A Study on Predicting Angle Instability in Power System using High-Order Derivatives Method

Woo Yeong Choi[1], Yilu Liu[1,2]

[1] The University of Tennessee, Knoxville [2] Oak Ridge National Laboratory, TN

Background

- Analysis method needed for prediction of angle instability in power system, rather than post-event prediction.
- High-order derivative methods applicable in fields predicting dynamic characteristics by mathematizing physical dynamics.
- Preliminary research conducted on angle instability assessment for large-scale power systems application

Conclusion and Future Works

- Verification of 100% proactive instability prediction in potential line-fault scenarios in the grid.
- Refinement needed for prediction based on PMU data or methods such as data filtering for practical grid environments.
- Future research will focus on feasibility assessment in large-scale grids with significant renewable energy integration, such as WECC and ERCOT system.

Methodology & Application

- Analysis of the phase dynamics of generators

$$\delta^{(1)} = \omega_0 \Delta\omega;\ \delta^{(2)} = \frac{\omega_0}{H}\left(P_m - \frac{V_1 V_2}{X} \sin\delta\right);$$

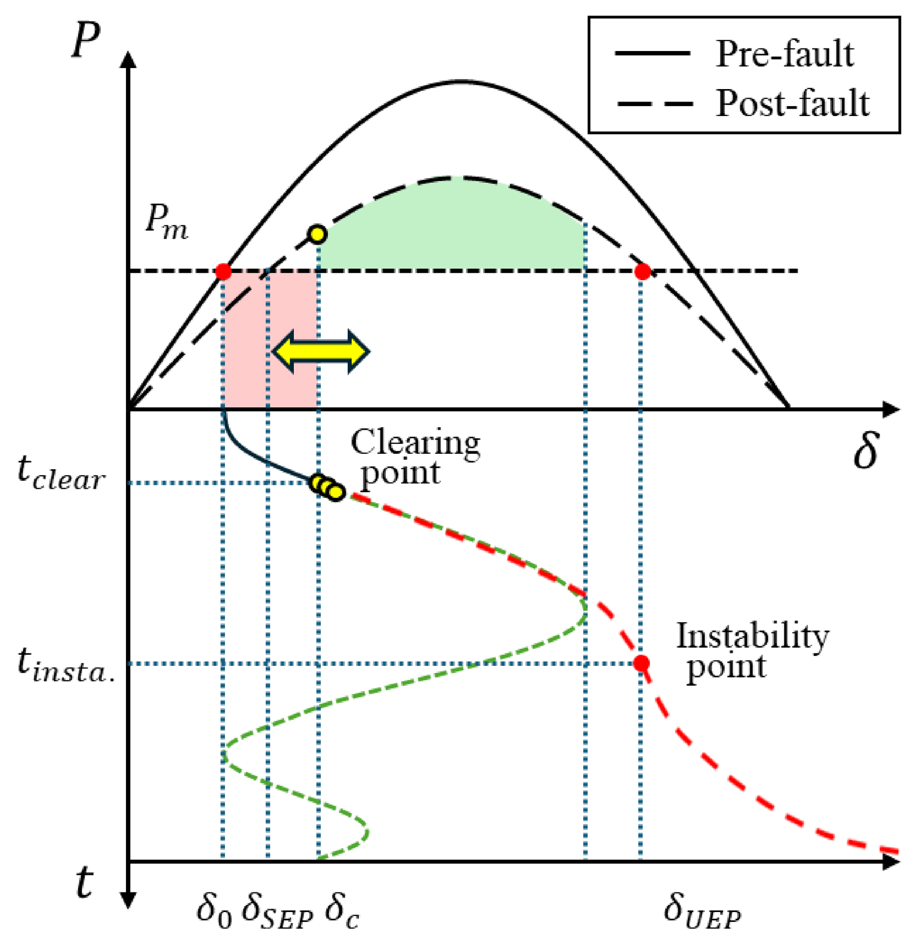
$$\delta^{(3)} = -\frac{\omega_0}{H}\frac{V_1 V_2}{X}\delta^{(1)}\cos\delta$$

- Apply high-order derivatives method

Assumed : $\delta^{(3)}(t) = (const.)$,

$$\delta^{(2)}(t) = c(t - t_0) + b;$$

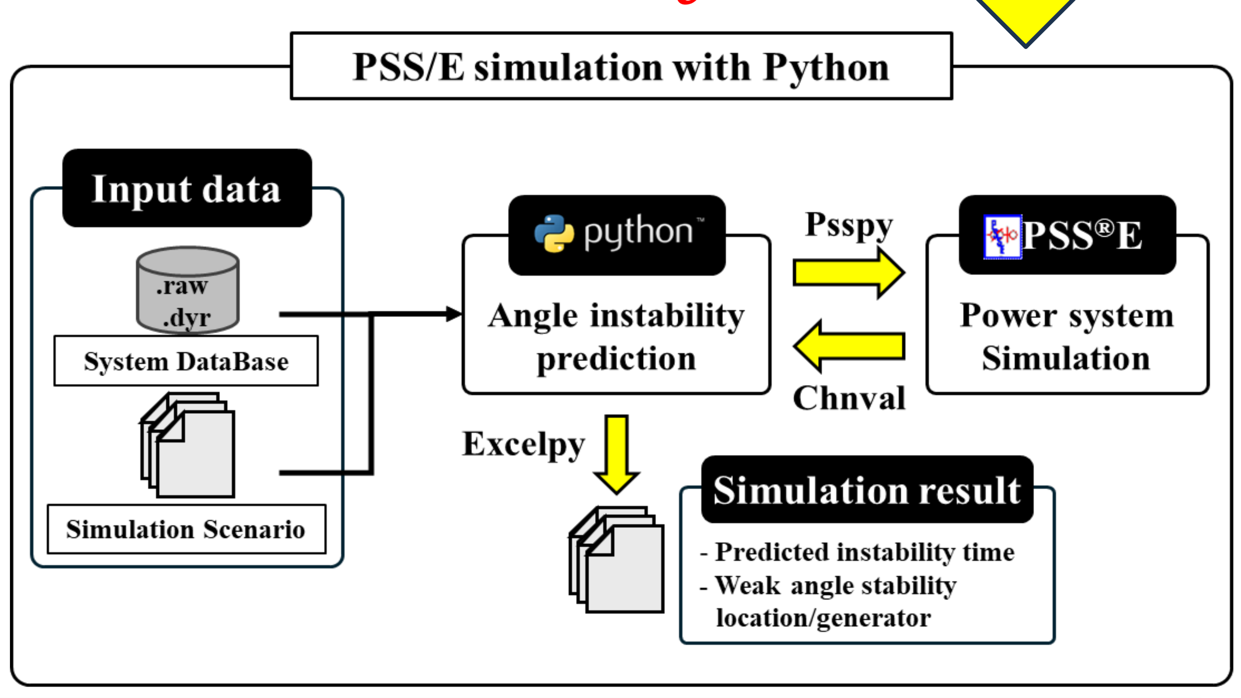
$$\delta^{(1)}(t) = \frac{c}{2}(t - t_0)^2 + b(t - t_0) + a;$$



➔ **Instability Point (at t^*):**

$\delta^{(1)} > 0,\ \delta^{(2)} = 0$ and $\delta^{(3)} > 0$

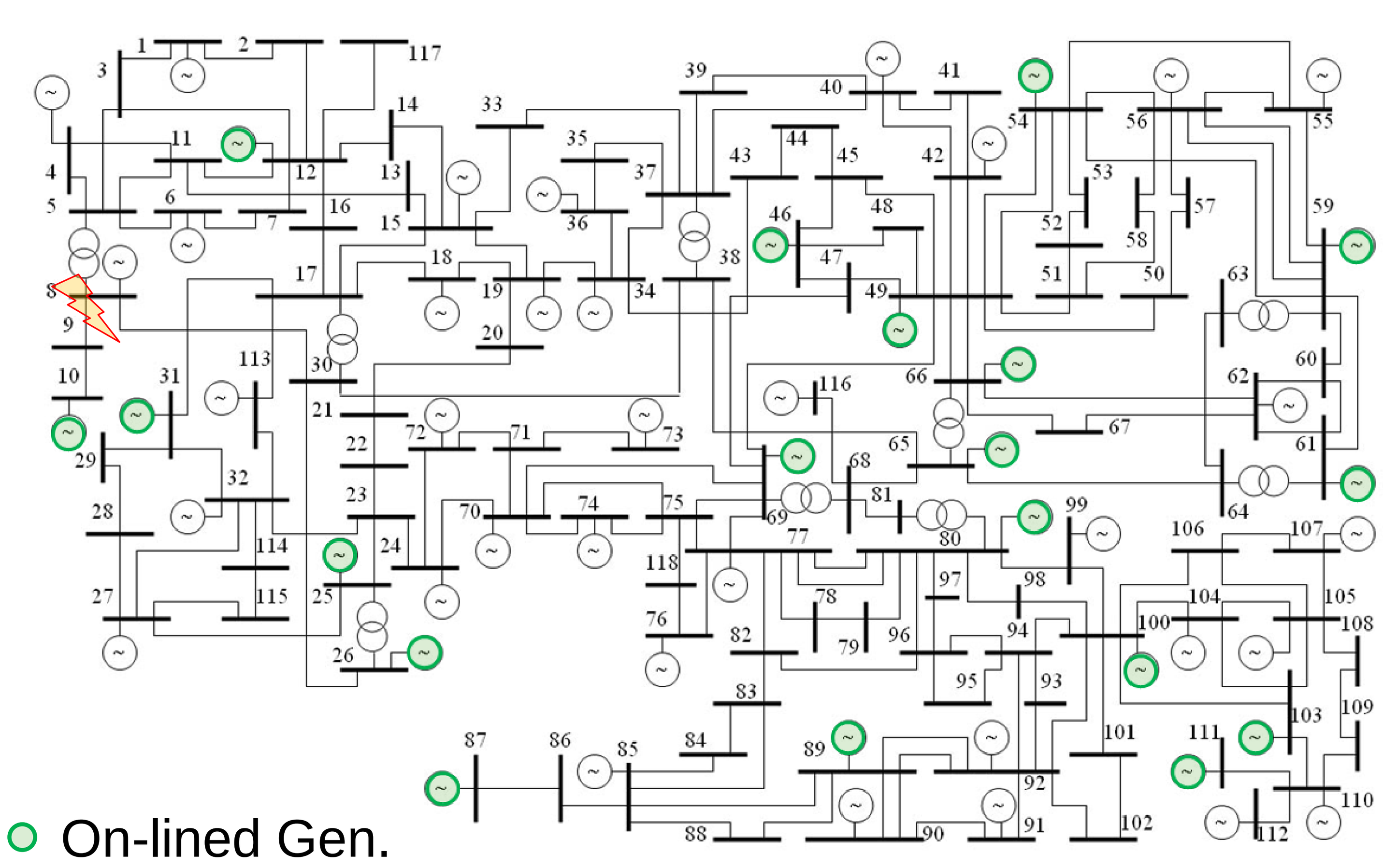
$\therefore \delta^{(2)}(t^*) = 0, \Rightarrow t^* = t_0 - \frac{b}{c}$



Case Study#1: Instability Prediction for System Single Line-Faults Scenario

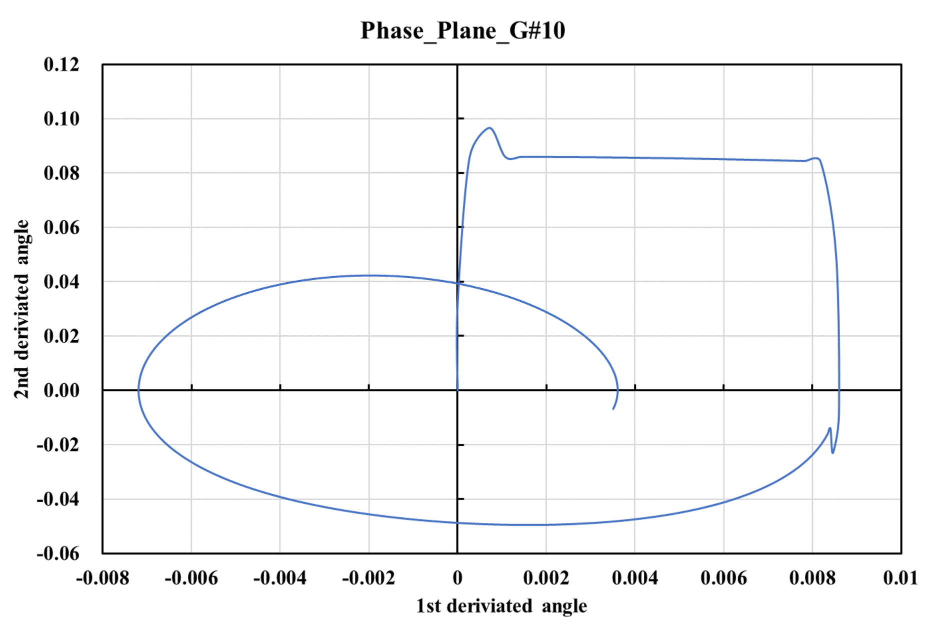
- Test system: IEEE 118 benchmark model.

 - System size: 3.94 GW

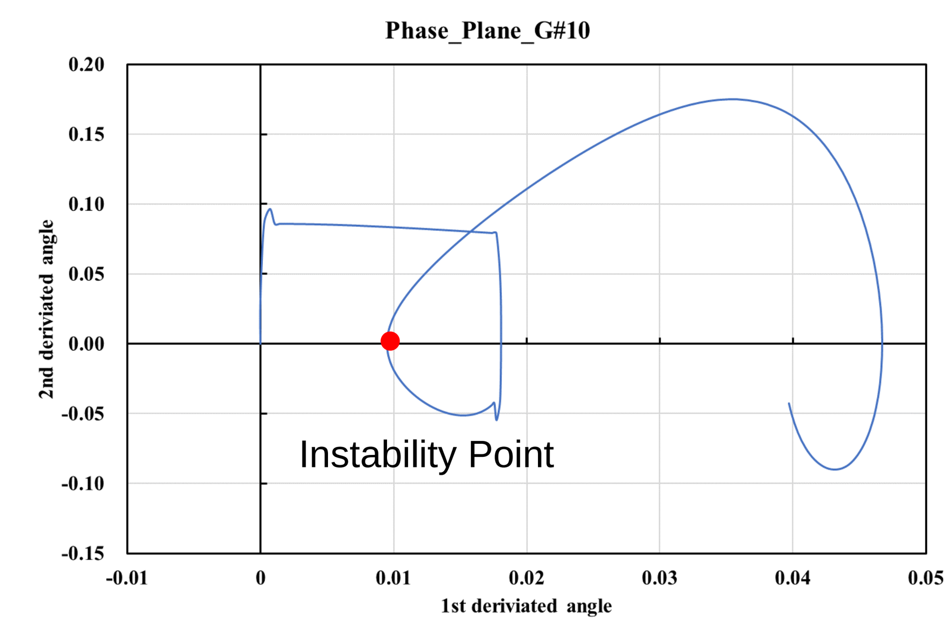


○ On-lined Gen.

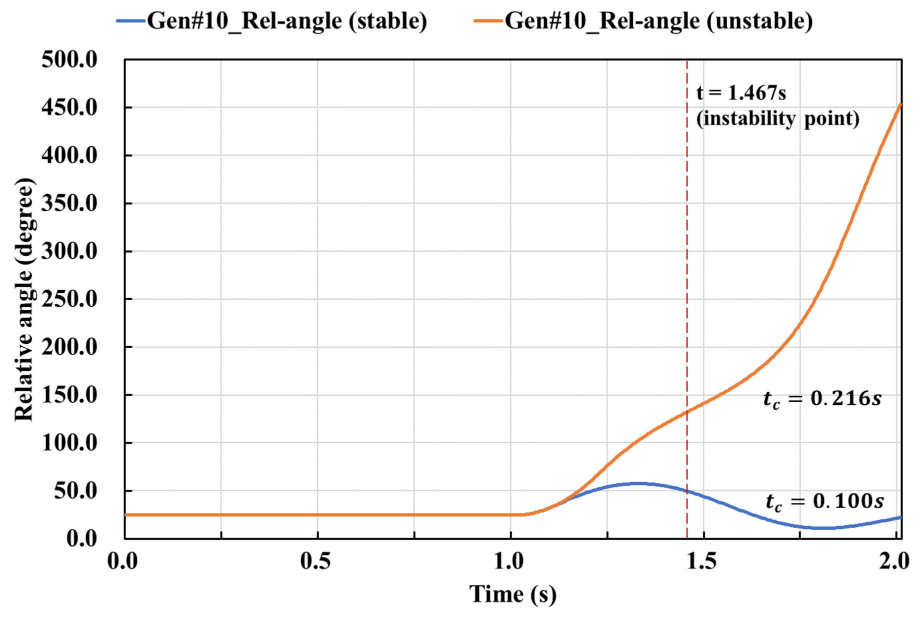
- Comparison of dynamic characteristics based on phase planes for stable and unstable conditions.
- Verification of angle instability prediction results.



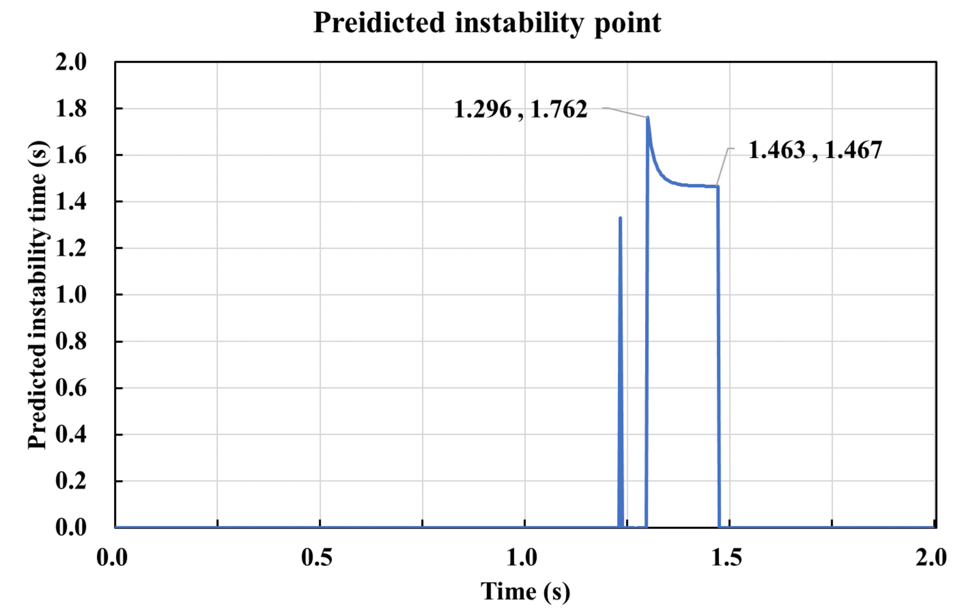
<stable case>



<unstable case>



<Generator angle>



<Instability prediction>

Case Study#2: Expanded Angle Instability Prediction Results

- Total simulation cases: 175

 (Cases with instability during line-fault: 105)

- Prediction Evaluation:

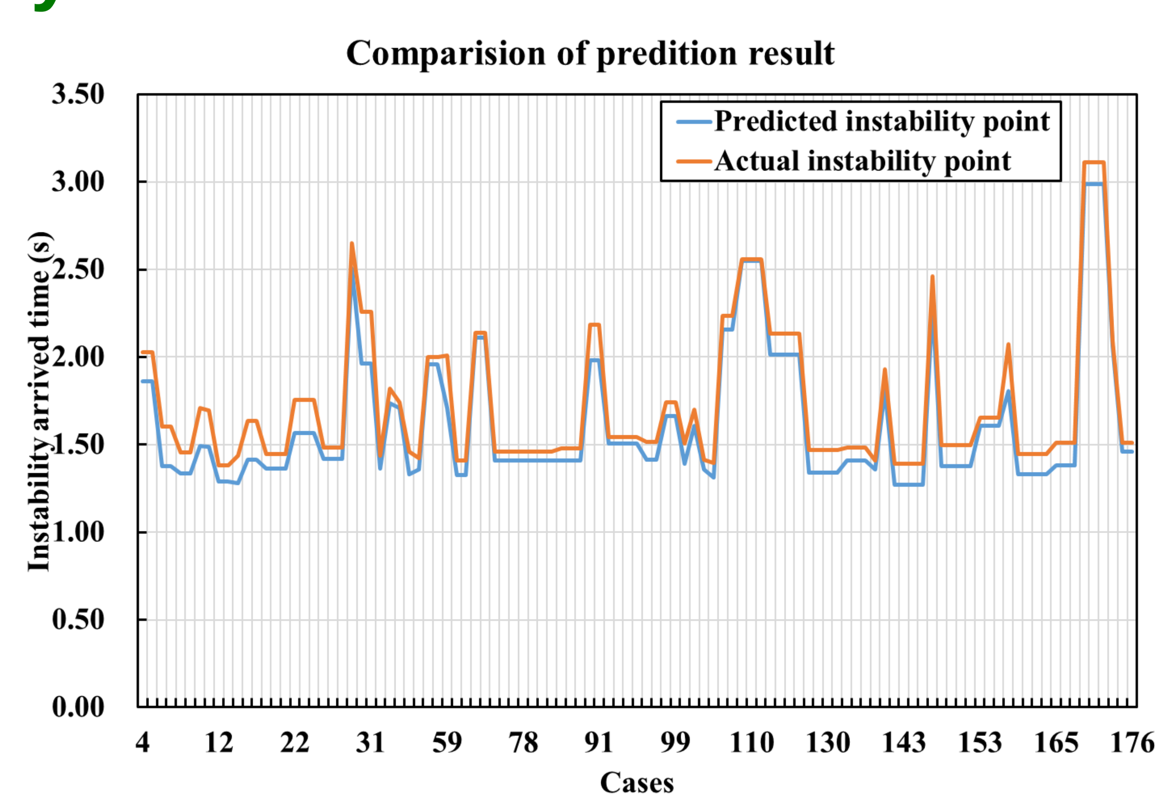
 - Verification of 100% instability prediction

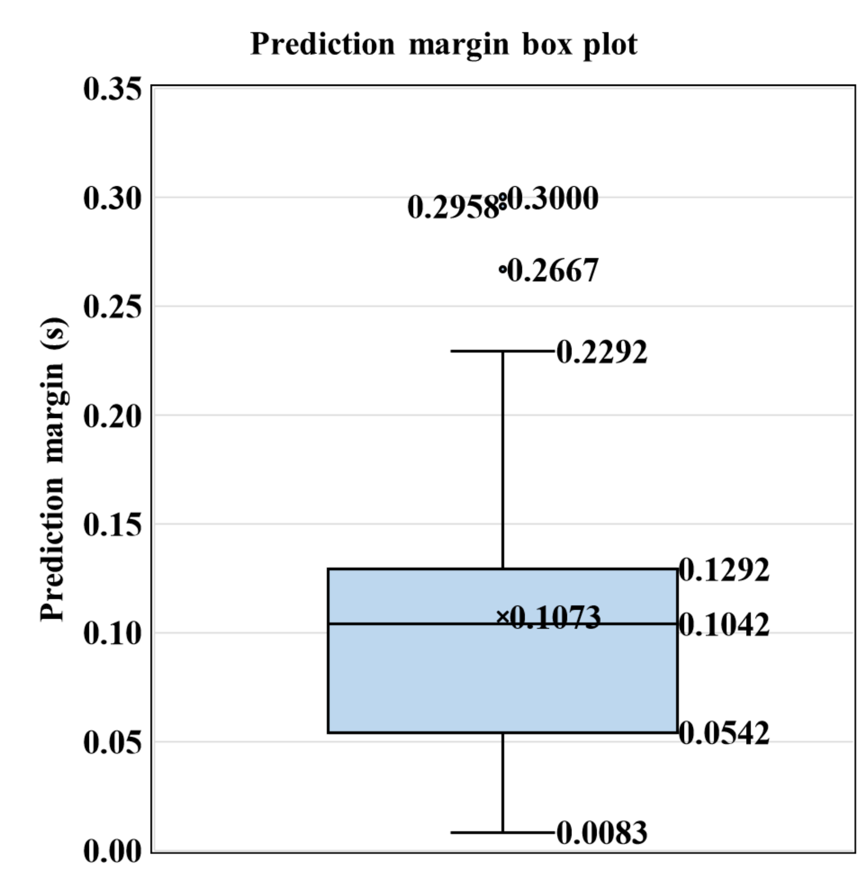
 - KPI based Evaluation

MAPE: $\frac{100\%}{n}\sum\frac{|A_t - F_t|}{A_t} = 6.343\%$

MAE: $\frac{1}{n}\sum|A_t - F_t| = 0.107$

RMSE: $\sqrt{\frac{1}{n}\sum|A_t - F_t|^2} = 0.125$





THE UNIVERSITY OF TENNESSEE KNOXVILLE