categories namely, statistical and artificial intelligence (AI) techniques. The boundary between the two categories is becoming more and more equivocal as time goes by; this is due to the multidisciplinary collaborations in the scientific community (Hong and Fan 2016b).

### Statistical Techniques

Statistical approaches can forecast the current value of a variable through the use of a mathematical combination of past historical values of the variable, and previous or current values of other variables (Amjady 2001). Examples of statistical techniques include; Multiple Linear Regression, Exponential Smoothing, Auto-Regressive Integrated Moving Average (ARIMA), etc.

### Artificial Intelligence Techniques

Artificial Intelligence algorithms are considered to be smarter and better, as they can easily learn and adapt to the non-linear and complex relationships between the load and other influencing factors (i.e., weather, time of day) automatically (Deng et al. 2019b). Examples of these algorithms are Artificial Neural Networks, Fuzzy Regression Models, Support Vector Machines, Gradient Boosting Machines, and so on.

### Finding the One Size Fits All Technique

Tao Hong spoke about the myth of finding the best technique; he concluded that it is important for researchers and users to know that a universally best technique doesn’t exist (Hong and Fan 2016b). The techniques selected should be based on business needs and the dataset to be used. Different algorithms perform better or worse with different datasets. The forecast errors could also differ significantly for different utilities, utility zones, and different periods.

In the research work, we use a publicly available dataset from Ontario IESO, as this would make it easier for our work and experiments to be reproduced by researchers and practitioners in this field.

## Multi-Step Load Forecasting

* ~~Explain what multistep load forecasting is in a bit of detail. Provide some commentary on the current state of art.~~

Multi-Step forecasting is a process that predicts a sequence of values in a time series. In application to electrical load forecasting, the sequence of values refers to future demand values for the time horizon of interest. Much of the literature on load forecasting focuses on short-term load forecasting, and also on single-step ahead forecasting (Deng et al. 2019b). Single-step forecasting is a process that predicts only one value into the future; it’s sometimes referred to as a one-step ahead method.

Let’s take an instance where we need to forecast the hourly demand for the next 24 hours. The single-step approach could run 24 times, whereby at each current hour it only needs to forecast the demand of the next hour. The multi-step approach could run 1, 2, or 3 times to forecast horizons of 24 hrs, 12 hrs, or 8 hrs respectively; depending on the method the forecaster would like to use. Making predictions farther into the future are less accurate; the limited information about future circumstances as well as the aggregation of errors in the multi-step approach has a role to play in this. This makes multi-step forecasting more difficult as compared to single-step forecasting (Ben Taieb et al. 2012). Also, multi-step forecasting is very essential for most utilities.

There are five major strategies used for multi-step forecasting namely; the recursive approach, the direct approach, the direct-recursive approach (DirRec), the multi-input – multi-output approach (MIMO), and the combination of the direct and the MIMO approach (DirMO) (An and Anh 2016; Bonetto and Rossi 2016a; Jha, Dewangan, and Verma 2019; Ben Taieb et al. 2012). The strategies mentioned above can be used with any underlying prediction models such as ANN, support vector machine (SVM), ARIMA, Linear Regression, etc.

## Research Focus

~~Explain what you intend to do, and why you think it needs to be done (don’t provide any details about how here…they will fall into the next part).~~

In this research work, we aim to compare the performance of convolutional neural network (CNN) technique with some classical ones that have been available for many decades. The four benchmark algorithms are: Seasonal Naïve, Multiple Linear Regression (MLR), Auto-Regressive Integrated Moving Average (ARIMAX), Artificial Neural Network (ANN). These benchmark algorithms have been available for many years and have been used by researchers and utilities (Hong, Wang, and Willis 2011)(Zhang et al. 2018)(Methaprayoon et al. 2007). It is important to see how much value a recently developed algorithm adds when it is compared with the classical and currently used techniques.

CNNs were

# Investigation

<Describe in some detail how you plan to try to solve the problem – aim for 5 pages. Be specific about exactly what aspects of the approach are under examination, and provide as many details as you can about the approach. Include any details you can provide about planned simulations or experiments, including the factors which are being evaluated, and performance metrics used for evaluation. If you borrow simulation/experimental data or methods from previous research, be sure to reference them.>

* ~~Restate the problem~~

Many papers lack detailed information about their experiments setup, this makes a hard for their experiments to be reproduced (Hong and Fan 2016b). For this reason, we are including a dataset from an independent system operator; the selected benchmarks algorithms are classical approaches with a lot of documentation about how they can be created. Also, there is a rising trend in the power demand at most utilities each year due to new systems and more sophisticated equipment been added. Therefore, it’s important to have algorithms that could adapt easily to these changes as they occur (Deng et al. 2019c).

* Describe the general approach we have to solving the problem – it could be useful to state this in a set of objectives 1) implement benchmark algorithms, 2) compare performance on X data sets 3) glean some information to try to make an improvement

Our solution is to make a comparison between some recently developed techniques and the benchmark algorithms. First, we begin by implementing the algorithms, then we compare their performances on two datasets, and see when one performs better or worse, then we will make an improvement based on the new information we get.

// To be continued. I need to identify which recent algorithm(s) I would be comparing it to.

## Benchmark Algorithms (3 pages)

* ~~Identify which ones, and explain why we chose them~~

Benchmark algorithms are good to have because it helps us to compare the performance of a newer algorithm with the classical ones already available. The chosen benchmark algorithms are the seasonal naïve approach, autoregressive integrated moving average with exogenous variables (ARIMAX), multiple linear regression (MLR), and the artificial neural network short term load forecaster technique (ANNSTLF). These benchmark algorithms have been used for many years by researchers and utilities (Nti et al. 2020)(Kuster et al. 2017)(Hong and Fan 2016b). The seasonal naïve is simple but it still performs well enough to be a benchmark for other sophisticated models. ARIMAX is a classical model, it has been used for many years and has been proven to be quite good for load forecasting (Bonetto and Rossi 2016b; Goswami, Ganguly, and Sil 2018). The MLR method is still used today for load forecasting; it can model non-linear relationships with the specification of independent variables to the dataset. ANNSTLF has been identified as the best forecaster in short term load forecasting, therefore it serves as a good benchmark (Hong and Fan 2016b; Weron 2006).

* ~~Describe each of the benchmarks~~

### Seasonal Naïve Approach

The naïve approach is considered to be the most cost-effective forecasting model; it often serves as a benchmark for developing much more sophisticated models (Wang, Liu, and Hong 2016)(Bracale et al. 2017). In the naïve approach, the forecast is taken as the previously observed value; this type of forecast is only suitable for time series data. This approach works best if the previous observation has a high similarity with the current; it is sometimes called a similar day approach. If there is seasonality in the time series; the seasonal naïve approach is preferable, because forecasts will be equal to the value from the last season. The seasonal naïve approach is most useful when there is a very high level of seasonality in the dataset (Da Liu et al. 2018).

The naïve approach, when used as a baseline for other methods; it gives us an understanding of how much value is being added to the current forecasting process. The formula for the naïve approach and the seasonal naïve approach is shown below respectively;



Where;  is the time series and is the seasonal period. In summary, the naive formula takes the last observed value as the future value, while the seasonal naive formula takes the value from the previous season.

### Auto-Regressive Integrated Moving Average with Exogenous Variables (ARIMAX)

ARIMA is a statistical technique that describes a given time series distribution based on its past values (its lags and the lagged forecast error); the final equation can then be used to forecast future values. The formula of the ARIMA can be seen below;



Where  is the lag1 of the time series,  is the coefficient of lag1 estimated by the model,  is the intercept that has been estimated by the model,  are the error terms from respective lags. ARIMA in its basic form is; the forecast  is the sum of a constant, the linear combination lags of (up to p lags), and the linear combination of lagged forecast errors (up to q lags). An ARIMA model is characterized by p, d, q; where p is the order of the AR term, q is the order of the MA term, and d is the number of differences required to make the time series stationary.

An ARIMA model is one where the time series was differenced at least once to make it stationary and you combine the AR and the MA terms (Weron 2013). Building an ARIMA model requires the time series to be stationary because the term “Auto-Regressive” in ARIMA means we are dealing with a linear regression model that uses its lags as predictors. Also, linear regression models work better in situations where the predictors are not correlated and independent from one another. The Auto-Regressive order p refers to the number of lags of the data that are used as predictors. While the Moving Average order q refers to the number of lagged forecast errors that go into the creation of the ARIMA Model (Bonetto and Rossi 2016a). If we would love to take into consideration exogenous variables like temperature, day of the week, etc.; the ARIMAX model would have to be taken into consideration (Goswami et al. 2018).

### Multiple Linear Regression

Multiple linear regression is one of the most used statistical techniques for load forecasting (Hong et al. 2010) (Saber and Alam 2018). The idea of MLR is to model the relationships between a continuous dependent variable (electricity demand) and one or more independent variables (i.e., temperature, the hour of the day, etc.) A common misunderstanding is that MLR models cannot model the nonlinear relationships between the electrical load and weather variables, which turns out to be false (Hong and Fan 2016b) (Weron 2006). For example, polynomial regression models can describe nonlinear relationships between dependent and independent variables using polynomials. The equation below shows an MLR with two independent variables:



where is the dependent variable, and  are the independent variables, ’s are parameters to be estimated, and is the error. The error term  is a representation of a set of random variables that are independent and identically distributed and having a mean of zero. MLR models are fitted such that the sum-of-squares of differences of actual and forecasted values are minimized. Although a large number of alternatives are currently available, linear regression models are still quite popular (Weron 2006)(Hong et al. 2014)(Saber and Alam 2018).

### Artificial Neural Network Short Term Load Forecaster (ANNSTLF) – Generation Three

The ANNSTLF model is built as a multi-layer feed-forward Artificial Neural Network (ANN) as identified by the creators in this paper (Khotanzad and Afkhami-Rohani 1998). The ANN models are still being used today due to their ability to learn complex and non-linear relationships in the data on their own. The specification of independent variables explicitly in ANNs is not mandatory, like in the case of MLR models. This ANNSTLF model has been identified as the best-known ANN implementation for STLF (Hong and Fan 2016b; Weron 2006)(Methaprayoon et al. 2007). The ANNSTLF and its improvements of it have been used by several utilities in Canada and the US. The figure below shows the block diagram of the system:

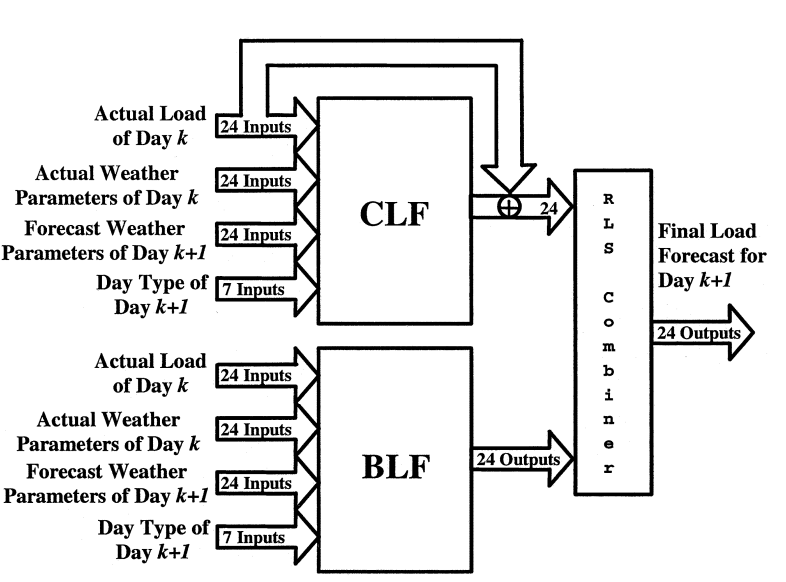


Figure :- The Block Diagram of the third generation ANNSTLF **(Khotanzad and Afkhami-Rohani 1998)**

ANNSTLF is a multilayer perceptron that is trained with the error backpropagation algorithm. The third generation of ANNSTLF has three models; a baseload forecaster (BLF), a change in load forecaster (CLF), and a recursive least squares (RLS) combiner. The two forecasters are created the same and given the same inputs; the difference can be found in their output. The BLF is trained to forecast the regular load of the next day, while the CLF is trained to forecast the change in the hourly load between yesterday and today. The final CLF forecast is the addition of the change in load forecast and the actual load of yesterday. The RLS combiner takes the outputs from these forecasts and combines them adaptively using the recursive least squares algorithm. It is also argued that the CLF forecaster allows the model to rapidly adapt to abrupt changes in temperature (Weron 2006)(Khotanzad, Zhou, and Elragal 2002)(Campbell and Adamson 2006).

## Data Sets and Metrics for Evaluation (1 page)

* ~~Characteristics of a data set that our solution could be applied~~ to
* ~~Based on that, our search and what we came up with for data sets to be used in the evaluation of benchmarks and improvement~~

The datasets to be used are time series sampled on an hourly horizon, and they contain the temperature variable as it plays a huge role in power demand. The more data available for training, the better the algorithms perform. The authors of the ANNSTLF algorithm mentioned that the algorithm works optimally when trained with at least 3 years of data. For this reason, the first dataset selected was gotten from the Ontario independent system operator (Anon n.d.). The demand for the city of Toronto was used. The second dataset was gotten from Saint John Energy (Anon n.d.); this isn’t a publicly available dataset but I believe it would be useful for my research work as it would help us see how well the algorithms perform, in a comparison between bigger and smaller cities (i.e. Toronto and Saint John). The weather variables for both datasets were gotten from the government of Canada website (Anon n.d.).

* ~~Metrics we plan to use to evaluate – list them, and explain what can be ascertained from them~~

The global metrics being used are: Mean Absolute Percent Error (MAPE), Mean Error (ME), Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and Standard Deviation. The MAPE tells us the size of the error of the forecasted values in terms of percentage. MAPE is the most common measure used for load forecasting; it works best when there are no near zeros or extreme values. ME is the mean error of the forecasts across the entire horizon. MAE is a measure of the average magnitude of the forecast errors without the consideration of their direction. RMSE shows the absolute fit of the model; the closeness of the actual values to the predicted ones. Standard deviation tells how spread the errors are; it’s a measure of how far each error is from the mean error.

Because the global metrics only show one value about the errors of the entire dataset. There is the need to classify the errors on hourly, daily, and monthly horizons. This shows us the distribution of error for each hour, month, and day; therefore, it helps us to identify situations where the algorithms perform better or worse.

## Approaches(s) for Improvement (1 page)

// To be filled

# Contributions

<Briefly list what contributions are made by completing this work – aim for 1 page. Don’t focus on what you learn by completing the work; instead, focus on what researchers will learn by reading the work, or what users will have as a result of this work.>

// A new improvement for the ANNSTLF gen 3. No improvement is publicly available right now.

// A much better algorithm/ method for load forecasting

// Predictions in bigger vs smaller cities. In terms of aggregation

// A reproducible experiment

Appendix A: How to use this Template

# Styles

Use this template to handle all of your formatting issues. They will ensure consistent fonts, spacing between sections etc. To select a particular style, open the *styles* pain as depicted below:

|  |
| --- |
|  |
| Figure 2: a) Where to find the Formatting Styles b) where to find ‘references’ to insert captions |

## Regularly used styles

Avoid using the Normal style. It is in place as a reference for other styles. Here is a list of regularly used text styles:

Body Text: your main text should be formatted with this style

Block Text: used to indent content from the left and right

Captions: Use Figure Captions, Table Captions and Equation Captions by navigating to: >references>insert caption>…

Nlists and BLists (for numbered and bulleted lists)

Heading 1

Heading 2

Heading 3

Specialty formats: Strong, Emphasis, Subtle Emphasis, Intense Emphasis

There are also a set of styles included in the list for one-time use:

Cover styles: Pretitle, Title, Subtitle, authorship…

Header and Footer

Table of Contents styles, TOC1, TOC2, and TOC3 (These are linked to Sections to automate your table of contents)

## Heading and Numbering

This is a bit tricky, but here is a brief explanation. Section Headings should be formatted according to Heading 1, Heading 2 and Heading 3 (Heading 2 and 3 are sub-heading formats). These styles are linked to the ‘list style’ called Headings so when you use a Heading style they are properly numbered.

|  |
| --- |
|  |
| Figure 3: Example of Properly formatted 5th section headings |

The template should apply the list style automatically, but if it doesn’t, when you select your first heading, go to the list style menu and select the Headings list style to apply it.

|  |
| --- |
|  |
| Figure 4: Where to find the List Style menu |

# Inserting Equations and Figures

Use the quick part tables to insert an equation or a figure. You can access these from the short cut icon indicated in Figure 1. When you navigate to this icon, it provides a list of tables. Use the Equation Table and the Figure Table as in the examples below: The first table is an equation table. The last column is an equation number, inserted by navigating to >references>captions>equation. The second table is a figure table. The last row is a combination of figure number with text describing the figure. To insert the number, navigate to >references>captions>Figure. Then add your text.

|  |  |  |
| --- | --- | --- |
|  | [use equation tool to place equation here] | ( 1 ) |

|  |
| --- |
| [place figure here] |
| [place caption here…if it is less than 1 line, center it] |

# Referencing

Use inline referencing according to IEEE referencing style [1, 2]. For instance, I have included the reference numbers after ‘IEEE referencing style’ and I will include a separate referencing section where I will list the sources in the order which I cite them. Use the *Rlist* style to create your reference list. If you want, you can automate their links with the inline citation by navigating to >references>cross-reference and choosing ‘Numbered Item’. Make sure you set ‘Insert Reference to’ paragraph number. The following are typical examples of items in a references list (I am not too particular about the detailed formatting in the citations, but include the standard information, and be consisten):

1. D Graffox (Sep-2009), IEEE Citation Reference, <http://www.ieee.org/documents/ieeecitationref.pdf>, last accessed, 2015-MAR-13.
2. (no author/date available), IEEE Citation Style, <http://library.queensu.ca/book/export/html/5846>, last accessed, 2015-MAR-13.
3. D MacIsaac, C Hrabi, “Our Favorite Topics”, Journal of Interesting Information, 1(24), 2010.

# Title Page and Headers and Footers

Don’t forget to update the standard content of each of these sections. Of special note is the #-of-pages field in the footer which should be updated manually at the completion of the document so that the Tite and Contents pages are not included. The Reference page should be included (even though it is NOT included in the page count of 10 pages). Also of special note are the ‘created’ and ‘updated’ fields on Title page AND in the footer. In the title page, these fields can be edited by double clicking them. In the footer they are linked to the title page fields through a cross-reference. To update them, simply double click them.

One final note – take a close look at the footer in this appendix compared to the footer in the main body. The paging is different in the appendix. This is because the appendix is a NEW SECTION and the footer for this section has been unlinked to the previous section. Be careful not to mess sections up, but if you do, you can reinstate them using >Page Layout>Breaks>(Section Break) next page. Another interesting thing about this Appendix is that its title uses the stye ‘Contents Heading’. If you don’t do this, it won’t show up in the table of contents properly.