FERC TECHNICAL CONFERENCE: INCREASING REAL-TIME AND DAY-AHEAD MARKET EFFICIENCY AND ENHANCING RESILIENCE THROUGH IMPROVED SOFTWARE (6/23 – 6/25, 2020)

PROBABILISTIC ZONAL RESERVE REQUIREMENTS FOR IMPROVED DELIVERABILITY WITH WIND POWER UNCERTAINTY

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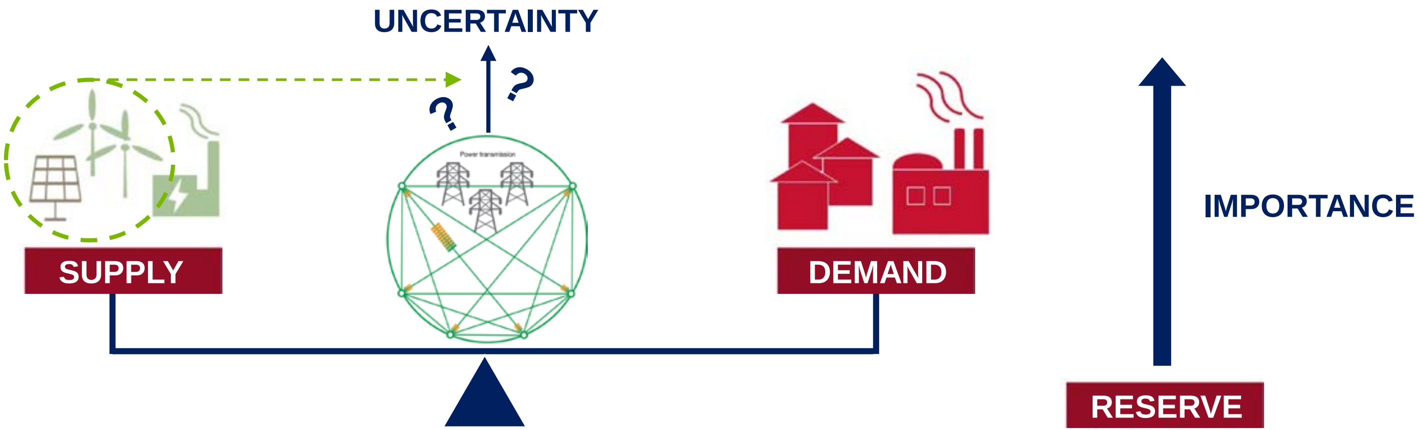
OUTLINE

- Introduction
- Probabilistic Zonal Reserve Requirement
- Enhanced Unit Commitment Formulation with Zonal Reserve
- Simulation and Results
- Discussion and Future Work

INTRODUCTION



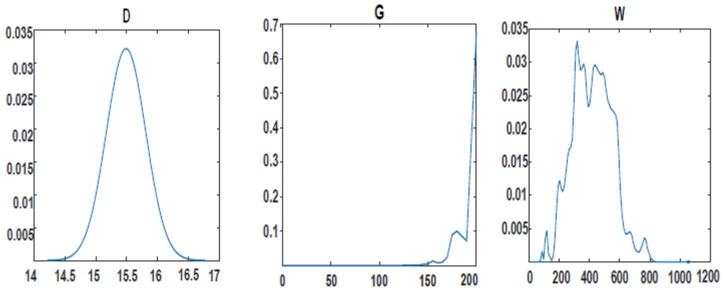
1. Additionally, zonal level reserve requirement is a potential solution to limit exposure to network congestion when dispatch reserve from outside.
2. Improve system flexibility and deliverability by zonal reserve requirement setting and deliverability assurance.

http://www.news.gatech.edu/features/building-power-grid-future

https://aemo.com.au/news/managing-frequency-in-the-power-system

PROBABILISTIC ZONAL RESERVE REQUIREMENT

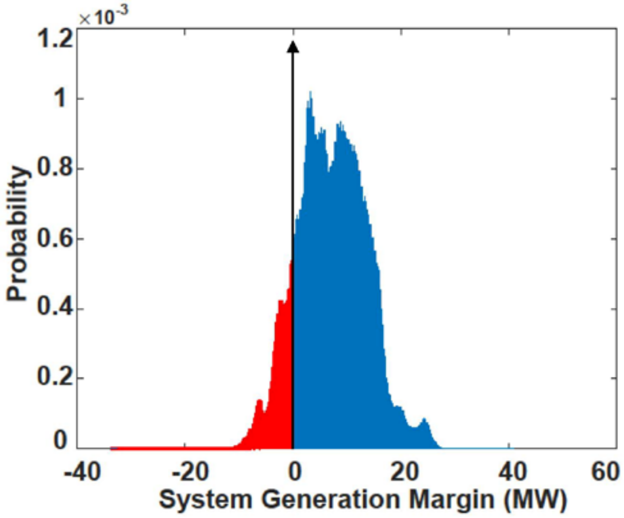
- Uncertainty sources – load, conventional unit, and wind generation



(a) Load (b) Conventional Unit (c) Wind

- Injection margin for each bus i

$$\begin{aligned} P_M^i(M_i) &= P_M^i(W_i + G_i + (-D_i)) \\ &= \sum_{d=-\infty}^{\infty} \sum_{g=-\infty}^{\infty} P_W^i(W_i = M_i + D_i - G_i) \\ &\cdot P_G^i(G_i) \cdot P_D^i(D_i) \end{aligned}$$



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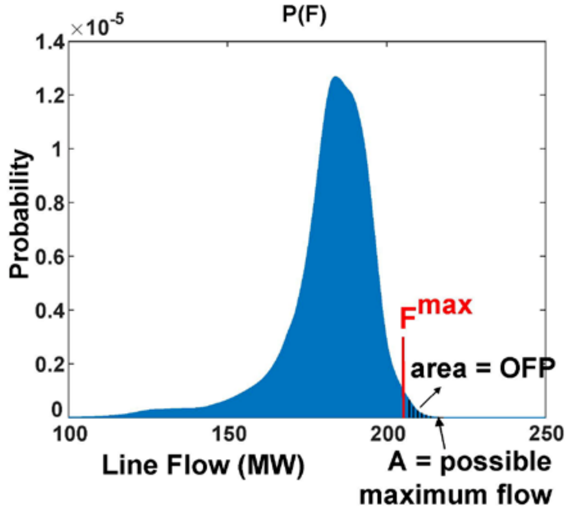
PROBABILISTIC ZONAL RESERVE REQUIREMENT

- Probability distribution of line flow

$$F_l = \sum_i ISF(l,i) \cdot (W_i + G_i - D_i)$$

$$P(F_l) = P(\sum_i ISF(l,i) \cdot M_i)$$



- Zonal generation margin

$$P(ZM_z) = P(\sum_{i \in N_z} M_i + \sum_{l \in L_z} F_l),\ z \in Z$$

$$\approx P(\sum_{i \in N_z} M_i) + \sum_{l \in L_z} mean(P(F_l)),\ z \in Z$$

$$Prob\big(ZM_z + ZN_z^{\text{up}} < 0\big) \le \alpha,\ z \in Z$$

- Energy Deliverability Improvement – critical line between zones

$$\sum_{i \in FZ_l} (ISF(l,i) \cdot Reserve_i) \le F_l^{\max} - A_l,\ l \in L_c$$

$$\sum_{i \in FZ_l} (ISF(l,i) \cdot Reserve_i) \ge -F_l^{\max} - A_l,\ l \in L_c$$

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ENHANCED UNIT COMMITMENT FORMULATION WITH ZONAL RESERVE SETTINGS

- Objective

$$\min \sum_{g,t} \tilde{c}_g\{p_{g,t}\} + SU_g z_{g,t} + SD_g y_{g,t} + RP_g^{\mathrm{up}}(r_{g,t}^{\mathrm{up}})$$
$$+ RP_g^{\mathrm{dw}}(r_{g,t}^{\mathrm{dw}}) + CR(rns_{g,t}^{\mathrm{up}}) + CR(rns_{g,t}^{\mathrm{dw}}) + \sum_{i,t} CE(e_{i,t})$$

- Reserve requirement constraints:
  - System level:

$$\sum_{g} r_{g,t}^{\mathrm{up}} + rns_{g,t}^{\mathrm{up}} \geq SYS_t^{\mathrm{up}}, \forall t$$

$$\sum_{g} r_{g,t}^{\mathrm{dw}} + rns_{g,t}^{\mathrm{dw}} \geq SYS_t^{\mathrm{dw}}, \forall t$$

  - Zonal level:

$$\sum_{g \in G_z} r_{g,t}^{\mathrm{dw}} \geq ZN_{z,t}^{\mathrm{dw}},\ z \in FZ_l, l \in L_c, \forall t$$

$$\sum_{g \in G_z} r_{g,t}^{\mathrm{up}} \geq ZN_{z,t}^{\mathrm{up}},\ z \in FZ_l, l \in L_c, \forall t$$

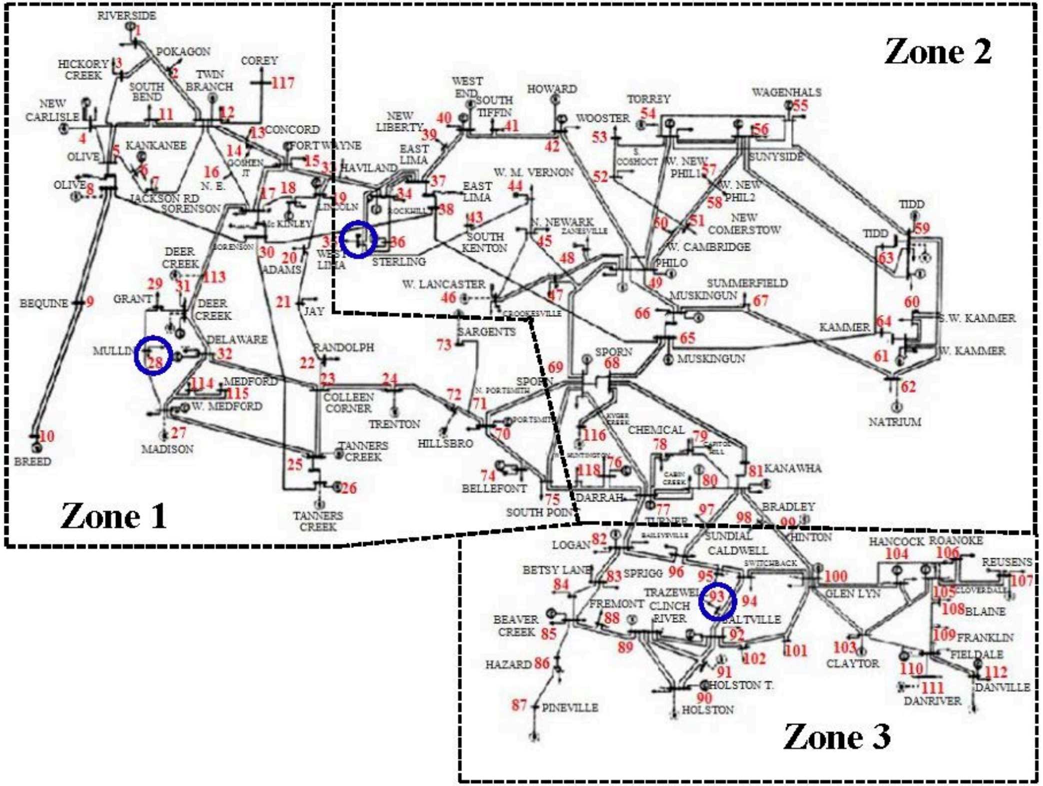
- Deliverability constraints

$$-\sum_{i \in FZ_l} (ISF(l,i) \sum_{g \in G_i} r_{g,t}^{\mathrm{dw}}) \leq F_l^{\max} - A_{l,t}, l \in L_c, \forall t$$

$$\sum_{i \in FZ_l} (ISF(l,i) \sum_{g \in G_i} r_{g,t}^{\mathrm{up}}) \geq -F_l^{\max} - A_{l,t}, l \in L_c, \forall t$$

SIMULATION AND RESULTS

- Test System



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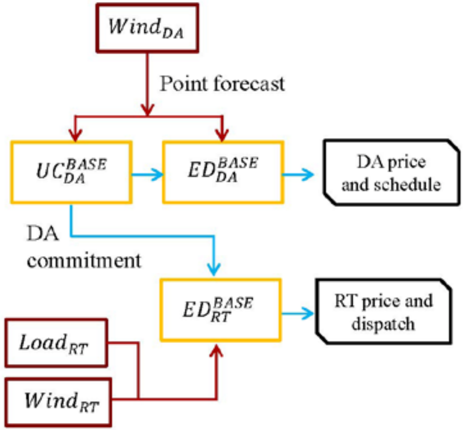
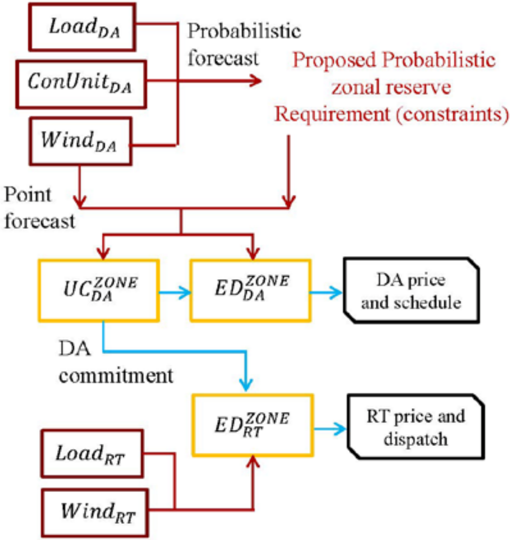
SIMULATION AND RESULTS

- Simulation Overflow





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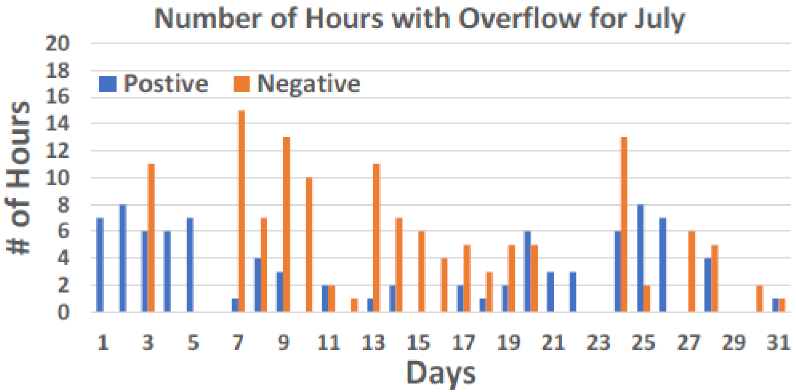
SIMULATION AND RESULTS

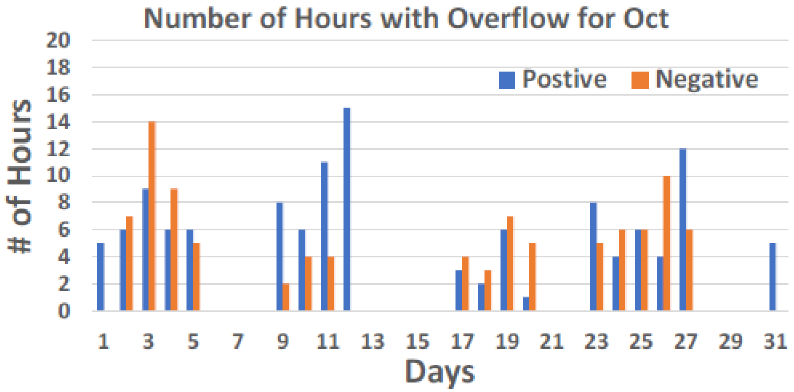
- Setting and Assumption
  - Two simulation periods: July 2006 (high load), and October 2006 (low load)
  - Load PDF is normal distribution
  - Wind generation is 20% of the load
  - Capacity reserve margin is 10%
  - System level reserve requirement: largest unit failure + 10% demand
  - Load/reserve curtailment penalty: $1,800/MWh, $500/MWh
  - Wind curtailment opportunity cost $30/MWh

SIMULATION AND RESULTS

- Critical line based on line overflow probability in DA



(a) July



(b) October

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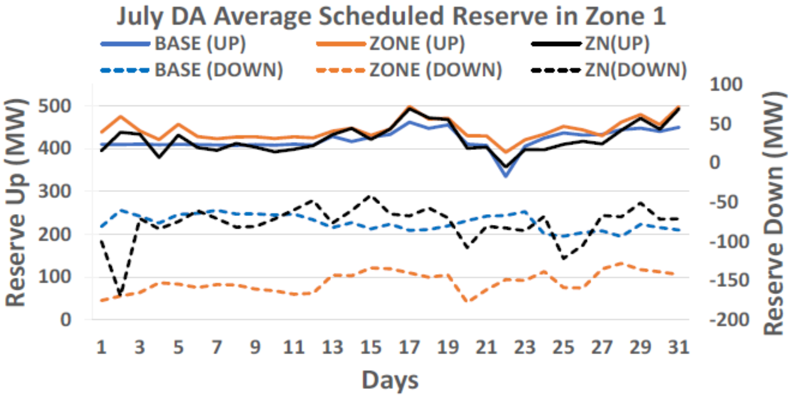
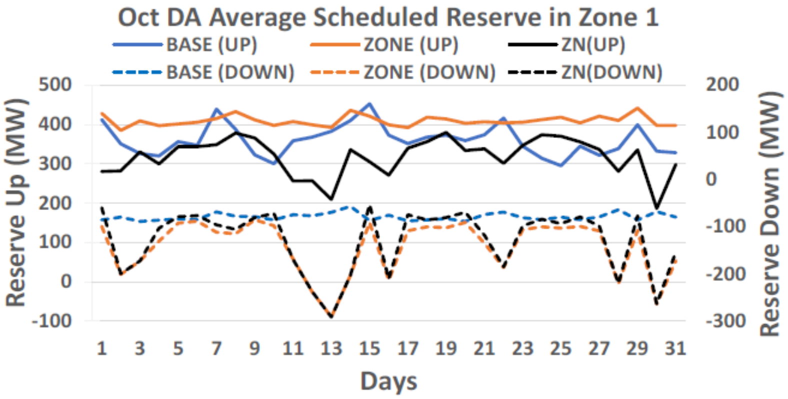
SIMULATION AND RESULTS

- Impacts on Operating Reserves
  - Scheduled reserve quantity in zone 1



(a) July



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SIMULATION AND RESULTS

- Operational Cost

TABLE I
RT AVERAGE OPERATIONAL COST IN JULY AND OCTOBER.

RT-Cost (K$)	July		October	
	BASE	ZONE	BASE	ZONE
Energy/Reserve	3896.17	3902.6	3230.25	3233.5
Unserved Energy	32.22	8.94	0	0
Unserved Reserves	79.51	58.22	16.32	8.38
Wind Curtailment	12.23	6.35	53.63	51.60
Total	**4020.13**	**3976.11**	**3300.2**	**3293.23**

  – The ZONE has a higher operational cost of energy/reserve than the BASE
  – The ZONE yields a fewer curtailments for energy, reserve and wind
  – The ZONE strategy schedules energy and reserves more efficiently to manage energy balance and potential congestions with wind power forecasts.

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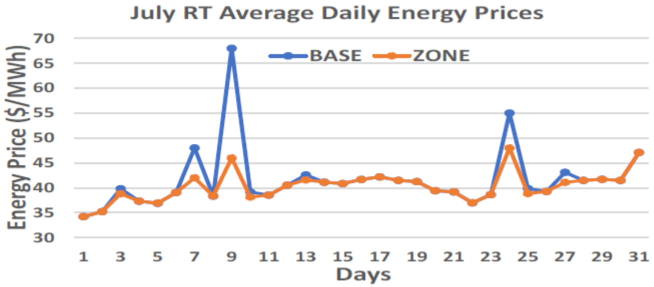
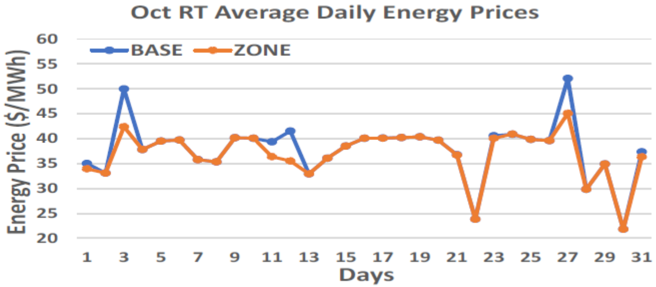
SIMULATION AND RESULTS

- Electricity and reserve prices



(a) July



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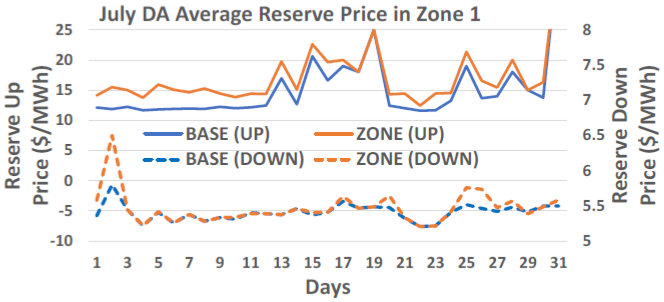
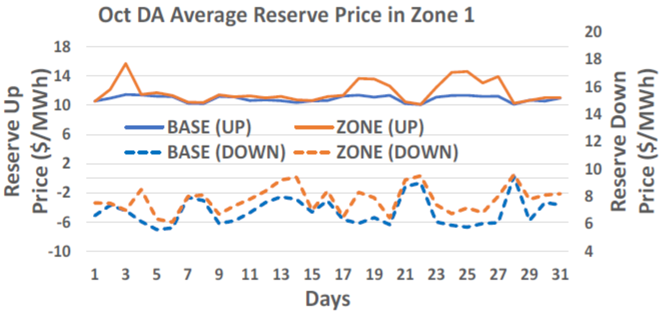


(a) July



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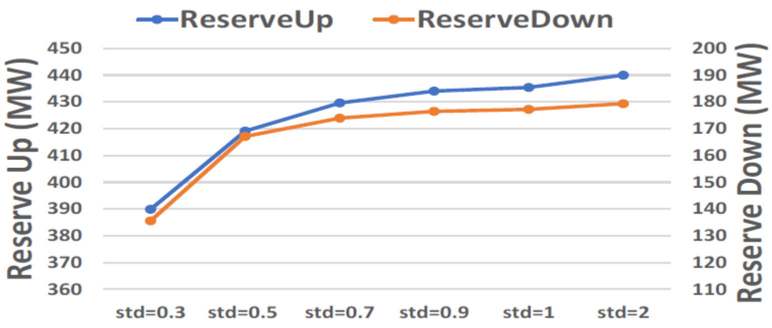
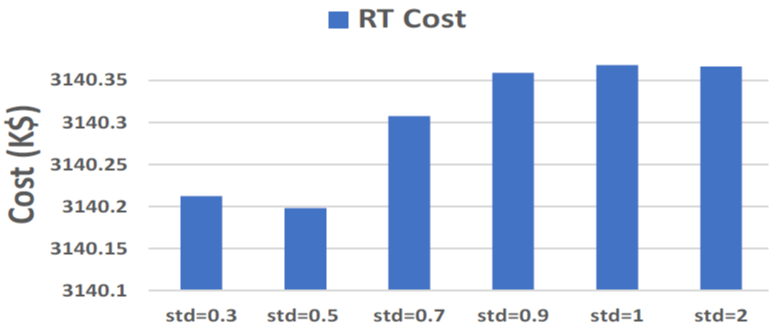
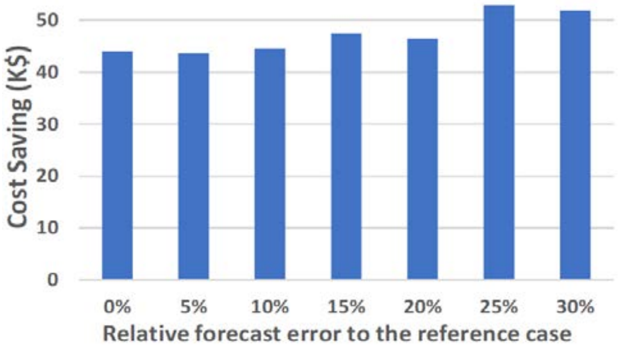
SIMULATION AND RESULTS

- Impacts of wind uncertainty on reserves and operational cost





- Impact of forecasting error on cost saving



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DISCUSSION AND FUTURE WORK

- Discussion
  - More energy and reserve will be scheduled with more critical line identified, hence provide more flexibility
  - Performance better with
    - Higher uncertainties.
    - With systems that requires more flexibility
- Future work
  - Power flow probability distribution estimation
  - Zonal reserve requirement accounting for line outages
  - Incorporation of machine learning techniques for the identification of critical lines and reserve requirements

REFERENCES

- Park, Byungkwon, Zhi Zhou, Audun Botterud, and Prakash Thimmapuram. "Probabilistic Zonal Reserve Requirements for Improved Energy Deliverability with Wind Power." *IEEE Transactions on Power Systems* (2020).
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THANK YOU!

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