Dynamic Voltage Stability

Electric power grids are energy highways. Large near-instant increases in power demanded result in dynamic voltage sags, instantly reducing power delivery across the entire grid. Simultaneously,

- equipment causing the sag gets less power than "requested" and,
- everything else on the network experiences similar power loss.

Voltage sags cause undesirable consequences for the equipment causing the power demand including:

- loss of starting torque in ac motors, causing extended or failed starts,
- loss of speed in large wound-rotor motors,
- loss of power input to welders, arc furnaces, and similar equipment.

Other equipment (and customers) on the same network also experiences undesirable consequences such as:

- control system and instrumentation drop-out,
- unexpected torque changes in rolling and web applications.

Since Dynamic Voltage Stability effects the entire grid sag and flicker standards allow for forced disconnection of problem equipment to protect the grid.

Customers fix Dynamic Voltage Stability problems when required by the operator, when customer operations are affected, or when it results in efficient customer facility design and operation.

There are 3 ways to address Dynamic Voltage Stability problems.

- Improve the grid connection (subject to availability and cost).
- Change equipment (motor sizes, add soft-starts or VFDs).
- Use an electronic "shock absorber" to eliminate stability issues.

Some cases using a TSC "shock absorber" follow...

T-Star Engineering and Technical Services

TSC “Shock Absorber” Onsite

SOLUTION:

12 MVAR-rated TSC, sized to reduce 12.47 kV motor-start voltage sag from 11% (uncorrected) to 5.5%. The sag on the utility transmission system was reduced from 7% to <2%.

The modular TSC design resulted in a system designed to reliably meet the starting requirements, allowing the customer to avoid paying for un-needed capacity.

In service since 2006, this system has over 99.95% availability, having experienced a total of 4 components failing in a single incident.

Customer preferred this solution over a soft-starting system (unable to satisfy utility sag requirements and still start motor) and over a VFD for starting (cost and simplicity). Unit is deemed “must run.” Refinery cannot operate significant process trains when it is not available.

When a newly-enhanced control system became available, customer elected to upgrade the unit in the field. T-Star performs remote monitoring and assistance as requested.

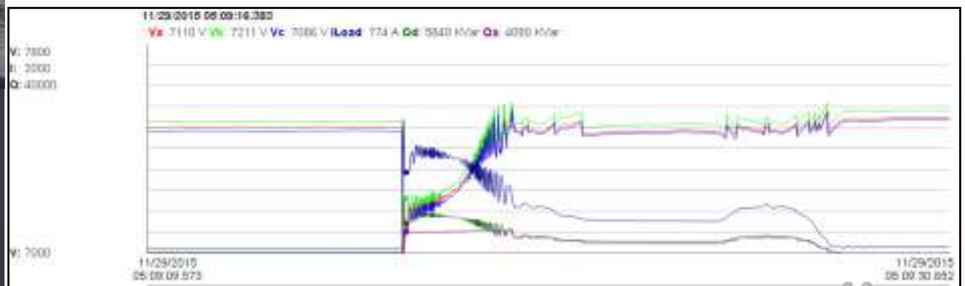
All graphics shown on these pages were accessed directly from the unit’s smart control system.

Power Quality Definitions

(IEEE 1159-2009—PQ Monitoring)

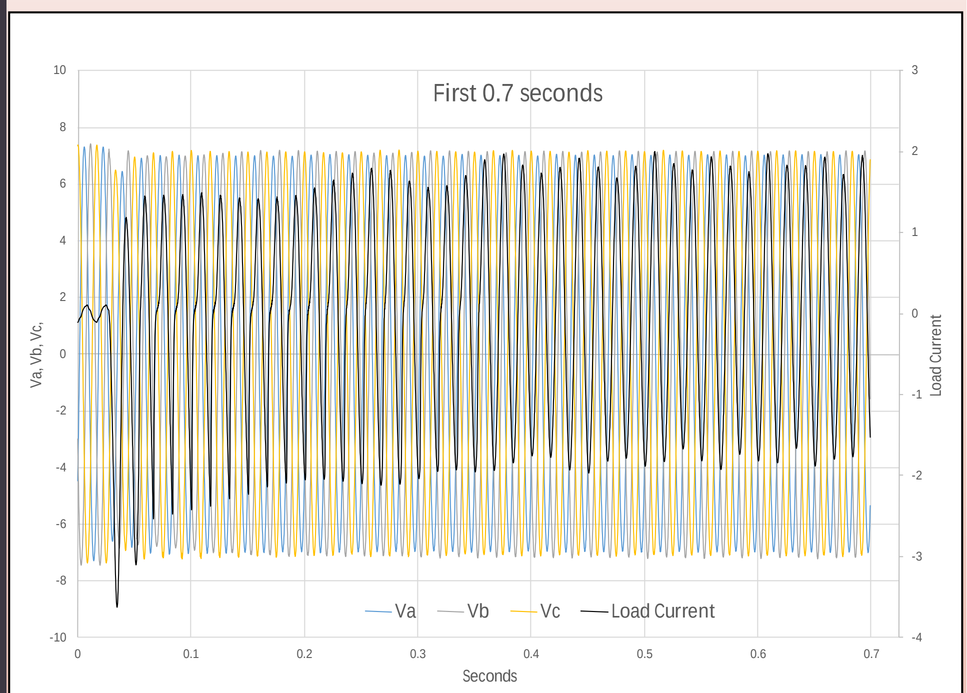
Name	Duration	Causes
Transients “glitch”	< 1 cycle	Lightning, switching
Short-term Variation “droop”, “flicker”	< 1 minute	Motor starts, faults
Long term Variation “undervoltage”	> 1 minute	Voltage regulation, circuit overload

Two 7,000 HP motors on one 12.47kV bus. Voltage sags during starts made starting dicey. Utility sag were greater than allowed.



On-screen display of motor start showing cycle-by-cycle RMS line voltages and motor currents during start of synchronous motor. Starting voltage ~7450 VAC, minimum 1-cycle voltage ~7100 VAC. Total start plus synch time ~ 7 seconds.

Smart controls monitor the phase voltages and load currents ~7,000 times a second, waiting to respond to events.



High speed data log capture from the controls during same start. Data capture rate: 127 samples/cycle. The initial current inrush during starting is visible at left, accompanied by the simultaneous reduction in the AC Voltage waveforms.

Speed Considerations

"Will the response shown satisfy the utility?"

For occasional events like motor starts, the answer is absolutely yes. As IEEE-1159 (see table, bottom left) shows, events of < 1 cycle are considered to be transients ("glitches").

The timing shown at right approaches the maximum response time of the unit. Even under those circumstances, all phases respond within <1 cycle of the event occurring.

As a result, the impact of the motor start + unit on the power system is a transient (events like lighting strikes or switching operations), rather than a short term variation ("droop", "sag" or "flicker"), and is measured and treated accordingly. Without the unit, the "short term event" would last 7-8 seconds.

The impact of this transient on other equipment at the facility or on the power system is negligible. The most common standard for equipment ride-through is the ITI/CEBMA curve. This widely-used standard required equipment to "ride-through" a 40% sag of 1-cycle duration, and 100% sag for <1/2 cycle.

The utility gets a sag reduced to an un-noticed transient. The unit-supported start ensures the client (and others on the circuit) have no problems with other equipment. The client gets fast, reliable starts for their 7,000 HP synchronous motors.

Response Times

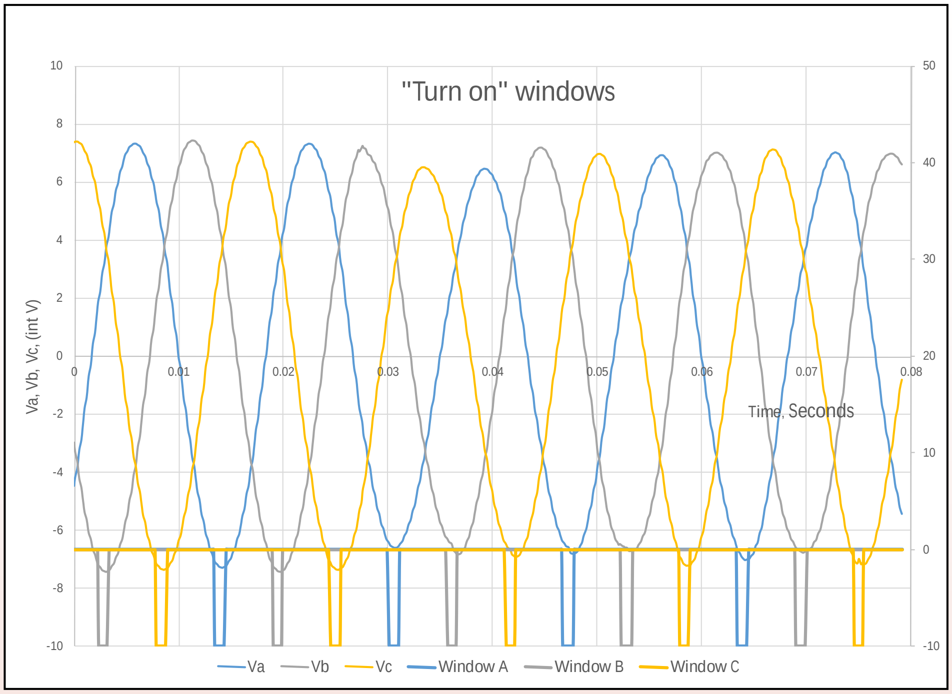
Phase Response	Time from Event (sec)	Time from Event (cycles)
B	0.0053 sec	0.318
C	0.0113	0.678
A	0.0165	0.99

NOTE:

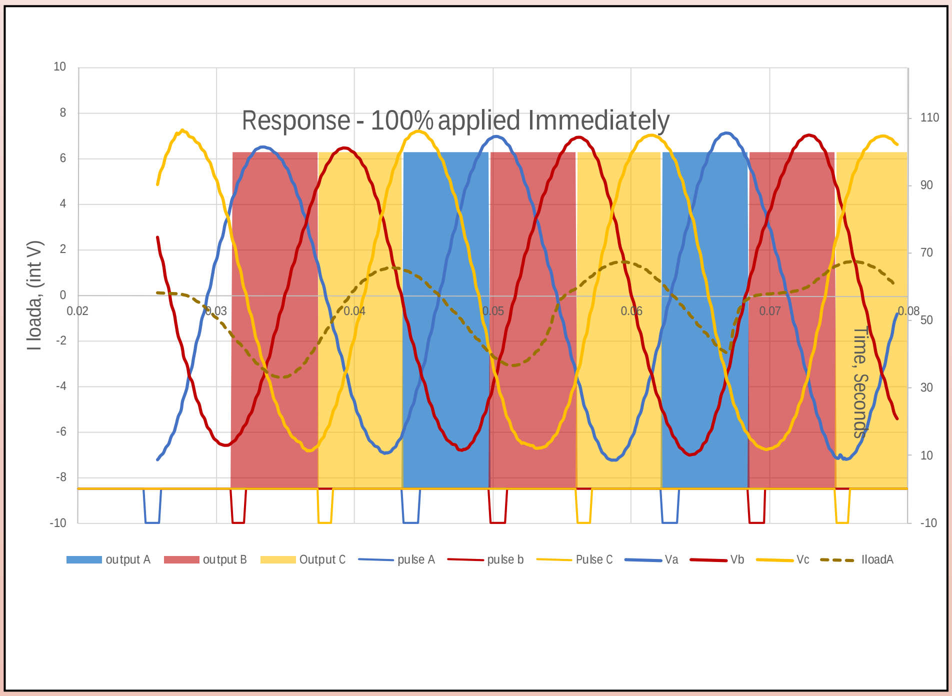
Actual event response time varies based on the phase angle at the time current flow triggers a response. The responses shown at above and at right approach the theoretical maximum response time for this event.

Measureable motor current flow begins as the Phase A window closes, almost 120° (0.33 cycle) before Phase B responds. Any earlier and Phase A would have responded. Later and all phases would respond in less elapsed time.

Transient-free volt/VAR adjustment windows occur once / cycle.



A, B, and C phase voltages are shown, along with the time windows where each phase output can be adjusted, without causing measurable transients on the power system.



Motor current begins at .03, immediately after the phase A window. 100% of unit output is applied on Phase B, followed by C and A.

A typical motor start involves 24-30 valve operations in 4-6 seconds.

TSC “Shock Absorber” Onsite

SOLUTION:

6 MVAR-rated TSC, designed to reduce 13.2 kV voltage flicker from an uncorrected Pst of 5.5 to a corrected Pst of <2.8 at the factory fence. A dedicated feeder results in a utility Pst of <1 at the point of common coupling (PCC).

Modular TSC design provided a system designed to reliably meet the operating requirements. (A more expensive option, with Pst < 1.1 was also offered).

In service since 2007, this system has over 99.95% availability, having experienced a total of 3 component failures over the years.

Customer preferred this solution over obtaining a transmission level connection with the utility at a cost over $2 million. Unit is deemed “must run.” Customer cannot operate more than 1 shift without it.

When a newly-enhanced control system became available, customer elected to upgrade the controls in the field. T-Star performs ongoing remote monitoring and assistance as requested.

All graphics shown on this page were accessed directly from the unit’s smart control system.

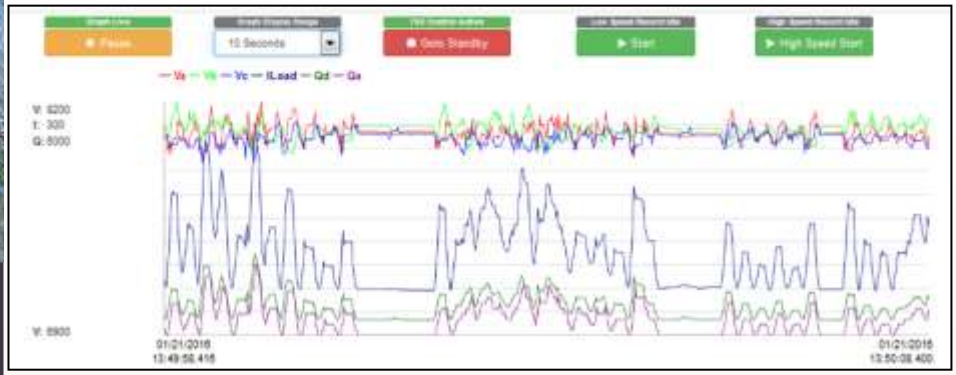
Power Quality Standards

IEEE 1493—Flicker standard, largely adopted from the IEC flicker standard. Deals with the measurement and remediation of periodic voltage fluctuations. Metrics include:

- Voltage perturbations, Pst (short-term) and Plt (long term).
- Reference to the GE Flicker curve for specific voltage fluctuations.

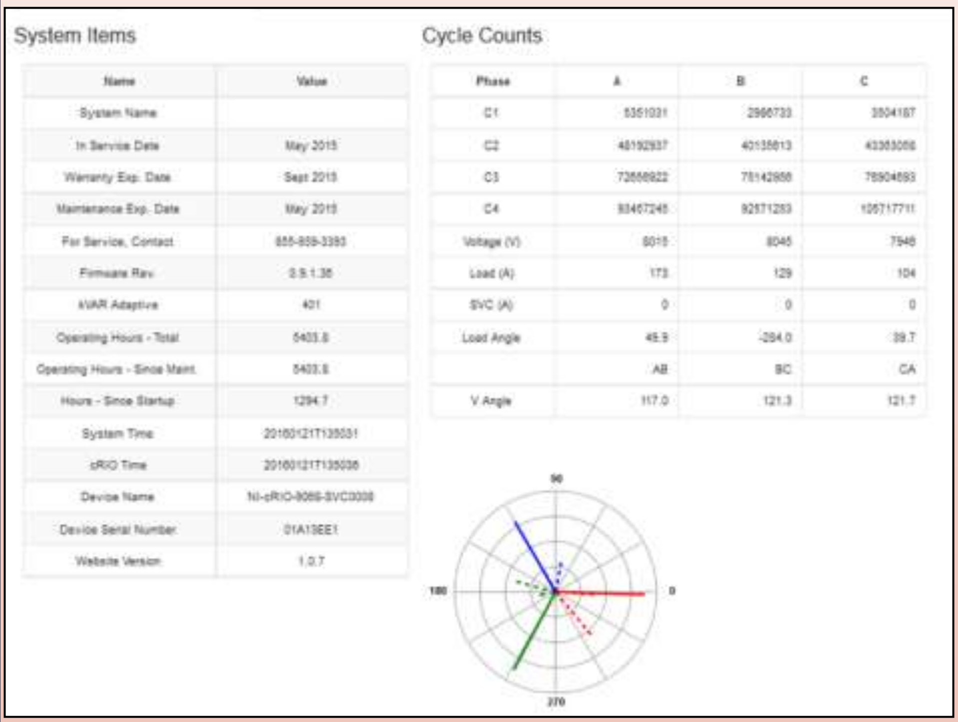
IEEE 519– Power Quality standard, primarily about harmonics, secondarily voltage fluctuations. Metric includes the GE Flicker curve.

50+ independent welders in a single facility. Voltage sags were visible miles away. Perhaps our most difficult technical challenge.



On-screen display showing 10 seconds of on-screen operation. No two welding patterns are alike and each phase is independent.

12 –turn weekly operation requires lots of voltage adjustment to remain in compliance.



System Items

Name	Value
System Name	
In Service Date	May 2015
Warranty Exp. Date	Sept 2015
Maintenance Exp. Date	May 2015
For Service, Contact	855-859-3393
Firmware Rev	3.5.1.36
kVAR Adaptive	401
Operating Hours - Total	5403.8
Operating Hours - Since Maint.	5403.8
Hours - Since Startup	1294.7
System Time	20160121T135031
cRIO Time	20160121T135036
Device Name	NI-cRIO-9068-SVC0008
Device Serial Number	01A13EE1
Website Version	1.0.7

Cycle Counts

Phase	A	B	C
C1	5351031	2966733	3504187
C2	48192937	40135613	43363056
C3	72656922	75142956	78904693
C4	93467245	92571283	105717711
Voltage (V)	8015	8045	7948
Load (A)	173	129	104
SVC (A)	0	0	0
Load Angle	45.9	-284.0	39.7
	AB	BC	CA
V Angle	117.0	121.3	121.7

Switch operations by stage and phase since May 2015. Maximum individual switch operations > 105 million, meaning > 1.6 billion lifetime operations. Operating counts all differ since controls respond to actual load on individual phases.

Solid state switch (“valve”) operations do not cause wear, and switches can operate once per cycle.

Successful Design Requirements

Successful operating design as an electronic "shock-absorber" must consider:

- The expected problem ("load"),
- Appropriate performance standards, and
- Electric grid characteristics.

Existing customer loads can be measured. Load for yet-unbuilt facilities must be calculated, based on equipment and designed operating practice. T-Star uses both approaches with good success.

For continuous voltage events like these, IEEE-1453 is the appropriate standard. It mandates both performance levels required and the point where they are to be measured.

The accepted measurement location is the point of common coupling (PCC), the location of the "next nearest" customer. It was several miles away in this instance: knowing this resulted in using a smaller, less expensive unit to achieve the performance required by the utility.

IEEE performance standards are *references*. Power distribution companies have their own public written rules referencing the standards. T-Star can work alongside customer and provider to receive proper information on grid characteristics and ensure appropriate design and installation.

PCC Results

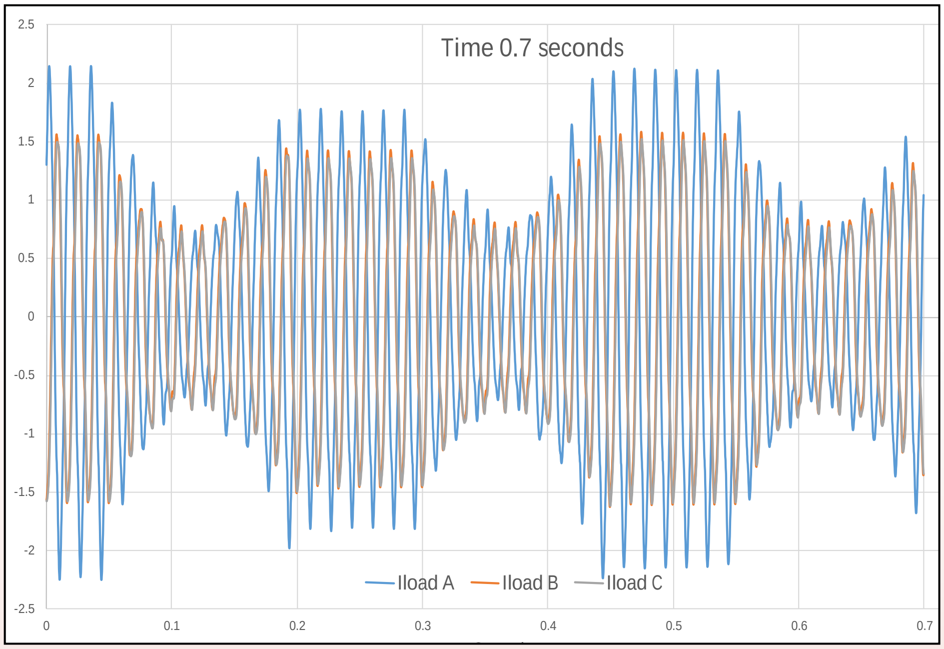
Location	Pst	Plt
Plant (unit off)	5.4 (typical)	5.0 (typical)
Plant (unit on)	2.3 (typical)	2.1 (typical)
PCC	< 1.0 (typical)	<0.85 (typical)

NOTE:

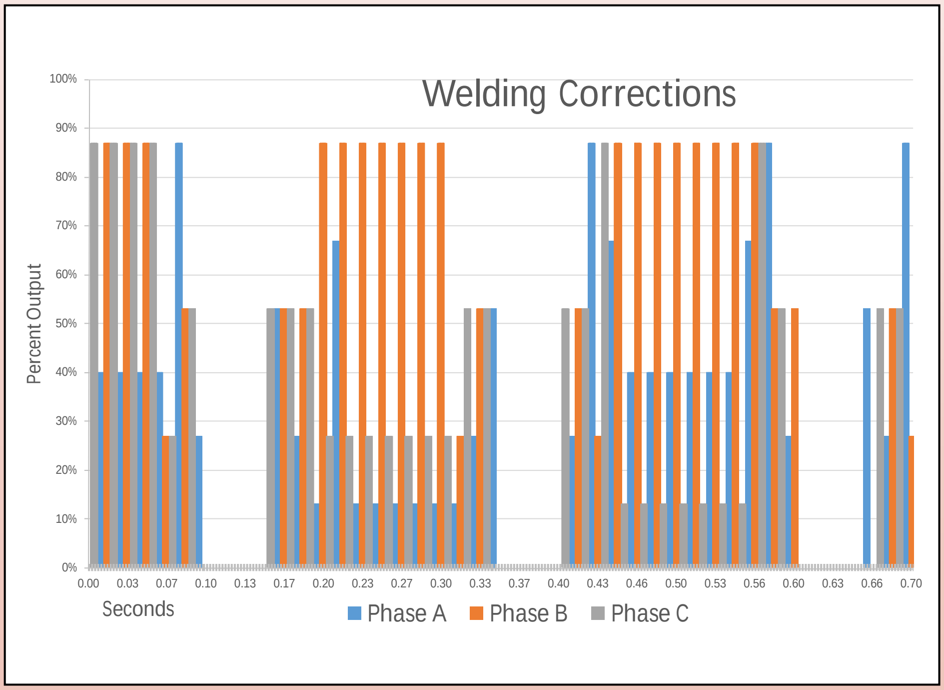
Pst measures short-term voltage fluctuations using rolling 10-minute intervals. Plt is a rolling 2-hour measure representing 12 sequential Pst measurements.

Plant operations vary irregularly. Both Pst and Plt measurements are collected on an ongoing basis establishing a distribution of values. A set percentage must be below threshold values.

Rapid Unbalanced Loads are Evident.



Above: A, B, and C phase load currents are shown. The welding loads are unbalanced on each phase and are non-sinusoidal within each phase.



The switches operate, varying VARs on each phase on a cycle-by -cycle basis to balance (offset) the electrical effects of welders. That's how an electrical shock absorber works. In these 0.7 seconds, its about 130 times...

None of the operating patterns are identical. With that many independent welders, the stability requirements are never identical.

It's a big technical challenge, but these systems can meet them.

Auto Shredding...

SOLUTION:

Located at a 5,000HP auto shredder this 12 MVAR-rated 4160v TSC reduces utility voltage flicker from 13.5% to ~2%, meeting utility requirements. Improved voltage support increases shredder output by 18%.

In service since 2002, this system was also recently upgraded.

TSC "Shock Absorber" Onsite

SOLUTION:

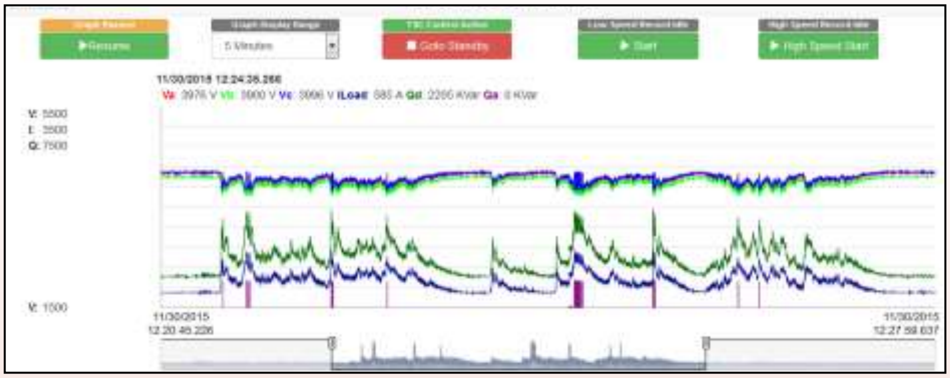
18 MVAR-rated TSC, designed to maintain steady 6.9 kV voltage and improve power factor. Benefits include improved rolling performance due to constant voltage AND avoiding purchase of a new 20 MVA transformer.

Modular TSC design provided a system designed to reliably meet the operating requirements.

In service since 2012, this system has over 99.95% availability, having experienced a total of 2 components failures over the years.

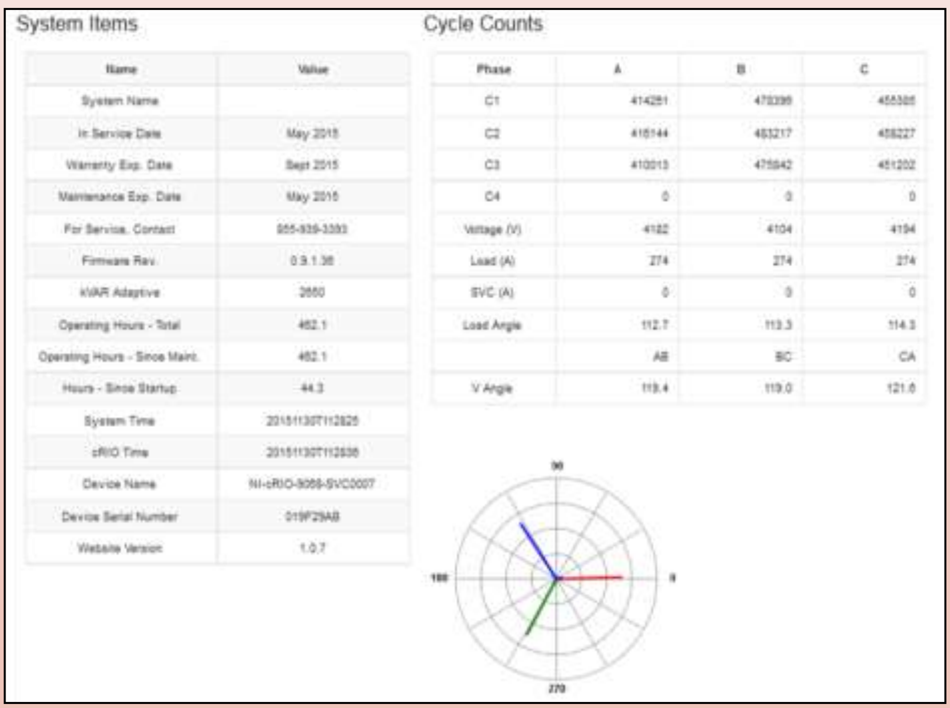
Customer reduced total project cost by eliminating transformer. Unit is deemed "must run." Improved voltage control results in meeting customer cold-rolled specs in fewer and faster passes.

Impacts of changing AC or DC Motor Loads including shredders, rolling mills, ball mills, and mining are common problems—



On-screen display showing 2.5 minutes of shredder operation. Load is normally balanced across all phases, but system also responds to single

Unit Response remains Frequent and Rapid.



System Items

Name	Value
System Name	
In Service Date	May 2015
Warranty Exp. Date	Sept 2015
Maintenance Exp. Date	May 2016
For Service, Contact	855-939-3393
Firmware Rev.	0.9.1.38
kVAR Adaptive	2660
Operating Hours - Total	462.1
Operating Hours - Since Maint.	462.1
Hours - Since Startup	44.3
System Time	20151130T112825
cRIO Time	20151130T112838
Device Name	NI-cRIO-9068-SVC0007
Device Serial Number	019F29AB
Website Version	1.0.7

Cycle Counts

Phase	A	B	C
C1	414281	478398	455385
C2	416144	483217	458227
C3	410013	475842	451202
C4	0	0	0
Voltage (V)	4182	4104	4194
Load (A)	274	274	274
SVC (A)	0	0	0
Load Angle	112.7	113.3	114.3
	AB	BC	CA
V Angle	119.4	119.0	121.6

System with new controller has operated 462 hours, with about 450,000 operations on each valve. That is a system rate of 8,800 operations per hour (147/minute or 2.4/second) while online. During actual shredding, operations spike at about 30/second.

Mining Operations

SOLUTION:

Mining operators bore into rock to remove the desired ores. Constantly loading and unloading motors causes voltage sags that decrease mine productivity and cause problems on utility circuits.

A common application, the 5 MVAR unit shown above entered service in 2006. T-Star monitors the unit remotely and addresses problems when and if they arise.

The modular nature of the TSC makes relocation and reuse easy—an important issue as mine life is generally 15 years or less. The unit can be moved to a new location as the old mine is decommissioned.

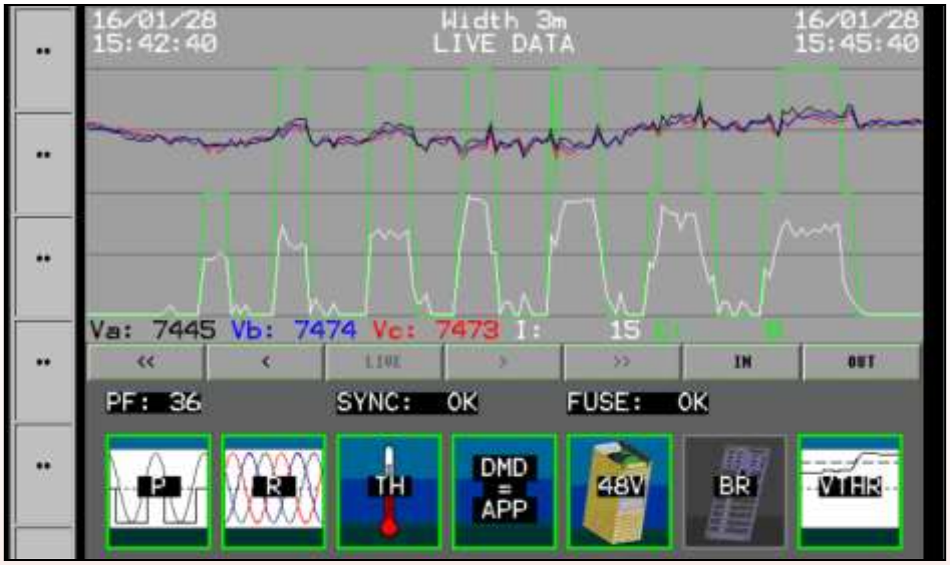
Remote Pumps

SOLUTION:

Located 24 miles from the nearest utility substation, with over 6,000 connected HP of pumps, this facility was run from large diesel generators until a 5 MVAR unit was installed. The savings from being able to connect to the grid provided a 4-month payback.

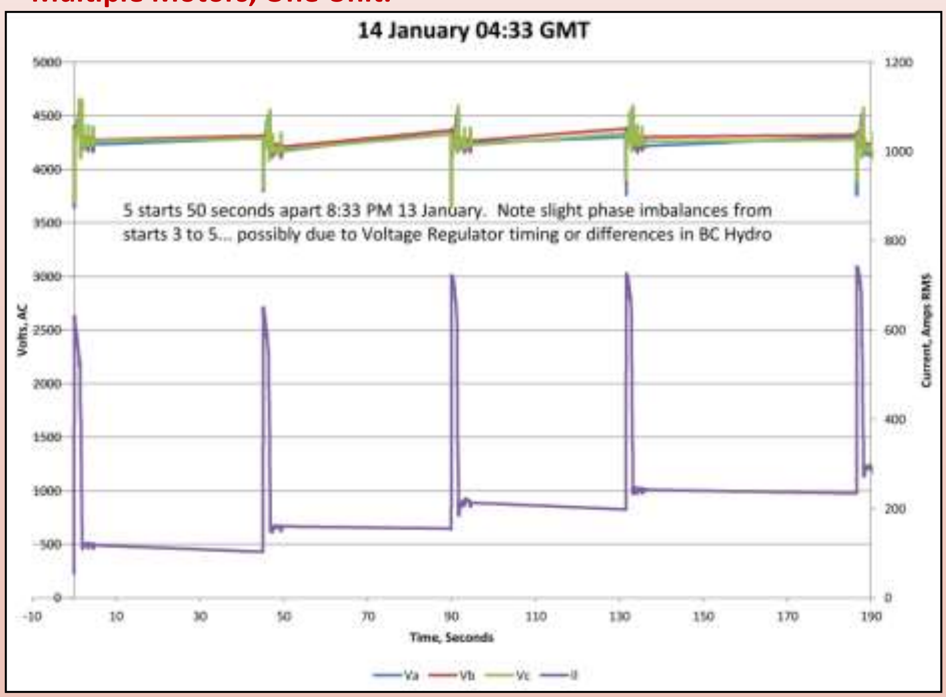
Consider an "electric shock absorber" whenever siting remote facilities. Benefits include cost savings, improved performance, and rapid delivery.

Continuing, Repetitive Loads are Common.



Phase current and unit output are shown above for a reversing hot mill application. Passes are approximately 30 seconds apart. (> 1,000/shift) Bus voltage is held within 100 volts, and the power factor remains above 0.90.

Multiple Motors, One Unit.



Designed to support sequential pump starts on the soft utility circuit, a single unit provides voltage control for the entire bus comprised of 6—1,000 HP pumps.

Controls work in conjunction with utility, delaying starts and allow the tap changer to boost circuit voltage for the running motors.

Product Scope

- Operating Voltage: 1 kV through 24.9 kV
- Impulse Withstand Voltage: 60kV —125kV BIL
- Reactive power rating: 200 KVAR to 100 MVAR (binary step design, 1 to 64 steps)
- Filter Type(s): Notch (Bank Pass), High-Pass, Multi-tuned
- Metal-Enclosed: NEMA 1, 3R, 4X, 12 | IEC IP10, IP14, IP56, IP52
- Comes fully assembled, tested, and ready for interconnection
- Integral air-disconnect /ground switch, circuit breaker

Specification and Design

Systems can be specified by rating (capacity, operating voltage, resolution) or performance (meeting voltage sag and flicker targets.) Using a performance-based approach reduces customer risk and increases success .

We perform an independent performance analysis based on customer-provided data after receipt of order to ensure system performance meets customer expectations.

Performance studies prior to receipt of order are available on a fee basis.

T-Star Engineering

T-Star specializes in manufacture of medium-voltage Thyristor switches and high-speed thyristor controls.

T-Star principals have designed and installed over 150 thyristor-switched capacitor systems. Many are maintained by T-Star under annual contracts.

T-Star personnel are available for design consultation, commissioning, customer training and maintaining Thyristor-switched reactive compensation systems.

T-Star thyristor designs undergo constant review ensuring that years of applications experience are translated into improved performance and reliability while maintaining backwards compatibility and simple customer-side requirements.

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