Episode Book

EPISODE #5881

How the Grid Loses Half Its Power — and How Delhi Fixed It

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SYNOPSIS

Losses scale with the square of current, which is why the grid runs at high voltage and why a crackling wire is money on fire. But the World Bank's loss indicator bundles physics with pilferage — so a country's grid ranking is partly engineering, partly governance. This episode unpacks the real numbers: Singapore at 0.23 percent, the US around six, the UK near ten, Iraq at 59. Then the case study: how Delhi cut losses from over 52 percent in 2002 to roughly 5.5 percent today, using capacitor banks, static meters, feeder-level analytics, and special courts that actually prosecuted theft.

TRANSCRIPT



Corn

There's a crackle under a transmission tower. Most people hear it and think nothing of it. That's money.



Herman

That's heat. That's electricity that got generated and never arrived.



Corn

Daniel sent us this one, and it's the kind of question that starts small and gets away from you. He wants to know how lossy the grid actually is. What percentage of generated electricity disappears between the plant and the socket. How much of that is physics and how much is theft and bad meters. What the international benchmarks look like, who's good at this, who's terrible at it, whether there's a floor you can't go below.



Herman

And then the case study.



Corn

And then Delhi, where losses were over fifty percent and are now around five or six. Which raises the obvious question of how you even pull that off, and how you find the leaks in a network that spans thousands of kilometres. So the shape of this is: the physics of the wire, then the politics of the meter.



Herman

6.51 percent. That's the global transmission and distribution loss figure for 2024, output-weighted. Which sounds fine until you look at the distribution.



Corn

Meaning?



Herman

That's the average. Half the world is worse than 9.8 percent. The mean across countries is 12.4. And more than half the countries that track this lost at least ten percent of their electricity in 2023. Twenty-four nations lost over twenty percent. Two lost more than half of what they generated.



Corn

Two countries losing more than half their electricity.



Herman

Iraq at 59 percent. Venezuela at 31.



Corn

So the honest answer to "how much is lost" is: somewhere between a rounding error and a coin flip.



Herman

That's the range. And here's the part that makes the whole topic interesting — the World Bank's headline loss indicator explicitly bundles physical losses with commercial losses. Their own glossary says "including pilferage." So a country's grid efficiency ranking is partly a measure of engineering and partly a measure of governance.



Corn

You can't separate the wire from the law.



Herman

You cannot. Statistics can't do it. The number that ranks Singapore at 0.23 percent is the same number that ranks Iraq at 59. And the World Bank's own rule of thumb is that physical losses in a sound grid rarely exceed eight percent, and anything above twenty almost always means metering and bill collection problems.



Corn

So a high number is not "their wires are bad." A high number is "somebody isn't paying."



Herman

Usually the second thing wearing the first thing's clothes.



Corn

Start with the physics, because the physics sets the floor.



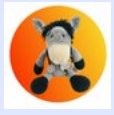
Herman

Losses scale with the square of current. That's the whole game. Double the current and you quadruple the losses. Which is why you transmit at high voltage — you get the same power at lower current, and the losses fall out of the equation.



Corn

And the lost energy goes where?



Herman

Heat. It's resistive heating in the conductor. You hear it as the crackle. You see it as sagging power lines, because the conductor heats up and expands.



Corn

So the sag is a bill.



Herman

The sag is a bill you're paying and can't read. In the US, the split is roughly two percent in transmission and four percent in distribution. About six percent total.



Corn

Why is distribution worse?



Herman

Lower voltage means higher current for the same power. And distribution is where the transformers are, and transformers have their own losses — core losses that run whether or not anyone's using power. Plus you've got thousands of miles of low-voltage line and no way to keep it all tight.



Corn

Six percent in the US. That's the baseline.



Herman

That's a sound grid. Roughly five percent on the EIA's numbers averaged over 2018 to 2022.



Corn

And then you cross into the countries where the number is thirty.



Herman

Then you cross into the countries where the number is thirty. And the interesting question isn't the wire anymore, it's the meter.



Corn

So give me the split.



Herman

The best granular look at this is a feeder-level study in Uttar Pradesh, published in January. One high-loss feeder. It lost 42 percent overall — three times the regulator's normative allowance. And it varied month to month between fifteen and fifty-eight percent.



Corn

Fifty-eight in a bad month.



Herman

Fifty-eight. That's not physics. Physics doesn't fluctuate like that. When they pulled it apart, commercial losses — metering gaps, under-billing, theft — accounted for two-thirds. Technical losses, the high-tension and low-tension line loss, transformer overloading, that was the remaining third.



Corn

Two-thirds commercial.



Herman

And the feeder-level detail is what gets you. Fourteen percent of consumers had no meter or a burnt or damaged one. Nearly half the bills were generated without an actual meter reading. Three percent of consumers were caught using hooks to bypass the meter. And eight percent of consumers were tagged to the wrong feeder entirely.



Corn

So a tenth of the customers weren't even being measured in the right place.



Herman

They were being billed, just not against the energy they actually drew. The accounting was fiction.



Corn

Half the bills generated without a reading. So the bill is a guess.



Herman

A guess with a due date. And the straight answer is that in a lot of systems the guess is optimistic for the utility and pessimistic for the customer, or the reverse, depending on who's doing the guessing.



Corn

Argentina.



Herman

Argentina is the counter-example and it's the most useful thing in this whole topic. Their losses nearly doubled. About twelve percent in 2015, about twenty-four percent in 2023. Middle-income country, no war, no collapse — they just stopped investing.



Corn

And the mechanism?



Herman

The transmission and distribution companies didn't have the capital to maintain the networks, and the smart-meter rollout got delayed. So the assets degraded and nobody could see where.



Corn

You don't have to have a catastrophe to lose half your grid efficiency.



Herman

You just have to stop spending on it. Losses are not a fixed property. They're a maintenance outcome.



Corn

Give me the league table.



Herman

Lowest losses: Singapore at 0.23 percent. South Korea at 3.24. China at 3.43. Finland 3.56. Israel 3.87. Czech Republic 3.91. Canada around four.



Corn

Singapore at a quarter of a percent.



Herman

Singapore went from about 6.6 percent to 0.2 over roughly twenty-five years. They're a city-state with a single utility and total metering discipline. It's the cleanest possible case.



Corn

And the worst?



Herman

Iraq at 59.25 in 2022. Venezuela 31. Argentina 23. Egypt 19.87. Morocco 18.19. Brazil 15.11. Pakistan 14.83. India 14.16. Nigeria 14.08.



Corn

And the middle?



Herman

US 5.48. Germany 5.04. Japan 4.93. France 6.96. UK 9.87, which surprises people given how modern their grid is.



Corn

Why is the UK at nearly ten percent?



Herman

Age of the distribution network, mostly. A lot of it is legacy cable in the ground. It's not a governance story, it's a "we built this in the nineteen-fifties and we're replacing it slowly" story.



Corn

So even the good countries have a physical story behind their number.



Herman

Every one of them does. The point is whether the number is mostly physical or mostly commercial. Singapore is almost purely physical. Iraq is almost purely commercial. Same indicator.



Corn

Now, the floor. Is there one?



Herman

I went looking for a hard theoretical minimum and I couldn't find a single authoritative statement of one. What I found is that you could, in principle, get to essentially zero with superconducting materials.



Corn

So the theoretical minimum is zero.



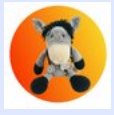
Herman

The theoretical minimum is zero. The practical minimum is nothing like zero, because the cost of superconductors far exceeds the value of the losses you'd save. You'd be spending a dollar to save a nickel.



Corn

What's the practical floor?



Herman

A few percent. Singapore at 0.23 is the empirical low, and they got there with a city-state and one utility and complete metering. The World Bank's rule of thumb is that physical losses in a sound grid rarely exceed eight. So somewhere between a quarter of a percent and eight is the real band, depending on geography and density.



Corn

Which means the interesting question isn't "what's the floor," it's "why are these two countries on opposite ends of a factor of two hundred."



Herman

And the answer is almost never the wire.



Corn

That brings you to Delhi.



Herman

Delhi is the case study Daniel's pointing at and it deserves the attention. In 2002, Delhi's aggregate technical and commercial losses were over fifty-two percent. Some pockets of east and central Delhi were running around sixty-three percent.



Corn

Six in ten units generated, never paid for.



Herman

Six in ten. And as of the financial year just ended, the Delhi Economic Survey put the number at 5.54 percent. A decade low. The Times of India put it at nearly six percent against a national average of just over fifteen.



Corn

Fifty-two to five and a half in about twenty-five years.



Herman

On the first of July 2002, the state-run Delhi Vidyut Board was unbundled into six entities and distribution was privatised to BSES and Tata Power. Tata Power inherited 53.5 percent losses in the north. BSES took 51.5 in South Delhi and 63.1 in East Delhi.



Corn

So the private operators started with the worst grid in the country.



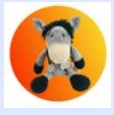
Herman

They started with the worst grid in the country. And then the national Electricity Act of 2003 did the structural work — it unbundled generation, transmission and distribution, opened the sector to private operators, and created the mechanisms to actually prosecute theft.



Corn

Which is the piece everyone skips. You can privatise and still lose if there's no consequence for stealing.



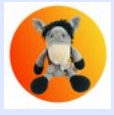
Herman

That's the whole hinge of it. Privatisation gave somebody an incentive. The Act gave them a tool.



Corn

So what did they actually do?



Herman

Capacitor banks first, and this is the least glamorous and most important thing. Reactive loads — motors, air conditioners, all the inductive stuff — were pushing current up without doing useful work. Higher current means higher losses and dragged-down voltage. Capacitor banks supply that reactive power locally instead of pulling it down the line.



Corn

So you fix the current by fixing the power factor.



Herman

You fix the current, and the losses fall because losses track the square of current. Then: replacing overhead lines with underground cable. Phasing out mechanical meters for static meters. Streamlining billing. Special electricity courts for faster theft prosecution, so a case doesn't take six years.



Corn

Courts. As grid infrastructure.



Herman

Courts as grid infrastructure. Inspection drives with police, and for a period with the Central Industrial Security Force. And then later the IT stack — data analytics, feeder-level monitoring, SCADA, AI for real-time visibility.



Corn

Hold on. Capacitor banks aren't new technology. Static meters aren't new.



Herman

None of it is new. That's the point. Grid Brief's summary of this is the line I'd put on the wall — "most of the fix was not new generation but plain distribution engineering combined with accountability."



Corn

Measuring what flows, billing what's used, and paying for reactive power where it's consumed.



Herman

And the results are the receipts. Tata Power Delhi Distribution's own losses fell from 53.1 percent in 2002 to 6.3 percent in 2023. The regulator's targets for the coming year are 5.49 for Tata Power Delhi, 6.22 for BSES Yamuna, 6.43 for BSES Rajdhani.



Corn

So they're still grinding down the last percent.



Herman

They're grinding, and that's where the story changes character. Delhi hit a record peak demand of 8,748 megawatts this year and buys seventy-six percent of its power from outside the city. And they still report about six percent losses with pockets of resistance.



Corn

What kind of pockets?



Herman

JJ clusters, non-regularised colonies, e-rickshaw charging. The e-rickshaws are drawing fifteen to twenty megawatts illegally. Power theft cost Delhi's discoms about 383 crore rupees in the year just gone — roughly six percent of revenue.



Corn

So the last few percent are people charging scooters in a lane.



Herman

The last few percent are people charging scooters in a lane, and it's the most politically difficult part because you're going into informal settlements to cut people off.



Corn

That's the short answer to "why can't everyone do this." The first forty points are metering and cable. The last four points are politics.



Herman

And the Delhi official's line on it is that it took infrastructure, technology, inspections and consumer trust, in that order, over decades.



Corn

How do you even find the leaks? That's the part I actually don't understand.



Herman

Energy accounting. You map every asset and index every consumer to a distribution transformer, then you compare the energy delivered at the feeder against the units billed.



Corn

And the difference is the loss.



Herman

The difference is the loss. But that only works if you know which consumers hang off which transformer — and in the Uttar Pradesh study, only about sixty percent of consumers were mapped to their distribution transformer. There was no digital asset repository at all.



Corn

So before you can find the theft, you have to find the wires.



Herman

The council built a mobile app just to map feeder assets and service lines, because there was no record of what was where.



Corn

You're doing an inventory of your own grid.



Herman

Because nobody had ever done one. That's the unglamorous truth of it — a lot of loss reduction is a man with a phone photographing a pole.



Corn

And the modern layer?



Herman

Smart metering. India's Revamped Distribution Sector Scheme launched in July 2021 with an outlay of around 3,03,758 crore rupees, roughly thirty-four billion dollars, and it funds both loss-reduction infrastructure and smart metering. As of June last year, 224 million smart meters had been sanctioned and 32 million installed.



Corn

A lot sanctioned, a tenth of that installed.



Herman

That's the gap that matters. Sanctioning is a press release. Installing is a truck and a man and a customer who has to let him in.



Corn

And the detection side?



Herman

Detection has moved to machine learning. There's a paper from March this year — a hybrid graph neural network plus LSTM framework — reporting 93.7 percent accuracy on imbalanced theft datasets. Earlier work used deep convolutional networks and recurrent GRU models.



Corn

Why is theft detection a machine-learning problem at all? Isn't it just "the meter says zero and the house has lights on"?



Herman

Because the obvious theft gets caught. What's left is the subtle stuff — a meter tampered to under-read by fifteen percent, consumption patterns that look plausible but aren't. You're looking for a statistical fingerprint, not a missing meter.



Corn

And at scale, you can't send a man to look at all of them.



Herman

You can't. At 224 million meters you need a model to tell you which twenty thousand are worth a visit.



Corn

What's the national trajectory in India?



Herman

All-India discom losses fell from 25.21 percent in the financial year ending 2015 to 16.37 percent in the year ending 2024. The national average for the year just gone was a bit over fifteen.



Corn

From a quarter to a sixth.



Herman

From a quarter to a sixth, and the scheme target is twelve to fifteen percent by March 2028. Which raises the Delhi question again — Delhi is at five and a half, the national average is fifteen, and the target is twelve. So Delhi is a genuine outlier, not the leading edge of a wave.



Corn

Which means Delhi's lesson is replicable in principle and hard in practice.



Herman

The electrical engineer at Jamia Millia who studies this put it plainly — replicating it requires a concerted effort from all stakeholders. Customers, the utility, the government, and their employees. Which is a polite way of saying it needs everyone to keep doing boring things for twenty years.



Corn

Delhi took twenty-five years. And the country as a whole is at fifteen and aiming for twelve.



Herman

Which tells you the last three points are the expensive ones.



Corn

I've been sitting here thinking about the capacitor banks, and I think you buried the lede.



Herman

Go on.



Corn

Reactive power is the silent thief. It's the current that does no work and still heats the wire. And the fix is a box of capacitors at the substation, which has been understood since before either of us was doing anything.



Herman

Since about the nineteen-twenties, honestly. Power factor correction is old knowledge.



Corn

So the most impactful intervention in the most dramatic grid turnaround in the world is a century-old piece of electrical engineering that costs almost nothing relative to the problem.



Herman

And it doesn't photograph well, so it doesn't get funded in a ribbon-cutting.



Corn

That's the actual story. Nobody wants to cut a ribbon on a capacitor bank.



Herman

You cut a ribbon on a smart meter pilot.



Corn

Meanwhile the machines that were actually doing the damage are the AC units and the motors.



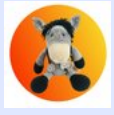
Herman

Which brings it back to something your brother would say. The grid doesn't care how clever your software is if the current is wrong.



Corn

Let me put the whole thing back to you as one picture and you tell me where it's wrong.



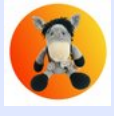
Herman

Go.



Corn

There are two grids. There's the physical grid, which loses a few percent no matter what, because copper heats up and transformers hum. In a sound grid that's under eight percent and often around six. And then there's the commercial grid, which is the same wires with a broken accounting layer on top, and that one can lose forty percent.



Herman

That's not wrong at all. The physical grid is a physics problem with a cost curve. The commercial grid is a governance problem with a physics problem attached.



Corn

And the difference between Singapore at a quarter of a percent and Iraq at fifty-nine is almost entirely which grid you're describing.



Herman

Almost entirely. And the physical grid has a floor. Superconductors could take it to zero, but the cost is absurd. Singapore's 0.23 is the empirical low. The practical floor is a few percent.



Corn

One thing I'd flag on the practical floor — it depends on density.



Herman

Say more.



Corn

A city-state with a million people packed into a small area has short wires and few transformers. A country the size of Canada is transmitting across a continent. So the same engineering discipline produces different numbers because the geography is different.



Herman

That's a real correction. Canada at four percent is doing well for its geography. Singapore at 0.23 is doing well for its geography. You can't compare them as if they were the same problem.



Corn

So the honest benchmark isn't "who's lowest," it's "who's closest to what's physically achievable for their shape."



Herman

That reframes Iraq entirely, because Iraq's problem is not that they're spread out. It's that the meter doesn't mean anything.



Corn

Which brings it back to Delhi. Twenty-five years, privatisation, courts, cable, capacitor banks, meters, and then AI on top.



Herman

In that order. The AI is the last thing, not the first.



Corn

Everyone wants the AI to be the first thing.



Herman

Everyone wants the model to find the theft. The model can only find the theft if you already know which transformer the customer hangs off.



Corn

Which is the man with the phone photographing a pole.



Herman

Energy accounting first, analytics second.



Corn

If somebody asked me what the lesson of this episode is, it's that the grid is a measurement problem before it's a technology problem.



Herman

The measurement problem is political, because the people you're measuring don't want to be measured.

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