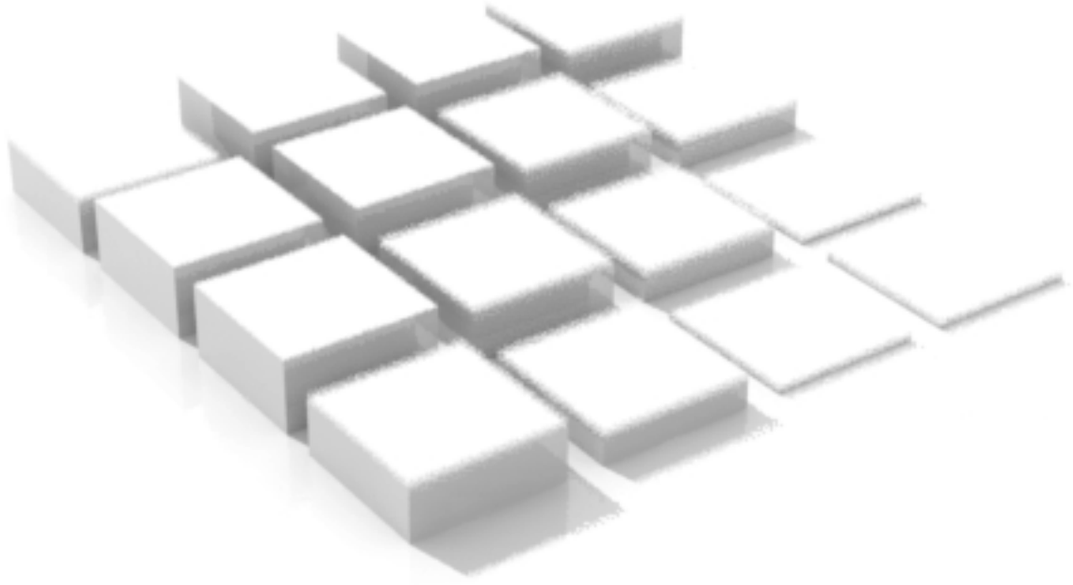
The Grid

An informational primer
for advocates of distributed renewable energy



Eric Daniel Fournier, M.A., M.E.Sc., Ph.D.
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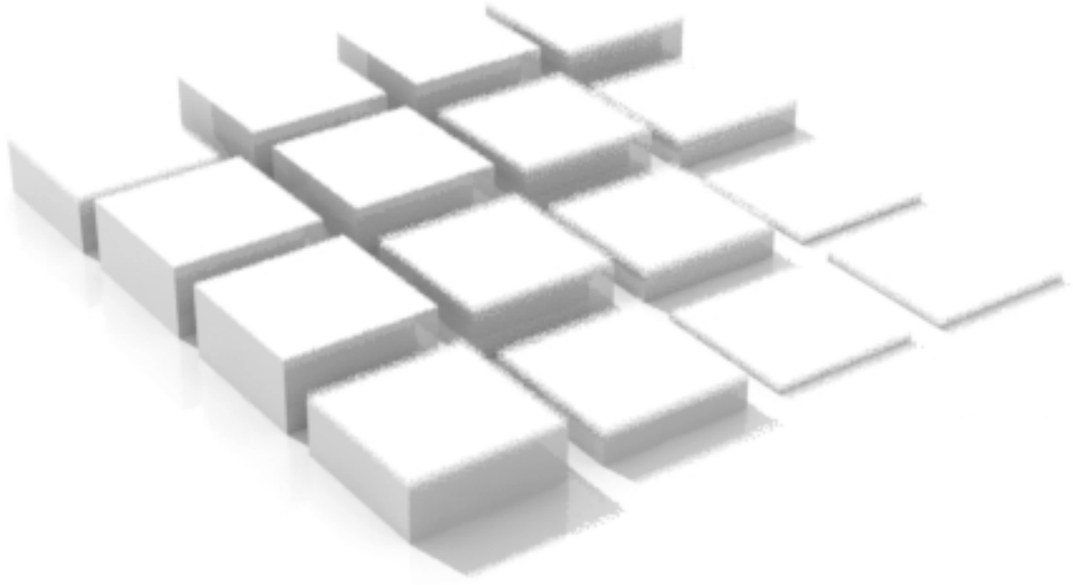

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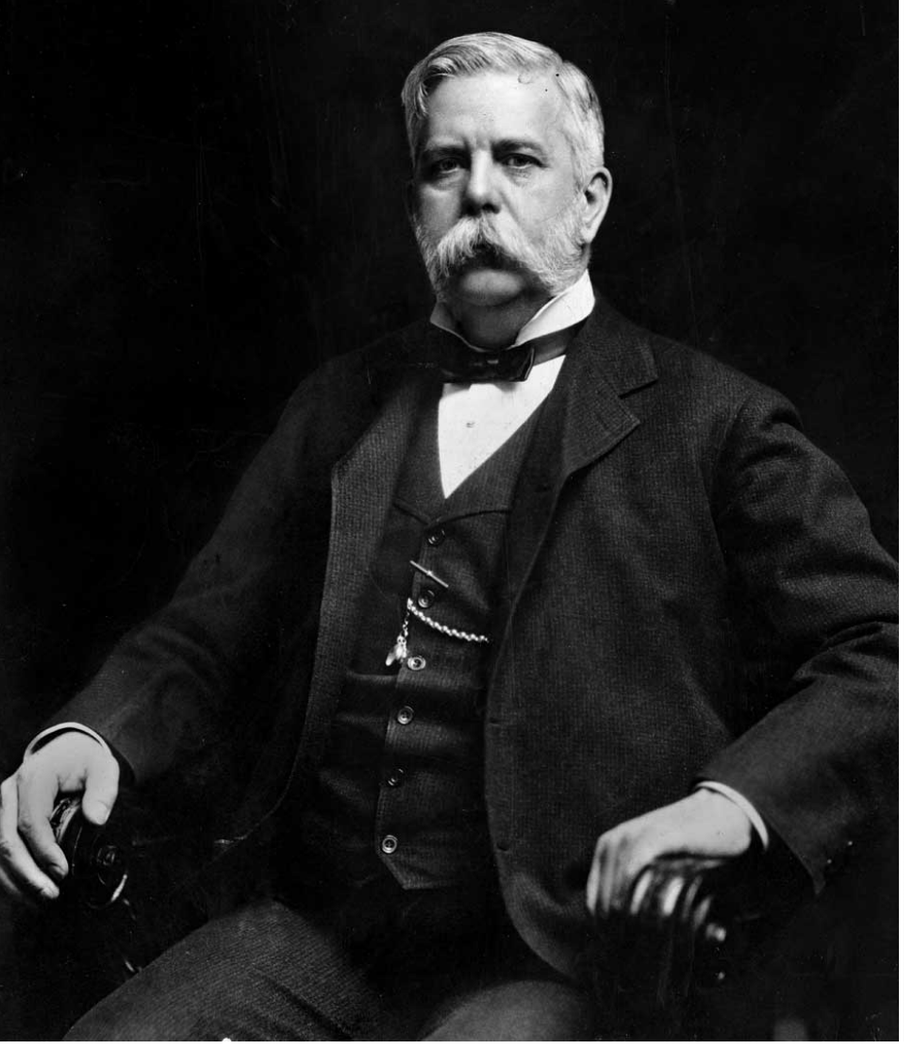
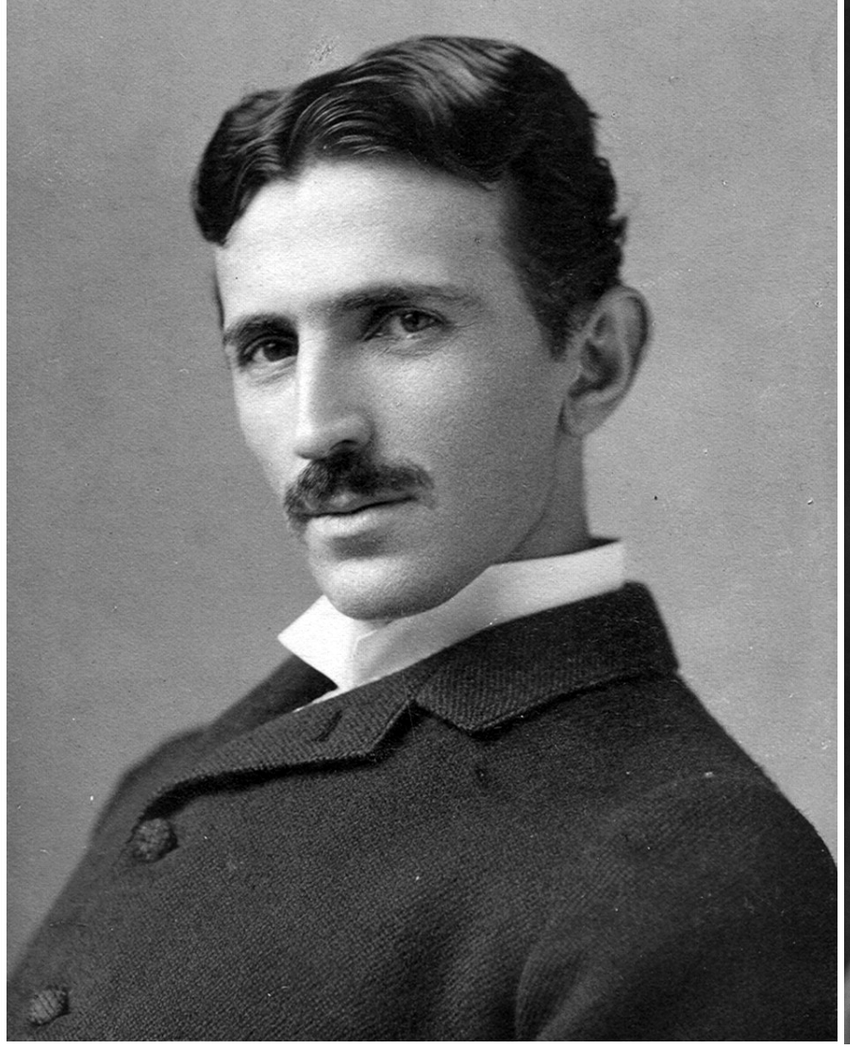
The Birthplace of the Grid

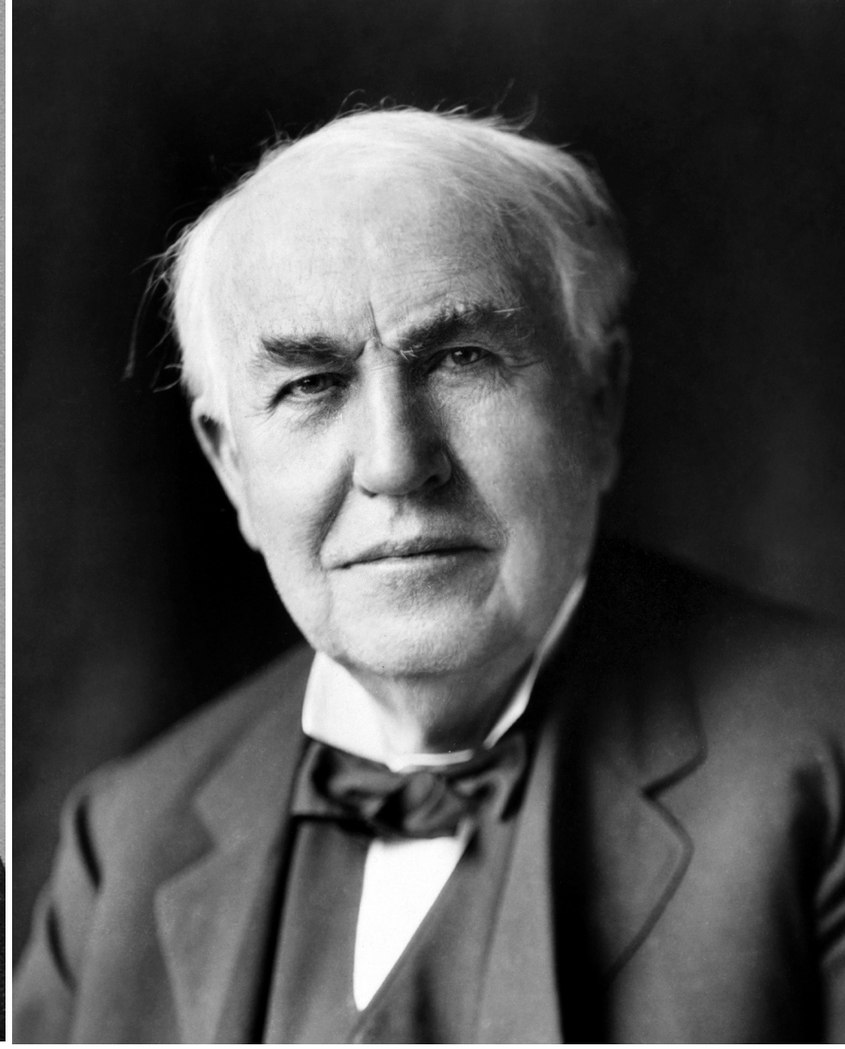
1893 Chicago World's Fair



George Westinghouse



Nikola Tesla



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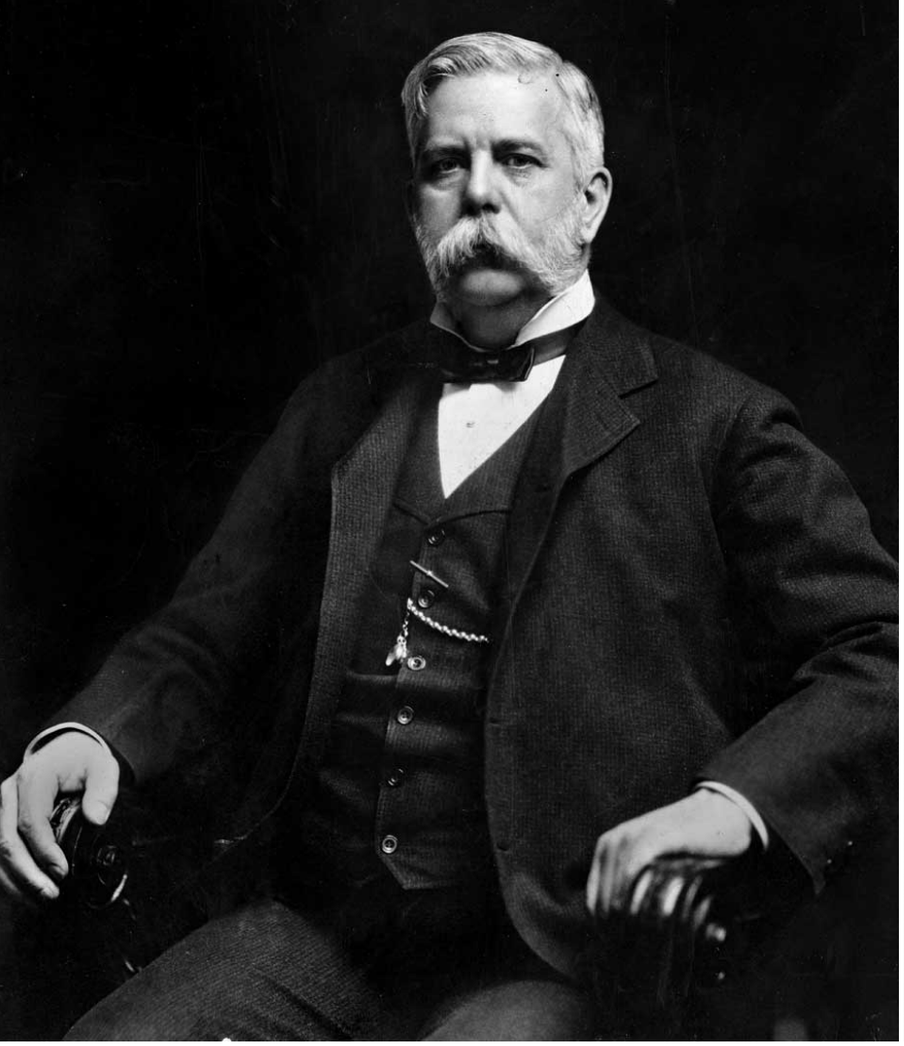

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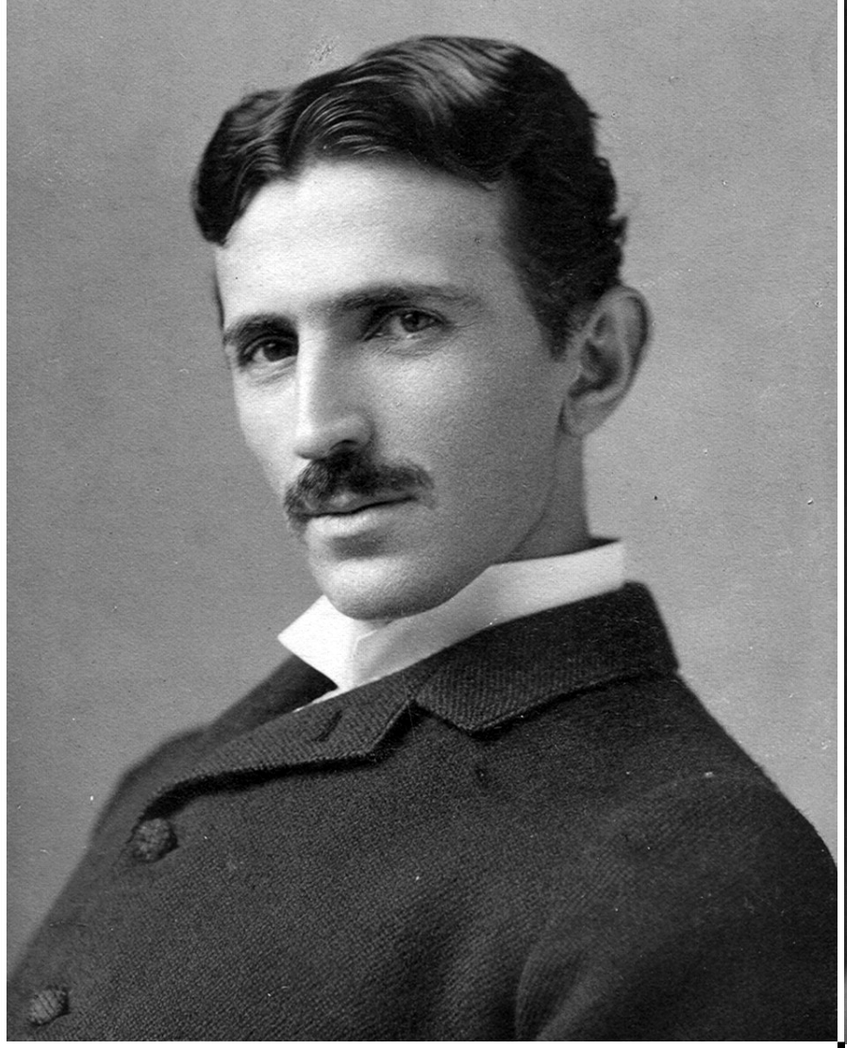

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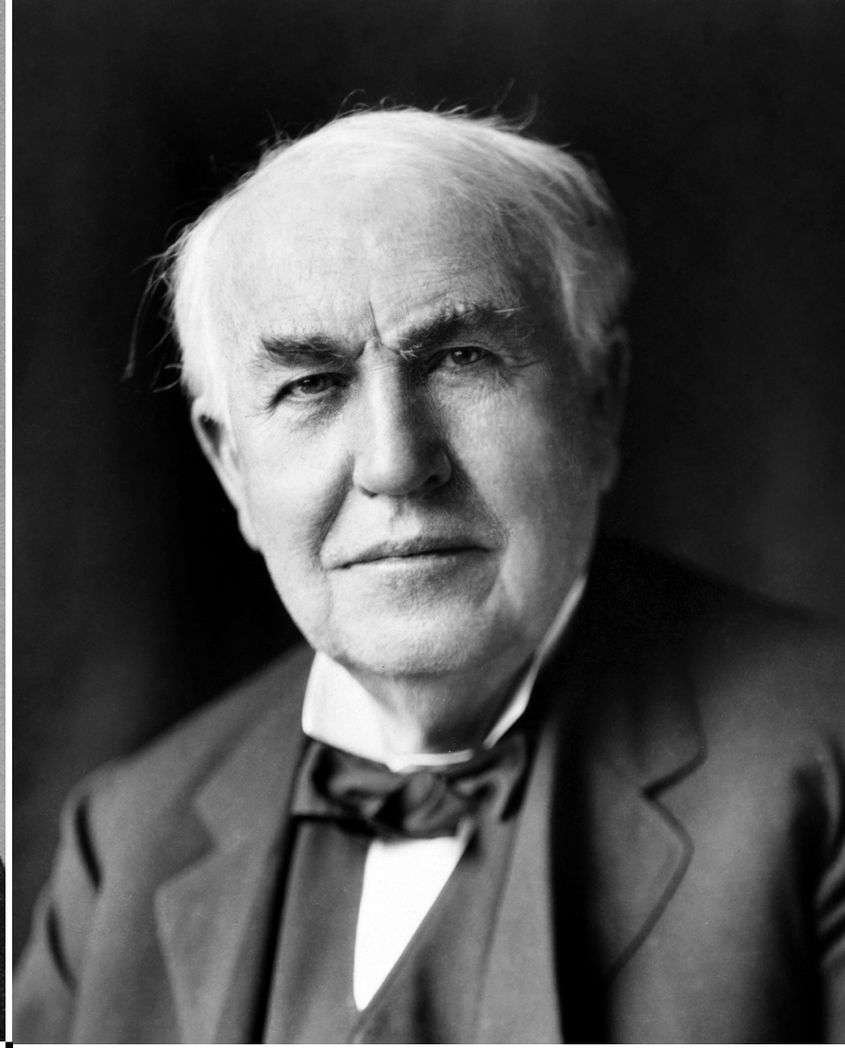

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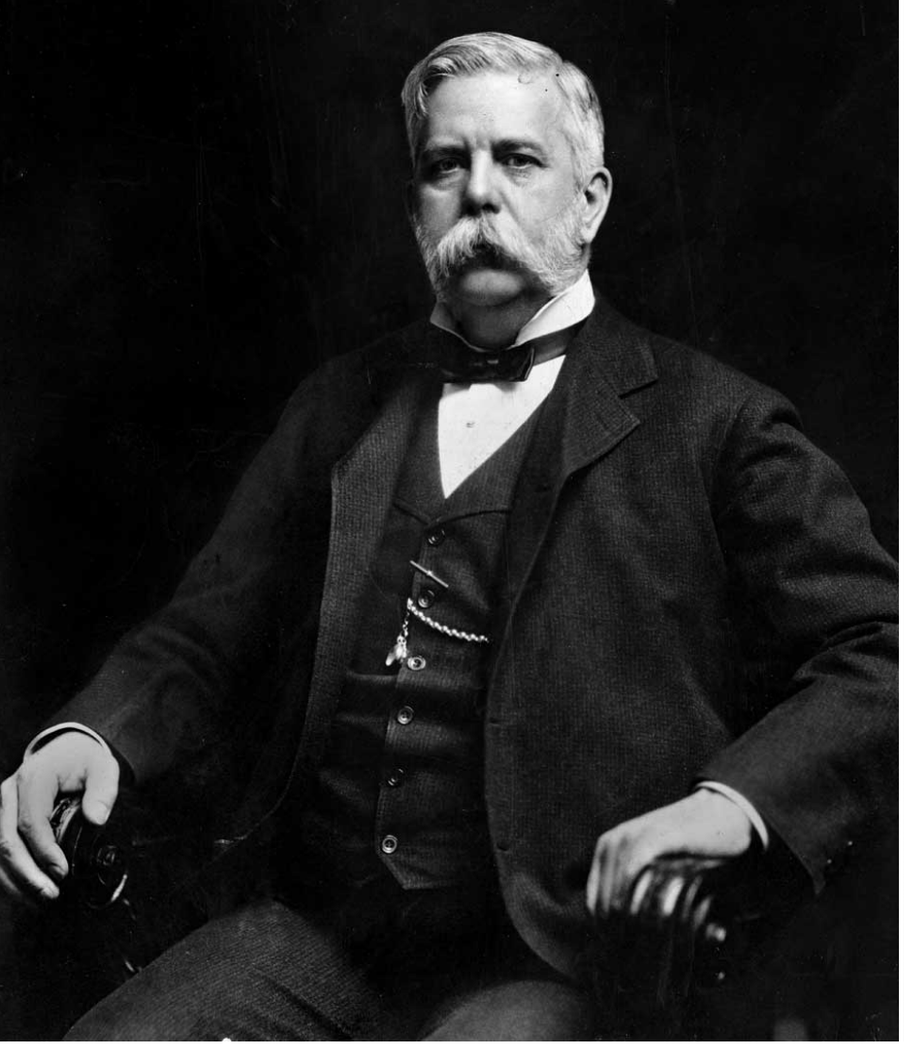

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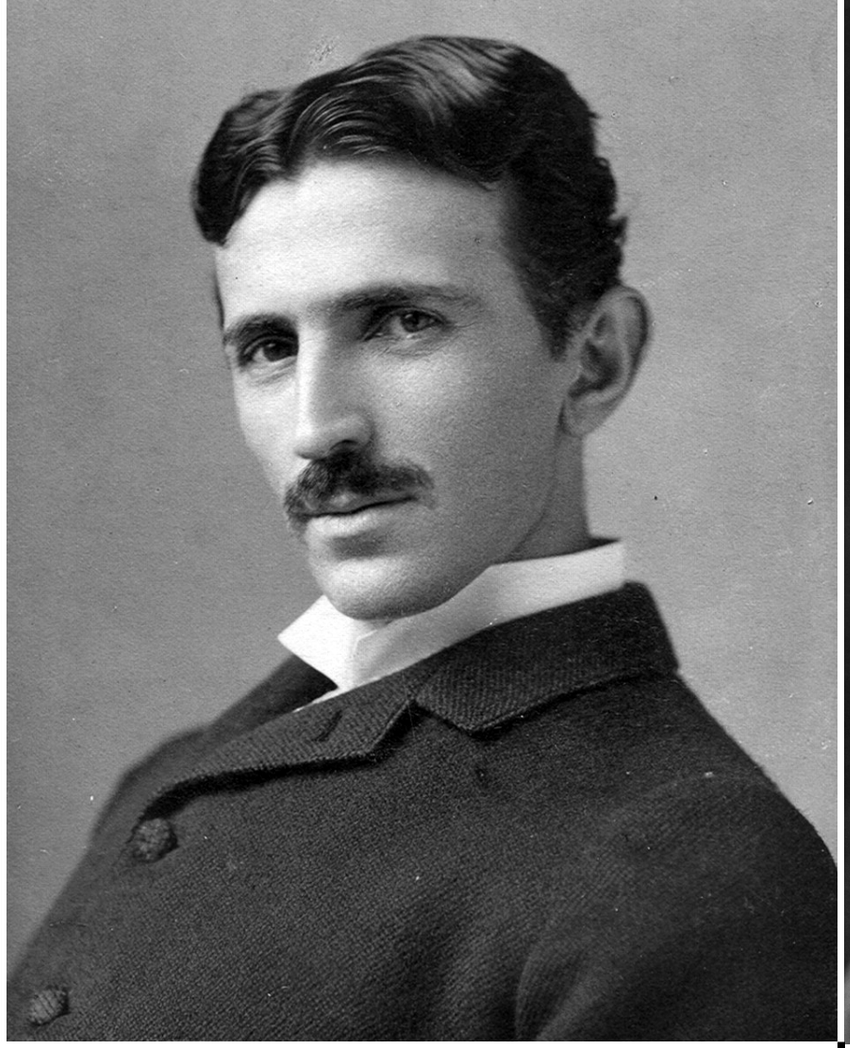

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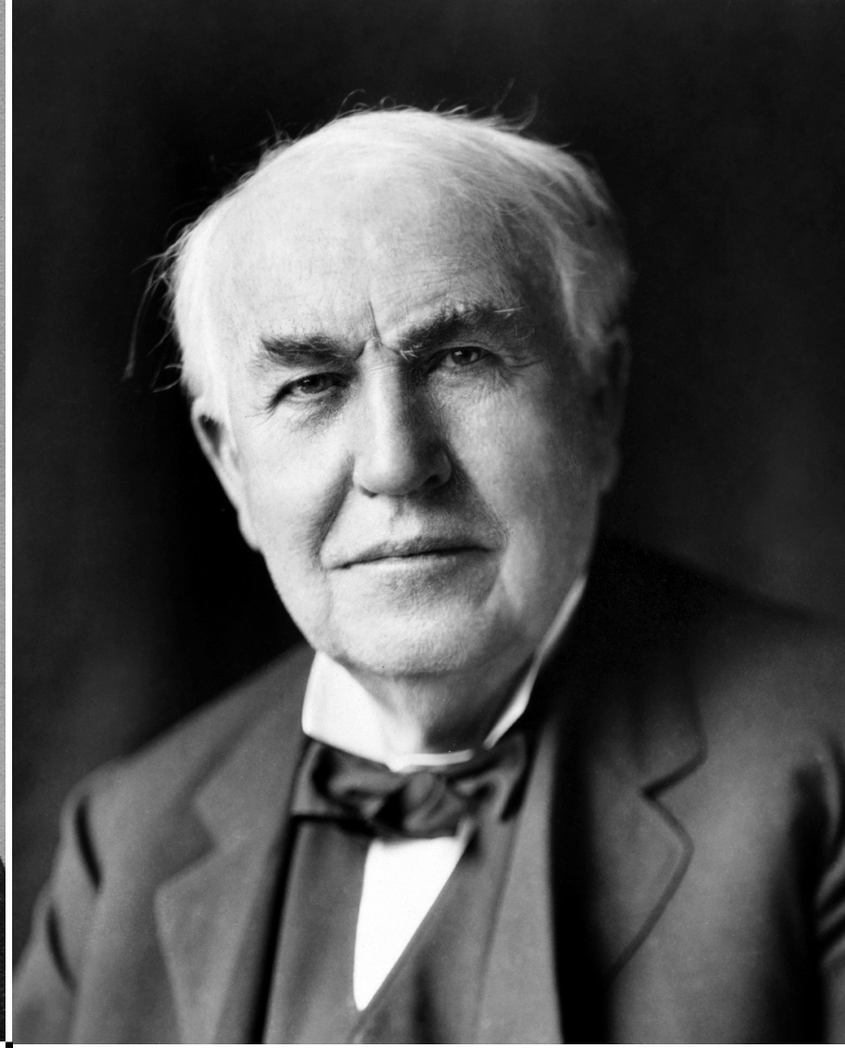

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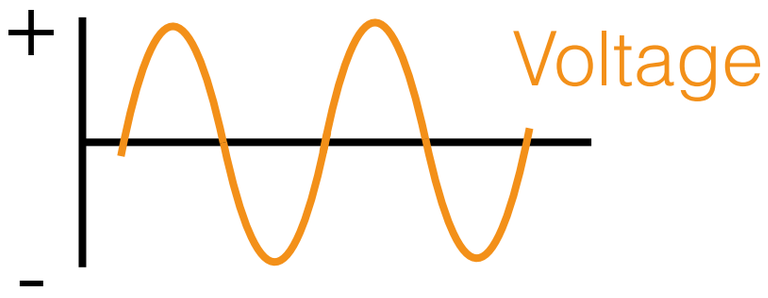
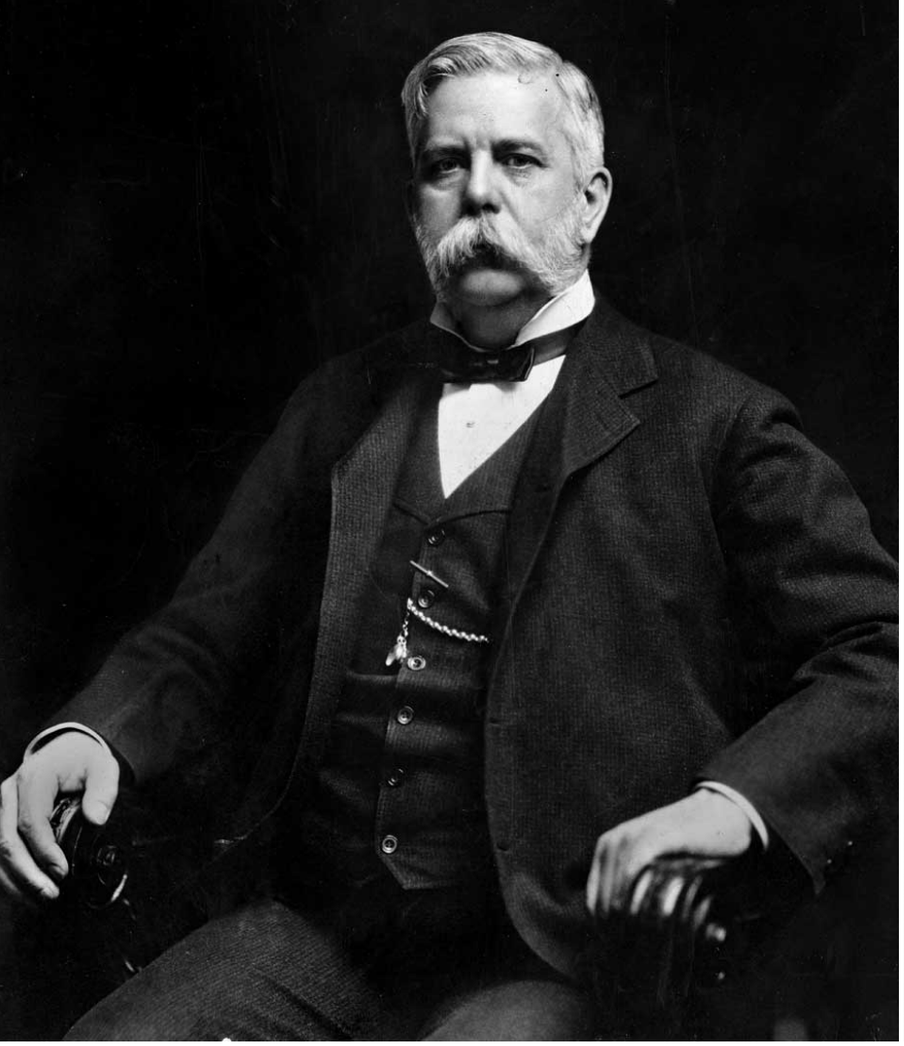


Alternating Current
(AC Power)



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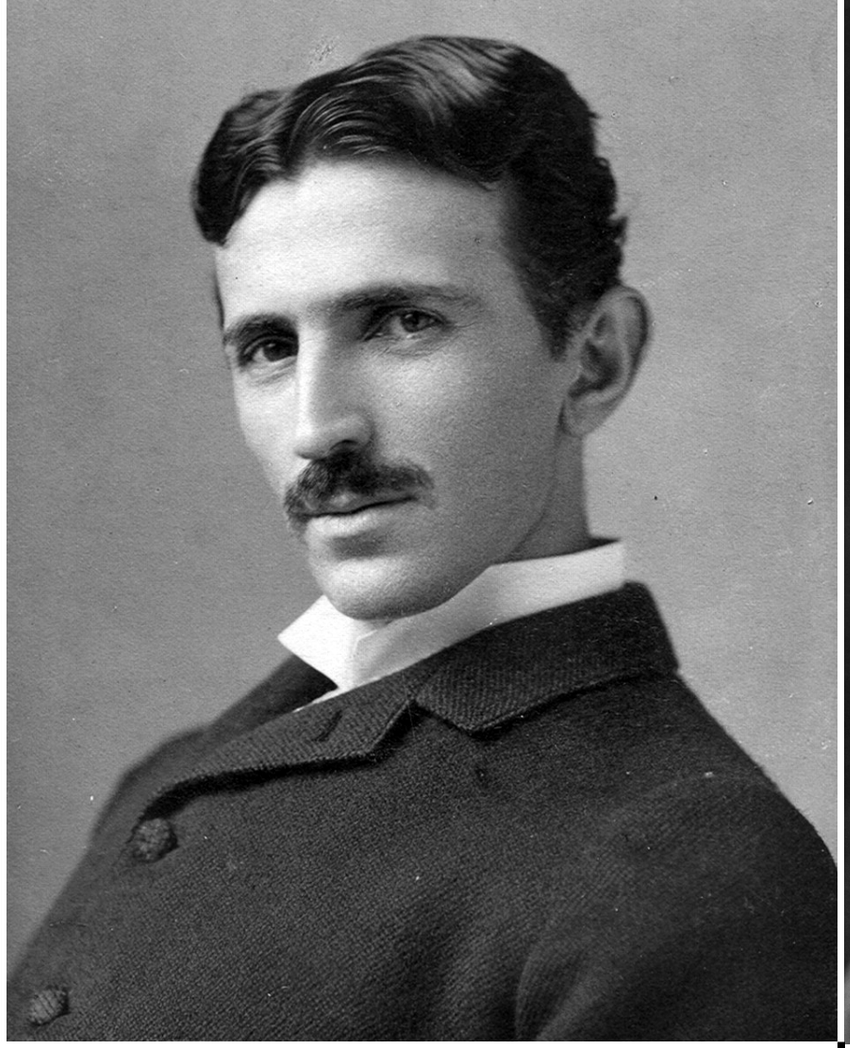

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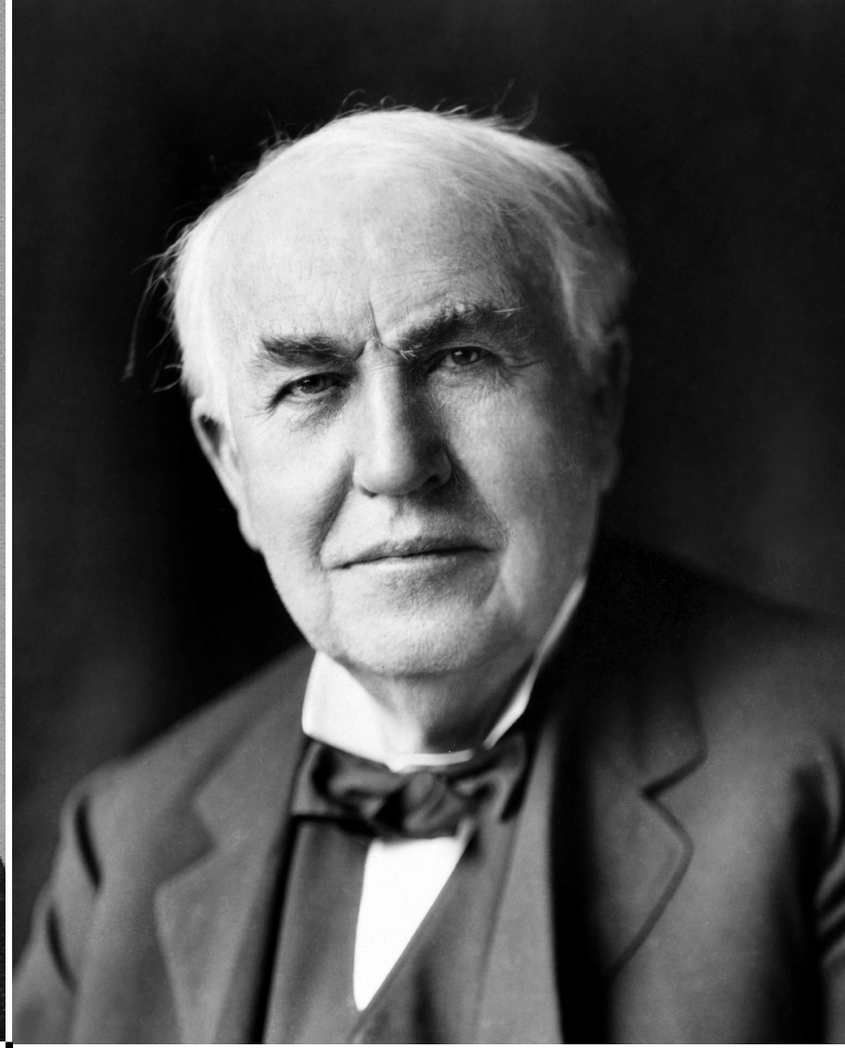

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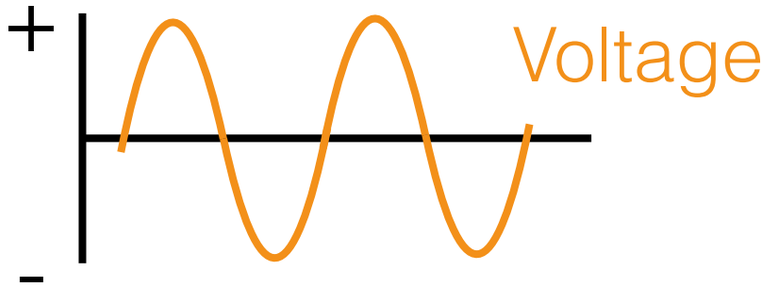

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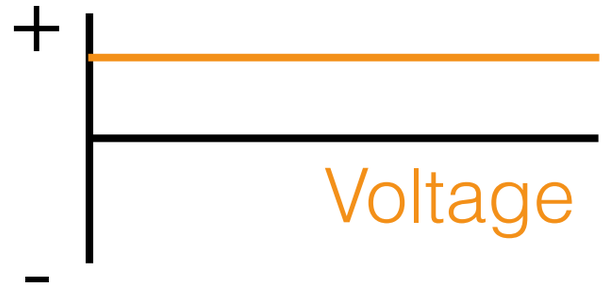
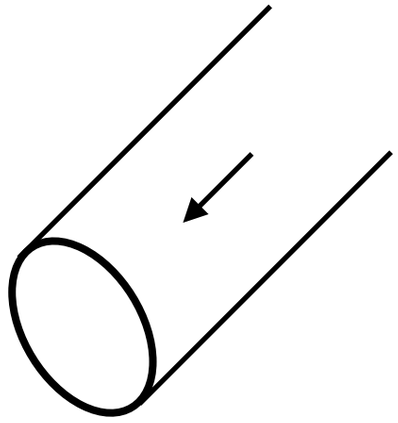


Direct Current
(DC Power)

Building a Flow Based Distribution Network

Building a Flow Based Distribution Network

Let’s say you have got a hose with some water flowing through it.



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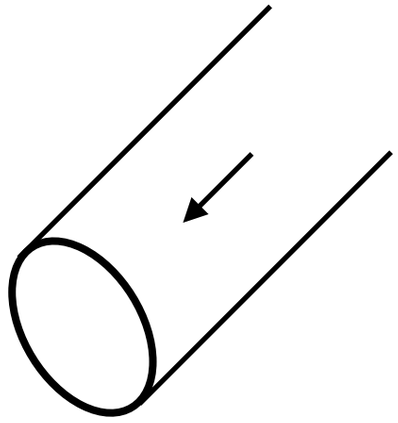

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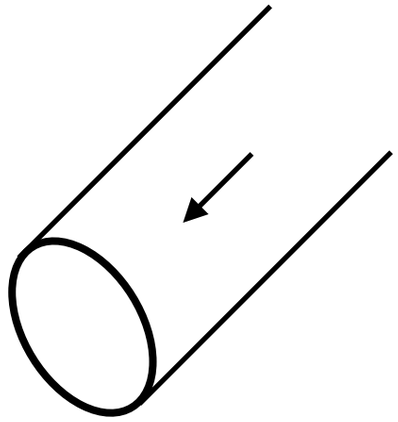

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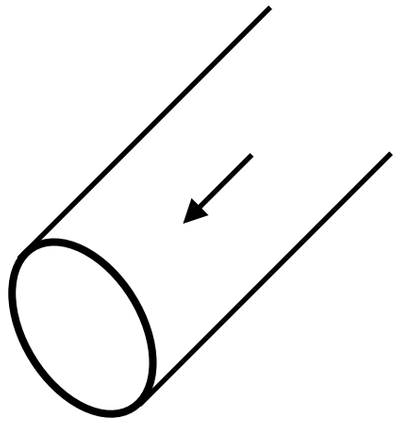

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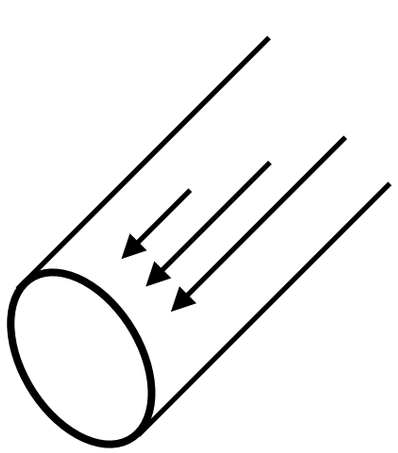

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This is like altering the voltage.

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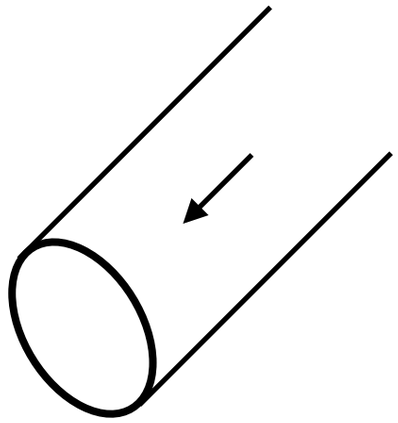

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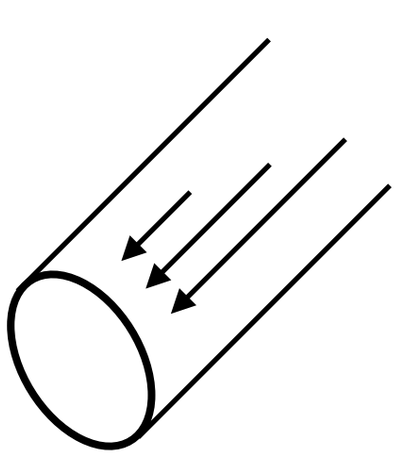

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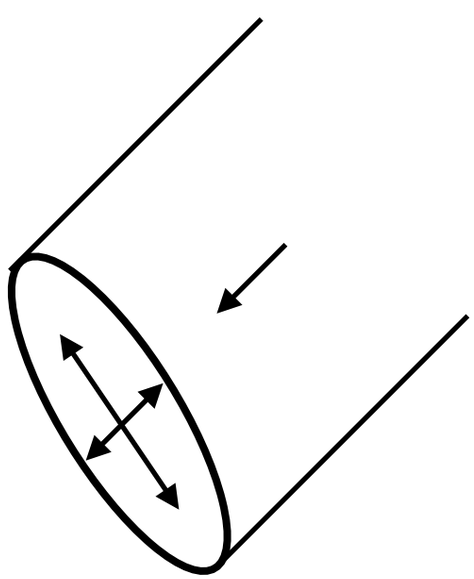

Keep the speed of flow constant and just control the width of the hose.

This is like altering the current.

It's usually not so easy to "get a new, wider hose." Electric power transmission infrastructure is weighty and expensive.

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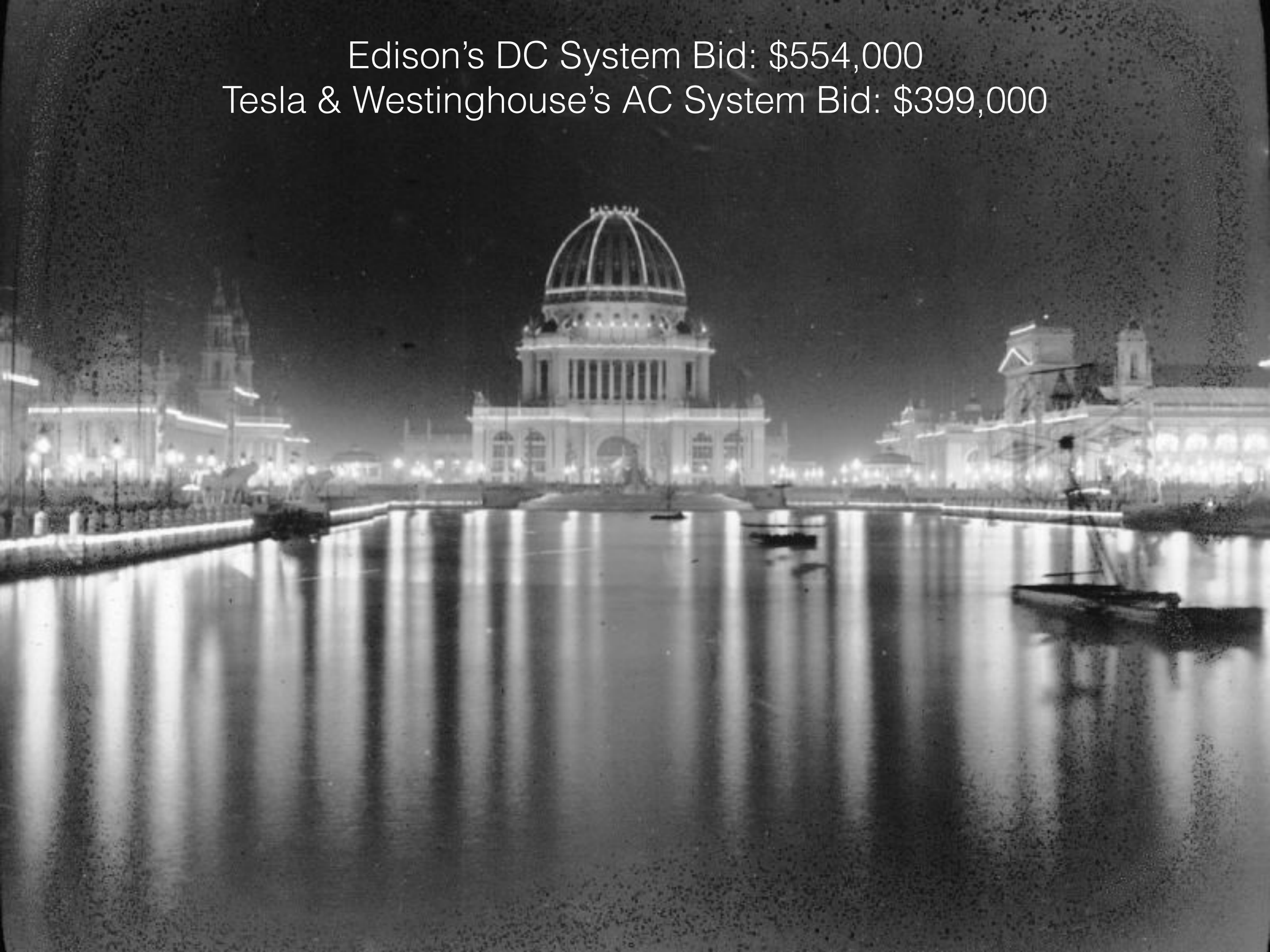
Having the ability push the water faster (i.e. to transform the voltage) is key.

Edison’s DC System Bid: $554,000
Tesla & Westinghouse’s AC System Bid: $399,000



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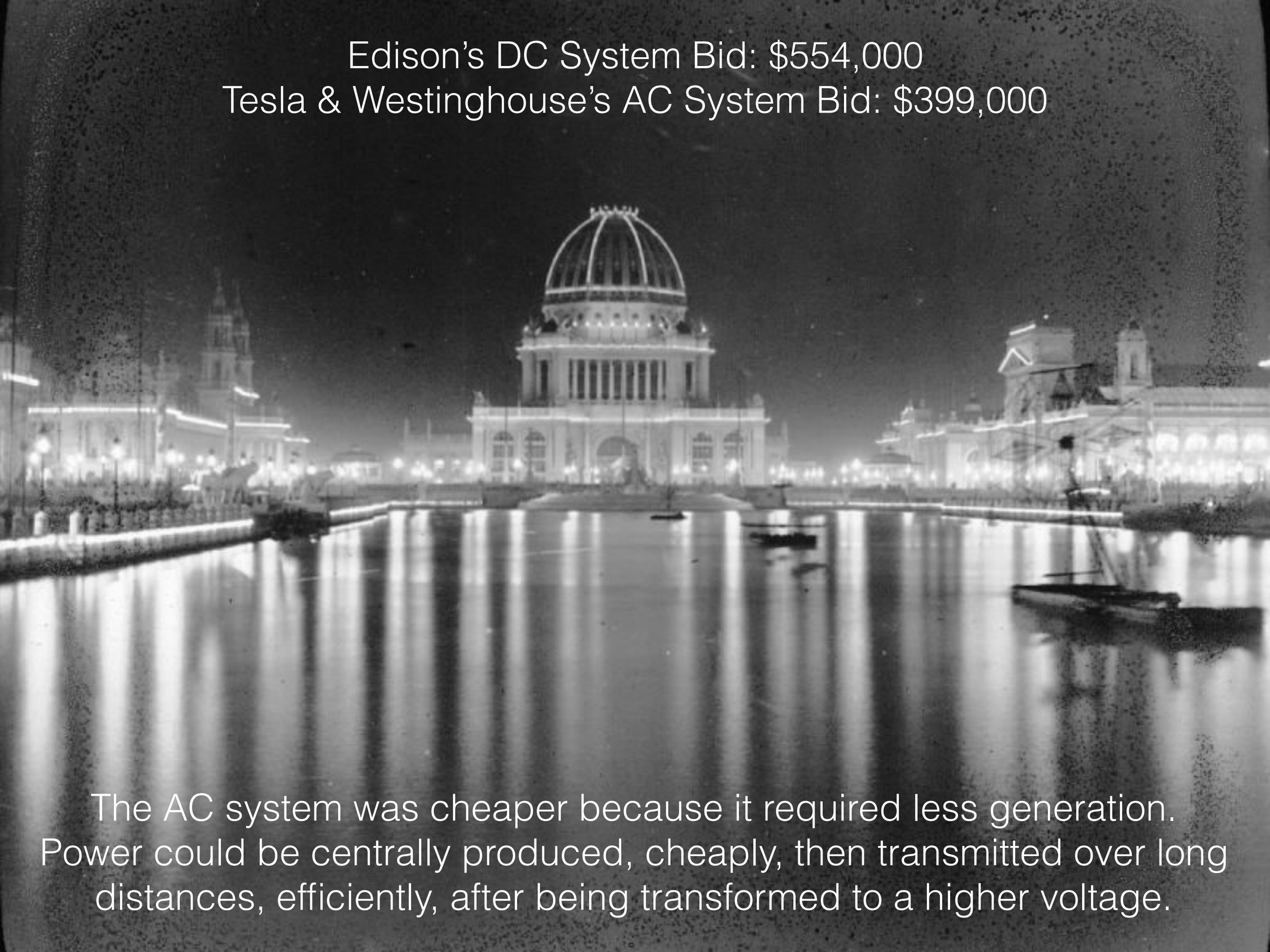
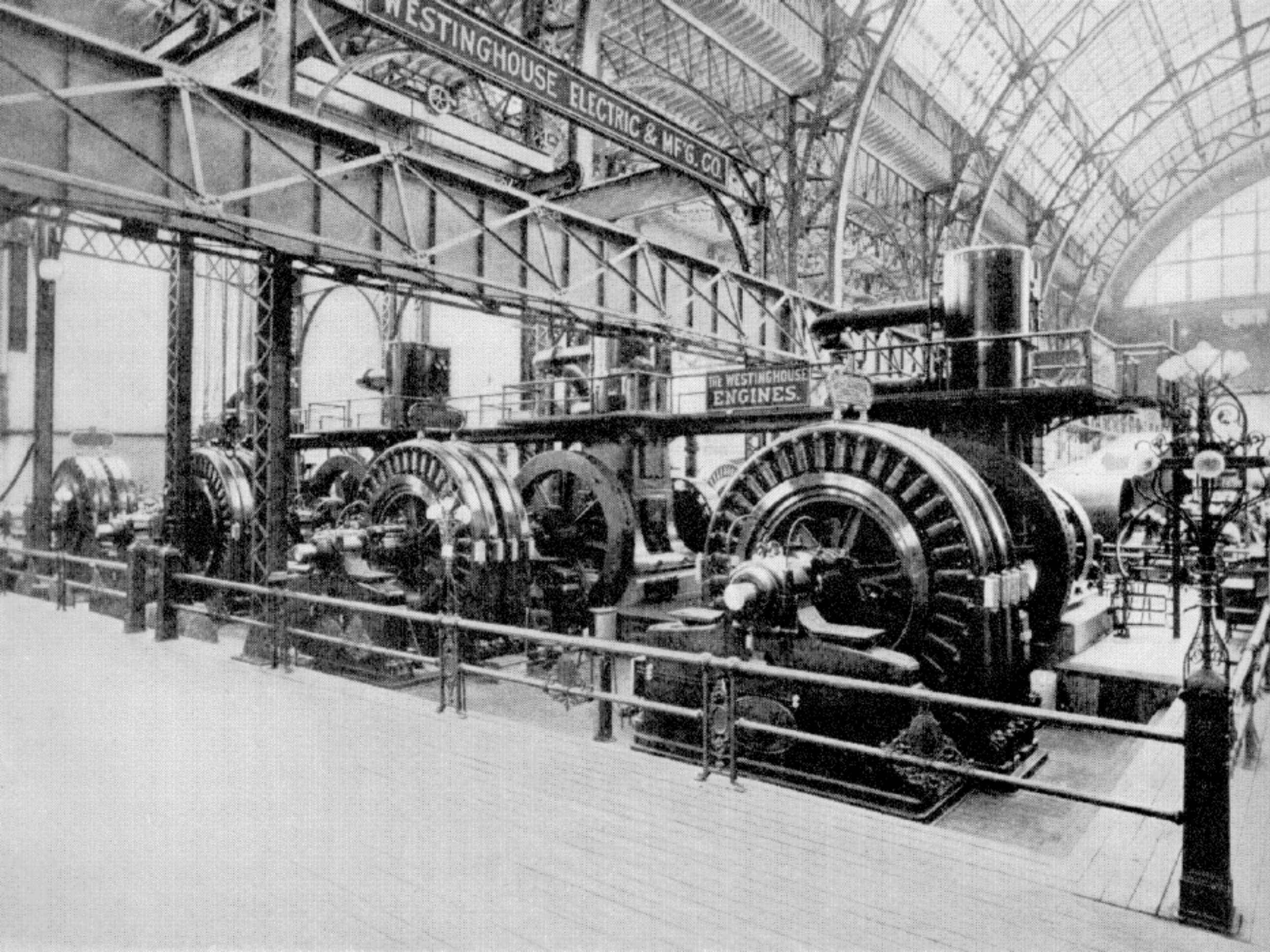
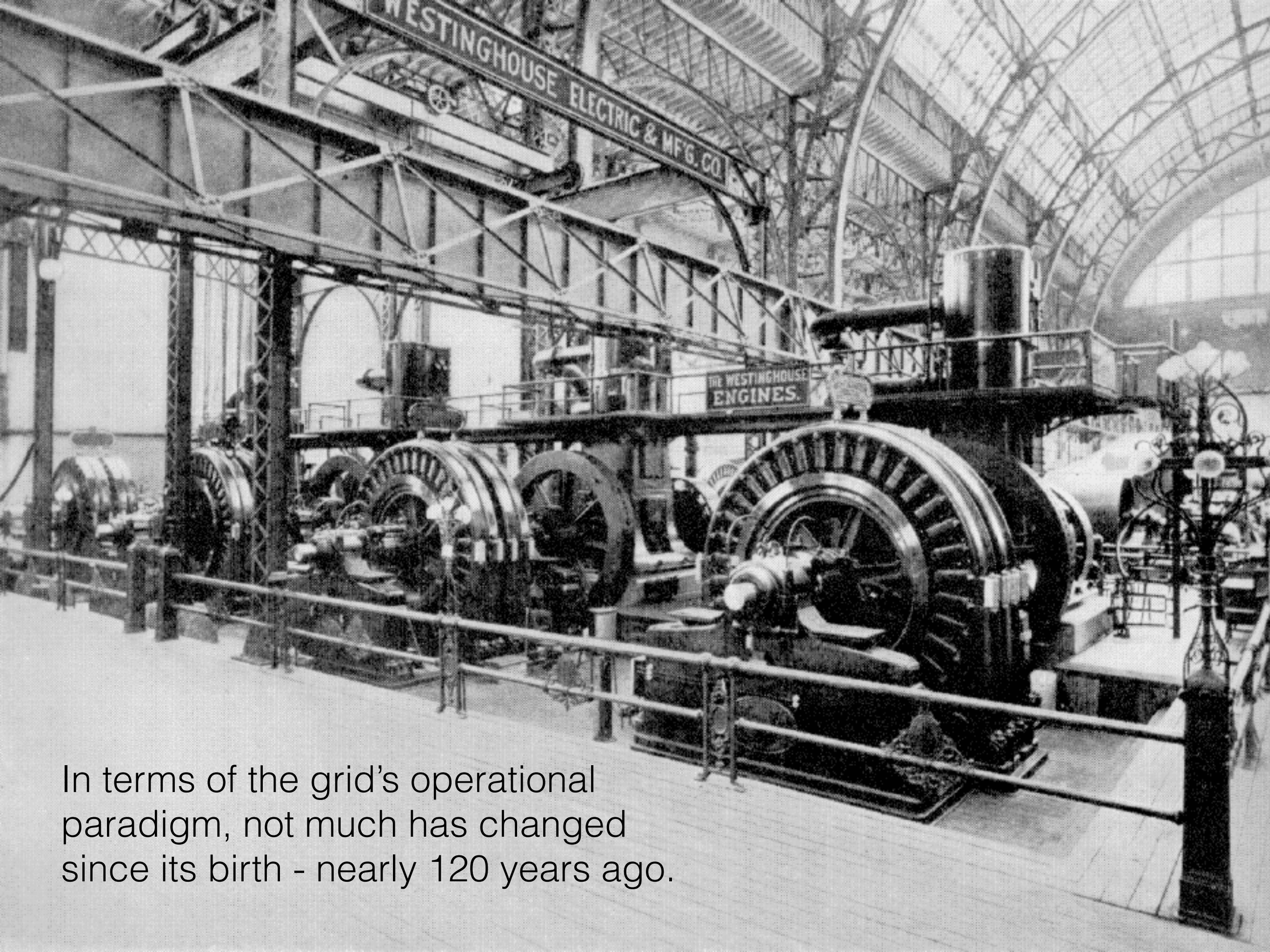


The AC system was cheaper because it required less generation. Power could be centrally produced, cheaply, then transmitted over long distances, efficiently, after being transformed to a higher voltage.


WESTINGHOUSE ELECTRIC & MF'G. CO.
THE WESTINGHOUSE
ENGINES.



In terms of the grid's operational paradigm, not much has changed since its birth - nearly 120 years ago.

Today, a new paradigm is beginning to take hold, one that is based upon distributed renewable generation.

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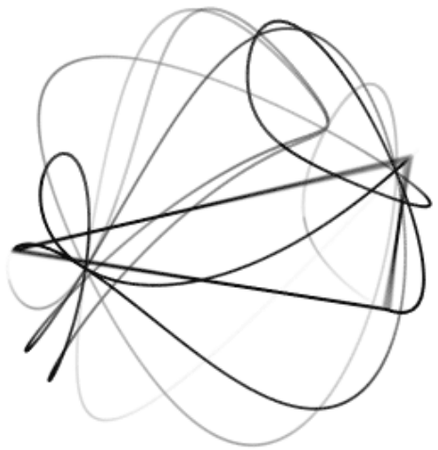
This rest of this talk is about what you need to know to think critically about these issues in your advocacy.

Challenges to the Grid Integration of Distributed Renewable Energy

Power Quantity



Power Quality

Virtually all of the technical challenges associated with interconnecting distributed renewable generation (DRE) sources onto the grid can be categorized as involving either the quantity or the quality of the alternating current (AC) power that they are able to produce over a given period of time.

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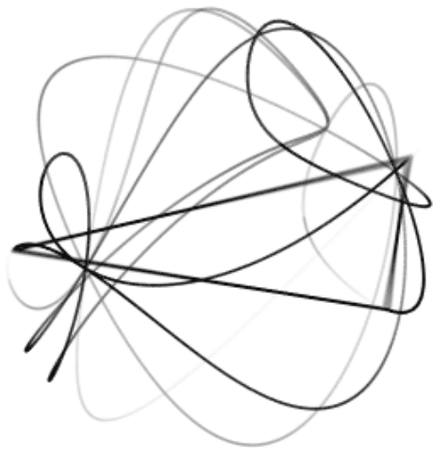

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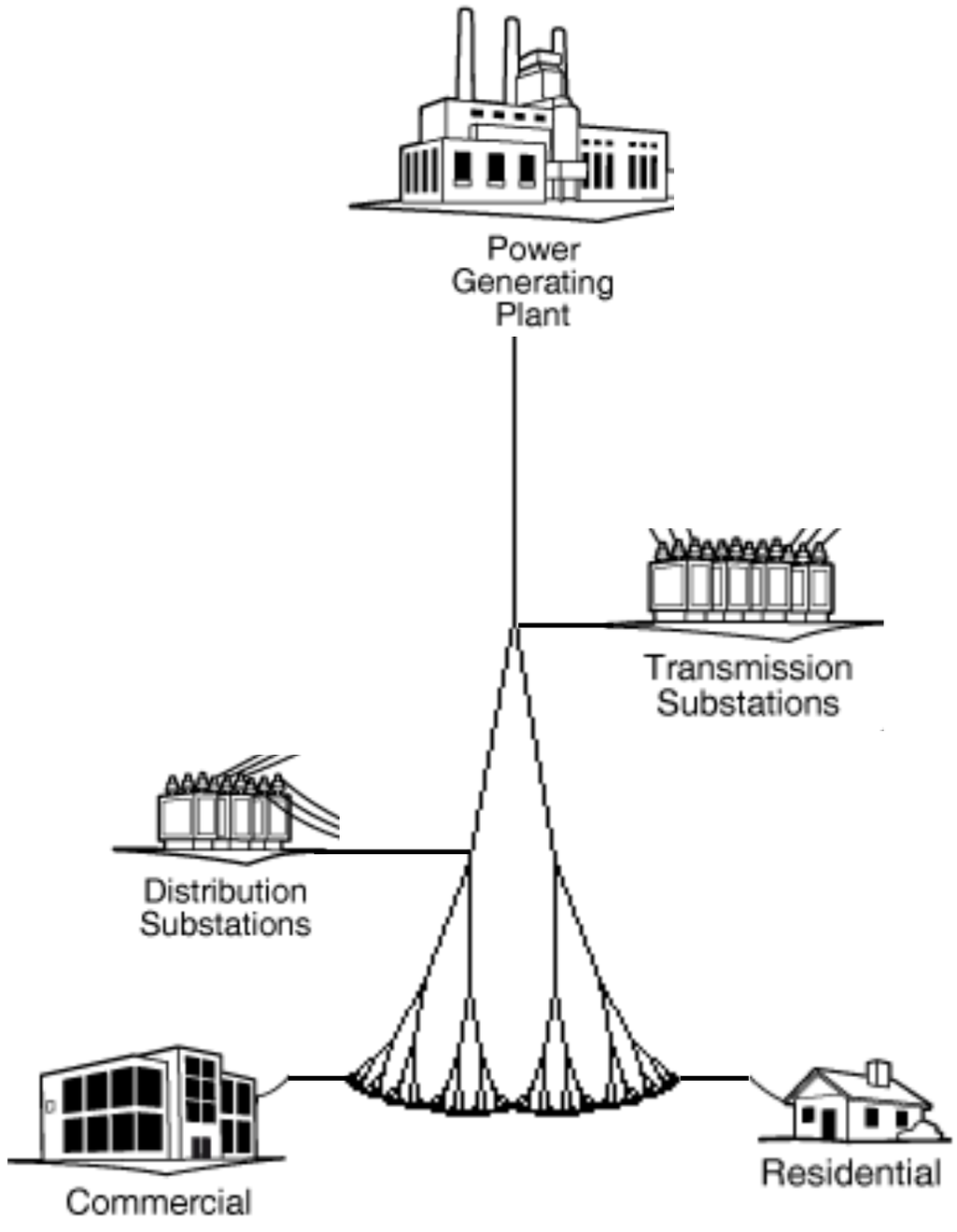
Classical Grid Topology



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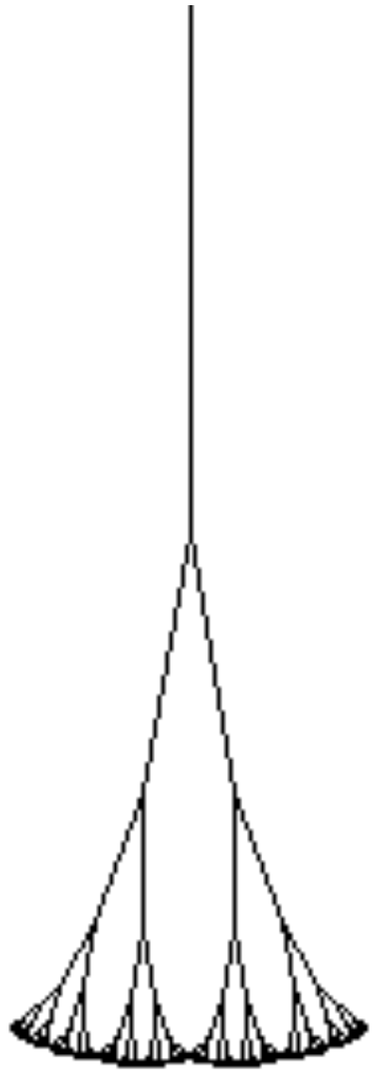

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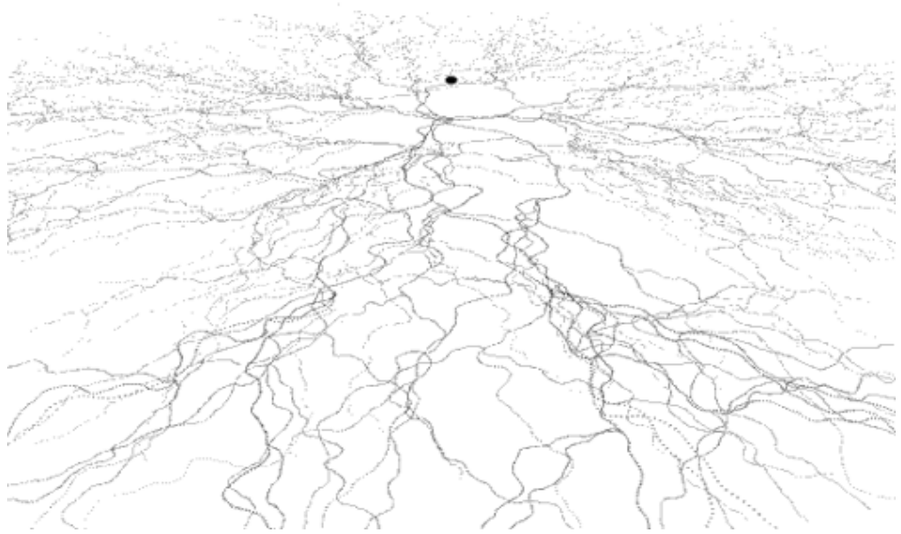
Grid Vital Signs

Frequency	Alternating Current - 60 Hertz	
Voltage	Secondary Distribution	120 V - 240 V
	Primary Distribution	4 kV - 13 kV
	Secondary Transmission	26 kV - 69 kV
	Primary Transmission	138 kV - 500 kV
	Power Plant Transmission	765+ kV



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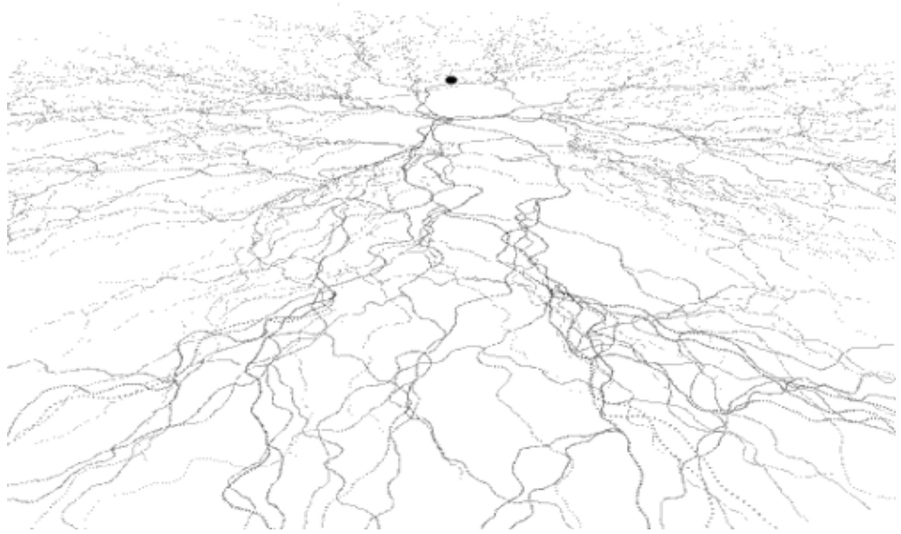

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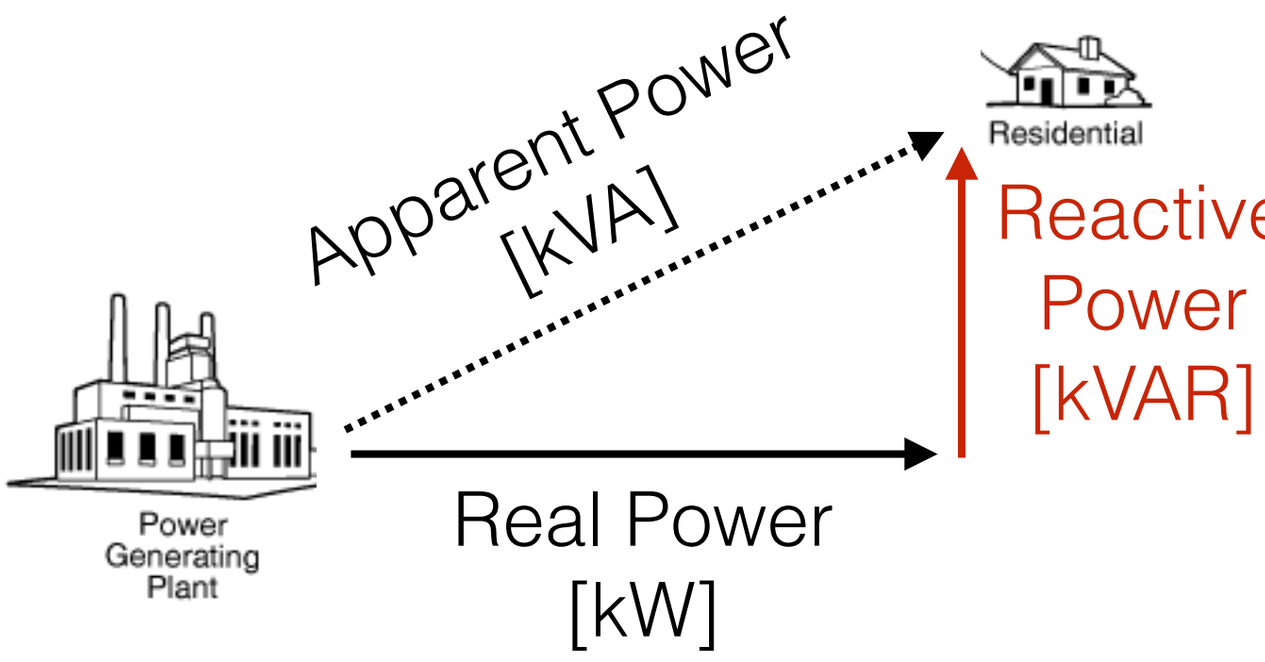

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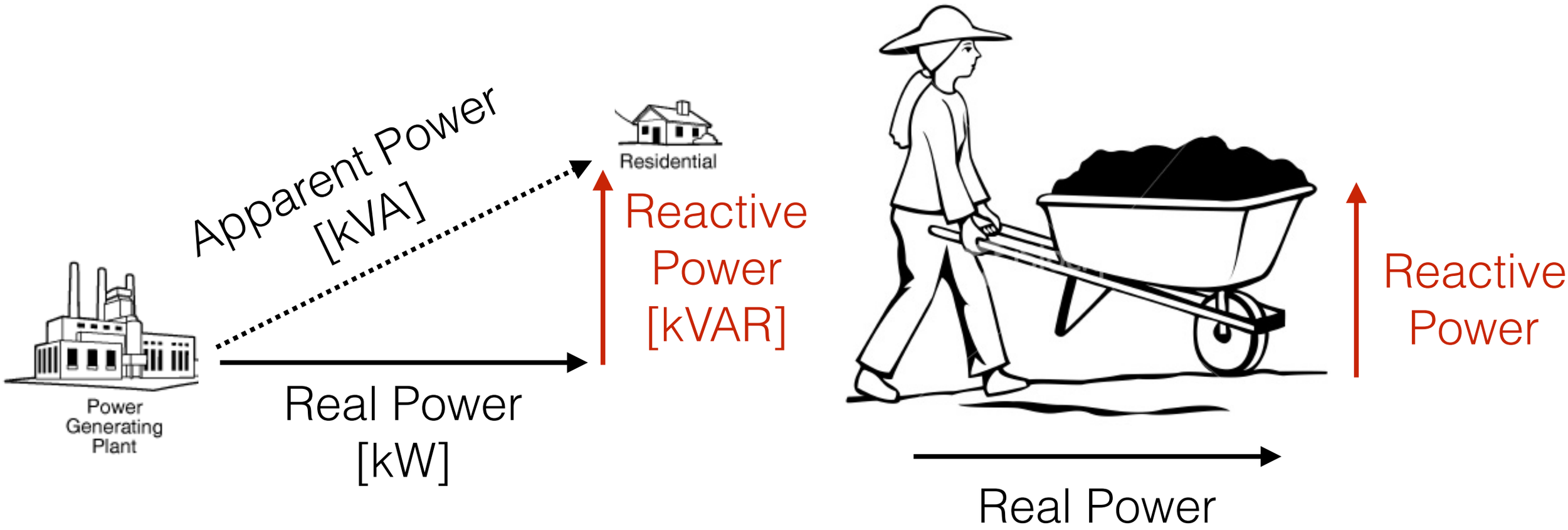

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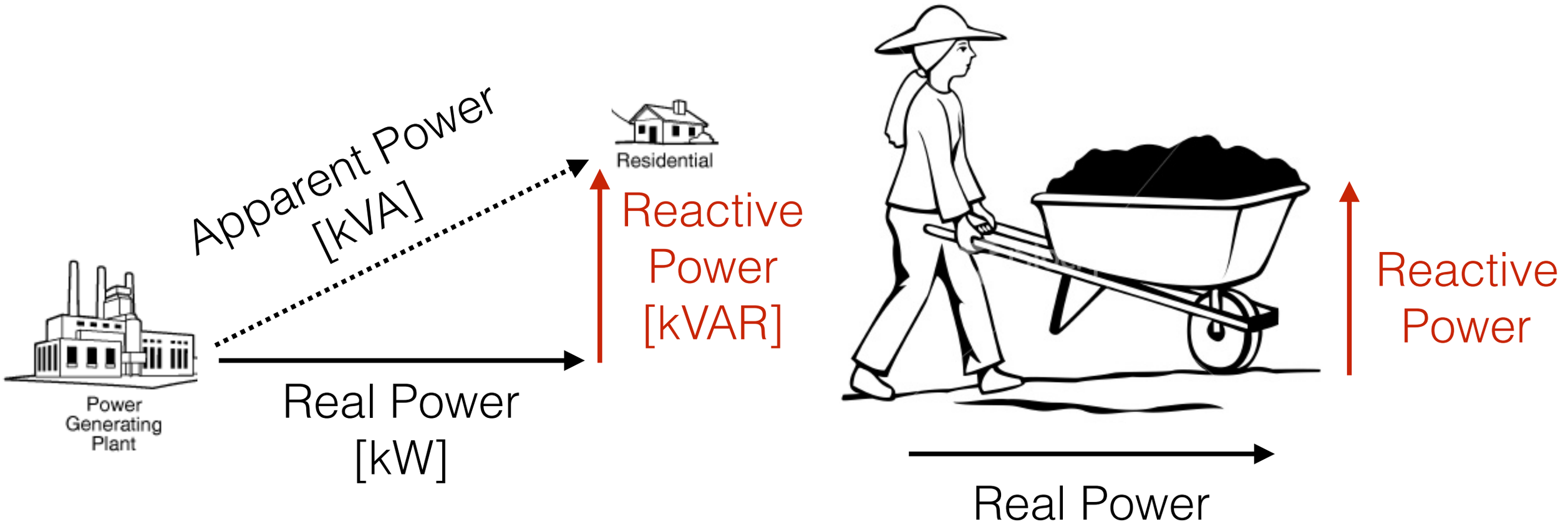
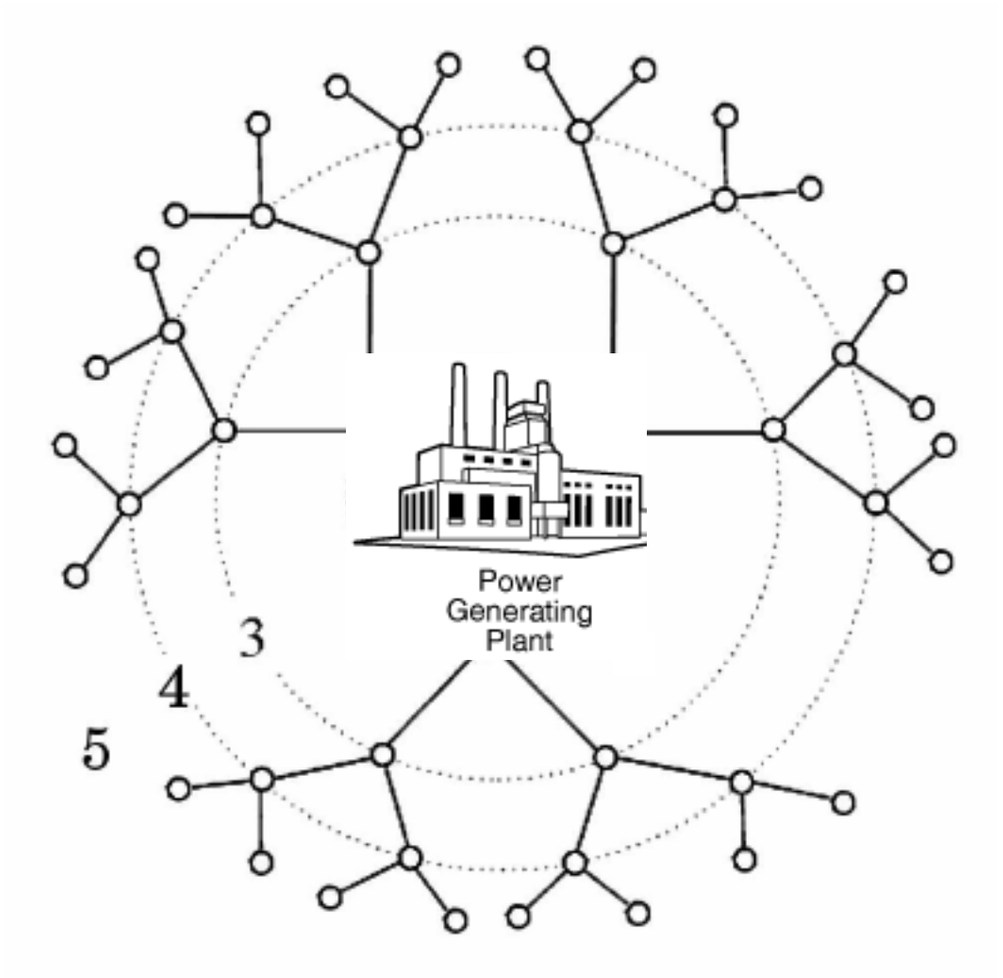


Reactive power is required to deliver real power.
Having insufficient reactive power can lead to “voltage collapse.”
This is actually the cause of most modern widespread system outages.

Power Quality Issue: Reactive Power Deficit



1000 kW

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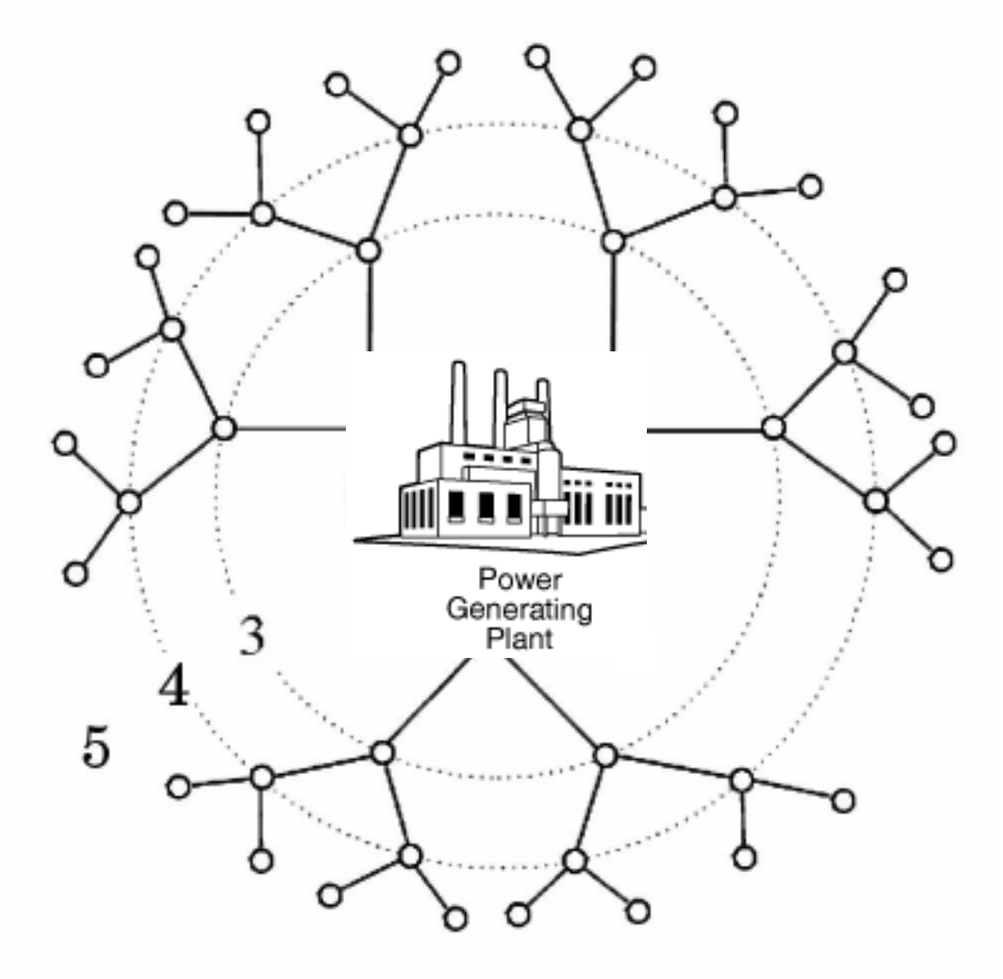

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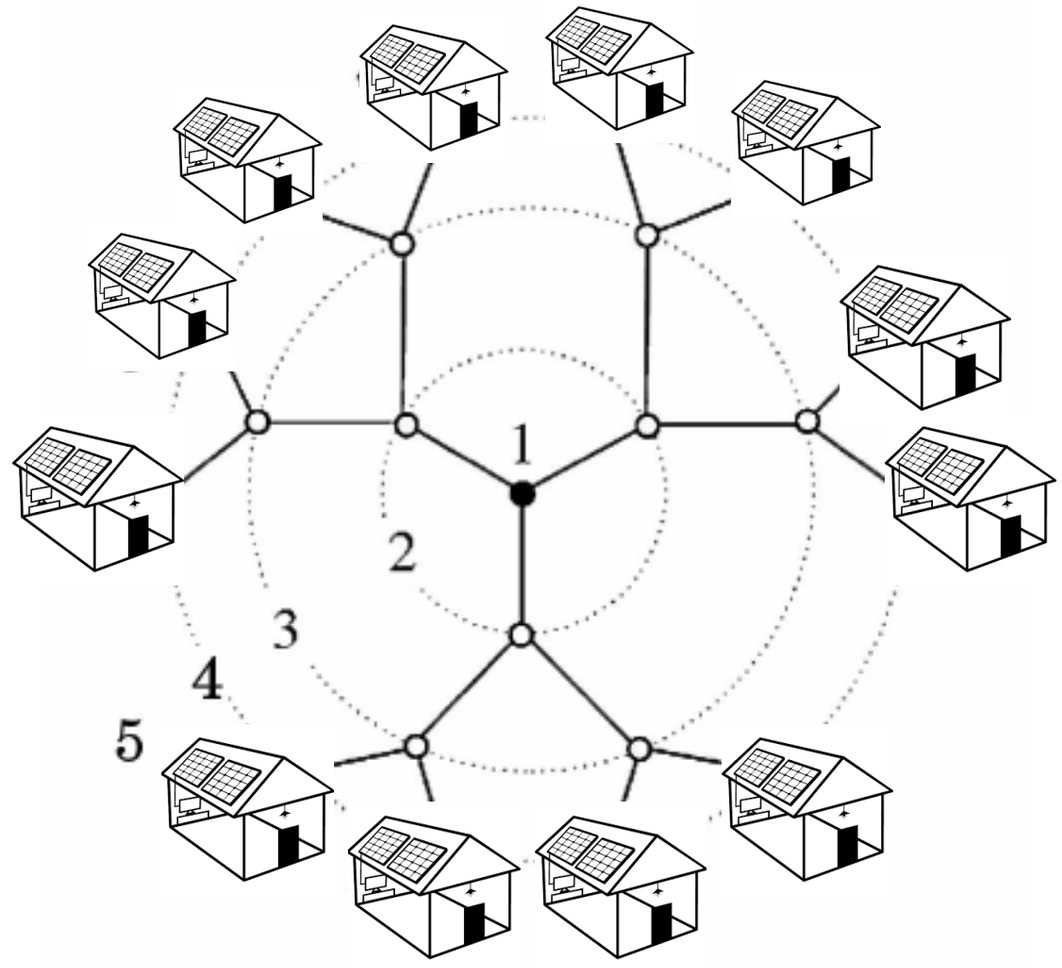

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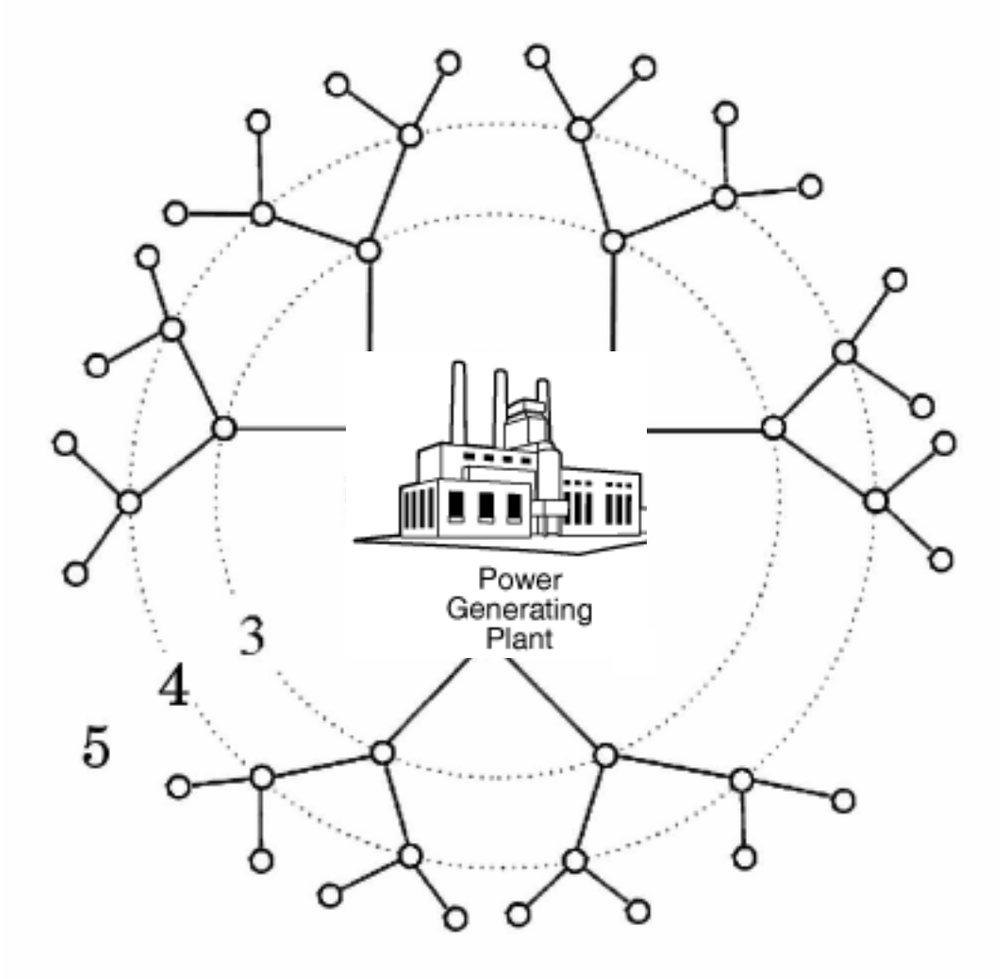

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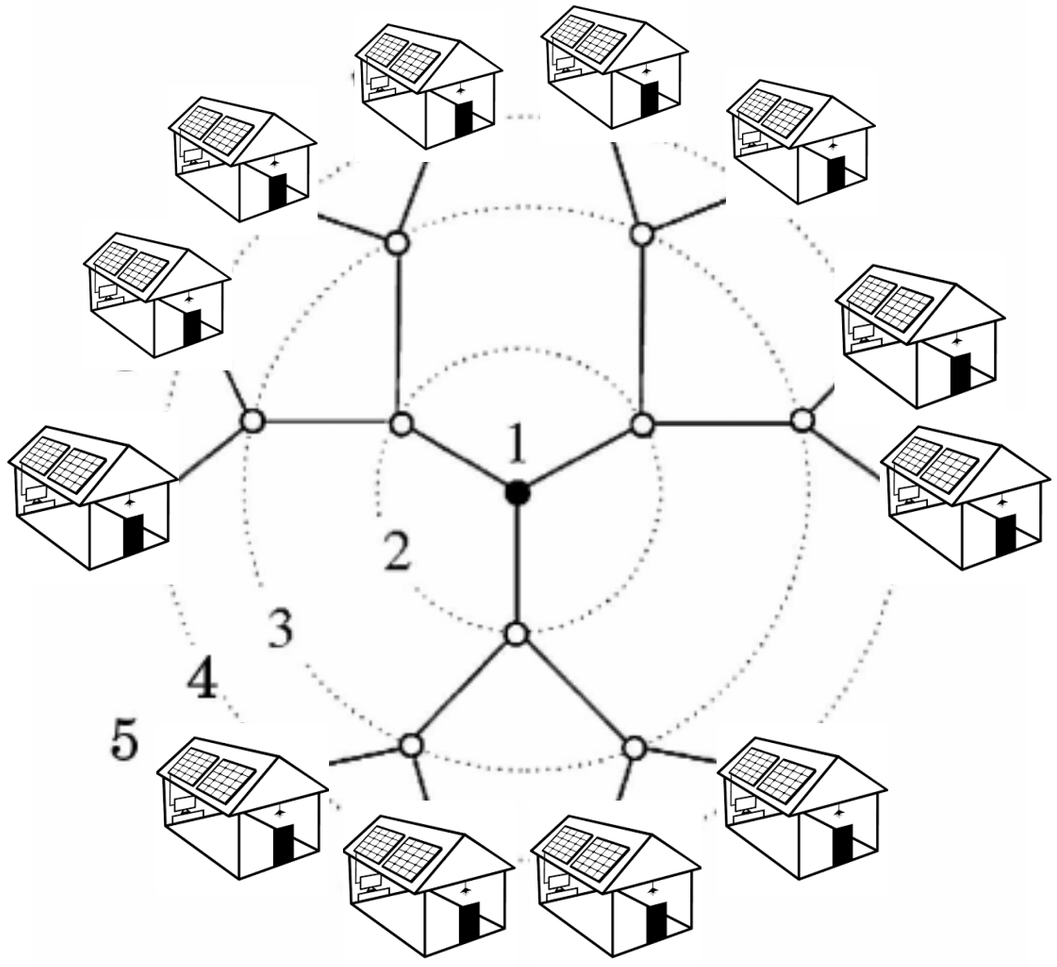

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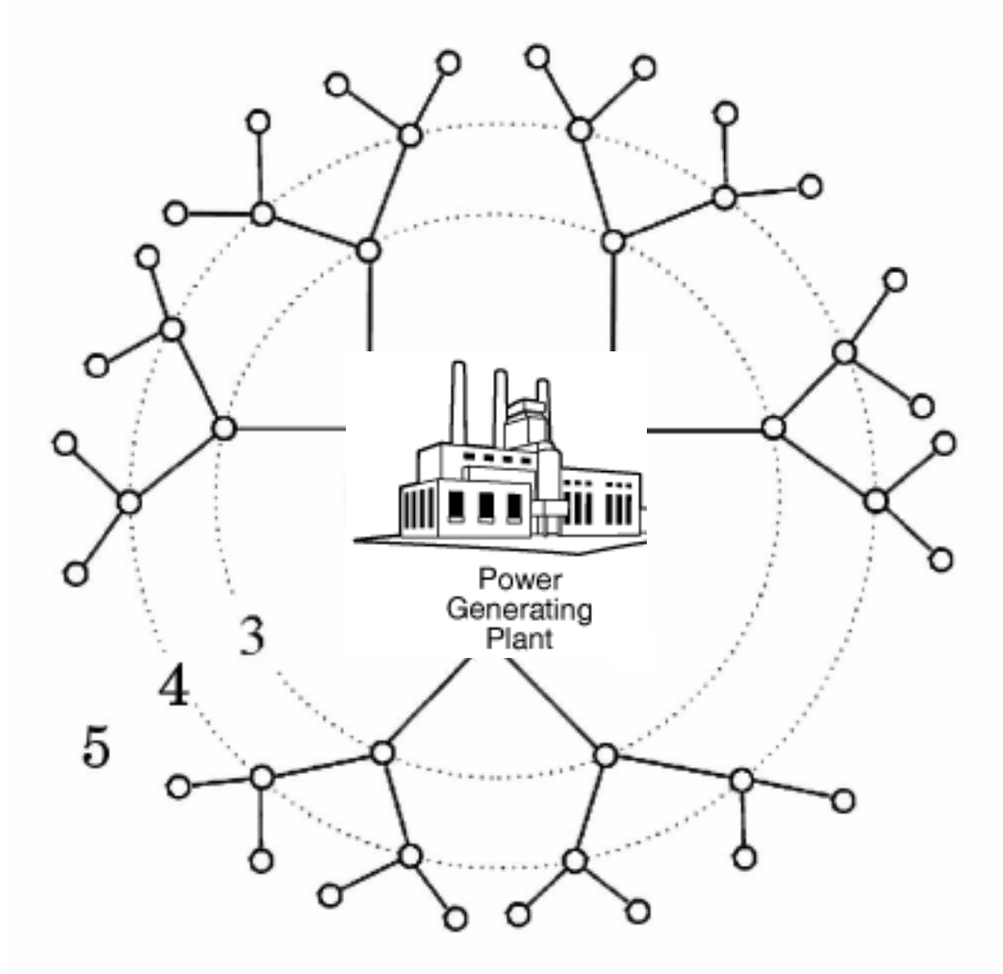

1000 kW

500 kVAR

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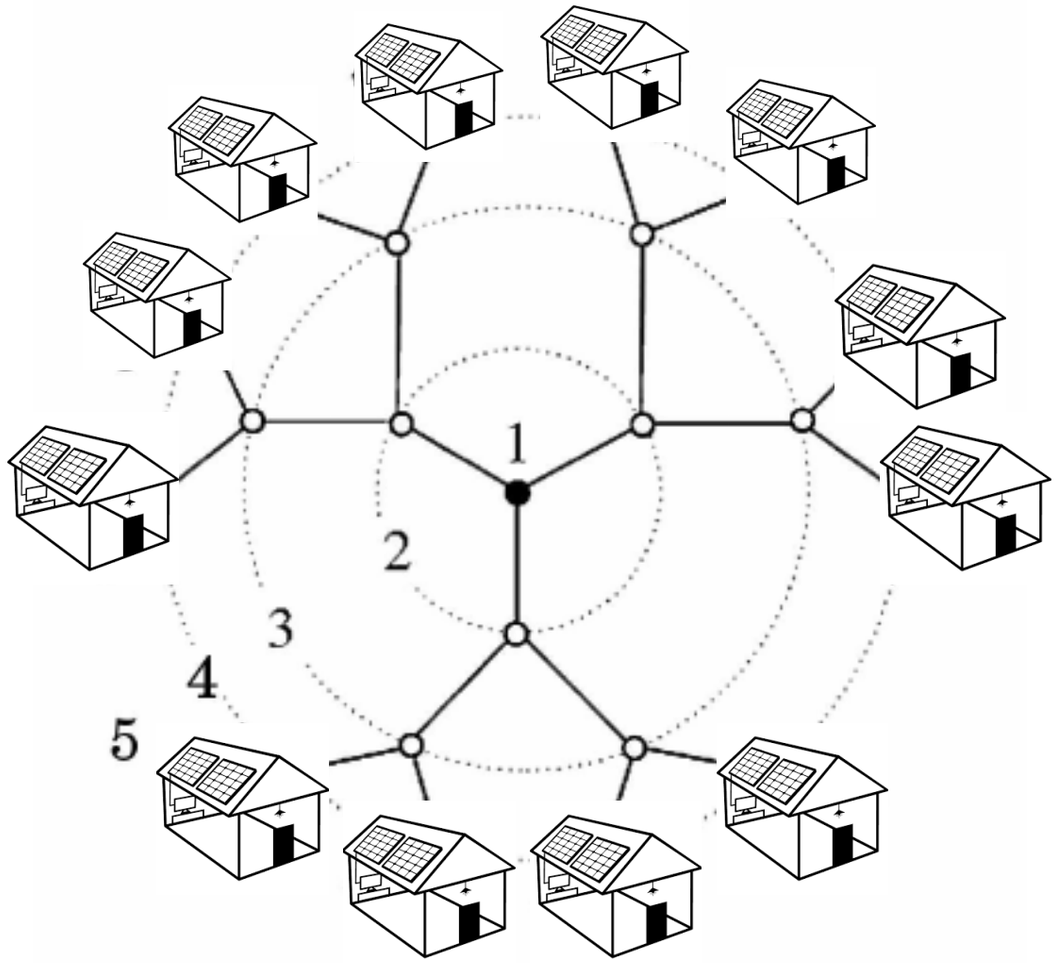

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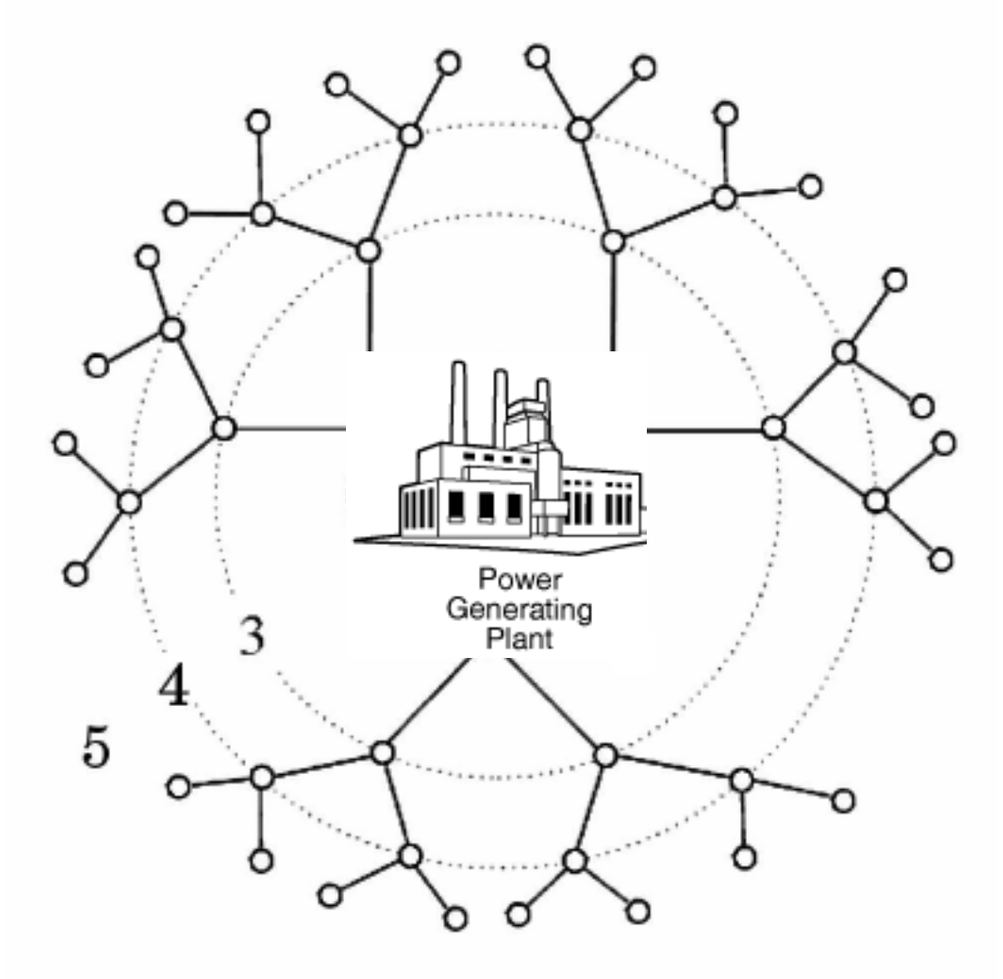

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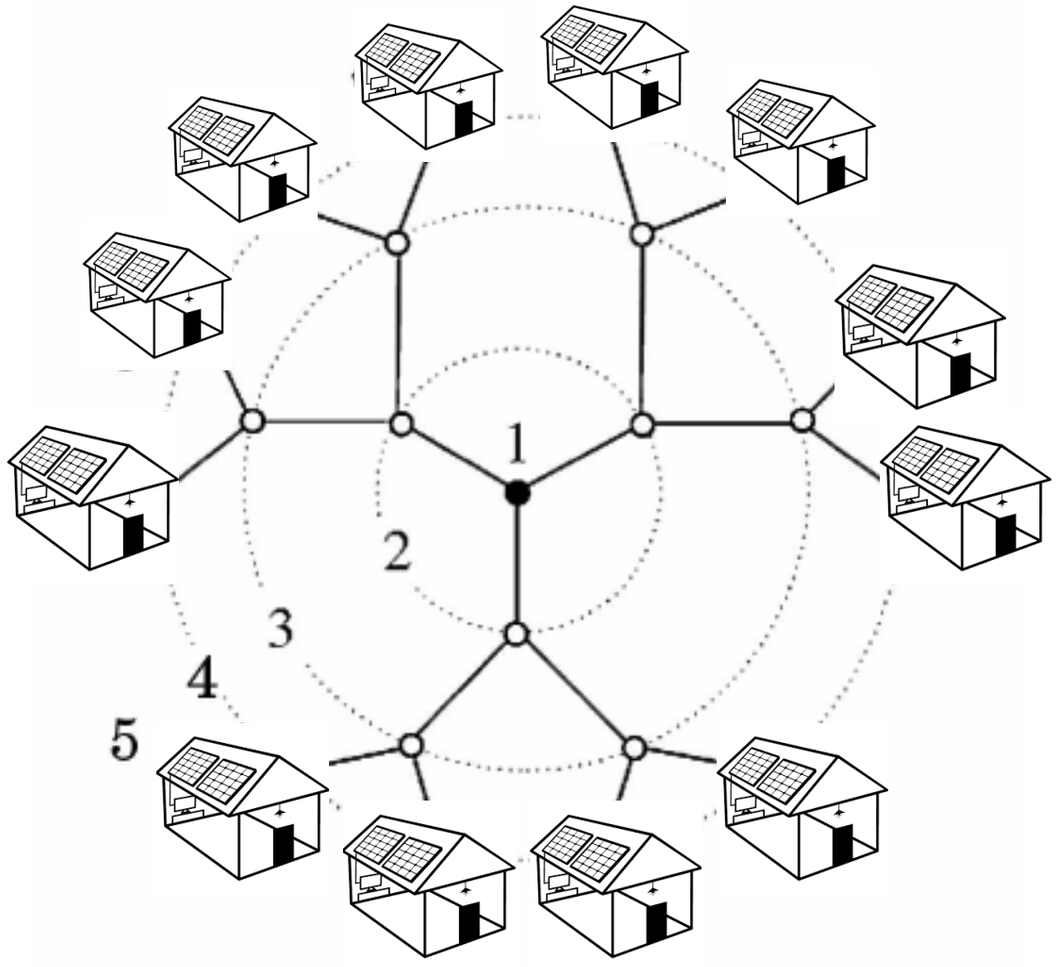

1000 kW

0 kVAR

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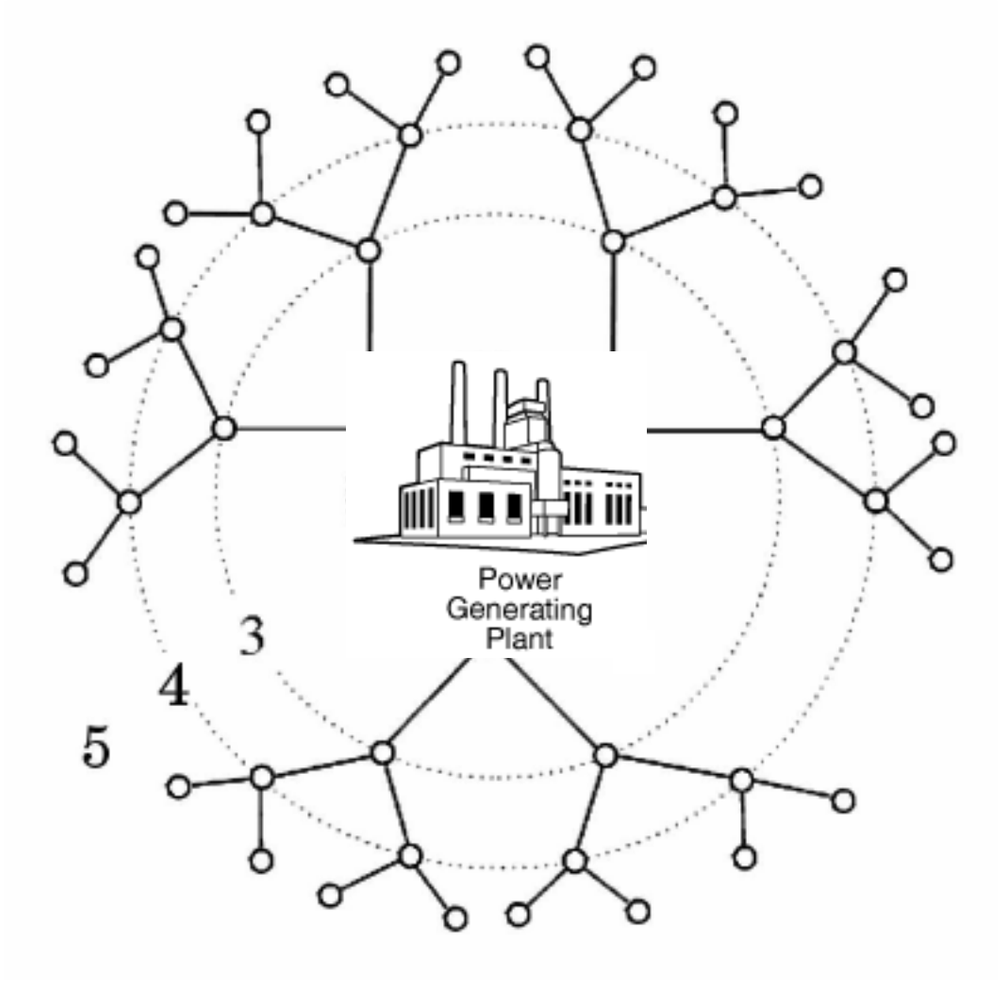

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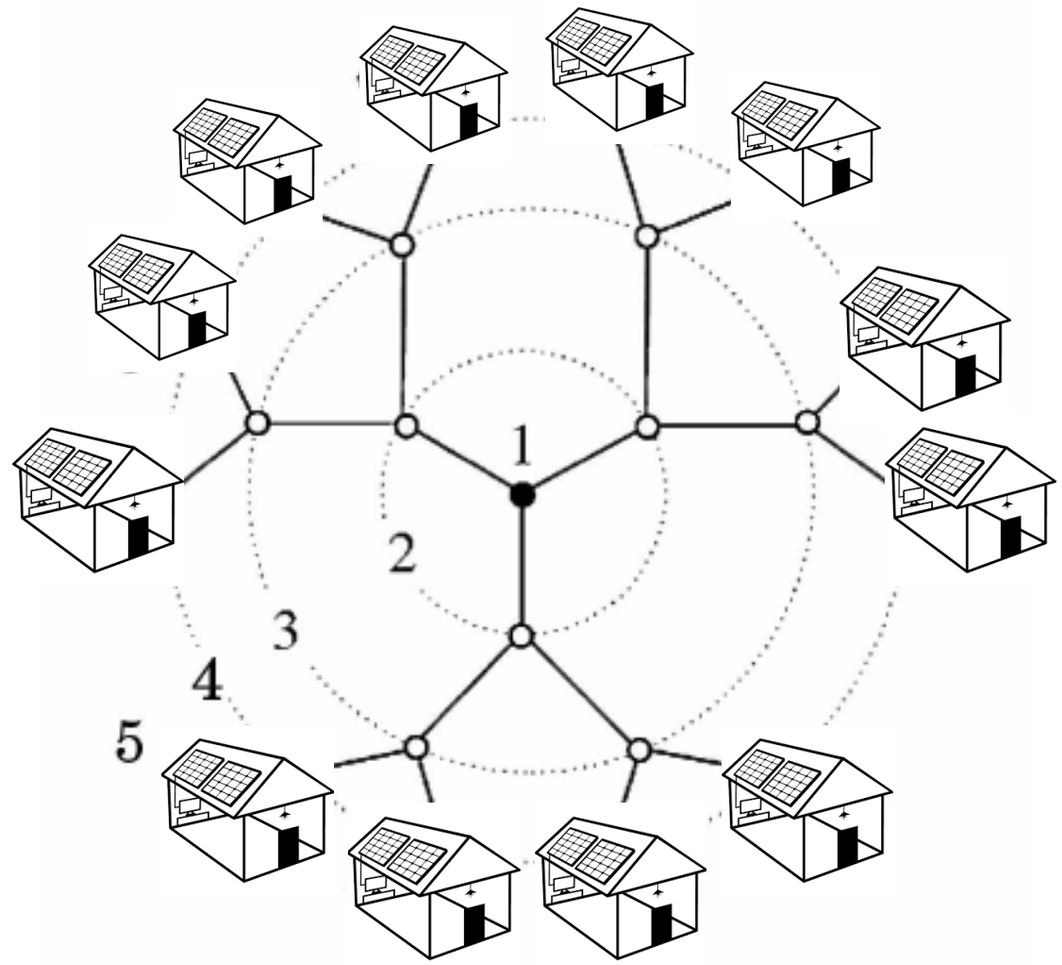

1000 kW
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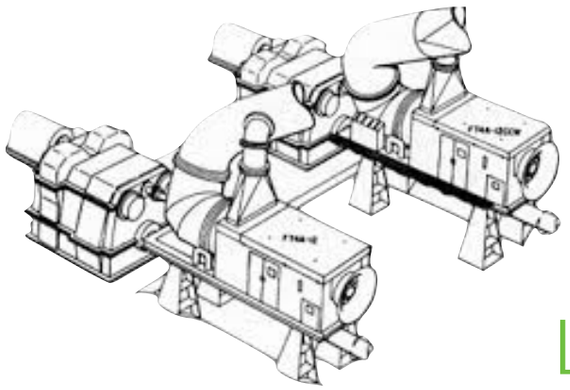
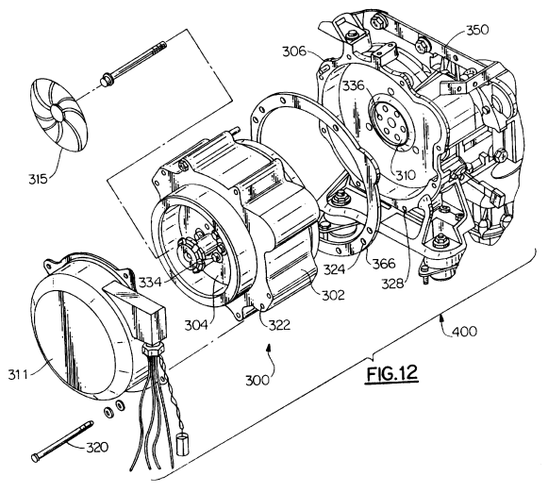
Renewables produce negligible quantities of reactive power.
Higher levels of DRE penetration will require reactive power support.

Options for Reactive Power Support



1. Throttle thermal generator output in order to provide dynamic reactive power supply.

Low Effort / Increased GHG Intensity, Frequency Issues



2. Install components called static synchronous condensers to provide dynamic reactive power supply.

Rapidly Scalable / High Cost

3. Install soft-start AC units, pool pumps, etc. to mitigate dynamic reactive power demand.

Low Cost / High Levels of Community Participation

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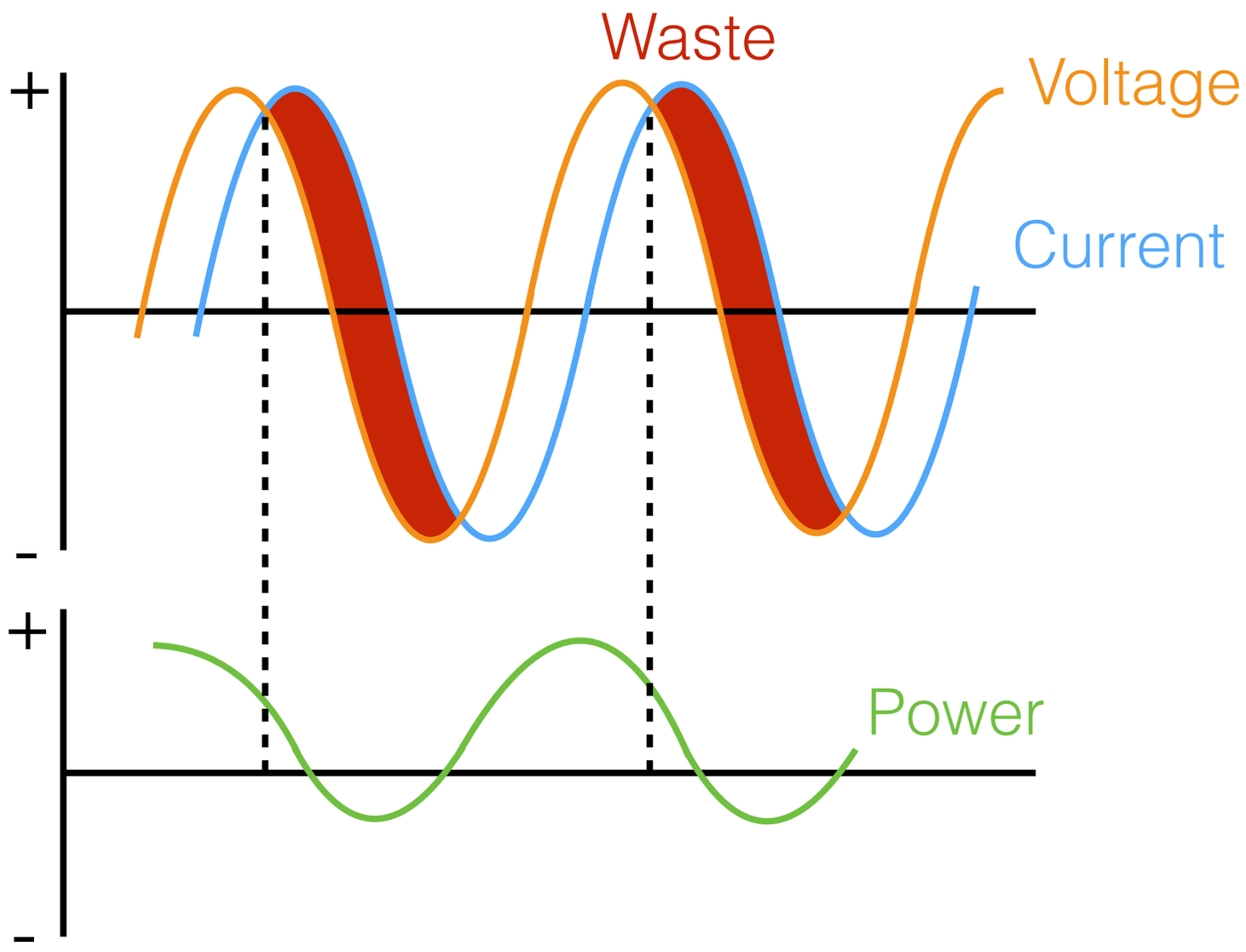
The geographic distribution of sources of reactive power supply relative to centers of demand is therefore a major grid planning consideration.

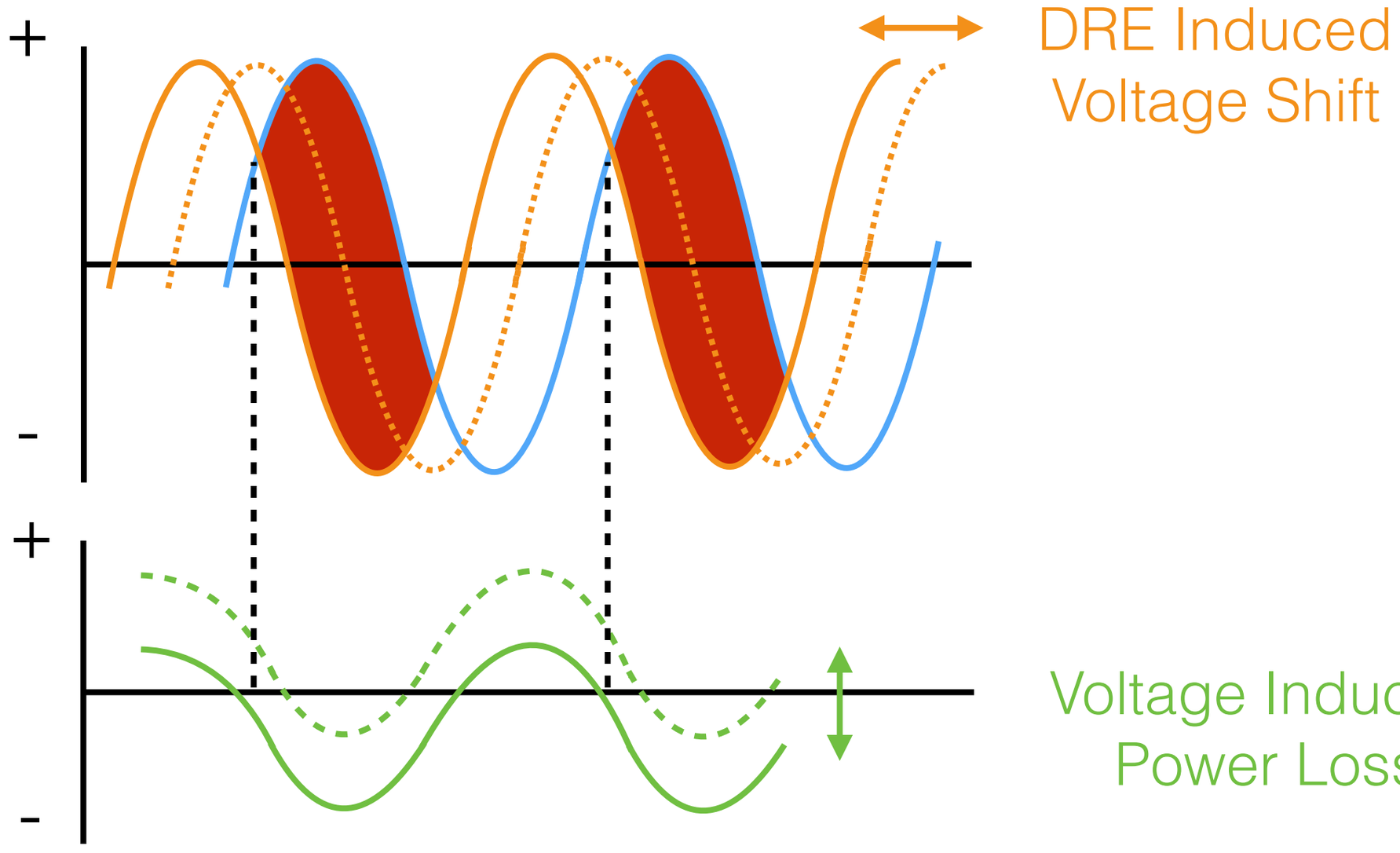
Basic Concepts: Voltage



Power = Voltage x Current

When there is a difference in phase between Current and Voltage within the system, Apparent Power output is reduced.

Power Quality Issue: Inconsistent Voltage



Adding distributed renewable generation capacity can locally alter the voltage of the current that is flowing along grid distribution feeder lines in ways that dramatically alter apparent power output / consumption.

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Consider a time period when intermittent DRE sources are at maximum power output (think solar PV systems at mid-day) the increased voltage on the local feeder lines can cause power consumption of connected loads to increase.

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Example 1:
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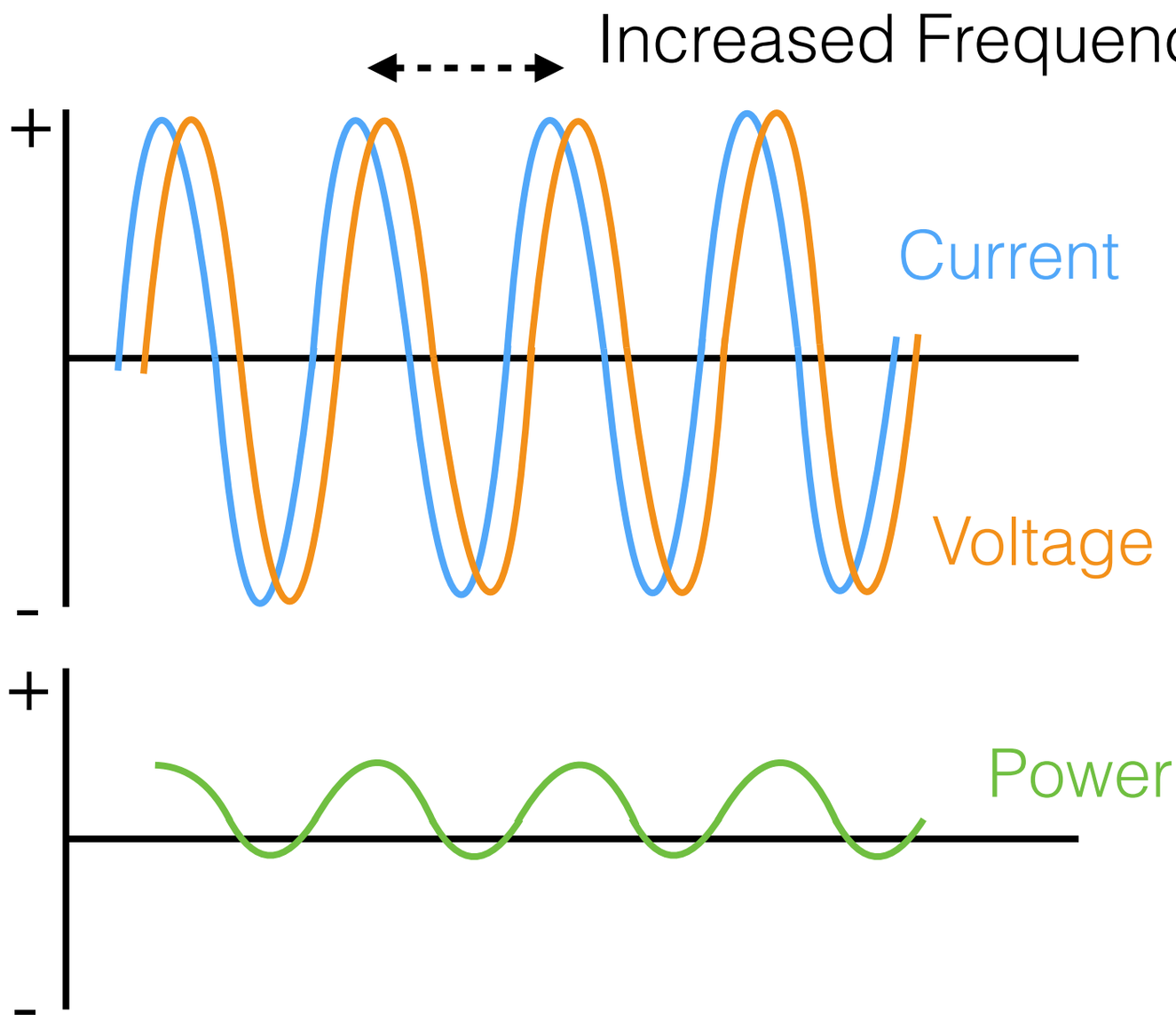
Example 2:
Consider a time period when intermittent DRE sources are at minimum power output (think solar PV systems at night) the decreased voltage on the local feeder lines can trip circuit breakers at the local substation if additional power is not provided.

Basic Concepts: Inconsistent Frequency



With conventional thermal generators, the frequency is sensitive to the load. Altering the load requires a change to the operation of the generator if the frequency is to be preserved.

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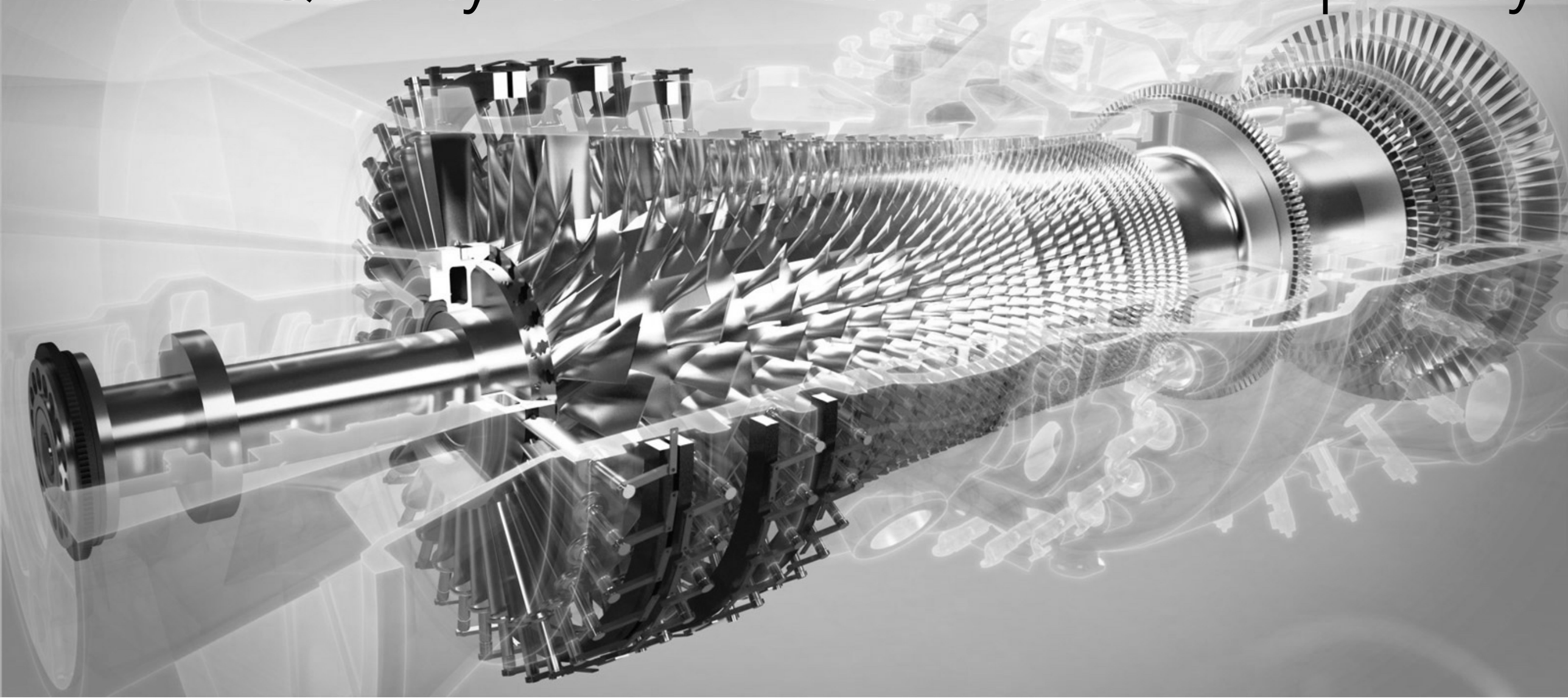

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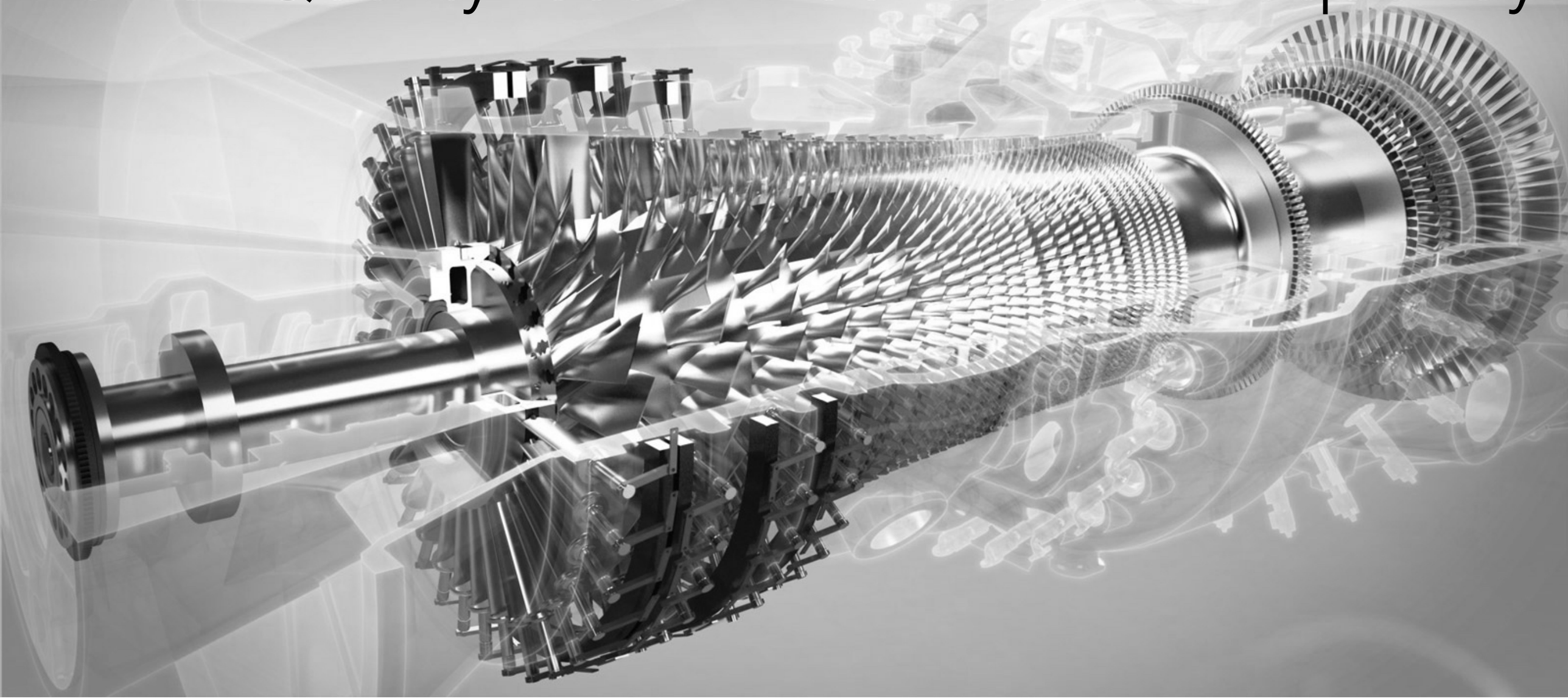
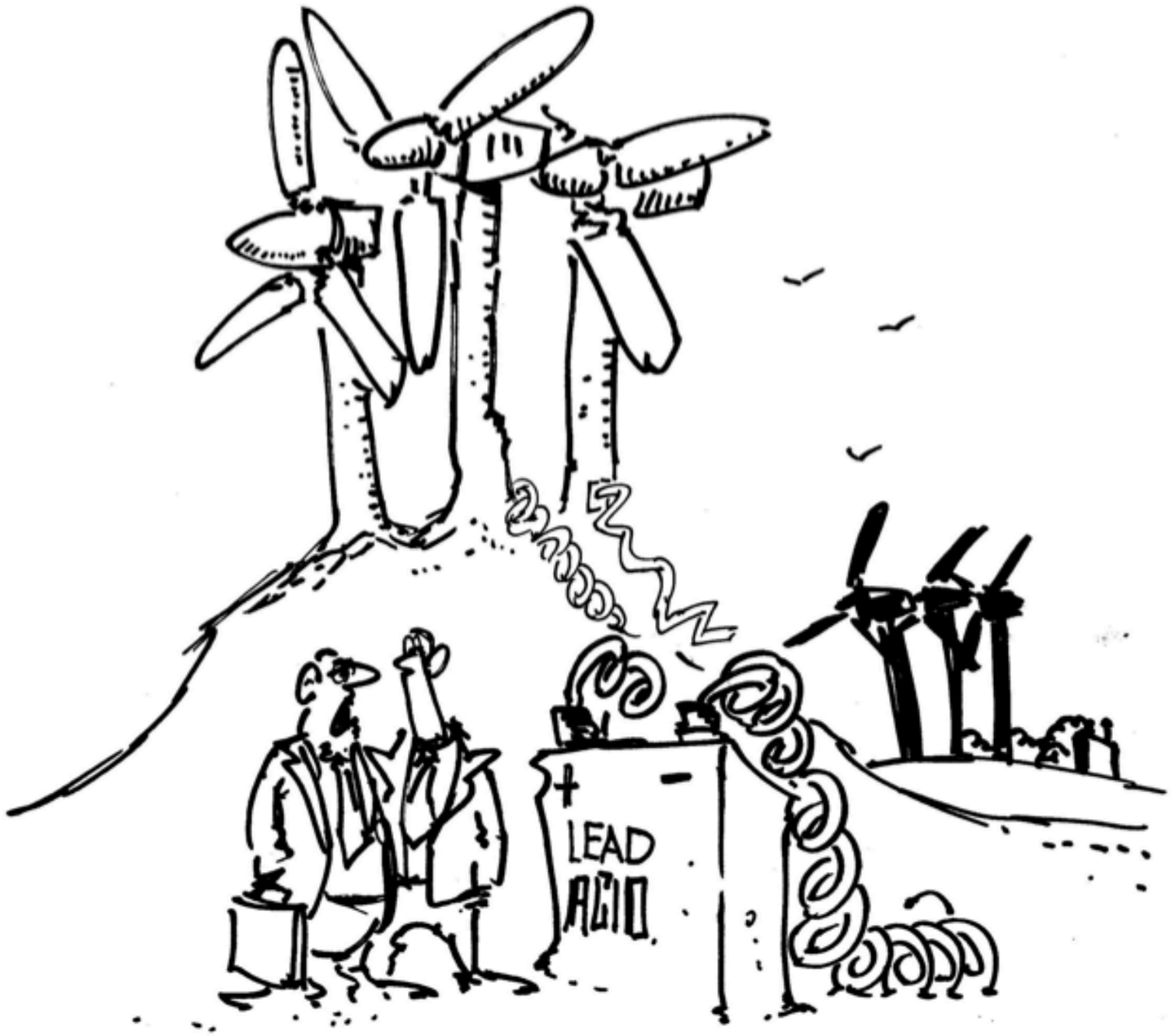


Adding intermittent renewable generation temporarily relieves some of the load on the grid. This means that the gas or coal fired turbines which generate power are effectively pushing against less resistance.

If you don't throttle down the combustion chambers which drive these turbines, than their blades will spin too fast, raising the power frequency.

Basic Concepts: Intermittency

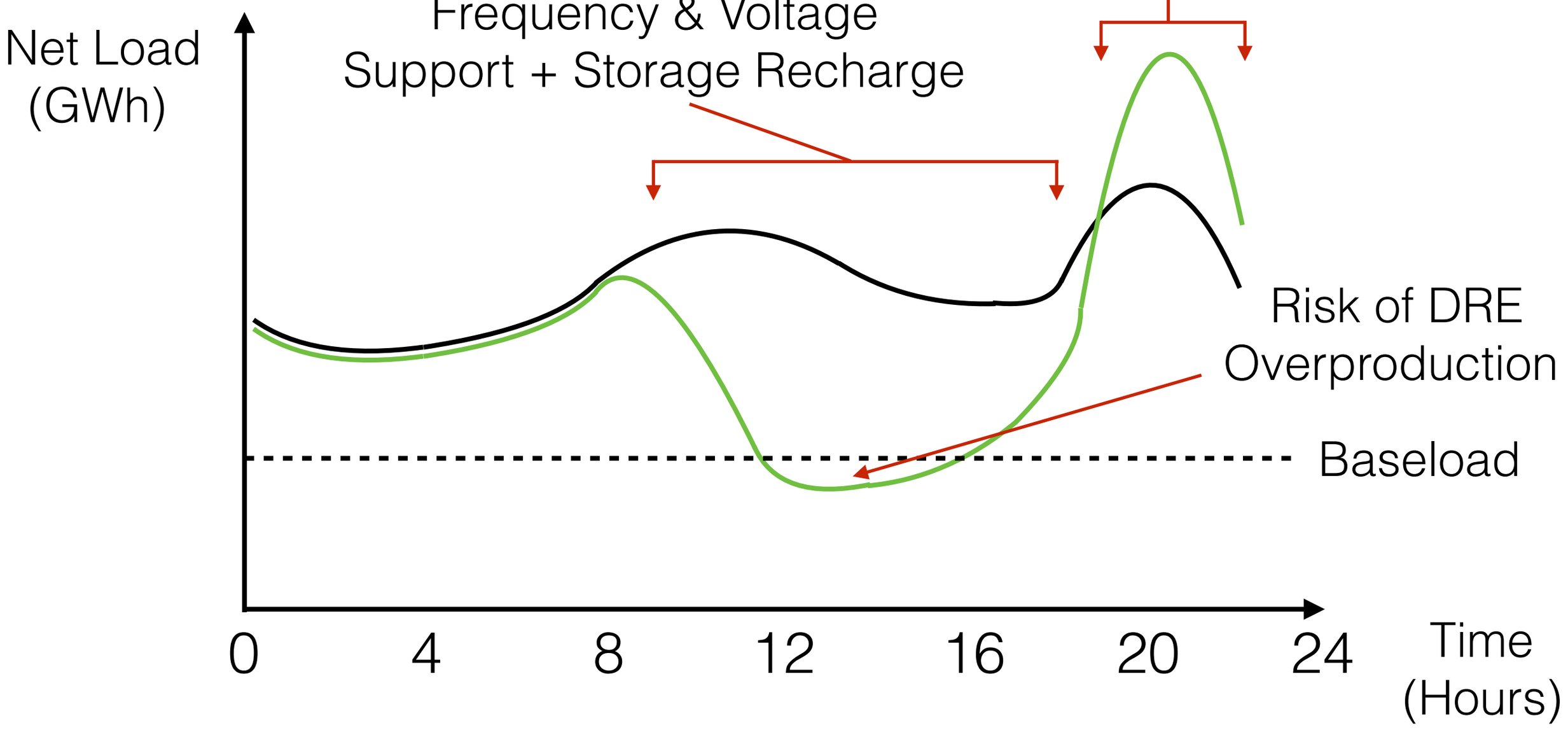


WE USE IT TO POWER THEM WHEN THERE'S NO WIND...

Duh…

Power Quantity Issue: Intermittent Output

Current ≠ High DRE Future



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and directly bill consumers for its use.

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Make data on grid infrastructure more widely and more immediately
available. This includes the installation date, location, and
operational characteristics of low level distribution components.