Hi, my name is BoHyun and I'm a master's student in Electrical Engineering at Minnesota State University, Mankato.

I'm very honor to give the presentation for the 2018 MSU Graduate Symposium.

The title of this presentation is 'Small Signal Model Averaging of Bi-Directional Converter.'

This research has done with Dr. Vincent Winstead.

And funding for this research was provided by Customers of Xcel Energy through a grant from the Renewable Development Fund.

We consider the problem of modeling a bi-directional AC/DC converter using a small signal approach coupled with cycle averaging to simplify the model for use in digitized control.

Renewable energy such as wind power, solar power, and the use of biofuels are promising alternatives to traditional energy sources derived from oil and gas, and promises to positively impact global climate change reducing the effects due to the combustion of fossil fuels mostly in cars, factories and power plants.

Electrical power converters allow for the transfer of power and improve power quality between renewable energy sources and the electrical grid.

For high efficiency and power density with bi-directional power flow, a Dual-Active-Bridge single-stage AC/DC converter is applied in this research.

And, for designing a closed-loop advance controller, a dynamic plant model of the converter should be obtained first but it can be computationally expensive.

In an effort to reduce the complexity of system control, we developed an averaged model which allows for advance controller design while keeping computations reasonable low.

Thus, we approached the plant modeling component through the derivation of a small-signal plant model and used a state-space averaging technique to simplify the model.

This is the topology of the proposed converter.

The primary side H-bridge is connected to an input AC source.

The switches S1, S2, S3, and S4 are four-quadrant switches and are realized with a pair emitter tied IGBTs.

It must be four-quadrant because the AC source voltage swings both positive and negative.

The secondary side H-bridge is connected to an output DC source.

The switches S5, S6, S7, and S8 on the secondary side H-bridge are two-quadrant switches.

The transformer is considered as an ideal transformer.

And the primary and secondary leakage inductance is connected to the secondary side as L.

A small-valued resistor, R, is added to enhance the accuracy of the model and facilitates a state-space average modeling for designing a small-signal transfer function.

Applying Kirchhoff's Voltage Law around the transformer yields the equation.

This equation derives this piecewise function.

This is the modulation cycle for one switching period when the input ac source voltage swings positive.

For modulation regarding the time-varying duty ratio, the sinusoidal pulse width modulation (SPWM) technique is applied.

The state variable, capital X is the inductor current and the input variable, capital U, is the input voltage.

This piecewise function follows the 3rd plot on the left side.

This converter is controlled via the time-varying duty ratio of the gate signals and changes to phase.

Thus, the converter is highly non-linear having both analogue and digital features.

As a result, the state-space average technique can be applied to linearize this system and obtain the dynamic model of the converter.

The equation in the green box is the averaged modeling equation by the state-space averaging technique.

Here, D can be rewritten as D bar + small d.

And, X can be rewritten as X bar + small x.

D bar and X bar are nominal values and small d and small x are small signal variations.

After expanding and dividing the equation then neglecting the high order small signal variation, we got this equation.

Here, E is the average between A1 and A6.

And F is the difference between A1 and A6.

And, by Laplace transform, the control-to-output small-signal transfer function in the green box is derived.

We got the simulation results by MATLAB and Simulink.

The left simulation result shows the original inductor current for one input wave cycle.

Because the given input frequency is 60 Hz in the simulation, the one input period shows 0.0167 seconds.

During the first half of the waveform, when time axis is restricted to the 43rd switching period, the right plot is obtained.

This shows the peak amplitude of approximately 45.

At this period, the time-varying duty ratio is also at its maximum.

We compared the simulation result with the theoretical result regarding the inductor current.

The shape of right simulation result follows the theoretical result.

This shows a comparison between the original and averaged model.

Looking at the left original model plot, thick central lines are prominent with respect to the lighter peripheral lines.

Thus, the peak amplitudes of the right averaged model have magnitude near 20.

Given that the averaged dynamics are sufficient in the modeling effort to represent the converter, the averaged model is computationally easier to implement but still captures the relevant dynamics.

A small signal model averaging method has been proposed to simplify the modeling dynamics of a bi-directional DAB AC/DC converter.

The averaged model result by MATLAB and Simulink shows computationally easier than the original model but still captures the relevant dynamics.

Thank you!