A Content Secondary Science Newsletter from the
Southern Nevada Regional Professional Development Program

# Science Dissected

## *AC vs. DC*
## *Model-Evidence Link Diagram (MEL)*

In the late 1880's, a different kind of war was being waged. Fueled by Thomas Edison's strive to have the world run on Direct Current (DC), and Nikola Tesla's unrelenting campaign for Alternating Current (AC), many events would unfold which would eventually take this from a personal vendetta to the power grid we have today.

Several undercurrents lay beneath this rivalry. Edison was a brute-force experimenter, but lacked formal training in mathematics and physics. Tesla, by contrast, had this education, which was needed to understand AC power. Edison carried out a campaign to discourage the use of alternating current, including spreading disinformation on fatal AC accidents, publicly killing animals, and funding the first electric chair to show the dangers of AC power. Despite his efforts, AC power was eventually adopted by the majority of the world...but did we make the right decision?

***Model A: AC Power is more practical for our society.***

***Model B: DC Power is more practical for our society.***

***Evidence #1:*** Alternating and direct current systems have similarities and differences, but only one is practical over long distances.

***Evidence #2:*** The efficiency of DC power supplies inside large data centers is greater than that of the power supplies currently used.

***Evidence #3:*** The energy production cost of different wind farms depends on which type of power system is used.

***Evidence #4:*** AC power has certain key advantages over DC power.

***Evidence #5:*** Despite the odds, Nicola Tesla won out the "War of the Currents" at the end of the eighteenth century.

**The following is a suggestion for using this MEL with students:**

1. Hand out the Climate Change Model Evidence Link Diagram (page 1). Instruct students to read the directions, descriptions of Model A and Model B, and the four evidence texts presented.
2. Handout the four evidence text pages (p. 3-11).
3. Instruct students to carefully review the Evidence #1 text page (page 3), then construct two lines from Evidence #1; one to Model A and one to Model B. Remind students that the shape of the arrow they draw indicates their plausibility judgment (potential truthfulness) connection to the model.
4. Repeat for Evidence #2-5 (pages 4-11).
5. For Evidence #5, show the video: **Tesla: The Master of Lightning** from PBS.
6. Handout page 2 for the students to critically evaluate their links and construct understanding.

Once students have completed page 2, they can then engage in collaborative argumentation as they compare their links and explanations with that of their peers. Students should be given the opportunity to revise the link weighting during the collaborative argumentation exercise. If time permits, have students reflect on their understanding of AC & DC Power and create questions that they might explore in the future.

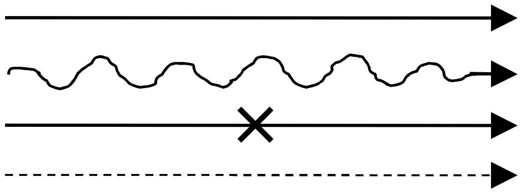
***Archived Issues of Science Dissected, http://www.rpdp.net/link.news.php?type=sciencedis. Instructional Resource resulting from Plausibility, It's All About Connecting the Models Workshop co-sponsored by CPDD and SNRPDP Science March 6, 2012***

*Written by: Ryan Zeedyk*

**Name:**______________________________________ ___________________ **Period:**_______________

**Directions:** draw two arrows from each evidence box. One to each model. You will draw a total of 10 arrows.

**Key**:



The evidence **supports** the model

The evidence **STRONGLY supports** the model

The evidence **contradicts** the model (shows its wrong)

The evidence has **nothing to do with** the model

Standard: P.12.B.2
The student will distinguish between alternating current (AC) and direct current (DC).

**Evidence #1**
Alternating and direct current systems have similarities and differences, but only one system is practical over long distances.

**Evidence #2**
The efficiency of DC power supplies inside large data centers is greater than that of the power supplies currently used.

**Model A**
Direct Current (DC) Power is more practical for our society.

**Model B**
Alternating Current (AC) Power is more practical for our society.

**Evidence #3**
The energy production cost of different wind farms depends on which type of power system is used.

**Evidence #4**
Advantages of AC power over DC.

**Evidence #5**
Despite the odds, Nicola Tesla won out the "War of the Currents" at the end of the eighteenth century.

Provide a reason for three of the arrows you have drawn. **Write your reasons for the three most interesting or important arrows.**

A. Write the number of the evidence you are writing about.
B. Circle the appropriate descriptor (**strongly supports | supports | contradicts | has nothing to do with**).
C.Write the letter of the model you are writing about.
D.Then write your reason.

**1. Evidence # ____ strongly supports | supports | contradicts | has nothing to do with Model _____ because:**

**2. Evidence # ____ strongly supports | supports | contradicts | has nothing to do with Model _____ because:**

**3. Evidence # ____ strongly supports | supports | contradicts | has nothing to do with Model _____ because:**

**4. Circle the plausibility of each model. [Make two circles. One for each model.]**

| | Greatly implausible (or even impossible) | | | | | | | | | Highly Plausible |
|---|---|---|---|---|---|---|---|---|---|---|
| **Model A** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Model B** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

**5. Circle the model which you think is correct. [Only circle one choice below.]**

| | | | | |
|---|---|---|---|---|
| Very certain that Model A is correct | Somewhat certain that Model A is correct | Uncertain if Model A or B is correct | Somewhat certain that Model B is correct | Very certain that Model B is correct |

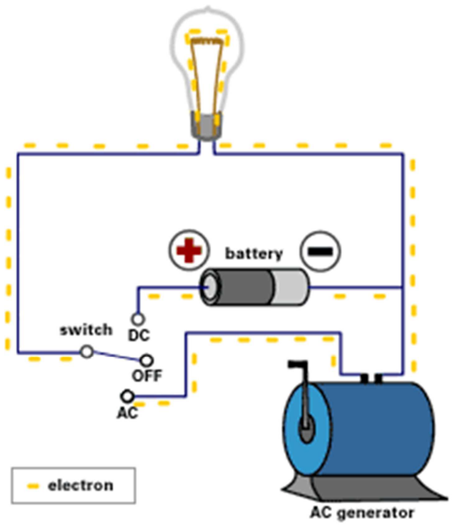
**Evidence #1: Alternating and direct current systems have similarities and differences, but only one system is practical over long distances.**

Adapted from http://www.prism.gatech.edu

**Similarities and differences:**

Though the observable effects of electricity are difficult if not impossible to distinguish, there are fundamental similarities and differences to be noted between the systems of alternating current (AC) and direct current (DC). In addition there are a few scientific terms that need be understood when discussing the properties of either system.

When discussing either current system, three common properties of electricity are employed: voltage, current, and power (AC/DC: What's the Difference?). These properties are related in an equation called Ohm's Law, which states that power is equal to the product of current and voltage (P=IE). In the case of alternating current, power is usually transmitted at high voltage (high tension) and low current (AC/DC: What's the Difference?). The opposite is true for direct current, which transits power at low voltage (low tension) and high current. Another important difference between the two systems is manifest in each system's name. That is in direct current, the electrons flow directly from the positive to negative terminal. In alternating current, the electrons essentially alternate direction within the wire and no single electron makes a very large journey. Thus, alternating current has an additional property, called frequency, which represents the number of oscillations an electron makes per unit time (AC/DC: What's the Difference?). These fundamental technical differences between the two systems are of critical importance especially for the phenomenal success of AC power, and highlight the advantages of alternating current over direct current.



**Advantages and disadvantages:**

The advantages of AC over DC hinge on its high voltage transmission and frequency property (see corresponding diagrams). Since alternating current operated on such a low current, there was little power dissipation, even over exceptionally long distances with minimal energy dissipation (AC/DC: What's the Difference?). This was due to the fact that the electrons did not move very far and consequently did not generate a lot of heat due to friction of motion. Direct current however, "ran out of pressure [(effective power deliverance)] about half a mile from the power station" (Lomas 65). This limitation meant that direct current needed high gauge copper wire (expensive) and a power station effectively in one's back yard (inconvenient). It is these factors which ultimately limited direct current to the extremely rich and made technologies like the telephone and "the electro-magnetic telegraph an impractical scheme" (Mendenhall 607). Alternating current however, could transmit comparably small amounts of electricity over very large distances, hundreds of miles, and it could be "stepped up" or "stepped down" as needed for its end process effectively giving it a high current at the end rather than along its entire length (Lomas 66).

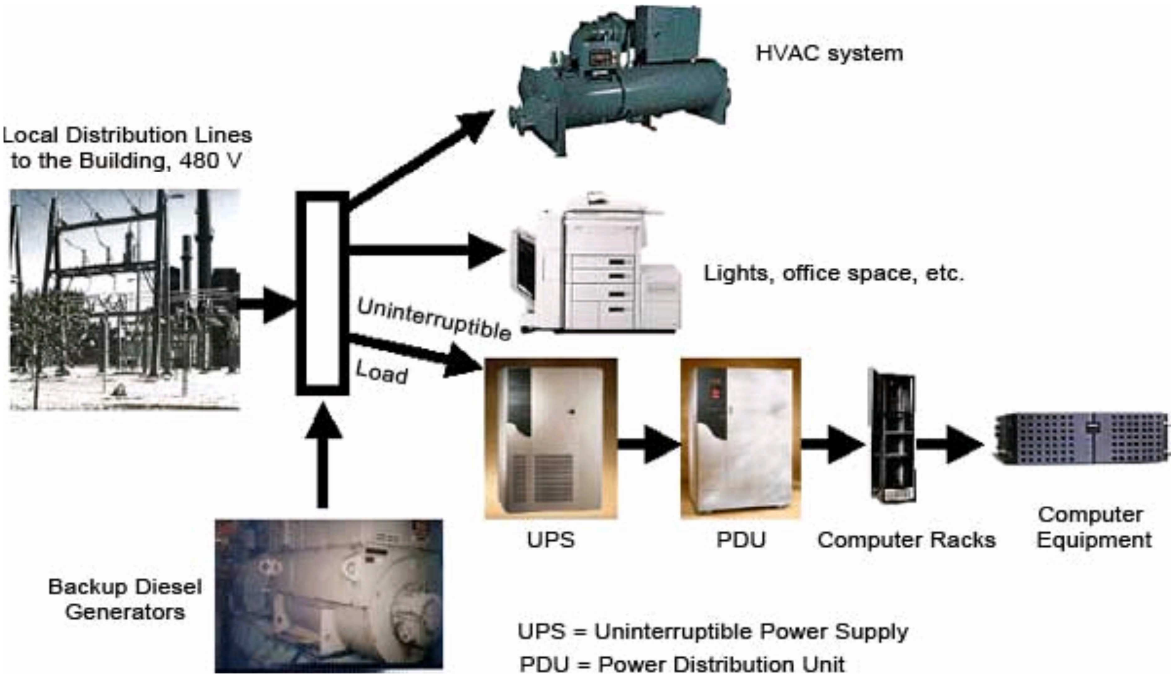
It is these properties which allowed alternating current to extend the range of human interaction and influence to the limit. Power could be generated at remote locations and transmitted over long distances (like in the Pan-American Exposition of 1901 in Buffalo, New York), or generated in city centers and connected to the suburbs and neighboring cities, and states (Jonnes 123). Alternating current also extended the range of human interaction i.e. communication by extending the range of existing technologies such as the telegraph and the telephone across the United States and beyond. This meant that information known in one place could be quickly known across the entire country, effectively eliminating the connection between distance and time. Families no longer needed to be close to maintain effective communication. People could spread out and yet remain more connected than ever before. This societal narrative would continue into the future with the advent of more advanced technologies, all relying on alternating current.

**Evidence #2: The efficiency of DC power supplies inside large data centers is greater than that of the power supplies currently used.**

## Overview of Data Center Power Use

From the beginning of commercial computing, data centers have been important to industries, institutions, and governmental agencies. However, it was the Internet and the rise of "mission-critical" computing facilities that brought energy consumption in data centers to the forefront. In 1999, a widely cited article by Mark Mills and Peter Huber posited that the "Internet" consumed about 8% of US electricity in 1998, and that this would likely grow significantly to account for 30 to 50% of U.S. electricity consumption by 2010 or 2020. They cited the dramatic growth in Internet-related equipment installed base since 1995, particularly servers and computer network equipment needed for the Internet.[5]

[5] Mills, M and P. Huber, "Dig More Coal—the PCs are Coming," Forbes, May 1999.




An optimal system might integrate the IT equipment with the facility in such a way as to minimize power conversions. For example, the individual power supplies in servers could be eliminated if the correct voltages of DC power could be supplied efficiently from a central system, or in the case of fuel cells, directly from the power source. One industry expert envisions the data center of the future similar to a computer in its case. Taking this idea a step further, the electrical system could be thought of as an integrated system from where it enters the data center to the ultimate end use. When viewed in this manner, optimized systems could be designed so as to optimize energy (distribution and conversion losses), reliability, power quality, and potentially provide additional benefits such as elimination of harmful harmonics.

The low efficiency of older power supplies suggested that large gains might be possible if high voltage DC input operation were developed. However, the most recent AC designs are now routinely 92% efficient or greater over a broad range of operating loads, according to published power supply efficiency data from various manufacturers. One of the world's largest power supply manufacturers, Delta Electronics, has published the power supply efficiency data of **Table 2.**

Table 2
*Difference between AC and DC power supply efficiencies (Delta Electronics)*

| Power Supply | Load 20% | 50% | 80% | 100% |
|---|---|---|---|---|
| AC (208V) | 85.0% | 93.2% | 93.7% | 93.6% |
| DC (400V) | 85.5% | 94.1% | 94.8% | 94.5% |
| Difference | 0.5% | 0.9% | 1.1% | 0.9% |

Note that the improvement in efficiency gained by DC operation is 0.9% at 50% load, and even less at the lighter loads where many IT power supplies operate. For this analysis, we will use the Delta Electronics data at 50% load.

| Reference values for power supply Efficiency at 50% load | |
|---|---|
| AC IT power supply | 93.2% |
| DC IT power supply | 94.1% |

Information provided by:

A Quantitative Comparison of High Efficiency AC vs. DC Power Distribution for Data Centers

Revision 3

by Neil Rasmussen and James Spitaels

**Evidence #3: The energy production cost of different wind farms depends on which type of power system is used.**

In Europe today (2006) there is a concern about the greenhouse effect and investments are done to decrease it. One part of this is to create a more $CO_2$ neutral society. For the energy sector this has lead to that more investments are done in renewable energy sources, such as wind power, biomass, and solar. Wind energy installations have gone from being small units erected one by one to larger units erected in groups. Today wind farms up to a size of 160 MW have been built and several plans of 1000 MW-parks exist. These larger wind parks are mainly considered to be located out in the sea, preferably at such a distance out in the sea that they cannot be observed from the shore. Another advantage of selecting an offshore site is that the average wind speed is usually higher than onshore. Drawbacks with offshore sites are that the accessibility to the wind park is lower than onshore, all equipment must be adapted for the offshore environment and the distance from the wind park to the connection point to the grid is usually longer than for an onshore site. In order for the wind parks to be economically reasonable it is important to keep the energy production cost down. This can be done by having a site with high average wind speed, a wind park layout that fits the site and to keep the number of operation hours high.

Another aspect, mainly of importance for smaller wind parks is to not violate any power quality issues at the point of common connection. For the largest wind parks it is a problem to find a suitable grid connection point, which is strong enough to handle the generated power from the parks. This leads to that, in many cases, the distance between the grid connection point and the wind farm is so long that a DC-transmission may become more favorable than a conventional AC-transmission [3]. Today all offshore wind farms that have been built use an AC-transmission.

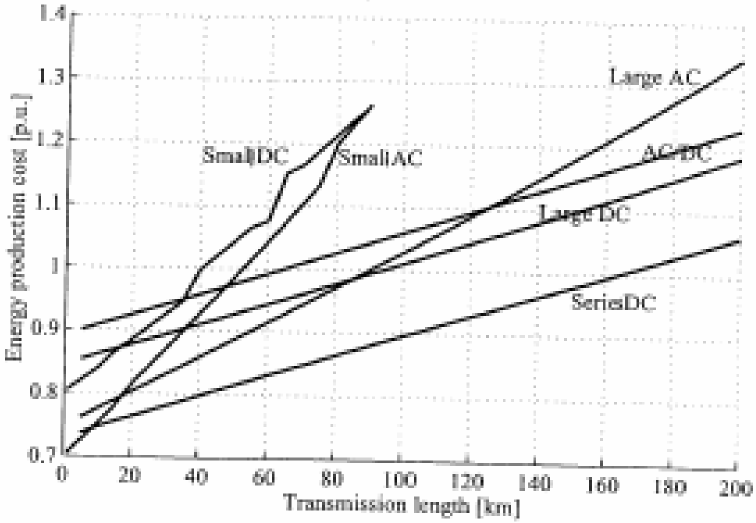



*Fig. 3.9* The normalized energy production cost of the different 160 MW wind farms as function of the transmission distance and at a average wind speed of 10 m/s.

**Wind Farm Configuration and Energy Efficiency Studies - Series DC versus AC Layouts**
STEFAN LUNDBERG
Department of Energy and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
Goteborg, Sweden 2006

**Evidence #4: Advantages of AC power over DC.**

From: http://www.school-for-champions.com/science/ac.htm

There are distinct advantages of AC over DC electricity. The ability to readily transform voltages is the main reason we use AC instead of DC in our homes.

## *Transforming voltages*

The major advantage that AC electricity has over DC electricity is that AC voltages can be readily transformed to higher or lower voltage levels, while it is difficult to do that with DC voltages.

Since high voltages are more effecient for sending electricity great distances, AC electricity has an advantage over DC. This is because the high voltages from the power station can be easily reduced to a safer voltage for use in the house.

Changing voltages is done by the use of a **transformer**. This device uses properties of AC electromagnets to change the voltages.

*(See AC Transformers for more information.)*

## *Tuning circuits*

AC electricity also allows for the use of a **capacitor** and **inductor** within an electrical or electronic circuit. These devices can affect the way the alternating current passes through a circuit. They are only effective with AC electricity.

A combination of a capacitor, inductor and resistor is used as a tuner in radios and televisions. Without those devices, tuning to different stations would be very difficult.

**Evidence #5: Despite the odds, Nicola Tesla won out the “War of the Currents” at the end of the eighteenth century.**

**From Tesla: Master of Lightning (2000)**

In spite of their differences
Edison hired Tesla to improve the performance of his DC generators.
Tesla said he was promised $50,000 if he was successful.
The offer seemed too good to be true.
I entered the Edison Machine Works
where I undertook the design of DC dynamos and motors.
My regular hours were from 10:30 am till 5:00 am the next day.
When I completed the task I went to Edison for payment
and he laughed.
Edison was very amused by this

and said: You just don't understand our American sense of humor, Mr. Tesla.
So Tesla had had enough by that time
and he picked up his hat and walked out.
Tesla paid dearly for his pride.
I lived through a year of bitter tears and hard labor
digging ditches for Edison's underground cables.
But he was still determined to develop his AC motor.
With help from a group of investors
he opened a laboratory on Liberty Street only a few blocks from the Edison's offices.
There he began to assemble a prototype of the motor he had envisioned seven years earlier.

Along with it he developed all the components of
the system of AC power generation and transmission still used today.
In May of 1888, Tesla was ready to unveil his motor to the world.
The subject which I now have the pleasure of bringing to your notice
is a novel motor which I am confident will at once
establish the superior adaptability of alternating currents.
Over the next five years 22 U.S. patents were awarded to Nikola Tesla
for AC motors, generators, transformers and transmission lines
the most valuable patents since the invention of the telephone.
One of the few men who understood the great potential of Tesla's inventions

was the Pittsburgh industrialist George Westinghouse.
He visited Tesla's laboratory and, on the spot,
he offered to purchase all the patents dealing with the alternating current system
for one million dollars.
Westinghouse also proposed a royalty of $2.50
for each horsepower generated by a Tesla invention.
The young Serb was on his way to fortune and fame
while other inventors looked on with fascination and with envy.

In all my troubles
I did not neglect to become a real American citizen
making me a proud and happy man.
During the late 1880s Edison began a negative media campaign
to discredit the alternating current system of electricity
being developed by Westinghouse and Tesla.
It became known as The War of the Currents.
My personal desire would be to prohibit entirely the use of alternating currents.
They are as unnecessary as they are dangerous.
Edison employees demonstrated the dangers of alternating current
by electrocuting animals in public demonstrations.
Just as certain as death Westinghouse will kill a customer

within six months after he puts in a system of any size.
None of his plans worry me in the least.
An Edison associate suggested using alternating current
as a means of executing criminals.
A test took place at New York's Auburn State Prison in 1890.
Several gruesome attempts were required to kill the victim.
Disgusted witnesses claimed his spinal cord burst into flame.
The infliction of the death penalty is not only barbarous and inhuman
but unnecessary as a factor in the scheme of modern civilization.
The war of the currents came to a dramatic head in 1893.