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A Study of How the Electric Grid Functions

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Abstract: The aim of this paper is to trace the evolution of the electric grid from early battery-powered circuits to the modern systems of today. It begins by examining the initial operation of telegraph systems and their subsequent upgrade to the Single Wire Earth Return (SWER) method—a configuration still utilized in certain power distribution grids. Furthermore, the paper discusses the optimization of earthing systems and explains how the adoption of Tesla's AC system prevented the electrochemical destruction of urban metal drainage and foundations, a common failure point of Edison's DC systems.

Keywords: Edison, Tesla, electric grid, batteries, telegraph, SWER.

INTRODUCTION

The Telegraph and the "Eureka" Moment

Most students learn that a battery's terminals must be connected to a bulb to complete a circuit. In such a DC circuit, the positive terminal sits at a higher potential (e.g., 1.5V) while the negative terminal is at zero potential (0V), creating the "electrical pressure" that forces current to flow in a continuous loop [Kumar, R. R. *et al*., 2023].

Early telegraph systems mirrored this principle. A battery was connected to a solenoid; when the circuit was closed, the solenoid generated a magnetic field that pulled an iron core to produce an audible "click." By alternating between long and short signals—Morse Code—messages like "SOS" (... --- ...) could be transmitted across vast distances [Pugh, D. 2024].

Initially, engineers believed two separate copper wires were mandatory to transmit a signal from Sibu to Bintulu. However, in 1838, German scientist Carl August von Steinheil made a breakthrough. While attempting to use railway tracks as dual conductors for the Nuremberg–Fürth line, he discovered that the ground itself could serve as a conductor, leading to the Single Wire Earth Return (SWER) system [Shrivastava, H., & Prasad, S. 2022].

Steinheil's mentor, the mathematician Carl Friedrich Gauss, had suggested using parallel railway tracks as conductors to avoid the cost of stringing wires. The experiment failed because the wooden sleepers and damp ground caused the electricity to "leak" across the tracks. Instead of giving up, Steinheil realized that if the ground was "stealing" the electricity, then the ground itself must be a conductor. He discarded the second rail and buried large metal plates at each station, proving the Earth could act as a massive return path and halving the copper requirements for future networks [Wendler, E. 2023].

The Earth as a Reservoir

In a SWER system, the path functions as follows:

- The Outward Path: Electrons leave the source battery at Sibu and travel through the copper wire to the Bintulu solenoid.
- The Work: The current energizes the solenoid to create the signal.
- The Return Path: The current enters the Bintulu earth plate and is "pulled" by the grounded negative terminal in Sibu.

The Earth's total resistance is remarkably low—not because soil is a superior conductor, but because its cross-sectional area (A) is effectively infinite. According to the resistance formula:

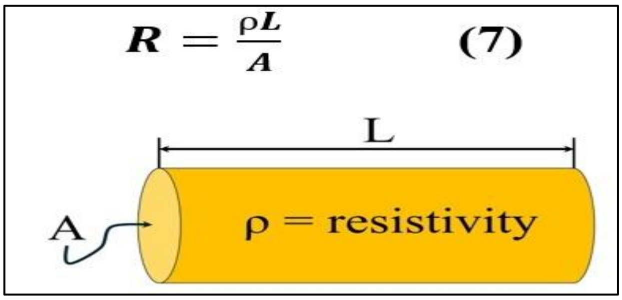

Fig 1: As A becomes gargantuan, the total resistance (R) of the earth path drops significantly below that of the copper wire itself [Ouedraogo, K. *et al*.,].

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Modern 275 kV AC Systems: The Electrical "Uphill"

In the modern 275 kV AC grid, earth rods serve as a safety reference. During balanced operation, the three phases mathematically cancel each other out, and no current flows through the ground. However, we keep this "proven path" ready. If a fault occurs, energy perceives the 0V substation earth rod as a shortcut, dissipating safely into the ground.

One can imagine the Bakun Hydroelectric Plant as being "uphill"—electrically speaking. Power is stepped up to 275 kV, creating the pressure that drives current toward the 0V reference of the substation earth rods. In an AC system, these electrons don't "flow away"; they shuttle back and forth 50 times per second. For 10 ms, an electron is pulled toward the Kuching substation; for the next 10 ms, it reverses toward Bakun. They are not traveling 800 km; they are vibrating in place, acting as the medium for a great oscillation of power [Arora, K. *et al*., 2022].

The "Global Pool" Concept

When I explained this to my son, who is also an electrical engineer, he raised a brilliant question: *"If there are telegraph batteries all over the region between Sibu and Bintulu, how does the current from Bintulu 'know' it must travel to that one specific battery in Sibu?"*

A common misconception is that specific electrons dumped into the soil at Bintulu must travel in a straight line back to Sibu. In reality, the Earth acts as a limitless reservoir of charge. When Bintulu "deposits" current, the Sibu terminal "withdraws" an equivalent magnitude locally. The "return" is not about the identity of the electrons, but the maintenance of the balance [Prescott, G. B. 2022].

The Interconnectedness of Systems

This concept of interconnectedness echoes the 2022 Nobel Prize in Physics, awarded to Alain Aspect, John Clauser, and Anton Zeilinger for their experiments with entangled photons [Rangwala, S. A. 2022].

- The Quantum Link: When two particles are "entangled," they share a single existence. If you change the state of one in Sibu, the state of the other in Bintulu—or even on Mars—changes instantaneously. This phenomenon occurs faster than the speed of light, defying our traditional understanding of distance [Achar, S. *et al*., 2024].
- The Electrical Link: While the electrical signal in a SWER system travels as an electromagnetic wave—at roughly 2 X 108 m/s, which is 66.7% the speed of light (c ≈ 3 X 108 m/s)—it shares a similar philosophical truth: the two distant points are not truly separate. They are tied together by the medium of the Earth, reacting to one another as part of a single, unified system [Andrews, S. S. 2023].

The Anatomy of the Generator

At the Bakun powerhouse, the stator contains three phase coils (R, Y, and B) joined at a common star point (neutral), which is connected to the grounding grid. In the R-phase, the winding forms a clockwise coil at the top and an anticlockwise coil at the bottom. As the rotor—a powerful electromagnet—spins, its North and South poles pass these coils simultaneously. Because of the reversed winding, the induced currents add together, doubling the magnitude of the generated power [Karre, R. K. *et al*., 2022].

The Vital Return Path

When the R-phase current "moves back" during its negative cycle, it redistributes through the Y and B phases via the star point. Because Bakun sits on resistive sandstone and igneous rock, engineers implement a sophisticated Earth Mat [Prabhakar, C., & Deshpande, R. A. 2014]:

- Grid Mesh: Large copper cables buried in a vast grid across the site.
- Deep Ground Rods: Driven 3 to 10 meters deep to reach the water table.
- Exothermic Welding: Fusing connections to ensure they never corrode.
- Soil Enhancement: Using conductive carbon-based clays (SEM) in high-resistivity areas.

The War of Currents: Destruction vs. Balance

During the "War of Currents," Edison's DC system suffered from its appetite for destruction. Because DC drives electrons in a one-way stream, any leakage caused electrolysis, acting like a slow acid that corroded the city's metal veins—its water and gas pipes.

AC, however, possesses an inherent balance. By oscillating, the electrons prevent this structural decay. They do not march forward to destroy; they vibrate in equilibrium, allowing energy to pass through the Earth without consuming the world around it. It is worth noting that Nikola Tesla, who pioneered the AC system, derived his ideas through flashes of intuition—a "knowing" that proved superior to Edison's tedious empirical

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testing and incremental improvement [Ghosh, A. 2025].

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