Episode Book

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Why Servers Have Two Power Cords

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SYNOPSIS

Every year, data centers draw roughly 415 terawatt hours of electricity — about 1.5% of the world's power. But why does the equipment pulling that load have two separate cords? This episode unpacks the layered architecture of data center power redundancy: 2N and N+1 topologies, automatic transfer switches, and the counterintuitive research arguing that redundancy can actually reduce reliability. It's a tour through the engineering decisions that keep the internet running when the grid doesn't.

TRANSCRIPT



Corn

There are four hundred and fifteen terawatt hours of electricity going into data centres every year. Roughly one and a half percent of the world's electricity. And the thing Daniel noticed last time, the thing that actually stuck, was that the equipment pulling that power has two separate cords coming out of it.



Herman

Dual-corded. Two inputs, meant to pull from two independent networks.



Corn

Right. And Daniel's written back in with a whole set of follow-ups on the back of it. He wants to know, first: if the guiding principle is that every piece of equipment should have redundant power, wouldn't it make more sense to implement that redundancy centrally rather than run parallel connections out to every single device? Or has he misunderstood the principle entirely?



Herman

That's a good place to start, because I think he's half right.



Corn

Second: he assumes somebody has implemented this at the building level. Say a critical government facility with connections to two independent electricity networks plus a backup generator. Is there an equivalent of centrally managed failover for electrical distribution? And is there something like intelligent load balancing, the way network traffic gets balanced? His analogy, roughly: send power from this connection to these circuits, and from the other source to different circuits.



Herman

That's the fun one.



Corn

And third, he wants to know what these redundant power systems actually look like, where they're implemented, and what they cost to run. So, three questions, plus the "did I misunderstand" check. Where do we start?



Herman

Start with the misunderstanding, because it unlocks the other two.



Corn

Alright. Unlock it.



Herman

The principle isn't "every device has two power cords." That's the visible symptom. The principle is eliminating single points of failure across the entire electrical chain, top to bottom. And the trick is that "the chain" is the right word — it's not one system, it's a stack of layers, and each layer protects against a different class of failure.



Corn

Define the terms for people, because the episode lives or dies on these two.



Herman

N plus one means one extra component beyond what's needed. So if you need four generators to carry the load, you have five. 2N means two complete, fully independent systems, each capable of carrying the entire load on its own. A side and B side. And the whole point of A and B is that they share nothing. Separate utility feeds, separate UPSs, separate power distribution units, separate cable routes. If they share anything, they aren't really two.



Corn

And the vertical stack, top to bottom?



Herman

Utility feeds at the top, ideally two independent ones. Then generators, plus battery banks or UPS to bridge the gap while the generators spin up. Then transfer switches to move load between sources. Then PDUs, floor-mounted and rack-mounted. And at the very bottom, the dual-corded servers, two power supply units per server, one on A, one on B.



Corn

So the "parallel connections to every device" that Daniel's asking about isn't the whole architecture.



Herman

It's the bottom of the stack. It's the last meter. Which is exactly why it can't be replaced by anything upstream of it.



Corn

Alright, let's answer his first question properly then. Why do this at every layer instead of just centrally?



Herman

They do both, and they have to. Central redundancy — dual utility feeds, 2N UPS, N plus one generators — protects against upstream failures. Grid loss, substation failure, transformer failure. But the last few feet are still failure points. The PDU, the power cord, and the power supply inside the server itself. No amount of central redundancy protects against a failed power supply inside a chassis. Only the server's own second PSU can do that.



Corn

Because the failure is downstream of where the central system stops.



Herman

And you can see it as a table. Utility feeds protect against a grid or substation outage, that's 2N. Generators protect against extended utility loss, usually N plus one. UPS and batteries bridge the gap before the generator spins up, and they clean up power quality, N plus one or 2N. Transfer switches protect against source failure. PDUs protect against distribution failure, A and B pairs. Server PSUs protect against internal PSU failure, dual-corded. Each layer covers a failure class the layer above literally cannot.



Corn

So the answer to "did Daniel misunderstand" is no, not really. He just assumed redundancy was one decision, and it's actually six or seven decisions stacked.



Herman

And they're complements, not alternatives. That's the thing the question is really probing at. If you only did it centrally, you'd lose device-level protection. If you only did it at the device, you'd lose everything upstream. You'd have a beautifully dual-corded server connected to two cords that both run back to a single failed substation.



Corn

Which is the classic failure case.



Herman

Two power supplies plugged into the same socket. They fail together. And that's the load-bearing assumption in the whole design — the probability math assumes independence of failure events. If the two paths share any component, the redundancy is arithmetic on paper and nothing in reality. Two "independent" utility feeds that trace back to the same substation are not independent.



Corn

So the strictness of 2N — physically separate utility entrances, separate cable routing — that's not gold-plating. That's the only thing stopping you from building an expensive illusion.



Herman

It's the entire value proposition. What 2N contradicts. A facility can have two feeds, two UPSs, two PDUs, and still go down, and the post-mortem reads "common-cause failure." The design had a single point of failure wearing a costume.



Corn

And the cost of the device-level layer specifically?



Herman

Double the cabling. Double the PDU ports. Much more complex cable management. It's expensive, and it's still the only mechanism that survives a PSU or cord failure. There's no cheaper way to protect the last meter, because the last meter is inside the thing you're trying to protect.



Corn

Hold on. I want to push on something before we move up the stack. Redundancy is supposed to buy reliability. But the research keeps insisting that adding it can actually reduce availability. Walk me through why that isn't just contrarian noise.



Herman

It's a serious engineering argument, and it dates back to Charles Perrow's Normal Accidents. The claim is that redundancy increases complexity, and more complex systems are more error-prone. And there's a specific mechanism — redundancy can cause shirking of responsibility. If there are two of something, nobody owns it. The person who would have maintained the single critical unit now assumes the other one will cover.



Corn

So the backup becomes a reason not to maintain the primary.



Herman

And production pressure erodes safety margins. You have a spare, so you push the system harder, closer to its limits, because you can afford a failure. And then the failure happens while something else was already degraded.



Corn

So redundancy is a trade, not a free reliability multiplier.



Herman

It's a trade. And the honest version of the argument is: redundancy is worth it when it's done with independence and monitoring, and it's a liability when it's done as a checkbox. Marc Brooker's framing is that redundancy increases complexity, which reduces availability unless the components fail independently and the system can actually detect which ones are healthy. If your monitoring is bad, you have two systems and no idea which one is lying to you.



Corn

That lands as a general rule about infrastructure, honestly. The spare is only a spare if you know the state of both.



Herman

And you can see exactly why the data centre industry still pays for it. The alternative — one cord into one PDU off one feed — fails in a way you cannot design out. So you accept the complexity, and you spend the money on the monitoring so the complexity doesn't eat the benefit.



Corn

So Daniel's first question is answered: they do it centrally, they do it at the device, and the reason is that the layers cover different failures and neither replaces the other.



Herman

And the second half of his question — whether anyone's built building-level centrally managed failover — the answer is yes, and it's been standard for decades. The technology that does it is the transfer switch, and it's a much more interesting device than it sounds.



Corn

So the hypothetical government facility with two independent grid connections and a generator — that's real.



Herman

That's a Tuesday. That's how you build a hospital, an airport, a telecom exchange, a serious data centre. And the transfer switch is the thing that makes it automatic, which is where the "centrally managed" part comes from.



Corn

Walk the taxonomy.



Herman

Automatic Transfer Switch. It senses loss of the primary source, commands the generator to start, breaks the utility connection, connects the generator, and when utility comes back and stabilises, it transfers back and shuts the generator down after a cool-down. That's open transition. Break-before-make. There's a brief interruption — typically under a sixth of a second — and that interruption is a deliberate feature, because it prevents backfeeding the utility. Linemen working on a line that's supposed to be dead expect it to be dead.



Corn

So the tiny gap in power exists to keep a human being alive.



Herman

That's the trade. You can eliminate the gap with closed transition. Make-before-break. Zero-interruption transfer. But now you're momentarily paralleling your generator with the grid, so both sources have to be synchronised. Voltage difference under five percent, frequency difference under zero point two hertz, phase angle under five degrees, and the whole overlap under a hundred milliseconds. And you need utility approval, because you're feeding the grid for a moment whether you mean to or not.



Corn

And closed transition is the one that gets specified where?



Herman

Explicitly recommended for data processing and electronic loads. Anywhere a load interruption of even the shortest duration is objectionable. Which is the entire reason the dual-corded server exists in the first place.



Corn

So there's a feedback loop here. The more sensitive the load, the more you care about the transfer quality, the more you care about the two-source topology.



Herman

And there are two more variants. Soft-loading transfer switch. It synchronises and runs the on-site generation in parallel with utility power, not just for backup but for peak shaving. You generate your own power during expensive hours, and you're already running the generator when the grid goes down. And a static transfer switch, which uses power semiconductors instead of moving parts and transfers within a quarter-cycle. Used where even a few cycles of interruption is unacceptable.



Corn

So the "centrally managed failover" is not a metaphor. It's a physical device, and it comes with a decision tree about how much interruption you can tolerate.



Herman

And the best real-world example of the whole thing is Toronto Pearson Airport. Four redundant electrical lines, each capable of supplying the entire airport. They use a spot network substation with reverse-current relays that open breakers to failed lines while power keeps flowing. So a line dies, the relay trips, everything carries on, and nobody in the terminal notices.



Corn

Four lines, each capable of carrying everything. That's 4N, effectively.



Herman

It's beyond what most data centres do. And it's exactly Daniel's hypothetical, built at building and campus scale. Two independent sources plus a generator is the conservative version. Pearson just keeps adding lines.



Corn

Now his third question, the network analogy. Which is the one I want to get into, because I think it holds right up to the point where it doesn't.



Herman

It holds further than you'd expect. Intelligent load balancing is literally listed as a feature of larger floor-mounted PDUs, right alongside power filtering, remote monitoring, and SNMP control. And intelligent PDUs meter power at the inlet, at the outlet, and at branch-circuit level, and they let you switch individual outlets on and off remotely.



Corn

There's software in the loop at the rack level already.



Herman

At the grid level. Transmission networks are built with redundant pathways precisely to prevent a single point of failure. If a line fails, power reroutes across the remaining lines. Circuit breakers disconnect overloaded lines, and power is redistributed across what's left. Functionally, that's identical to network traffic routing around a failed link.



Corn

The spot network at Pearson is doing the same thing. Reverse-current relays isolating failed feeds while the others carry on.



Herman

Demand response, load shedding — that's traffic shaping. A utility or a large facility shifts or drops load dynamically to keep the system in balance.



Corn

Where does it break?



Herman

Three places, and they're all physics. First: electricity is synchronous and instantaneous. Packets can be buffered, queued, reordered. AC power has to be in phase and at matching frequency to be combined or switched between sources. You can't just route a watt from source A to circuit B without respecting the phase relationship. That's why closed transition has those absurdly tight sync parameters — under five percent voltage, under zero point two hertz, under five degrees phase angle. Those numbers exist because you physically cannot combine unsynchronised AC.



Corn

You can't buffer a packet of electricity at the switch.



Herman

Not cheaply. Network switches buffer in memory — that's trivial. Electrical switches generally can't. Storage is the buffer, and storage is batteries or pumped hydro, and it's expensive. So the network analogy assumes a buffering layer that the electrical system mostly doesn't have.



Corn

Second point?



Herman

The "load balancer" is largely mechanical and electrical, not software. Transformers, tap changers, protective relays, transfer switches. Software — SCADA, smart grid — is increasingly layered on top, but the foundation is physical. A network load balancer is a software function. An electrical load balancer is a copper-and-steel device with a computer bolted onto it.



Corn

The third, which I suspect is the real one.



Herman

The failure modes are physical and dangerous. Backfeeding, arc faults, phase mismatches — those can destroy equipment or kill people. Which is why the strict isolation requirements have no network equivalent. A dropped packet is an inconvenience. A phase mismatch at a closed-transition switch is an explosion.



Corn

The analogy is real at the level of "reroute around failure." It's false at the level of "just send it wherever you like."



Herman

That's the honest answer to Daniel's question. Yes, there's intelligent load balancing. No, it isn't the same thing as a network load balancer, because the medium is fundamentally different.



Corn

Which brings us to the smart grid, because that's the closest thing to closing the gap.



Herman

The smart grid is the closest thing to a true software-defined electrical load balancer. Two-way communication, distributed intelligent devices, smart meters, smart distribution boards and breakers integrated with demand response, and automatic surplus distribution through auto-smart switches.



Corn

And microgrids?



Herman

The modern framing. A local grid that can disconnect from the regional grid and island itself, running autonomously on its own resources. Generators, batteries, renewables. That's the architecture for a facility that wants to be able to operate independently of the grid entirely. Which is the logical endpoint of everything we've been describing.



Corn

Now the cost side, because Daniel asked what these systems cost to run, and I suspect the number is going to be bigger than people expect.



Herman

Power is the largest recurring cost to a data centre user. Electricity is over ten percent of total cost of ownership for high-power-density facilities. A high-availability one-megawatt data centre is estimated to consume around twenty million dollars in electricity over its lifetime, and cooling alone accounts for thirty-five to forty-five percent of that ownership cost.



Corn

Twenty million for one megawatt.



Herman

The way we measure the efficiency of it is PUE — Power Usage Effectiveness. Total facility power divided by IT equipment power. Average US data centre sits around two point zero. State of the art is around one point two. And the best-in-class, two-phase immersion cooling, gets down to about one point zero one.



Corn

Which means almost all the power you buy is doing compute work.



Herman

Almost all of it. And the reason PUE matters here is that the redundancy sits in that denominator, not the numerator. Every UPS, every transfer switch, every redundant PDU is facility power that isn't doing compute. So 2N roughly doubles the electrical infrastructure capital, and it runs at lower utilisation, because you have two systems each sized for the full load and each normally carrying half of it. That hurts efficiency.



Corn

Redundancy has a running cost, not just a build cost.



Herman

A real one. There's a line in the literature I like — in two years, the cost of powering and cooling a server can equal the cost of the server hardware itself. The metal and silicon are a one-time purchase. The electricity is forever.



Corn

Which explains why the industry keeps pushing efficiency even while it piles on redundancy.



Herman

It explains the scale problem. Data centres consumed roughly four hundred and fifteen terawatt hours globally in twenty twenty-four. About one and a half percent of world electricity. That's projected to roughly double to about nine hundred and forty-five terawatt hours by twenty thirty. The largest facilities now consume over three thousand megawatts. In the US, data centre power demand is projected to account for almost half the growth in electricity demand between now and twenty thirty.



Corn

Half the growth in national electricity demand. That's not an engineering footnote any more, that's a grid planning question.



Herman

There's a practitioner's caveat I want to bring in, because it cuts against the clean picture. A working engineer reported twice experiencing data centre hard outages caused by the power distribution system failing oddly — once switching between mains and UPS, and once between UPS and generator. The transfer mechanism itself was the failure.



Corn

The thing designed to prevent failure became the failure.



Herman

His conclusion was: the failover mechanism may have dependencies you didn't plan for, so you have to actually test it. Which means the architecture on paper and the architecture in the room are two different things.



Corn

Which, honestly, sounds like the part nobody writes about.



Hilbert

It's usually not the thing you designed for.



Hilbert

The failure. It's almost never the thing you designed for. I watched a transfer test once where the generator started, the switch threw, the load came back up, everybody ticked the box. And it passed. Only it hadn't. The UPS downstream of that switch had been sitting on bypass for months. Nobody had noticed. So the successful transfer had been riding on utility power the whole time. We'd been testing the switch against a live grid and calling it a generator test.



Herman

The test passed because the source it was supposed to move away from never actually went away.



Hilbert

The switch did exactly what it was told. It just wasn't carrying what we thought it was carrying. That's the whole thing in one line — the design is right, the as-built is right, and then somebody puts a unit on bypass during maintenance and nobody updates the drawing.



Corn

How long was it on bypass before anyone caught it?



Hilbert

Long enough that the maintenance window it was set for had been closed out twice. The paperwork said it was back in service. It wasn't. And here's the part I'd add to what you two were saying — the failure pattern is almost never the component. It's the breaker somebody racked out six weeks ago for a repair and never racked back in. It's the bypass nobody wrote down. Everything's correct in the schematic, and the room doesn't match the schematic.



Herman

You're describing a gap between the design and the as-maintained state.



Hilbert

I'm describing a room. The drawing's a drawing. I spent a lot of nights in rooms like that and the drawing was always older than the room. It's not that people are lazy. It's that the person who racked the breaker out was on shift and the person who was supposed to rack it back in wasn't, and between those two there's nobody whose actual job is the state of the thing.



Corn

The architecture isn't the hard part.



Hilbert

The architecture's the easy part. The architecture's what gets sold. What's hard is somebody at three in the morning knowing which of the two identical-looking panels is actually fed from the generator.



Corn

That reframes the whole episode, actually.



Hilbert

Anyway. That's what I'd have added.



Corn

You know what this does to Daniel's question? He's asking whether the redundancy should be central or distributed, and the answer might be "yes, and neither," because the failure lives in the maintenance state, not the topology.



Herman

That's exactly why the testing regime matters more than the design premium. You can spend double on 2N and have a better drawing and a worse outcome than an N plus one facility where somebody actually walks the room.



Corn

The misconception to kill here is the one everybody holds. That redundant power means every device has two cords.



Herman

Every device having two cords is the bottom layer of a layered architecture, and it's the layer most visible and least important on its own. Strip it out of context and it looks like waste. In context it's the only thing covering the failure classes nothing upstream can reach.



Corn

Second misconception, and this is the one Daniel's question is really circling: that two independent feeds are automatically independent.



Herman

If they trace back to the same substation, or share a transformer, or a breaker, or a cable tray, they are not independent, and the redundancy is arithmetic on paper. That's common-cause failure, and it's the reason 2N insists on physically separate entrances and routing.



Corn

The third: that adding redundancy automatically improves reliability.



Herman

Perrow's argument is that it can do the opposite. More complexity, more failure paths, shirked ownership, and production pressure that erodes the margin you built. And Hilbert's version of that is the one I'll remember — the redundancy was fine, and the system had quietly stopped being the system the drawing said it was.



Corn

If the failure pattern is almost always the gap between the design and the as-built state, what does that mean for the 2N versus N plus one trade-off as data centre demand roughly doubles by twenty thirty?



Herman

It changes the calculus, because 2N buys you redundancy on paper, and the maintenance regime is what decides whether that redundancy exists in the room. If you're planning to add nine hundred and forty-five terawatt hours of demand and data centre growth is going to be almost half the US electricity demand increase, then the cost of redundancy stops being an engineering footnote and becomes a grid planning question.



Corn

The network analogy Daniel reached for is real, but bounded. It holds at the level of rerouting around a failure. It breaks on synchronisation, on the cost of buffering, and on the fact that the failure pattern are physical and can kill somebody. The smart grid is the closest thing to closing that gap, and it is not there yet.



Herman

Not yet. Islanding microgrids, software-defined switching, intelligent PDUs with per-outlet metering — that's the direction. But the medium still does whatever the medium does.



Corn

If you want to pitch in on where this is going, leave us a review wherever you get your podcasts. Thanks as always to Hilbert Flumingtop, our producer, for keeping the desk running while we argue about switchgear.



Herman

He does it quietly.



Corn

That's been My Weird Prompts. You can find everything at my weird prompts dot com.



Herman

We'll be back soon.



Corn

See you then.