Management of Power Systems With In-line Renewable Energy Sources（Final Presentation)

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MOTIVATION

- Power Comparison: Compare real power and reactive power graphs changes before and after adding renewable energy generator in the transmission process. Use voltage booster function to replace the function of renewable energy.

- Voltage Control: Involve renewable energy to control voltage and observe the value of initial voltage and final voltage.

- Losses Reduction: Compare the graph of final values before and after putting renewable energy into the power line, trying to make the difference between real and reactive power final values similar in the two situations.

GOAL

- Control the fluctuation of voltage along the line by adding reactive power
- Compare voltage changes after adding renewable energy, then speculate how to adjust renewable energy injection power to figure out real power and reactive power have the same final value before and after involving renewable energy.

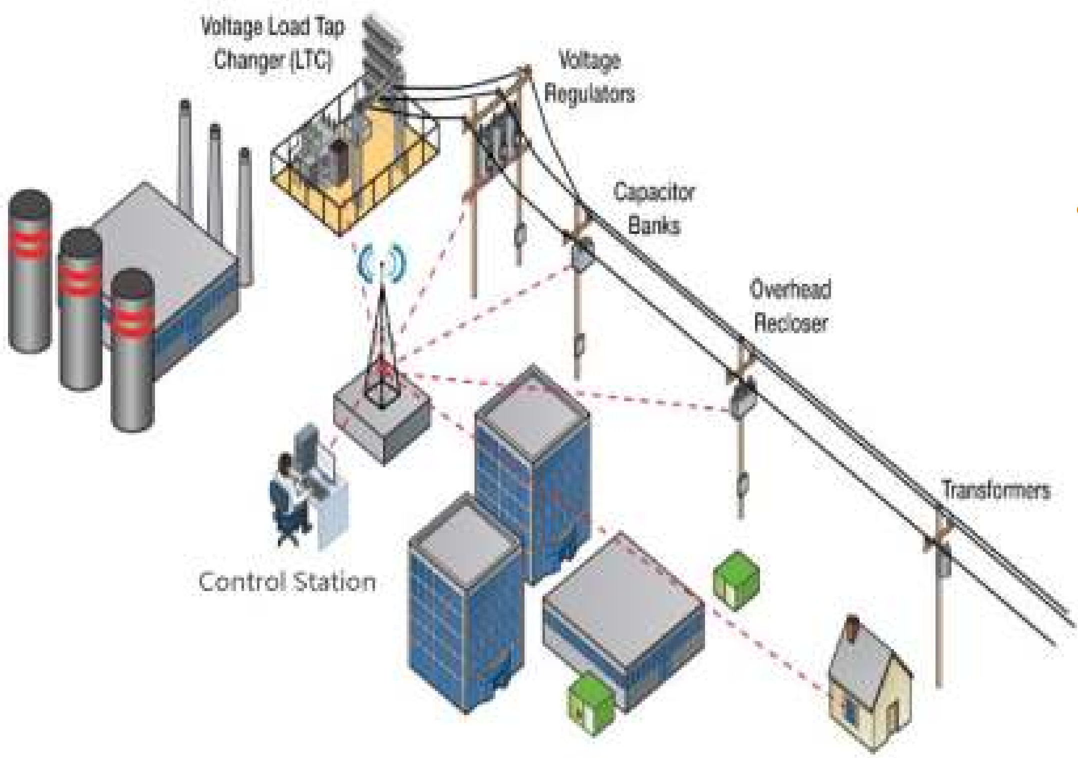
Background

- **Renewable energy:**
  - Security. Microgrids (rooftop solar) reduce vulnerabilities of the power grid. Provide continuous energy in extreme whether situation.

- Usage of traditional energy only drops voltage. Real power is larger than reactive power in loads. Involving that renewable energy can increase utilization of voltage and change this situation.

- Control appropriate renewable energy function injection power to increase or decrease voltage, real power and reactive power in the power transmission, avoid overload or excessive losses.

- **Capacitor bank**: increase the power factor and stabilize the voltage



Capacitor Bank

- Shunt capacitor banks:
  - primarily used to improve the power factor in the network
    - High power transmission capability
    - improve the voltage stability i.e. control of the power flow
    - reduce network losses
- Reactive power bank:
  - Shunt capacitor being stacked together
  - The major advantage: the compact design; small footprint; easy maintenance

Variables and Parameters

Variables:

P, Q -input real/reactive power

p, q – real/reactive power consumption

r – resistance over the feeder line

x – inductance over the feeder line

V – voltage

L – total length of the feeder line

N – number of loads

z –relative position along the feeder line

β – total power injected

$\mathcal{E}$ – arbitrary width of area

PREVIOUS RESULTS

Primary goal: Manage the renewable energy to maximize the utility of real power and minimize the consumption of reactive power

What we got: The distribution flow ODE function of real power, reactive power, and voltage:

$$\frac{d}{dz}\begin{pmatrix} P \\ Q \\ V \end{pmatrix} = \begin{pmatrix} p - r\frac{P^2+Q^2}{v^2} \\ q - x\frac{P^2+Q^2}{v^2} \\ -\frac{xQ+rP}{V} \end{pmatrix}$$

where v(0) = 1.05, P(L) = 0, Q(L) = 0, L = 0.5

Engineering voltage margin: [0.9, 1.05]

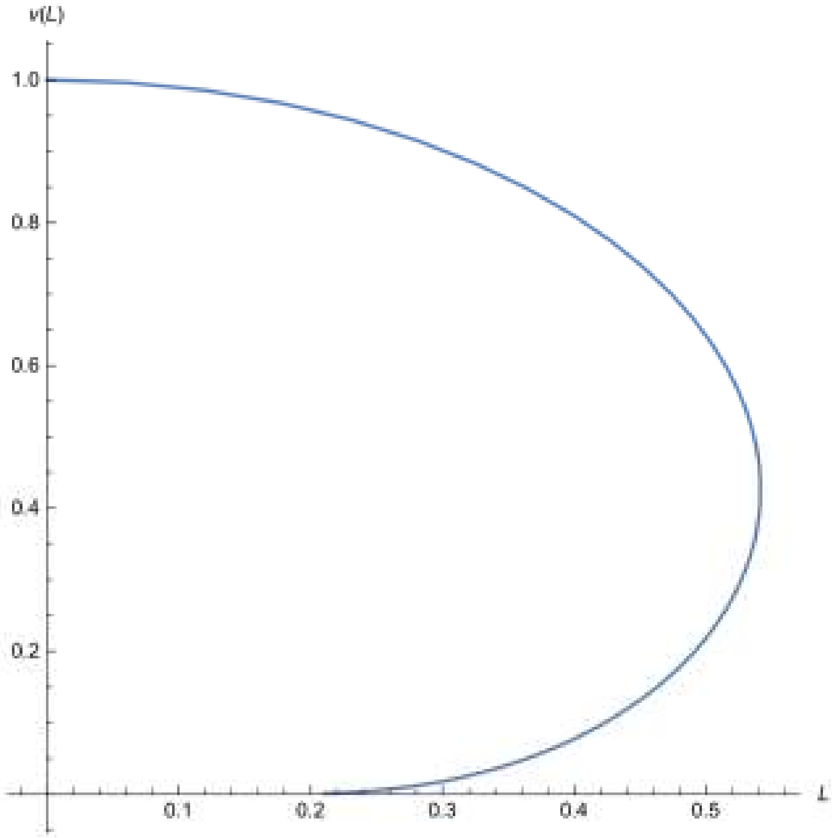
The Nose Curve

- Two solutions of voltage at loads
- Computers only catch the first branch, so we need to catch the second branch
- Mix problem: have multi-value boundary conditions
- In order to solve the problem, we find voltage values with respect to distance

The Nose Curve

- In this case, the starting point is the ending point, tracing back to the start point.

- There will be two critical points in two branches, and as the distance goes further, the points will be closer, and once it reached the end, the power is eliminated and there will only be one critical point at this position.



The Nose Curve

When p = -1, q = -0.5,

Plug in the point $\left(\frac{\mathrm{h}}{v[h]\sqrt{Abs[p]r}}, \frac{1}{v[h]}\right)$ into the equation:

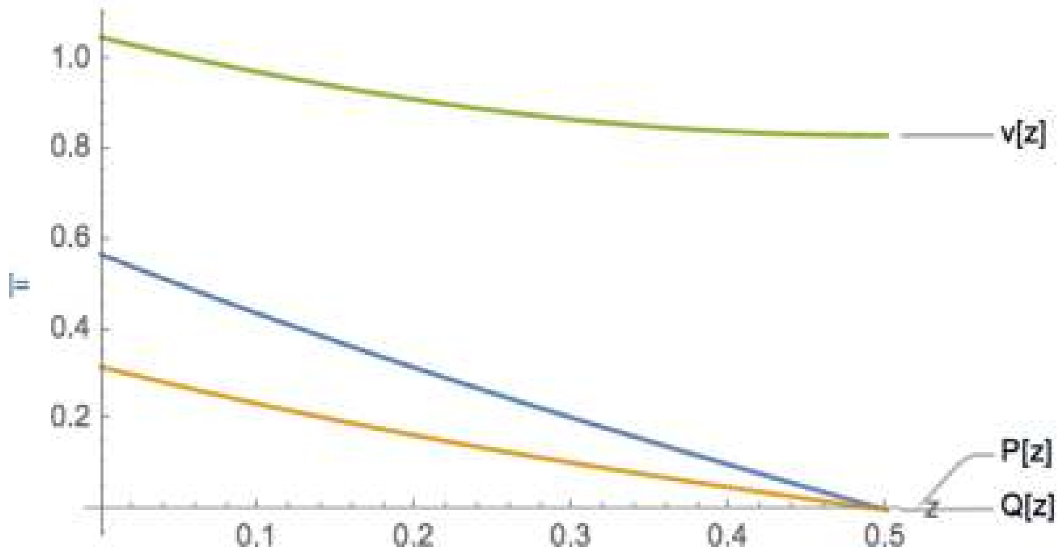
$$-\frac{d}{ds}\begin{pmatrix}\rho\\ \tau\\ \vartheta\end{pmatrix} = \begin{pmatrix} sign(p) - \frac{\rho^2+\tau^2}{\vartheta^2} \\ A - B\,\frac{\rho^2+\tau^2}{\vartheta^2} \\ -\frac{\rho+B\tau}{\vartheta} \end{pmatrix}$$

where h: arbitrary length

t: computation backward

Graph in Normal Situation

❖ Before adding renewable resources into the feeder line:



$v(0) = 1.05$, $P(L) = 0$, $Q(L) = 0$, $L = 0.5$

Our Model

The basic layout of a distribution line is shown in Figure 1.

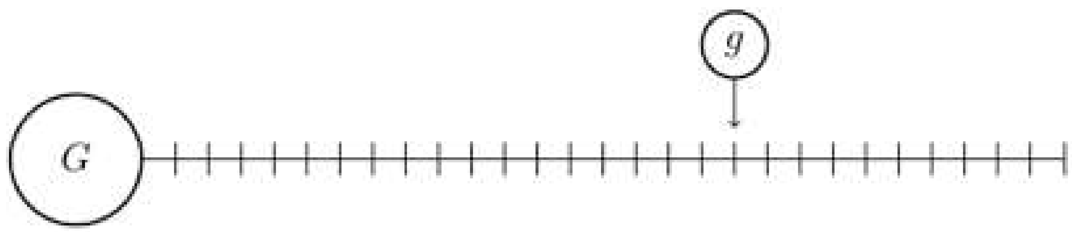


Figure 1: A diagram of a distribution line with a renewable source injecting power at some point in the line

First Step Thought

- The DistFlow ODE function graph shows that voltage drops dramatically during the transmission on the feeder line.

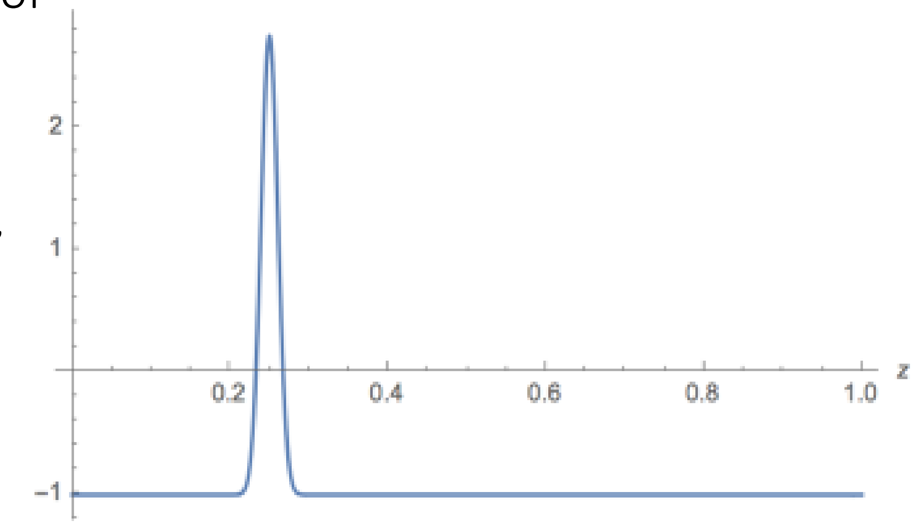
- so we replace the renewable energy generator with a voltage booster to simulate the voltage that the generator brings to the power line.

the Approximation of Dirac’s Delta Function

- That is, to use the Dirac’s Delta function, which we call it the booster equation, to represent the change of voltage over the feeder line:

  - $g(z) = -1 + \frac{\beta}{\varepsilon\sqrt{\pi}} Exp((-\frac{z-0.5L}{\varepsilon})^2),$

where ε = 0.015, L = 0.5, z = [0, 0.5].



How to use the Approximation of Dirac's Delta Function

- Solution: add the power at some point on the feeder line (g in the figure)

- Mathematical method: variate the value of β in the Dirac's Delta function

Renewable Energy Added in Real Power

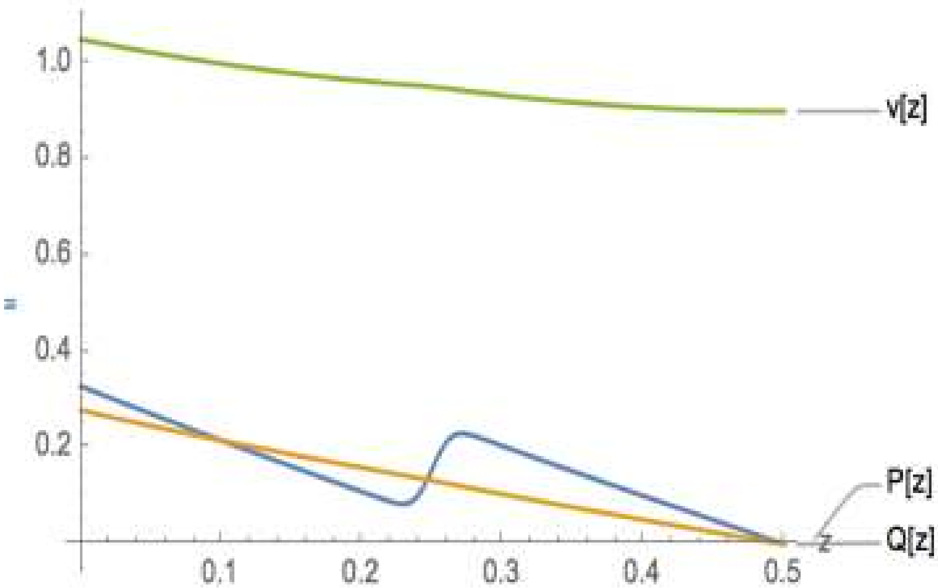
❖ Method: Add g into the real power;

❖ New ODE Function:

- $P'[z] = p + \frac{\beta}{\epsilon\sqrt{\pi}} Exp\left[-\left(\frac{z-0.5L}{\varepsilon}\right)^2\right] - r\frac{P[z]^2+Q[z]^2}{v[z]^2},$
- $Q'[z] = q - x\frac{P[z]^2+Q[z]^2}{v[z]^2}$
- $v'[z] = -\frac{r*P[z]+x*Q[z]}{v[z]}$

But the voltage still drops steeply!

How to solve it?



Renewable Energy Added in Real & Reactive Power

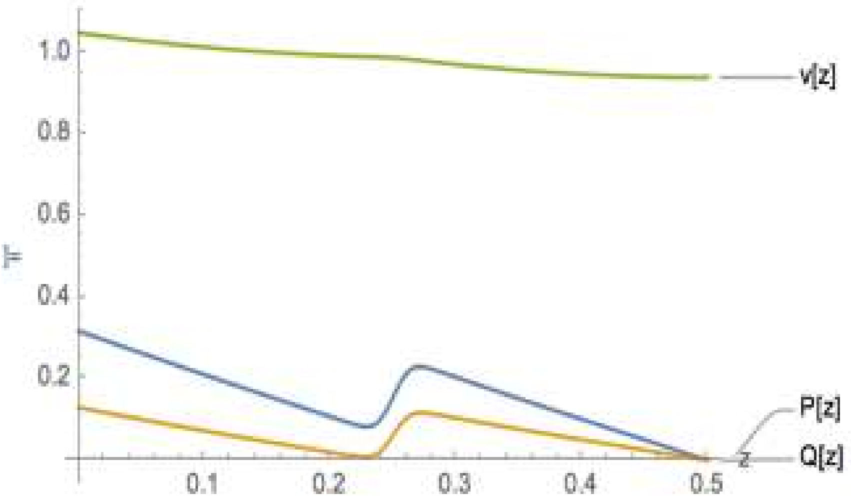
❖ Advanced Method (by Dr. Gabitov's suggestion) : Add the bump into both real and reactive power:

$$P'[z] = p + \frac{\beta}{\epsilon\sqrt{\pi}} Exp\left[-\left(\frac{z-0.5L}{\varepsilon}\right)^2\right] - r\frac{P[z]^2+Q[z]^2}{v[z]^2},$$

$$Q'[z] = q + \frac{\beta}{\epsilon\sqrt{\pi}} Exp\left[-\left(\frac{z-0.5L}{\varepsilon}\right)^2\right](v[z]-0.3) - x\frac{P[z]^2+Q[z]^2}{v[z]^2}$$

$$v'[z] = -\frac{r*P[z]+x*Q[z]}{v[z]}$$

Engineering voltage margin: [0.9, 1.05]



Voltage is in the margin! Then at which minimum value of β?

Finding the Value of Power

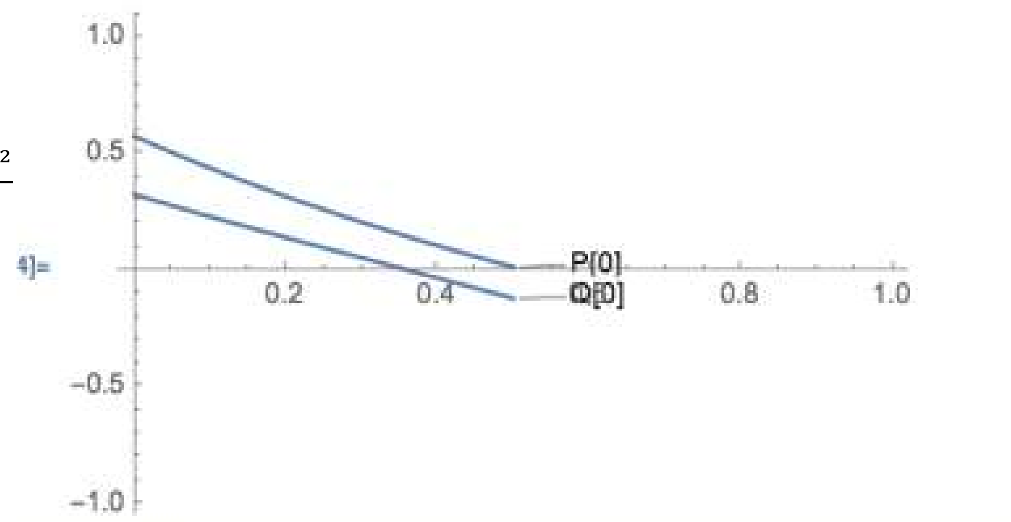
- Voltage is in the margin.
- To find the minimum value of power, we first look at the relationship between the bump & real power, that is β vs. P(0) function, and the bump & reactive power, that is β vs. Q(0) function:

$$P'[z] = p + \frac{\beta}{\epsilon\sqrt{\pi}} Exp\left[-\left(\frac{z-0.5L}{\varepsilon}\right)^2\right] - r\frac{P[z]^2+Q[z]^2}{v[z]^2}$$

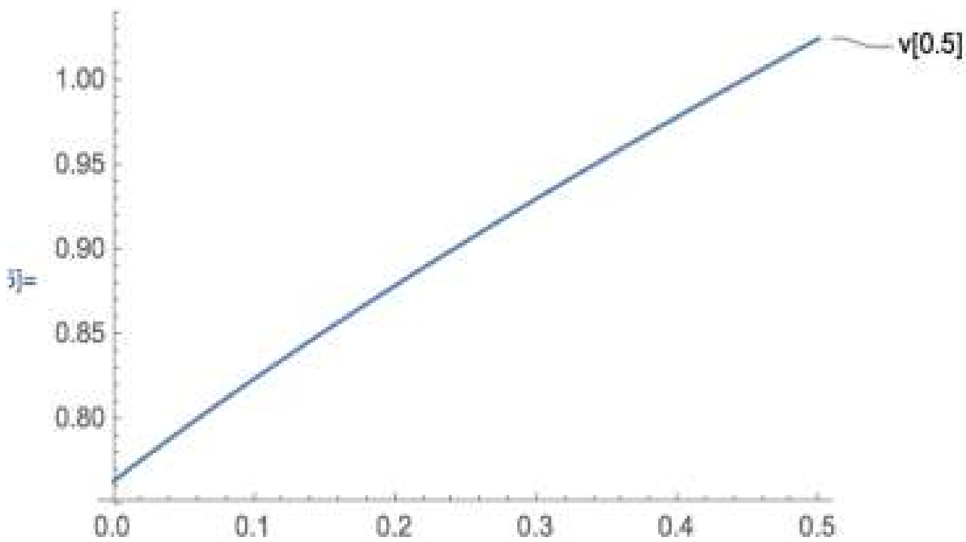
$$Q'[z] = q + \frac{\beta}{\epsilon\sqrt{\pi}} Exp\left[-\left(\frac{z-0.5L}{\varepsilon}\right)^2\right](v[z]-0.3) - x\frac{P[z]^2+Q[z]^2}{v[z]^2}$$

$$v'[z] = -\frac{r*P[z]+x*Q[z]}{v[z]}$$

where $v[0] = 1.0, P[L] = 10^{-10}, Q[L] = 10^{-10}$

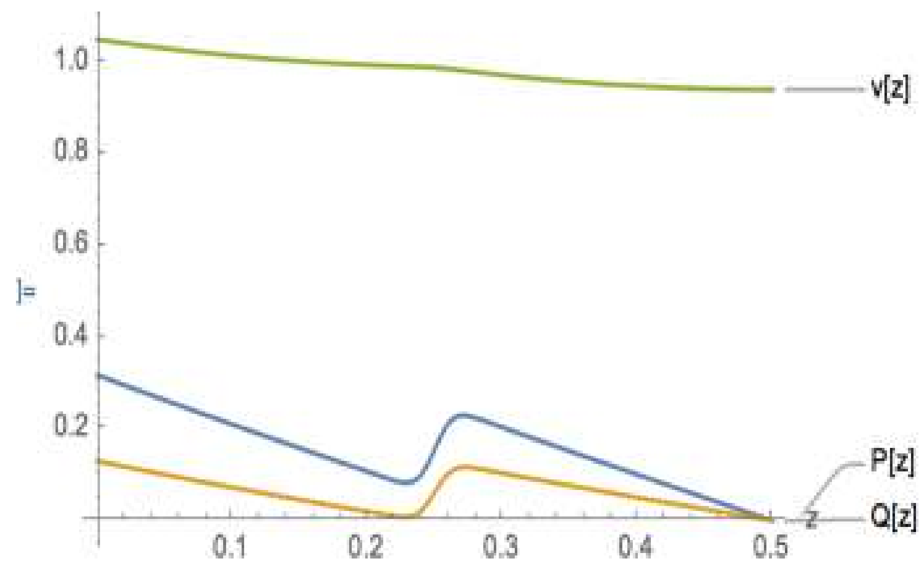


Value of Power for Constant Voltage



Relationship between β and v(0.5)

v reaches the boundary region [0.9,1.05] at end



When β = 0.2, voltage fluctuation is controlled

Result

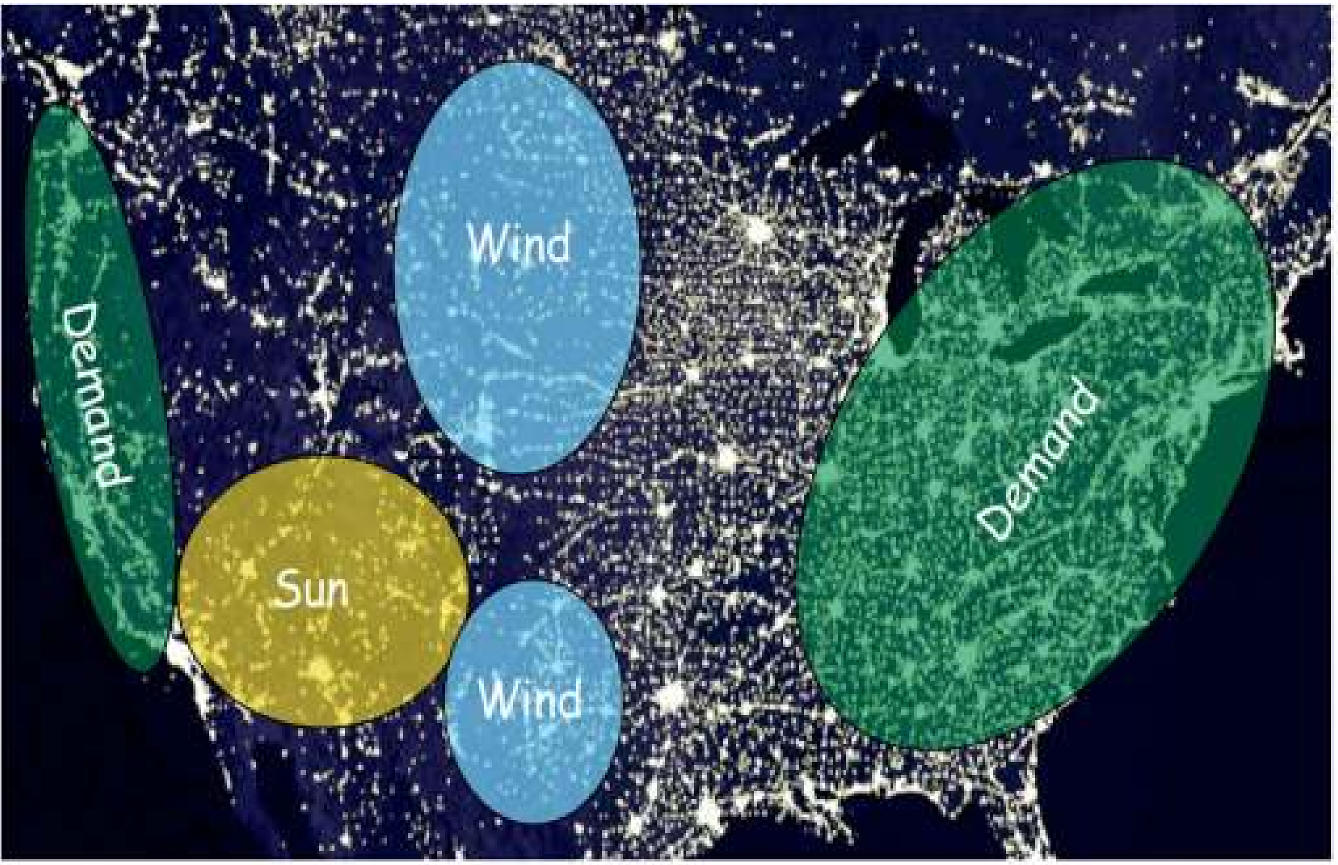
- Adding the renewable energy injection power into the feeder line can make a better voltage by controlling its fluctuations

- After adding the renewable energy, we need to control and adjust the renewable energy power to keep the voltage at the end point to be within the margin.

- When β = 0.2 as minimum value, the voltage reaches the engineering voltage margin.

Potential Application

- For cities that can collect renewable resources, such as Tucson, this model can be used to achieve the constant high-voltage transmission from the energy generator to loads.
- With the increment of size of renewable energy farms, one energy generator can support more than one city due to its constant voltage and limited power loss during the transmission process.



Source: Map based on information from NASA and the National Renewable Energy Laboratory.

Figure 9. The large separation between renewable sources and demand centers requires new long distance transmission lines.

References

- **A very grateful thanks to our mentor Mr. Jared McBride and instructor Dr. Gabitov!**

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Thank you!