# **Using TFT for the energy industries — efficiency with full context**

## **Abstract**

The energy industries face compounding pressures: rising peak demand, aging infrastructure, variable renewable integration, and escalating grid-balancing costs. This paper introduces TFT, a resonance‑based triadic control framework that aligns generation, storage, and load as a coordinated system rather than a linear chain. We provide a primer on current challenges and technologies, outline cost and inefficiency drivers, and then evaluate expected efficiency and resilience gains when shifting from linear control to triadic resonance. We also examine how mid‑level portable power stations paired with hybrid solar and scheduled AC on/off controls can shave peaks, arbitrage time‑of‑use pricing, and enhance backup readiness at household and feeder scales. Finally, we sketch how TFT principles could improve battery system efficiency by reducing impedance mismatches, conversion steps, and harmonic losses. This is a decision‑maker’s draft: quantitative templates, system equations, and deployment heuristics are included for replication and refinement.

## **Introduction**

Power systems were architected around centralized, dispatchable generation feeding largely passive loads through unidirectional networks. As distributed energy resources (DERs), electrification, and variable renewables proliferate, the traditional linear planning‑operate paradigm struggles with volatility, local congestion, and costly peaks. Triadic frameworks offer a different stance: treat generation, storage, and load as a resonant ensemble, dynamically matched in phase, impedance, and intent. TFT formalizes this stance to reduce losses, orchestrate flexible demand, and convert household assets into a coordinated, grid‑supportive fleet. We ground the concept in practical mechanisms—smart inverters, portable power stations, hybrid solar, and scheduled HVAC—to show how triadic coordination can be executed with available hardware and software.

## **Industry challenges and technology advancements**

### **Current challenges**

* **Peak demand volatility:** Peaks drive disproportionate capacity and network costs, with widening evening ramps as solar grows.
* **Aging infrastructure:** Thermal limits, protection coordination, and voltage regulation constraints amplify integration friction for DERs.
* **Intermittency and forecast error:** Renewable variability and load uncertainty increase reserve and ramping requirements.
* **Inefficient end uses:** Poorly tuned HVAC and motor loads create reactive power and harmonic penalties, inflating system losses.
* **Fragmented control:** Device‑level optimizers work locally but can fight grid‑level objectives without coordination.

### **Notable advancements**

* **Smart inverters and grid codes:** Fast VAR support, frequency‑watt, volt‑VAR/volt‑Watt, and ride‑through stabilize feeders.
* **Demand response to VPPs:** From manual TOU response to automated aggregations orchestrating thousands of devices.
* **Hybrid solar systems:** DC‑coupled PV‑battery reduces conversion steps; AC‑coupled retrofits add flexible dispatch.
* **Battery chemistries and BMS:** LFP safety and cycle life, improved coulombic efficiency, and smarter state estimation.
* **Edge‑cloud coordination:** Open protocols enable fleet‑level scheduling, baseline estimation, and settlement.

## **Cost overview and known inefficiencies**

### **Cost and loss drivers**

* **Capacity and demand charges:** System and customer bills hinge on short peak intervals rather than energy totals.
* **Conversion and mismatch losses:** Multiple AC/DC conversions and impedance mismatches stack losses across components.
* **Thermal drift and harmonics:** Off‑design operation increases I²R losses and distortion, shortening equipment life.
* **Forecast and control latency:** Missed ramp windows force conservative reserves and curtailment.

### **Accounting templates**

* **Baseline system efficiency**

*ηlinear=ηpv→dc⋅ηdc→ac⋅ηac→dc⋅ηbatt⋅ηac→load\eta\_{\text{linear}}=\eta\_{\text{pv}\to\text{dc}} \cdot \eta\_{\text{dc}\to\text{ac}} \cdot \eta\_{\text{ac}\to\text{dc}} \cdot \eta\_{\text{batt}} \cdot \eta\_{\text{ac}\to\text{load}}*

* **Triadic system efficiency**

*ηTFT=ηpv→dc⋅ηdc bus⋅ηdc↔batt⋅ηinverter harmonic-aware⋅ηload matched\eta\_{\text{TFT}}=\eta\_{\text{pv}\to\text{dc}} \cdot \eta\_{\text{dc\,bus}} \cdot \eta\_{\text{dc}\leftrightarrow\text{batt}} \cdot \eta\_{\text{inverter\,harmonic-aware}} \cdot \eta\_{\text{load\,matched}}*

* **Peak cost exposure**

*Cpeak=Pmax⋅πcap+Epeak⋅πTOUC\_{\text{peak}}=P\_{\text{max}} \cdot \pi\_{\text{cap}} + E\_{\text{peak}} \cdot \pi\_{\text{TOU}}*

* **End‑use inefficiency**

*Lharm=E⋅(1−PF)+f(THD, unbalance)L\_{\text{harm}}=E \cdot \left(1-\text{PF}\right) + f(\text{THD},\,\text{unbalance})*

Use these templates with local tariffs, device specs, and measurement data to quantify current cost leakage and loss mechanisms.

## **TFT framework and comparative evaluation**

### **TFT principles**

* **Triadic resonance:** **Generation–Storage–Load** are phase‑ and intent‑aligned to minimize circulating energy and mismatch losses.
* **Impedance matching:** Dynamic matching at interfaces reduces conversion steps and reactive power.
* **Harmonic‑aware control:** Inverters synthesize waveforms that match load spectra, reducing THD and copper losses.
* **Coordinated scheduling:** Device fleets follow a shared rhythm: charge, coast, and discharge as an ensemble rather than as isolated optimizers.

### **Expected efficiency shifts**

* **Fewer conversions:** DC‑preferential routing and hybrid coupling reduce cascaded efficiency penalties.
* **Spectral matching:** Lower harmonic currents decrease I²R losses in conductors and transformers.
* **State‑aware dispatch:** Storage operates in high‑round‑trip‑efficiency windows; HVAC pre‑cools/pre‑heats when COP is favorable.
* **System utilization:** Aligning flexible demand with generation boosts capacity factor of both assets and feeders.

### **Quantitative estimate template**

* **Conversion reduction gain**

*Δηconv≈1−∏i=1nηi∏j=1mηj′\Delta \eta\_{\text{conv}} \approx 1-\frac{\prod\_{i=1}^{n}\eta\_i}{\prod\_{j=1}^{m}\eta'\_j}*

where *n>mn>m* as TFT removes stages.

* **Harmonic loss reduction**

*ΔLharm≈k1⋅ΔPF+k2⋅ΔTHD\Delta L\_{\text{harm}} \approx k\_1 \cdot \Delta \text{PF} + k\_2 \cdot \Delta \text{THD}*

* **System‑level gain**

*ηsystemTFT≈ηlinear+Δηconv−ΔLharm+ΔU\eta\_{\text{system}}^{\text{TFT}} \approx \eta\_{\text{linear}} + \Delta \eta\_{\text{conv}} - \Delta L\_{\text{harm}} + \Delta U*

where *ΔU\Delta U* captures utilization improvements from coordination.

Use measured inverter curves, PF/THD logs, and dispatch profiles to bound *Δ\Delta* terms.

## **Portable power stations and hybrid solar for grid support**

### **Mid‑level power station use case**

* **Definition:** 1–5 kW inverter with 1–10 kWh storage, grid‑chargeable, optionally PV‑integrated.
* **Objective:** Shift critical loads to battery during peak TOU windows; recharge off‑peak or via PV; preserve reserve for outages.

### **Scheduled AC on/off and peak shaving**

* **HVAC preconditioning:** Pre‑cool/pre‑heat before peak; coast on battery during peak; resume off‑peak.
* **Critical loads routing:** Fridges, networking, lighting, and fans ride the battery during peak windows; deferrables pause.
* **Control rhythm:** Morning charge, midday PV opportunism, evening discharge, overnight trickle charge.

### **Savings and readiness model**

* **Daily arbitrage savings**

*Sgross=ηrt⋅Cusable⋅Δp⋅nS\_{\text{gross}}=\eta\_{\text{rt}} \cdot C\_{\text{usable}} \cdot \Delta p \cdot n*

* **Battery wear cost**

*Cdeg=Ccycled⋅cdegwithCcycled=Ethroughputcycle lifeC\_{\text{deg}}=C\_{\text{cycled}} \cdot c\_{\text{deg}} \quad\text{with}\quad C\_{\text{cycled}}=\frac{E\_{\text{throughput}}}{\text{cycle life}}*

* **Net savings**

*Snet=Sgross−Cdeg−CauxS\_{\text{net}}=S\_{\text{gross}}-C\_{\text{deg}}-C\_{\text{aux}}*

* **Backup readiness**

*R=CreserveLcriticalhours of autonomous supportR=\frac{C\_{\text{reserve}}}{L\_{\text{critical}}} \quad\text{hours of autonomous support}*

Where *ηrt\eta\_{\text{rt}}* is round‑trip efficiency, *CusableC\_{\text{usable}}* is usable capacity allocated to arbitrage, *Δp\Delta p* is TOU differential, *nn* is cycles/day, *cdegc\_{\text{deg}}* is degradation cost per kWh, and *CauxC\_{\text{aux}}* captures parasitic and control overheads.

### **Fleet‑level impact**

* **Aggregation potential**

*Pfleet=N⋅Punit,Efleet=N⋅EunitP\_{\text{fleet}}=N \cdot P\_{\text{unit}}, \quad E\_{\text{fleet}}=N \cdot E\_{\text{unit}}*

* **Feeder relief:** Synchronized two‑hour evening discharge across *NN* homes trims the feeder peak, cuts transformer thermal stress, and lowers marginal emissions.
* **VPP alignment:** Fleet adheres to a triadic schedule: midday PV absorption, evening discharge, overnight reserve top‑up—exporting flexibility when it’s most valuable.

## **Expected battery efficiency improvements under TFT**

### **Mechanisms**

* **Fewer conversions:** Prioritize DC‑coupled paths between PV, battery, and DC loads.
* **Impedance and thermal matching:** Actively match internal resistance and temperature to keep cells in high‑efficiency zones.
* **Harmonic‑aware inverter operation:** Reduce non‑fundamental currents that heat wiring and transformer copper.
* **State‑selected cycling:** Limit depth‑of‑discharge in routine arbitrage; reserve deep cycles for rare contingencies.

### **Plausible improvement ranges to validate**

* **Round‑trip improvements:** Incremental gains from control and topology often accumulate; measure for 1–3% absolute in RTE via stage reduction and harmonic control.
* **System‑level utilization:** 5–15% more useful kWh/year delivered to loads through better scheduling, curtailed idle losses, and reduced curtailment.
* **Lifetime energy throughput:** Extended cycle life via DoD and temperature management can raise lifetime delivered energy by 10–30%, lowering effective $/kWh‑delivered.

All values above are to be field‑validated; they provide hypotheses and measurement targets, not fixed claims.

## **Discussion and next steps**

### **What to measure next**

* **Device telemetry:** Per‑stage efficiencies, PF, THD, temperatures, and SOC windows under linear vs TFT control.
* **Tariff coupling:** Real TOU spreads, demand charges, and event payments to calibrate arbitrage economics.
* **HVAC response curves:** COP vs ambient and setpoint strategies for preconditioning efficacy.
* **Feeder impacts:** Peak reduction, voltage profiles, and transformer loading under coordinated schedules.

### **Deployment blueprint**

* **Controls stack:** Local controller executes TFT schedules; cloud coordinator aligns fleets to grid signals.
* **Interoperability:** Open protocols for portable power stations, thermostats, and hybrid inverters.
* **Safety and resilience:** Default‑safe modes, reserve bands, and graceful degradation during comms loss.

## **Appendix — worked example templates**

### **1. Household TOU arbitrage with readiness**

* **Inputs:**
  + **Usable capacity:** *Cusable=5 kWhC\_{\text{usable}}=5\ \text{kWh}*
  + **Round‑trip efficiency:** *ηrt=0.90\eta\_{\text{rt}}=0.90*
  + **TOU differential:** *Δp=$0.25/kWh\Delta p=\$0.25/\text{kWh}*
  + **Cycles per day:** *n=1n=1*
  + **Degradation cost:** *cdeg=$0.05/kWhc\_{\text{deg}}=\$0.05/\text{kWh}*
* **Compute:**

*Sgross=0.90⋅5⋅0.25⋅1=$1.125 per dayS\_{\text{gross}}=0.90 \cdot 5 \cdot 0.25 \cdot 1=\$1.125\ \text{per day}*

*Cdeg=5⋅0.05=$0.25 per dayC\_{\text{deg}}=5 \cdot 0.05=\$0.25\ \text{per day}*

*Snet≈$0.88 per day (≈$320 per year)S\_{\text{net}}\approx \$0.88\ \text{per day}\ (\approx \$320\ \text{per year})*

* **Reserve:** If *Creserve=3 kWhC\_{\text{reserve}}=3\ \text{kWh}* and *Lcritical=300 WL\_{\text{critical}}=300\ \text{W}*,

*R=30.3=10 hoursR=\frac{3}{0.3}=10\ \text{hours}*

### **2. Feeder‑level peak shaving**

* **Inputs:**
  + **Homes:** *N=1,000N=1{,}000*
  + **Per‑home discharge window:** *Punit=1.5 kWP\_{\text{unit}}=1.5\ \text{kW}* for 2 hours
* **Compute:**

*Pfleet=1,000⋅1.5=1.5 MWP\_{\text{fleet}}=1{,}000 \cdot 1.5=1.5\ \text{MW}*

*Efleet=1,000⋅1.5⋅2=3 MWhE\_{\text{fleet}}=1{,}000 \cdot 1.5 \cdot 2=3\ \text{MWh}*

This trims a typical feeder peak block while preserving per‑home reserves.

If you want, I can plug in Detroit–Ann Arbor area tariffs, representative device specs for mid‑level power stations, and measured HVAC performance to convert the templates into a data‑tight draft. Also, confirm how you want TFT formally defined in the paper’s glossary so we propagate the exact language you prefer.