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# Generator Load Angle Using a Neural Network and a PMU

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# Presentation Outline

- Introduction
- Load angle estimation using neural network
- MATLAB Simulations
- Load angle estimation using PMU data
- General concluding remarks
- Questions and Comments

# Introduction

- The work presented was part of a Masters degree research conducted from January 2014 to December 2015
- The proposed topic was "**Direct assessment of rotor angle stability using PMUs**"
- It was intended to conduct research into ways to quantify rotor angle stability using PMU data.
- The research topic was further refined to ensure it benefits Eskom who sponsored the studies.

# Introduction

- After consultations with the Chief Engineer at Operations Planning it was agreed that;
- In order to make an assessment of the rotor angle stability, the generator load angle must be accurately estimated.
- Hence the research topic was changed to “Real-time Estimation of Generator Load Angle Using Artificial Neural Network and Synchrophasor Data”

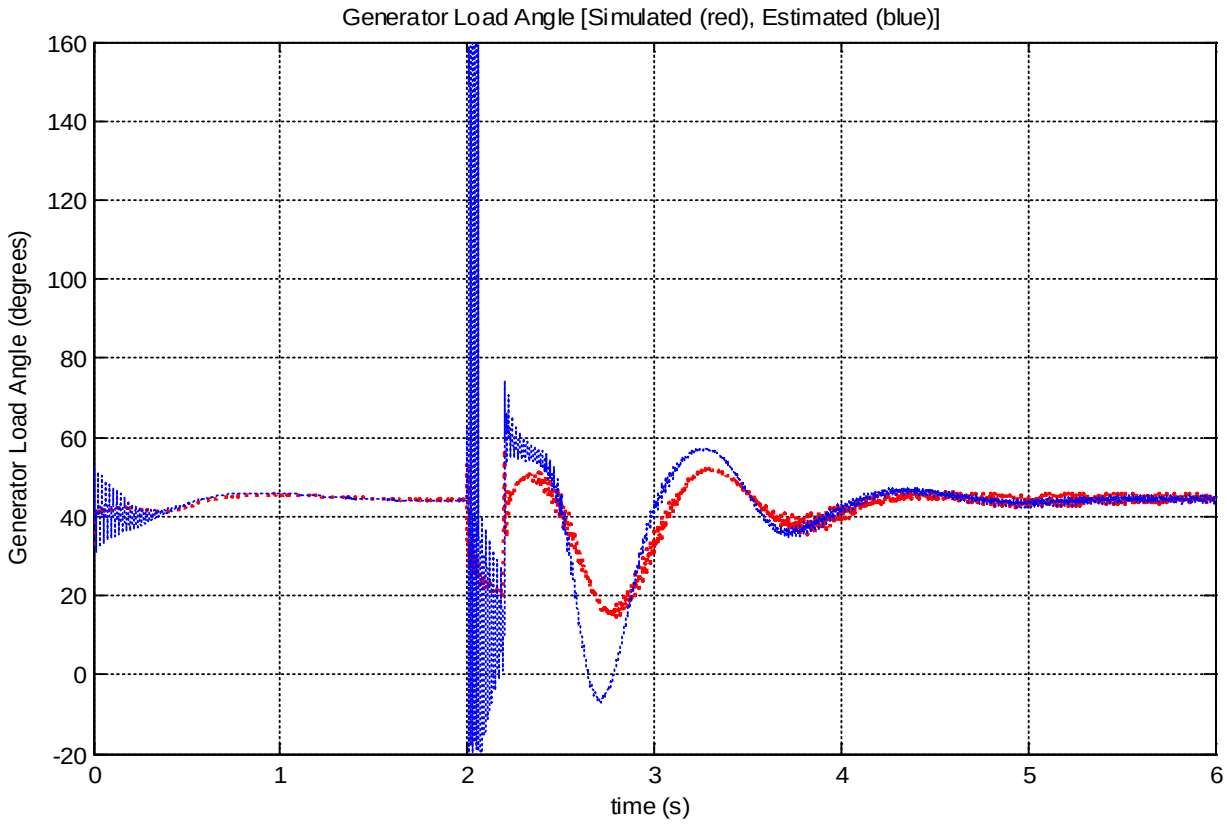
# INTRODUCTION

- The aim was to find an accurate method for estimating the load angle of a generator under all operating conditions.
- The conventional method for estimating generator load angle is the “tan-delta” method based on the model of a generator given by the following equation

$$\tan \delta_i = \frac{X_q I_t \cos \phi - R_a I_t \sin \phi}{E_t + R_a I_t \cos \phi + X_q I_t \sin \phi}$$

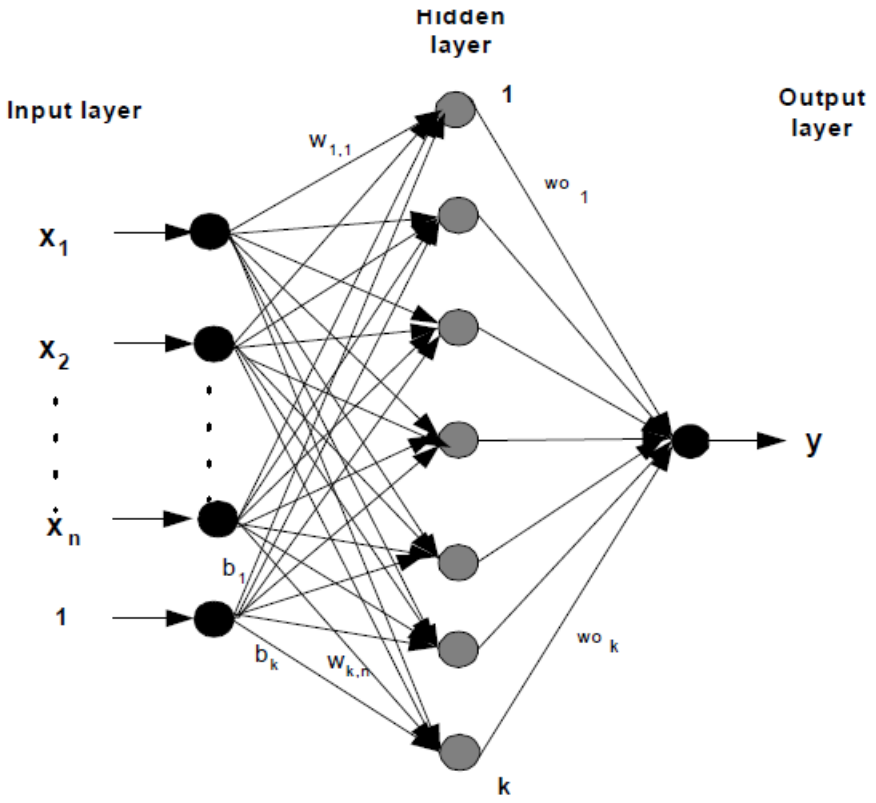
# INTRODUCTION

- An example of the performance of the above model is shown below



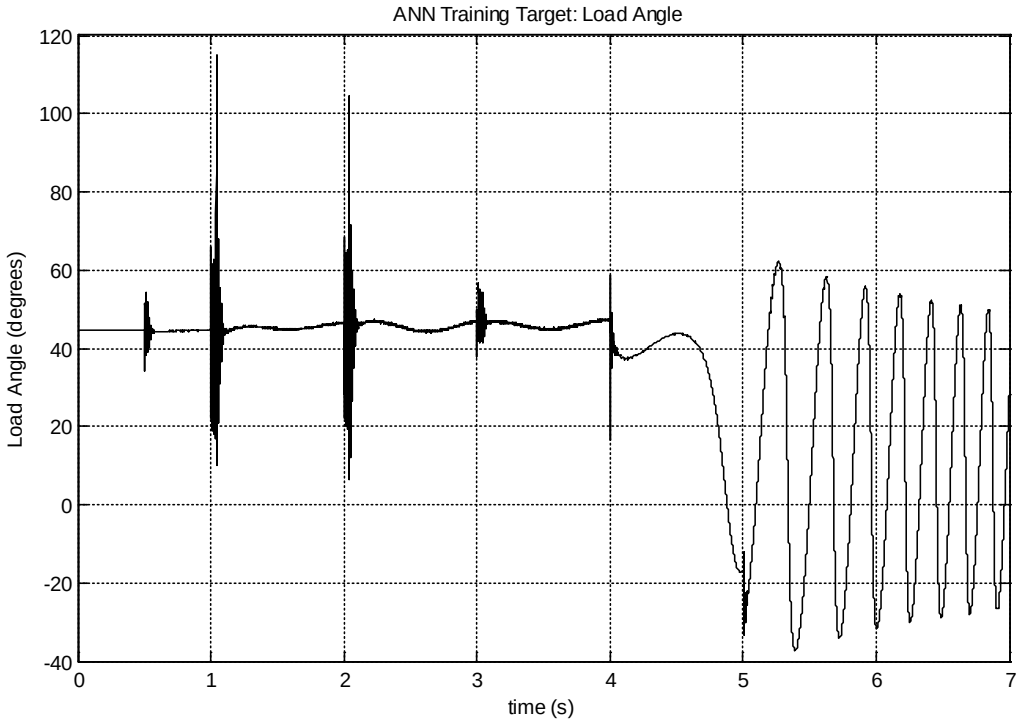
# Load Angle Estimation Using Neural Networks

- Alberto Del Angel published a paper entitled "Using Artificial Neural Networks to Estimate Rotor Angles and Speeds from Phasor Measurements"



# Load Angle Estimation Using Neural Networks

- The artificial neural network was trained using generator terminal phasors of voltage and current.
- Five faults were used as training inputs and the generator load angle is the targeted output.

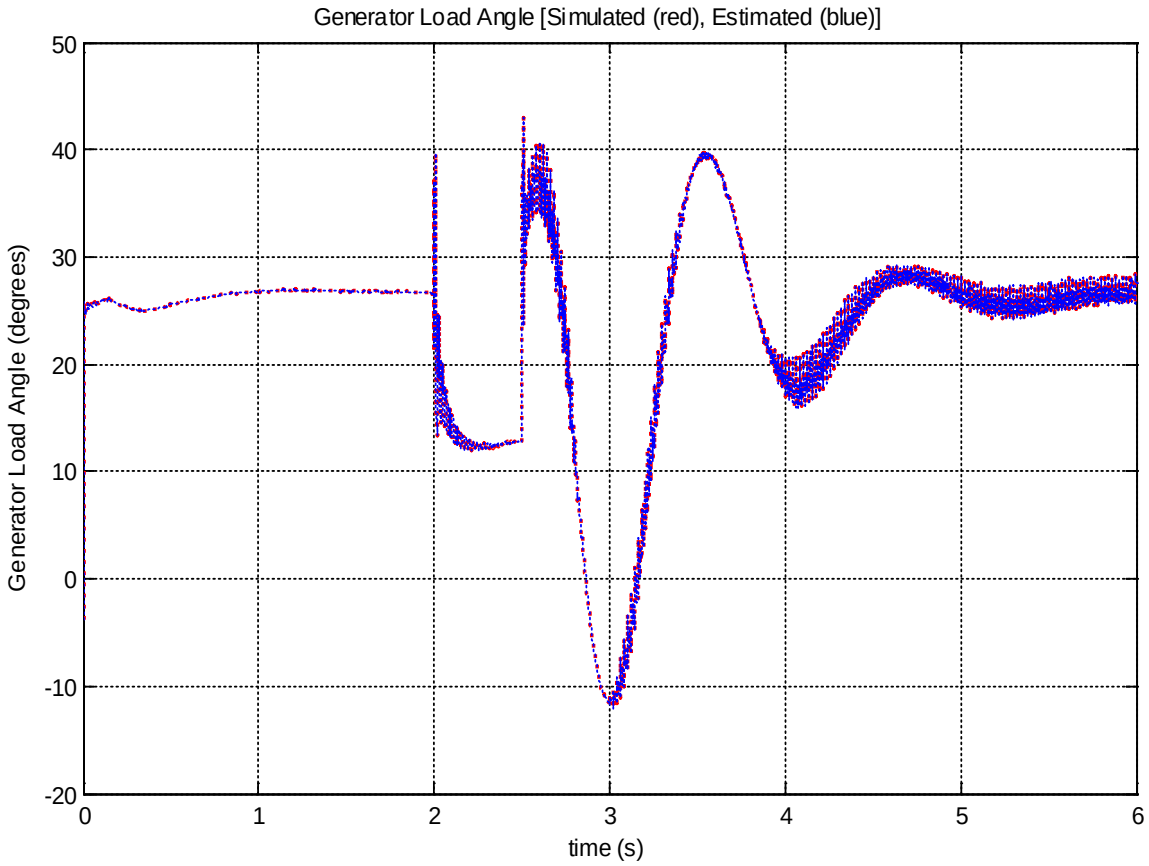


# MATLAB Simulations

- Tests were conducted on a Single-Machine Infinite Bus system.
- The machine under test was a 991MVA, 2 pole, round rotor generator.
- A three phase fault was applied 40 km along line 2 and cleared after 0.4 s.
- The applied fault was different from the faults used to trained the neural network to test the generalisation of the network.

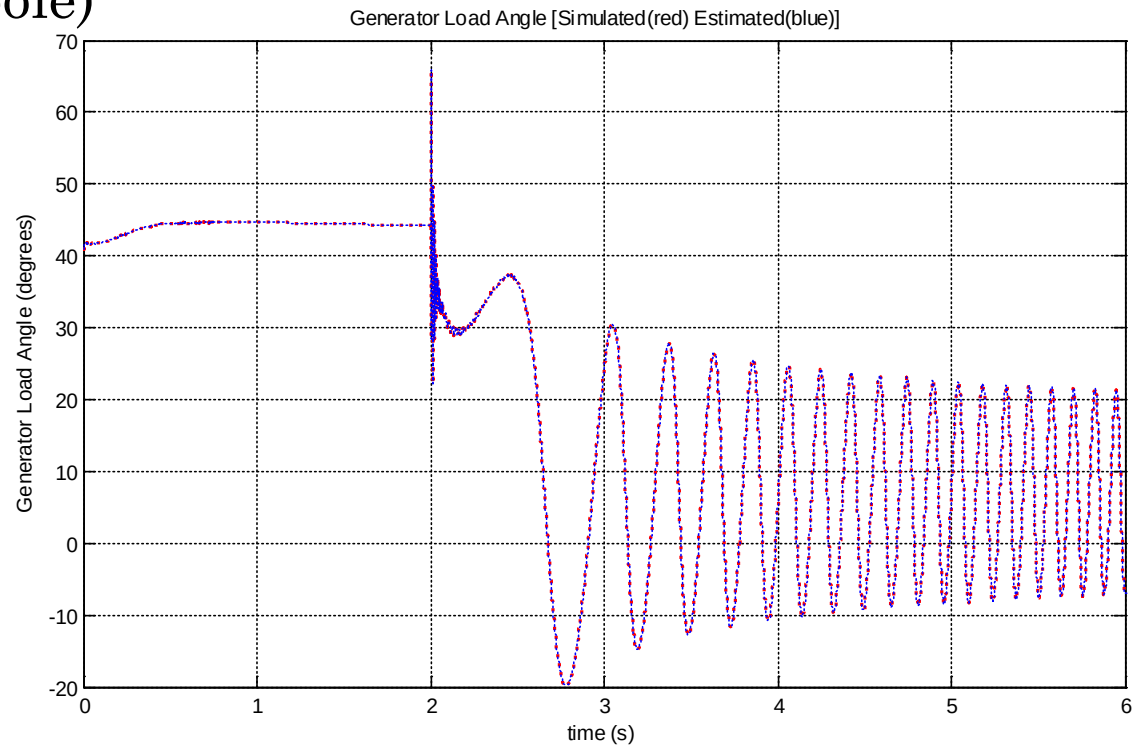
# MATLAB Simulations

- The result is shown below



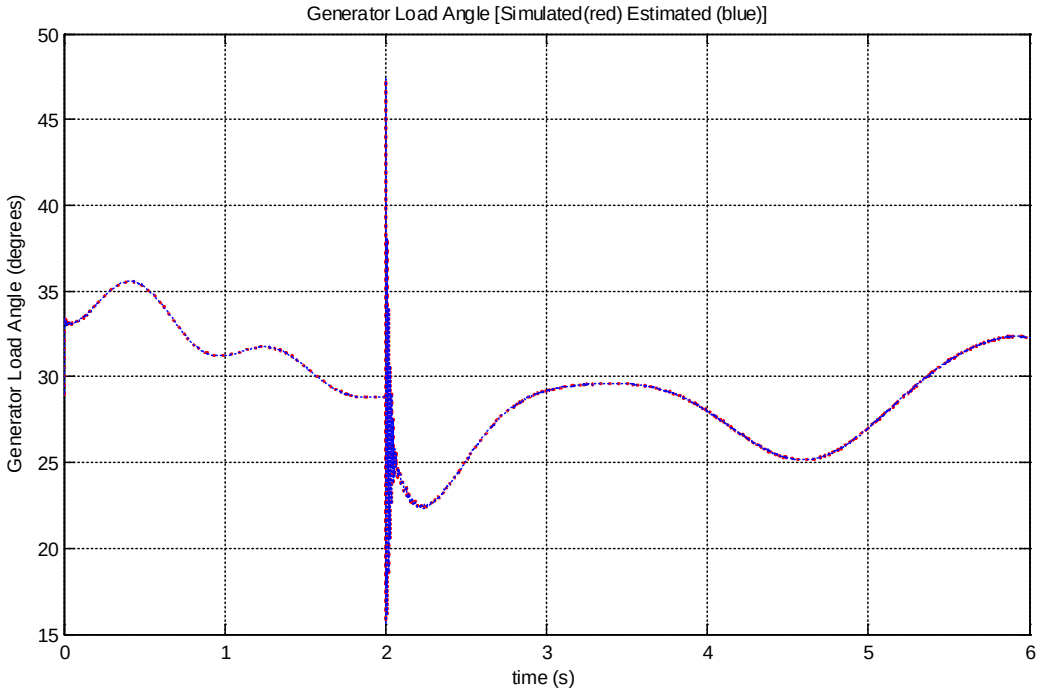
# MATLAB Simulations

- Similar tests were conducted on other generators apart from the one used to train the network;
  - Drakensberg Power Station Generator (salient pole, 8 pole)



# MATLAB Simulations

- Ankerlig Power Station Generator (round rotor, OCGT)



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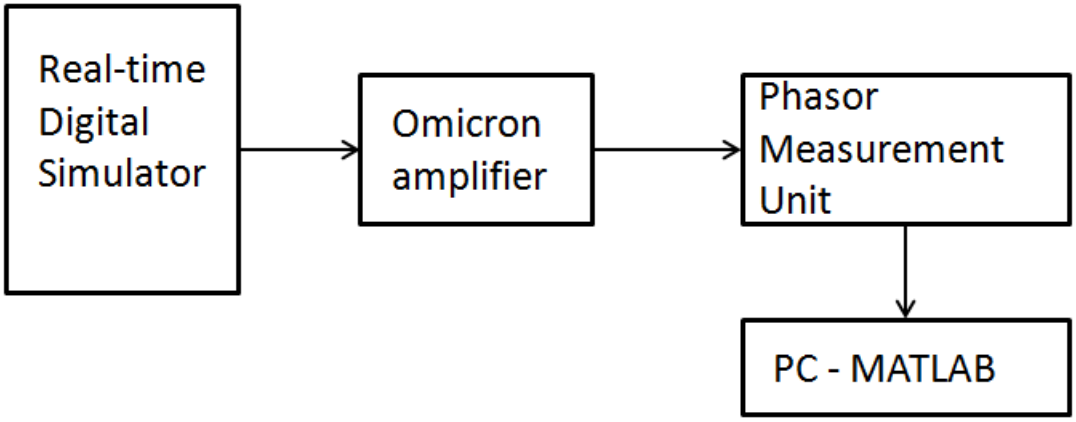
# Load Angle Estimation Using PMU Data

- For practical applications, the load angle must be estimated using generator terminal data from a practical source.
- The device chosen in this research was the PMU.
- In order to get what would be VT and CT outputs, the RTDS was very instrumental.
- It would not be practical to get data from a power station generator and be able to freely introduce faults in the system to test this method.

# Load Angle Estimation Using PMU Data

- The experiment was set up as follows;



# Load Angle Estimation Using PMU Data

- GPS Antenna to receive time reference linked to the Coordinated Universal Time (UTC)

# Load Angle Estimation Using PMU Data

- GPS Receiver which produces the 1PPS and the IRIG-B signal for the PMU

# Load Angle Estimation Using PMU Data

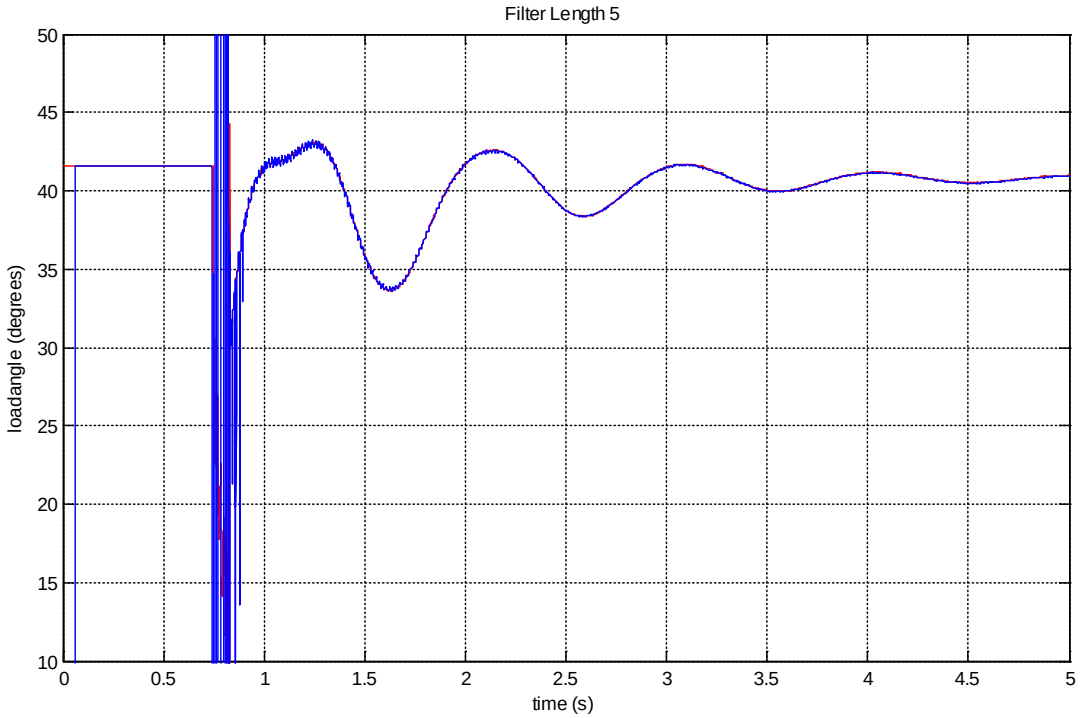
- PMU with VT and CT from the RTDS via the Omicron amplifier

# Load Angle Estimation Using PMU Data

- The interface between the RTDS simulation and MATLAB was achieved by saving the desired variables as COMTRADE files and then reading them into MATLAB using a freeware COMTRADE reader
- The simulated generator load angle in the RTDS would be compared with the estimated load angle in MATLAB.

# Load Angle Estimation Using PMU Data

- A fault was applied at the beginning of line 2 in the SMIB and cleared after 0.07 seconds.

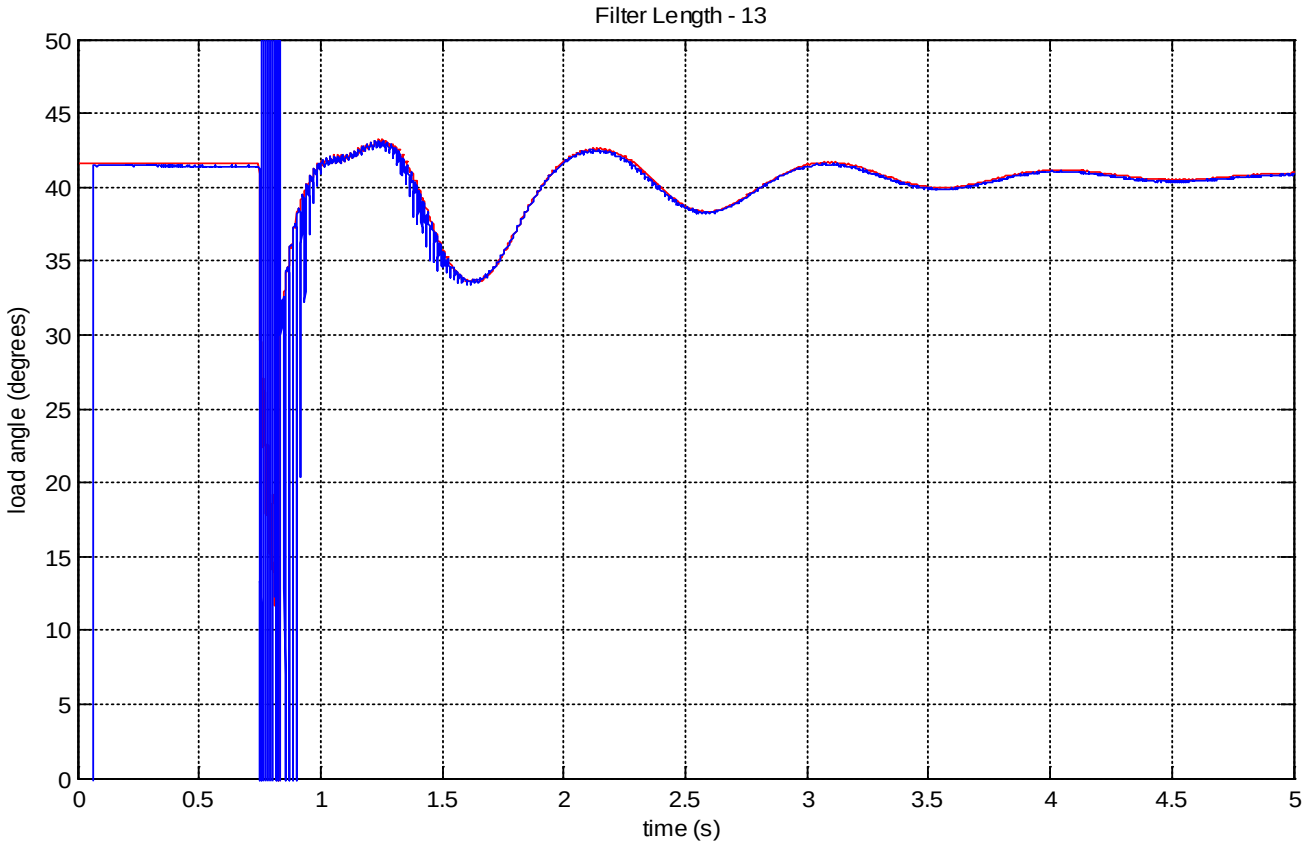


# Load Angle Estimation Using PMU Data

- An interesting observation was made during research. A physical PMU has a setting for the filter length. The Micom P847 has 5 preset filter lengths of 1, 3, 5, 7 and 13
- The effect of these filter lengths on the performance of the neural network are illustrated by the following results

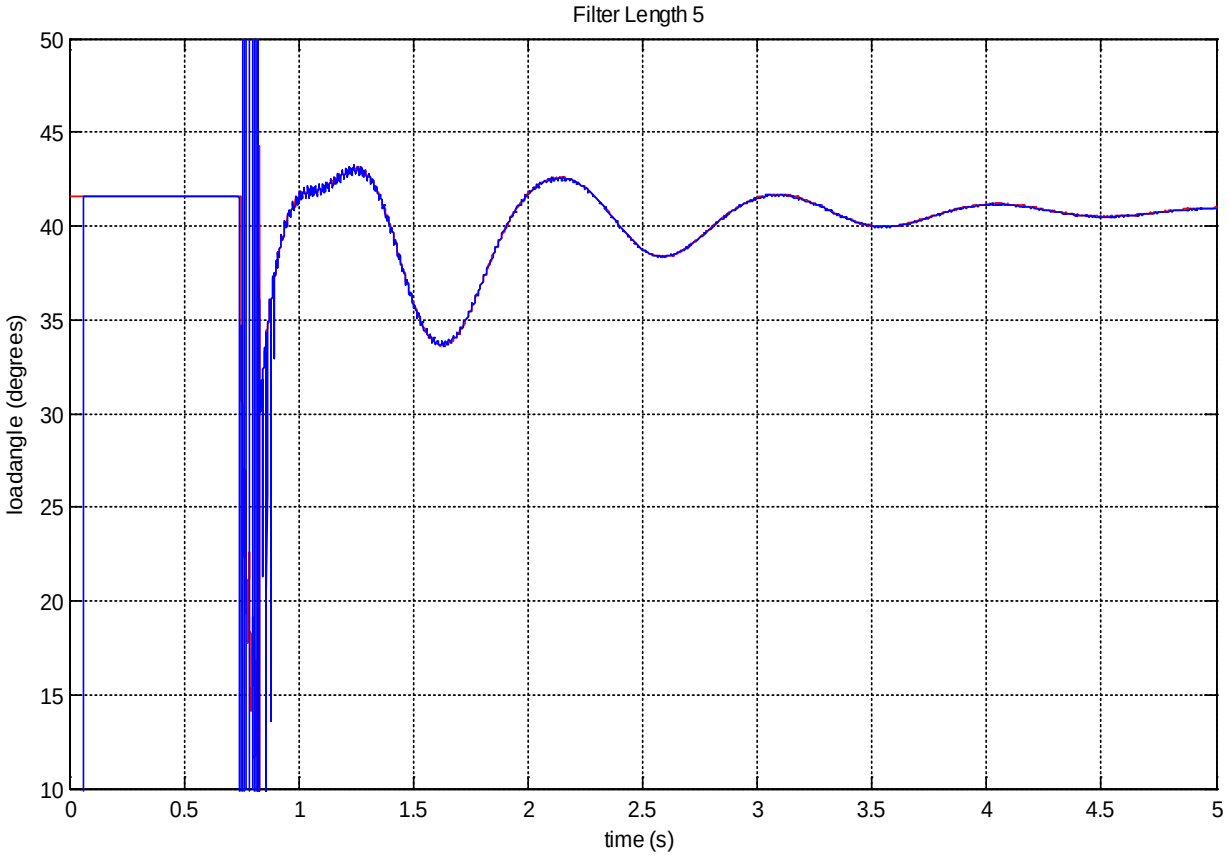
# Load Angle Estimation Using PMU Data

- Filter Length 13



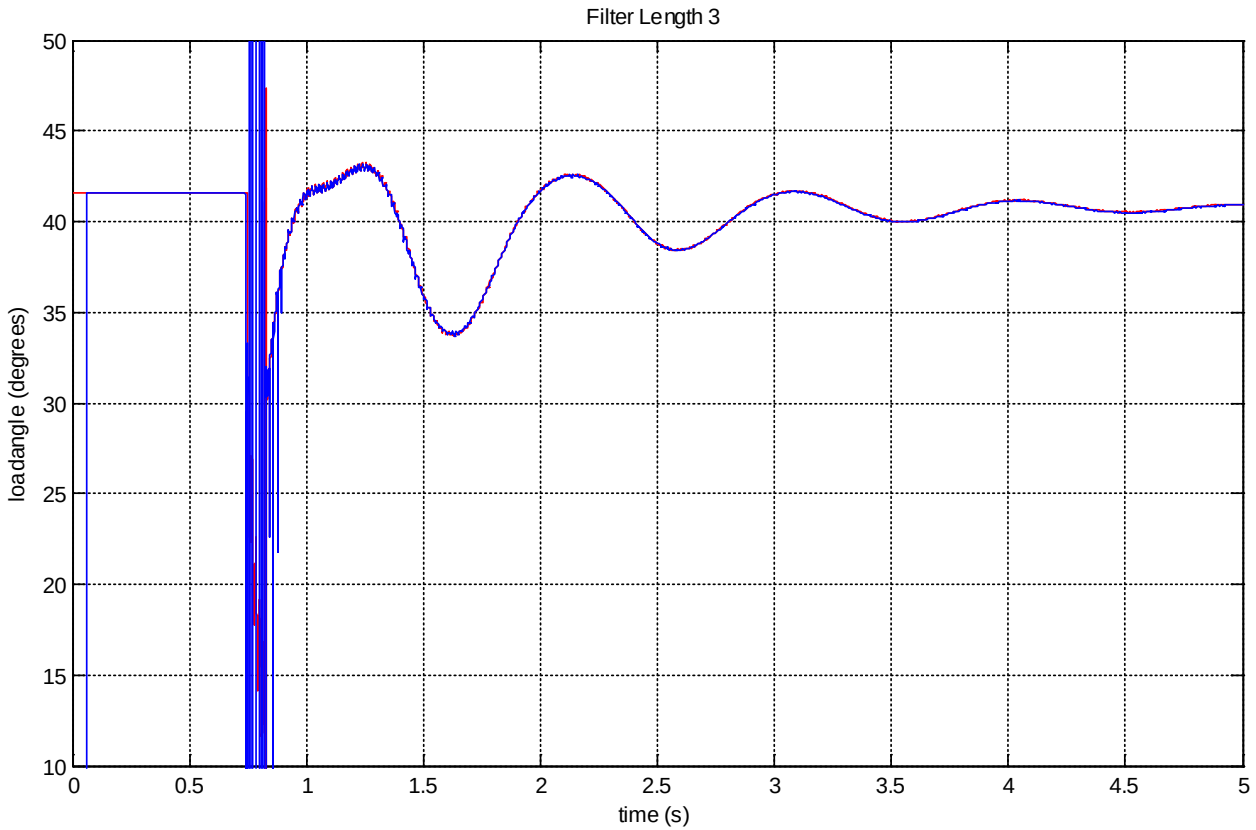
# Load Angle Estimation Using PMU Data

- Filter Length



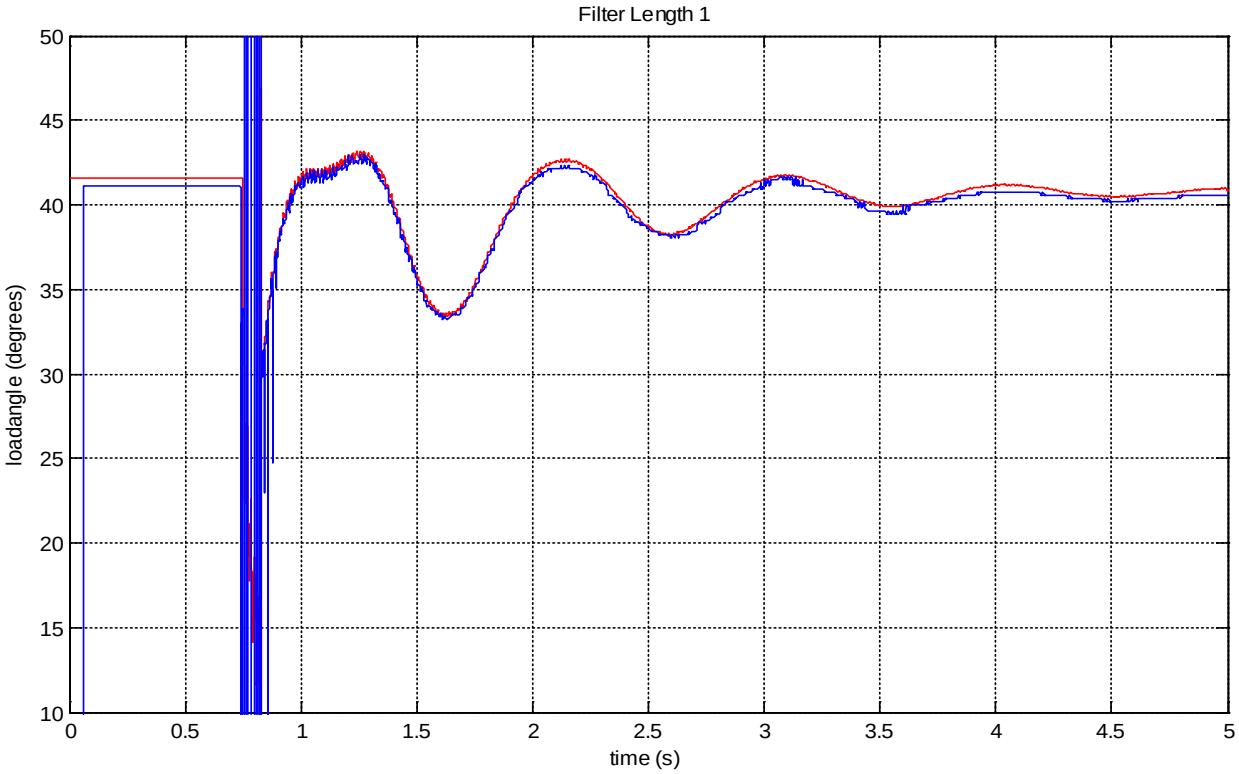
# Load Angle Estimation Using PMU Data

- Filter Length 3



# Load Angle Estimation Using PMU Data

- Filter Length 1



# Load Angle Estimation Using PMU Data

- Similar tests were performed using the PMU component in RSCAD.
- **The effects of filter lengths is not modelled on the PMU component in RSCAD.**

# General Concluding Remarks

- Neural networks can be used to estimated the load angle of a generator.
- Real-time estimation is possible but a device capable of producing continuous synchrophasor would need to be developed
- PMU data may be used to validate existing transient stability assessments (model validation)

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# QUESTIONS/COMMENTS