# BEYOND MONITORING

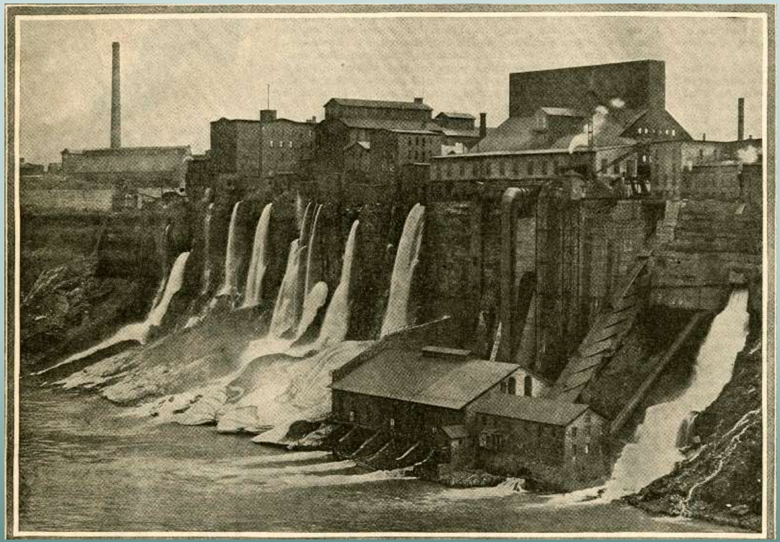
## MSCADA FOR DER-INTEGRATED DISTRIBUTION GRIDS

Bangkok 2025, Sept

# 'Battle of the Currents'

The "War of the Currents" between **Thomas Edison's DC (direct current)** and **Nikola Tesla & George Westinghouse's AC (alternating current)** transmission took place in the **1880s–1890s**.

The decisive moment came in **1893,** when **Westinghouse and Tesla won the contract to build the power system for the Chicago World's Fair.** This was the first large-scale public demonstration that AC could safely and efficiently power an entire city-sized event.



In **1895,** the first large hydroelectric power plant at **Niagara Falls** began operation, designed by Tesla and built by Westinghouse. It transmitted power over 20 miles to Buffalo, New York — proving AC could carry electricity long distances, something DC could not do economically at the time.

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# The ESI Defining Model

- **The "classic" model emerged**
- **Bulk generation (large thermal/hydro plants, later nuclear)**
- **High-voltage transmission (220 kV, 400 kV, 765 kV, etc.)**
- **Step-down to MV (distribution, typically 33 kV, 11 kV, 6.6 kV depending on country)**
- **Step-down to LV (400/230 V, 240/120 V for end users)**
- **One-way flow from central station to consumer**
- **This became the universal template for power systems worldwide from roughly the 1920s through the late 20th century. It was efficient, scalable, and fit the economic model of large centralized utilities.**

From the 2000s onward, distributed generation (solar PV, wind at MV/LV, EVs) has **broken the one-way flow model.** Power can now flow **upwards** from LV → MV → HV, requiring new protection, control, and market structures

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# Universally Adopted Except . . . .

- **Early isolated systems (pre-grid era)**
  - In many rural or colonial contexts, generation was **local diesel or small hydro** feeding directly at LV or MV, with no high-voltage backbone.
- **DC traction and local networks**
  - Some cities built **urban DC networks** (for trams, subways, mining).
- **Soviet Union / Eastern Europe (pre-1990s)**
  - Broadly the same, but with **very high-voltage long-distance transmission** (up to 1150 kV in Kazakhstan).
- **Japan (still unique today)**
  - Has **two frequency systems** (50 Hz in the east, 60 Hz in the west) **Off-grid & island microgrids**
- Even today, some remote communities use **local LV/MV microgrids** without a HV backbone.
- **"For over a century, electricity flowed one way — from giant power stations through high-voltage networks down to passive consumers. Since the turn of the millennium, that model has been overturned by renewables, climate policies, and falling generation costs, creating a dynamic, bidirectional grid where every consumer can also be a producer."**

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# Why the change?

- **Renewables**
  - **Solar PV and wind** are inherently distributed — they can be built at LV (rooftop PV) or MV (wind farms, community solar) without central station scale.
  - Their variability requires grid flexibility that the old one-way model never had to handle.
- **Government policies**
  - Climate change commitments (Kyoto Protocol 1997, Paris Agreement 2015, EU Directives, U.S. state-level mandates, etc.) have pushed utilities to integrate renewables.
  - Feed-in tariffs, renewable portfolio standards, and tax credits made small-scale generation economically viable.
- **Generation costs**
  - Dramatic falls in **solar module** and **wind turbine** costs since 2010 made distributed generation cheaper than many conventional plants.
  - In some regions, **levelized cost of energy (LCOE)** for renewables is now below fossil fuels, without subsidies.

# The Result

- **Bidirectional power flows:** consumers can become "prosumers".
- **Decentralized architectures:** microgrids, community energy, storage.
- **New operational challenges:** balancing, protection, voltage control, frequency support.
- **Policy-driven markets:** peer-to-peer trading, demand response, locational pricing.
- Since ~2000, the century-old **centralized, one-way, top-down model** has been steadily giving way to a **distributed, multi-directional, policy-driven system**, shaped by renewables, climate policies, and cost competitiveness.

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# Origins of Solar

**1954**: Bell Labs produced the first practical silicon solar cell (about **6% efficiency**, cost ~$1,000 per watt in today's money).

**Late 1950s–1960s**: Solar cells were **too expensive for terrestrial use** but perfect for **space applications** (satellites, where weight and reliability mattered more than cost).

Example: Vanguard I satellite (1958) — first satellite powered by PV.

**1970s:** Oil shocks and early climate concerns triggered government R&D programs.

**1980s–1990s:** Efficiency improved, but costs still in the tens of dollars per watt.

**2000s onward:** Mass production (especially in China), better manufacturing, and economies of scale drove costs down rapidly.

**Cost & Efficiency Trends**

**Cost:**

1970s: >$70 per watt. -> 2010: ~$4 per watt. -> 2020s: **below $0.30 per watt** for utility-scale panels.

**Efficiency:**

From ~6% in the 1950s → ~15–20% for mainstream panels today → >25% for top commercial modules.

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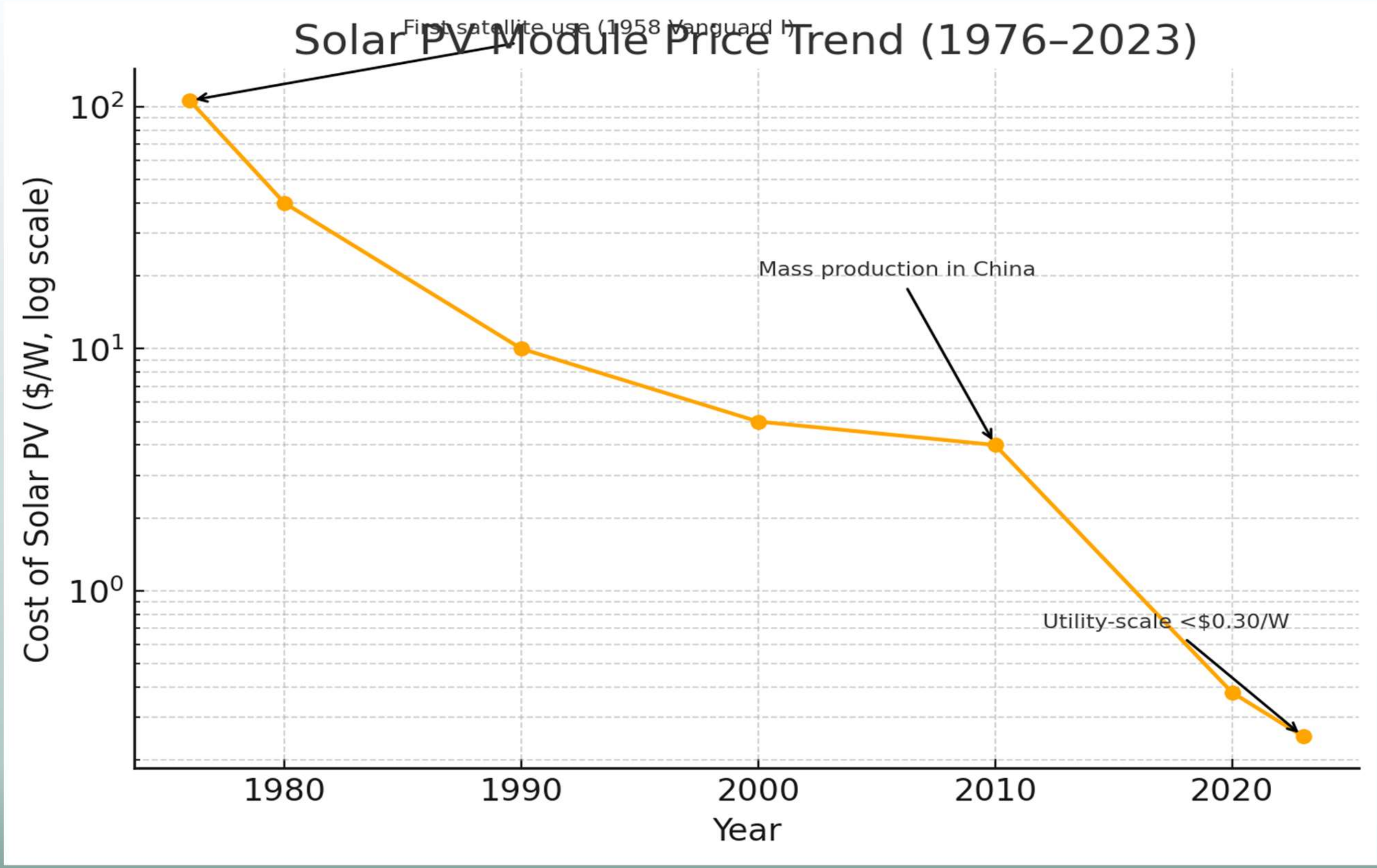
# Solar Price Trends Graphically

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# Evolution of wind

- **Origins & Early Use**
  - **Ancient:** Windmills used for grinding grain and pumping water for centuries.
  - **Modern era:**
    - First electricity-generating wind turbine: **1891, Denmark (Poul la Cour).**
    - 1970s oil crisis → renewed interest.
    - 1980s California "wind rush": early commercial farms (expensive, unreliable by today's standards).
- **Cost & Performance**
  - **1990s–2000s:** Steady growth in Denmark, Germany, Spain; costs remained relatively high.
  - **Since 2010:** Turbine size grew dramatically (from ~50 kW in 1980s to 10–15 MW offshore today).
  - **LCOE** (Levelized Cost of Energy):
    - 1990s: >$200/MWh.
    - 2020s: <$30/MWh (onshore), ~$40–60/MWh (offshore).
- Wind started small and costly, but with scale, bigger turbines, and global supply chains, it is now **one of the cheapest bulk generation sources.**

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# Battery Storage

- **Origins & Early Use**
  - **19th century:** Lead-acid batteries (still used in cars, backup power).
  - **20th century:** Nickel-cadmium, nickel-metal hydride for portable devices.
  - **Lithium-ion (Li-ion):**
    - Developed in the 1980s (Sony commercialized in 1991). Originally for laptops, phones — not grids.
- **Grid & EV Transformation**
  - **2000s–2010s:** EV push (Tesla, Nissan Leaf) → mass production of Li-ion cells.
  - **2015 onward:** Grid-scale battery farms emerge (Tesla Hornsdale Power Reserve in AU, etc.).
  - **Cost & Performance**
  - **2010:** Li-ion cost ~$1,200/kWh.
  - **2023:** ~$140/kWh (almost a **90% drop**).
- Performance: Higher energy density, longer lifetimes, better safety management.
- Batteries evolved from consumer electronics to **critical enablers of renewables,** providing peak shifting, frequency control, and resilience — at costs that have fallen nearly tenfold in a decade.

# Common Thread

•**Solar, wind, and batteries** all started either as niche or high-cost technologies.
•**Mass production, scale, and innovation** drove costs down >80–90%.
•Together, they overturned the old “one-way” grid model and enabled today’s **distributed, flexible, low-carbon power systems**.

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# Summary of Generation Costs / Trends

| Technology | 1980s | 2000 | 2020s | Trend |
|---|---|---|---|---|
| **Coal** | $40–60 | $40–70 | $60–120 (new builds, CCS higher) | Rising (fuel, carbon) |
| **Gas (CCGT)** | $60–80 | $50–70 | $40–80 | Stable but fuel-price sensitive |
| **Nuclear** | $40–70 | $80–120 | $100–180+ | Rising (construction, safety) |
| **Solar PV** | >$4000 | ~$300 | $20–40 | 99% drop |
| **Wind (onshore)** | $200–600 | $100–150 | $25–50 | 80–90% drop |
| **Batteries (Li-ion, $/kWh)** | N/A | ~$1000 | ~$140 | 85–90% drop |

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# Unstoppable Change

**•Traditional fuels (coal, gas, nuclear): Costs flat or rising due to fuel, carbon pricing, safety, and construction complexity.**
**•Renewables (solar, wind): Massive cost collapses since 2000, mainly from mass production, technology learning curves, and policy support.**
**•Storage (batteries): Costs down nearly 90% since 2010, enabling renewables to operate flexibly.**
**•This is upending the century-old grid model, forcing utilities and regulators to rethink distribution networks, tariffs, and market design.**

**Implication: The Emergence of the Prosumer**
Historically, power flowed **one way —** central plants → consumers.
With **cheap solar,** households and businesses can now **produce their own power.**
Batteries add flexibility → consumers become **prosumers** (producers + consumers).
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# New Challenges

**1. Intermittency of Renewables**

**Solar and wind** don't follow demand — they follow the weather.

Results in **voltage swings, reverse flows, and unpredictability** at the LV and MV levels.

The old model assumed generation was always dispatchable (coal, gas, nuclear).

**2. Two-Way Power Flows**

Traditional networks were designed for **top-down, one-way** distribution.

Now with rooftop PV, EVs, and storage:

- Power can **flow back up** the feeder.
- Transformers and protection schemes face stresses they weren't built for.
- Fault current directionality and protection coordination become more complex.

**3. Electrification of Demand**

**EVs:** High, clustered charging loads can overwhelm LV feeders.

**Heat pumps:** Replace gas with large electrical demand for heating.

**Electric cooking & appliances:** Increases baseline LV demand.

Net effect: **peak loads rise** at the same time as supply becomes variable.**4.**

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# New Challenges (cont.)

**4. Inverter-Dominated Grids**

With PV, batteries, and EV chargers, the grid sees more **power electronics** and fewer synchronous machines.

This reduces **system inertia**, making frequency more volatile.

Also introduces **harmonics and power quality issues.**

**5. Operational Complexity & Data Needs**

Legacy DNOs didn't need **real-time data visibility** at LV.

With prosumers, they must monitor **millions of small assets.**

Requires **smart meters, digital twins, SCADA at LV, and advanced forecasting.**

# DNO to DSO

As the **Distribution Network Operator (DNO**) evolves into a **Distribution System Operator (DSO**), the **traditional problems of intermittency and bidirectional flows** are **compounded** by new **power quality challenges**:

**Voltage fluctuations** — rooftop PV injections cause over-voltage at LV feeders, EV charging causes voltage dips.

**Harmonics & distortion** — widespread inverters (PV, EV chargers, heat pumps) inject harmonic currents and distort waveforms.

**Reduced inertia** — inverter-dominated grids respond faster but lack the stabilizing effect of synchronous machines.

**Unbalanced loading** — single-phase PV and EV chargers create **phase imbalance** in 3-phase LV networks.

**Flicker & transients** — rapid fluctuations from PV/cloud cover or EV fast charging create local instability.

**Islanding risks** — prosumer microgeneration can keep small sections energized, endangering maintenance and safety.

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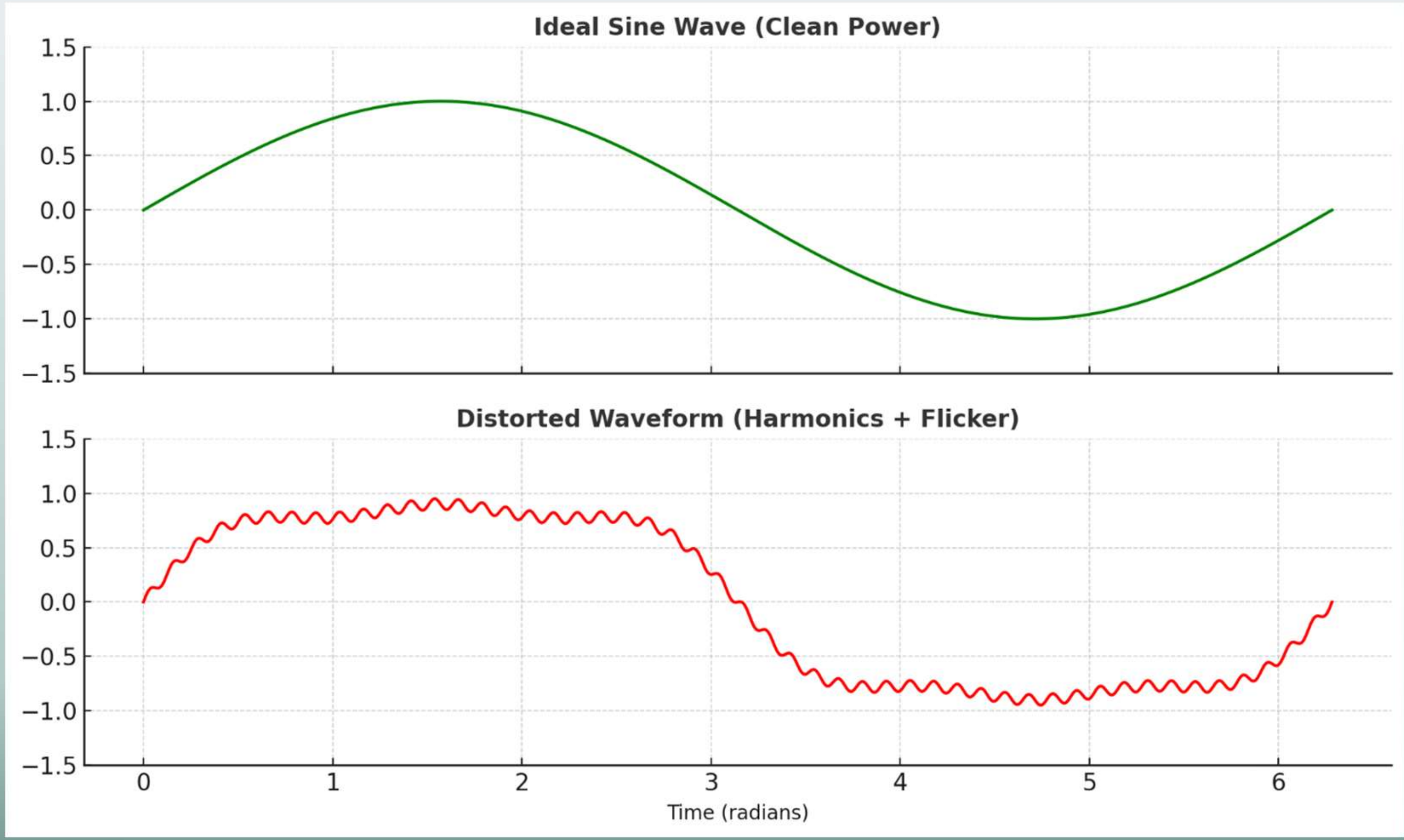
# DSO Power Quality

The DNO is not just facing more complex power flows — it is facing a fundamental shift in **power quality management**. As it becomes a DSO, it must ensure stability, voltage control, and waveform integrity in networks that were never designed for millions of small, intermittent, inverter-based sources."

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# Three different Grids are emerging

**Macrogrid**
The **traditional distribution network,** fed from the transmission system. Delivers power one-way (historically) from substations to consumers. Now facing **two-way flows** and integration of DERs. Operated by the **DNO/DSO.**
**Microgrids**
Defined portions of the grid (often a feeder or a bounded area). Can operate **connected or islanded** from the macrogrid. Examples:

University campuses, Military bases, Shopping malls, Amusement parks, Industrial estates

Typically include **local generation + storage + control system.** Key feature: **intentional controllability** as a subsystem.

**Nanogrids**
Local systems **within a consumer's premises.** Rooftop solar, batteries, EV chargers, smart appliances, heat pumps. Consumer becomes a **prosumer.** Can coordinate with a microgrid or operate stand-alone in limited form (e.g. home backup during outage).

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# Evolution of the SCADA Market

- **First generation: "monolithic"**

  Early SCADA system computing was done by large minicomputers. No Common network no connectivity to other systems. protocols were strictly proprietary. Expensive back-up

- **Second generation: "distributed"**

  More like DCS systems connected through a LAN. Information near real time. which reduced the cost as compared to First Generation SCADA. network protocols still not standardized. Difficult to Engineer

- **Third generation: "networked"**

  networked design, spread across more than one LAN  Effectively a DCS  with a single supervisor and historian.

- **Fourth generation: “embedded"**

  µ-SCADA embedded in the process use open network protocols; provides comprehensive decentralization; requires a different approach to SCADA - traditional SCADA binds MMI to the data stored in specific PLC now pertinent information can be web based info.

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# Traditional SCADA / DMS

- **Centralized Architecture**
    - Designed for *bulk transmission* + *one-way flows*.
    - Limited visibility below HV/MV substations → little or no LV monitoring.
    - Assumes consumers are passive, not active participants.
- **Slow & Coarse Control**
    - Data polled every few seconds to minutes.
    - Works fine for large generators, not for **fast PV/EV dynamics** at LV.
- **Limited Scalability**
    - Built to manage *thousands of nodes* (plants, substations).
    - Struggles with *millions of devices* (rooftop solar, EV chargers, batteries).
- **Rigid, Monolithic Systems**
    - Proprietary protocols (IEC 60870, DNP3) → inflexible, hard to adapt.
    - Extensions (DERMS, ADMS) bolt on complexity instead of rethinking.
- **Power Quality Blind Spot**
    - Legacy SCADA focuses on *voltage, current, breaker status*.
    - Limited/no insight into **harmonics, flicker, phase imbalance** at LV.

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# Transition to Localized SCADA

**1.Distributed Intelligence**
- Local SCADA nodes (edge computers) embedded at **microgrid and nanogrid** level.
- Near-real-time decision-making without waiting for central DMS.

**2.Fine-Grained Visibility**
- Direct monitoring of **LV feeders, prosumer inverters, EV chargers, batteries**.
- Captures **fast fluctuations** that traditional SCADA misses.

**3.Interoperability**
- Native support for **open protocols** (Modbus, OPC-UA, MQTT, IEC 61850, Zigbee, LoRa).
- Seamlessly integrates diverse DERs.

**4.Resilience & Islanding**
- Microgrids and nanogrids can **island with local SCADA coordination**.
- Improves reliability under faults or cyberattacks.

**5.Real-Time Power Quality Management**
- Local analytics detect **voltage sags/swells, harmonics, unbalance**.
- Automated correction using **smart inverters, storage, demand response**.

**6.Scalability by Design**
- Each micro/nano unit runs independently yet **synchronizes upward**.
- System grows naturally as prosumers and DERs expand.

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# Effects on Quality

- **Reliability:**
  - Faults localised and contained within micro/nanogrids.
  - Faster fault detection, restoration, and reconfiguration.
- **Power Quality:**
  - Continuous monitoring and mitigation at source (inverter, EV charger).
  - Avoids propagation of harmonics/instability up to the macrogrid.
- **Flexibility:**
  - Dynamic balancing of local supply/demand → reduces stress on macrogrid.
  - Supports **peer-to-peer trading** and **demand-side response** natively.

Traditional SCADA and DMS were built for a one-way, centralized world. They are too slow, too coarse, and too blind to manage the complexity of prosumers and inverter-based resources. By localizing SCADA at the microgrid and nanogrid level, as we do with LinX, we gain fine-grained control, real-time power quality management, and resilience — transforming reliability and stability in the distribution network."

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# Then and Now

| | Original MC680x0 | Raspberry Pi 5 | Indicative Difference |
|---|---|---|---|
| CPU | MC 68030 25MHz, 32 bit, separate FPU, 18 MIPS | 2300 MHz Quad Core, 64 bit, Integrated FPU 5000 MIPS | 275 x the processing speed |
| Memory | 4 Mbytes RWM | 8GByte RWM * | 2000 x capacity |
| HDD | 250MByte SCSI, 20MB/s | 500 Gbyte Micro SD, 1TB NVMe >700 MB/s | 2000x Capacity, 35x speed |
| GPU | None | Integrated@ 400 MHz<br>2 x HDMI (4K @75FPS) | |
| Conns | Serial, Parallel, Ethernet | Serial, Ethernet, Wi-Fi, SPI, I2C, TWI, USB, Bluetooth, etc., | |
| PCB Price | £2,500** (£4,000 today) | £100 (Board + NVMe) | 40 x Cheaper |
| System | £23,500 (£37,500 today) | £900*** | 50 x Cheaper |

*some shared with GPU **Plus OS ***Includes I/O board

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# Closing Statements

- For a century, distribution grids were **one-way highways** delivering bulk power to passive consumers.
- Since 2000, **renewables, prosumers, EVs, and electrification** have overturned that model, creating **two-way, dynamic, inverter-based networks**.
- Traditional SCADA/DMS systems are **too centralised, too slow, and too blind** to manage this new complexity.
- The answer lies in **localized, intelligent SCADA** — bringing visibility, control, and resilience down to the **microgrid and nanogrid** level.
- With this approach, we can ensure not just **reliability**, but also **power quality, flexibility, and resilience** in the age of the prosumer.

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# Conclusion

**“From one-way wires to two-way intelligence.”**

The grid of the past kept the lights on.
The grid of the future must keep the lights on —
**cleanly, reliably, and in both directions.”**

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