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A Hybrid Single-Phase and Three-Phase Power Supply for Electrostatic Precipitators

2014 APC Round Table

Louisville, Kentucky – July 14-15, 2014

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Challenges Experienced in Upgrading to Low Ripple Power Supplies

- ▶ **The reliability of existing low ripple power supplies does not match that of single-phase conventional power supplies**
- ▶ **Controls for the low ripple power supply are integrated into the transformer and may be located and serviced in a harsh environment**
- ▶ **The cost of existing low ripple power supplies is significantly higher than conventional power supplies**
- ▶ **Mixing low ripple and conventional power supplies on the same precipitator often requires two different control systems and software interface**



Addressing the Challenges

- ▶ **In 2010, B&W PrecipTech initiated a research and development project to compare common precipitator power supply offerings**
 - **As a manufacturer and seller, we want the facts**
 - **We wanted to understand the benefits of a low ripple power supply**
 - **Customers needed help with the options**
- ▶ **The project included:**
 - **Extensive use of electrical circuit models, where the many real-world field variables can be controlled and valid comparisons made**
 - **Laboratory tests using an in-house Test Precipitator**



Electrical Modeling Results

- ▶ Power supplies fell into two different classes: conventional, high ripple and newer, low ripple power supplies
- ▶ There were several technologies that could provide a low ripple output

Precipitator Power Supply Characteristics¹

Power Supply	Low Ripple Output	Frequency	AC Line Input		DC Voltage and Current Output					Sparking	
			Power Factor	Total Harmonic Distortion (Input)	Ripple in Output Voltage ²	Peak to Average Voltage Ratio	Ripple in Output Current ²	Peak to Average Current Ratio	Total Harmonic Distortion (Output) ³	Maximum Time to Spark Quench	Energy Delivered to Spark by Power Supply ⁴
Single-Phase	No	Low	0.566	21.40%	11.80%	1.235	72.59%	2.132	0.97%	8.33 x 10 ⁻³ seconds	7.8 x 10 ⁻³ Joules < .1% of Total Spark Energy
Single Phase with External Filter ⁵	Yes	Low	0.580	18.15%	2.39%	1.036	68.19%	1.883	0.75%	8.33 x 10 ⁻³ seconds	22.05 x 10 ⁻³ Joules < .1% of Total Spark Energy
Switch Mode - Phase Controlled	Yes	Medium	0.917	29.61%	1.68%	1.033	71.64%	2.281	40.21%	1.25 x 10 ⁻³ seconds	≈ 8.53 x 10 ⁻³ Joules < .1% of Total Spark Energy
Switch Mode - Amplitude Controlled	Yes	Medium	0.917	29.43%	1.35%	1.032	58.69%	2.050	44.25%	1.25 x 10 ⁻³ seconds	≈ 4.17 x 10 ⁻³ Joules < .1% of Total Spark Energy
Switch Mode - Frequency Controlled	Yes	High	0.926	35.17%	0.11%	1.002	122.55%	3.324	132.34%	30 x 10 ⁻⁶ seconds	55.7 x 10 ⁻⁶ Joules < .1% of Total Spark Energy
Switch Mode - Phase Controlled	Yes	High	0.914	36.25%	0.02%	1.000	48.57%	1.589	69.07%	60 x 10 ⁻⁶ seconds	70.9 x 10 ⁻⁶ Joules < .1% of Total Spark Energy
3-Phase	Yes	Low	0.826	13.01%	0.57%	1.009	10.45%	1.126	1.78%	5.55 x 10 ⁻³ seconds	5.7 x 10 ⁻³ Joules < .1% of Total Spark Energy
Perfect Power Supply ⁶	Yes		1.000	0.00%	0.00%	1.000	0.00%	1.000	0.00%	0.00 seconds	0.00 Joules

¹ Modeled for power supply rated at 80 KV, 1000 mA, field capacitor 0.1 μF, field resistor 80KΩ.

² Percent Ripple (RMS of Ripple/Average Output)

³ Harmonic frequency content above 1000 Hz

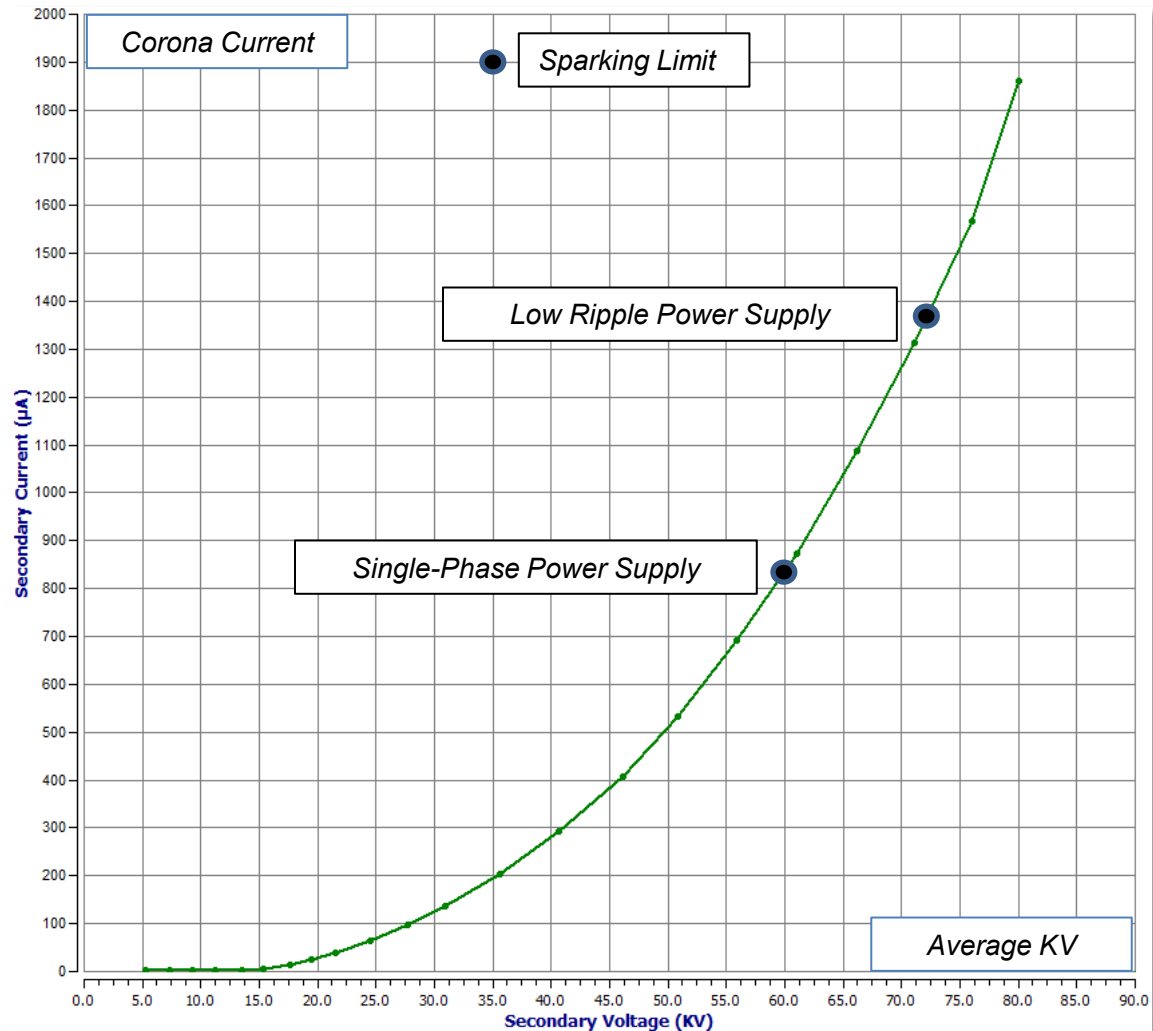
⁴ Total spark energy = 320 Joules

⁵ External filter .37 μf capacitor, 335Ω resistor

⁶ Theoretical ideal data

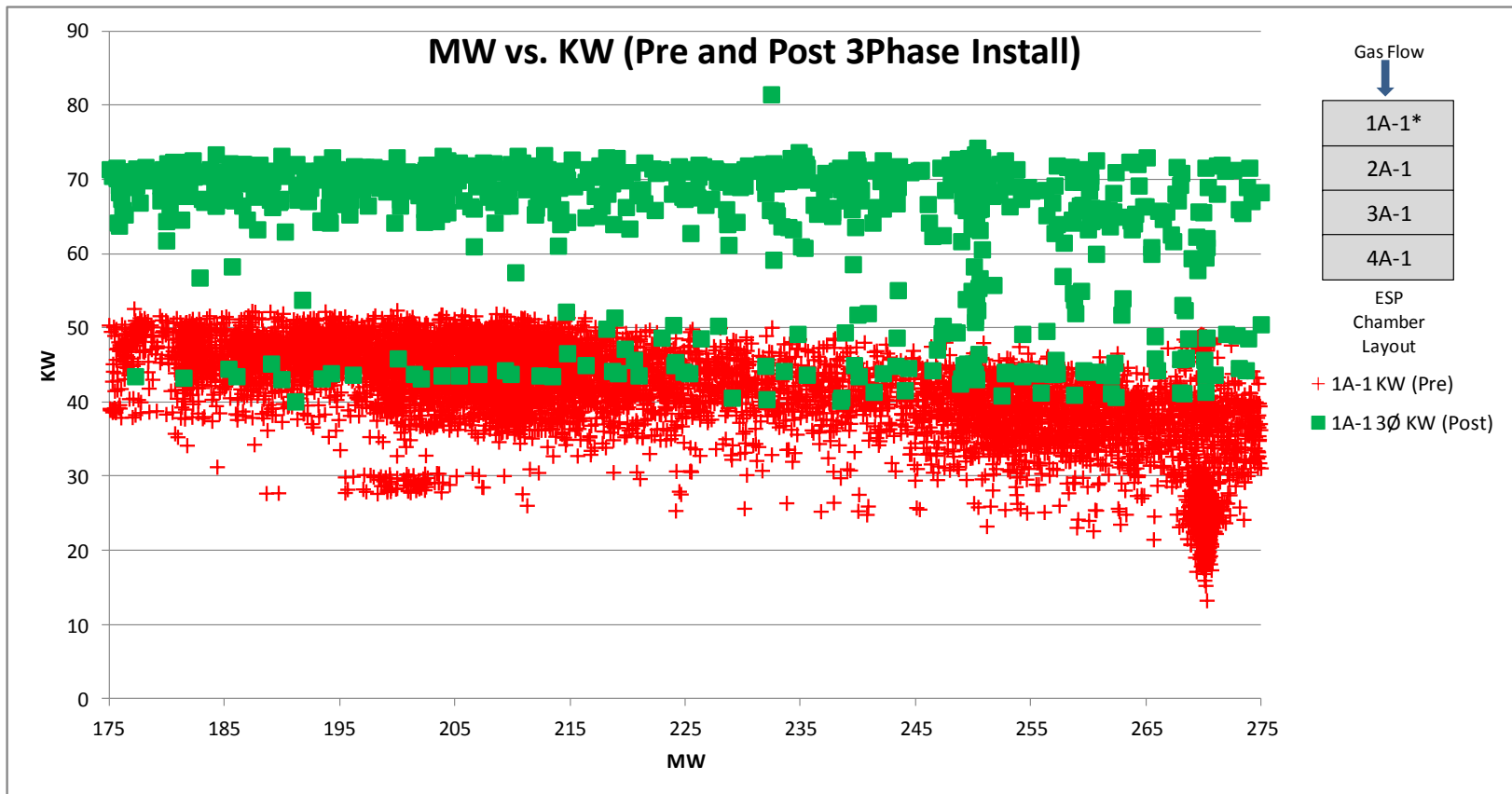
Why Low Ripple?

- ▶ **Since sparking occurs at the peak voltage, a low ripple power supply will provide more average voltage than a conventional, single-phase power supply**
- ▶ **This also increases the average current**
- ▶ **The net result is more corona power to the ESP**



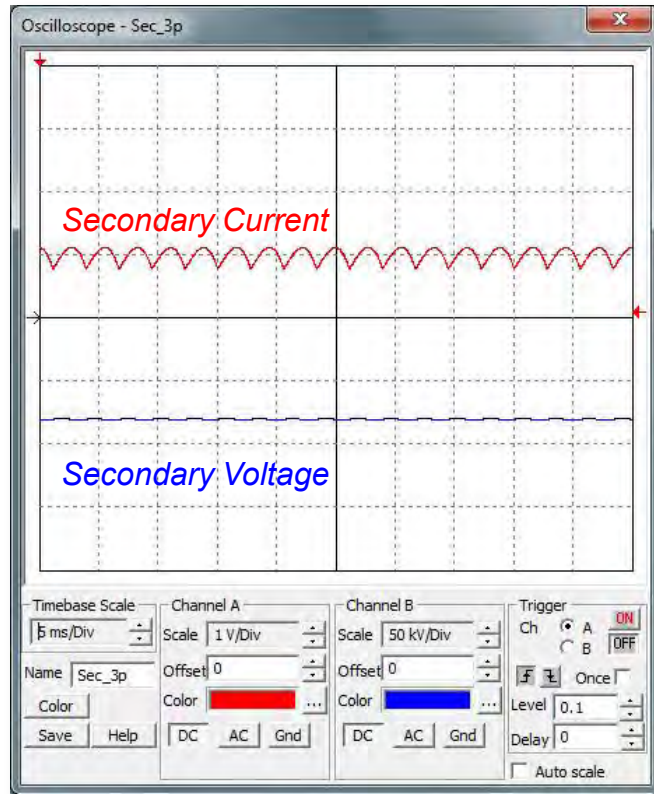
Why Low Ripple?

- Below are field test results *before* the replacement of a conventional single-phase power supply (in red), and *after*, with the 3-phase low ripple power supply (in green)

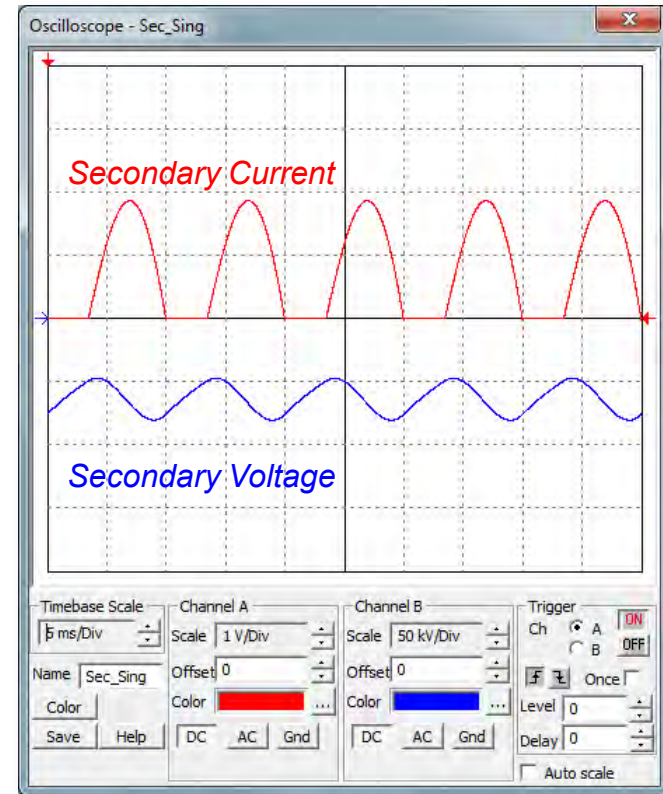


Low Ripple vs. Conventional Power Supply

3-Phase



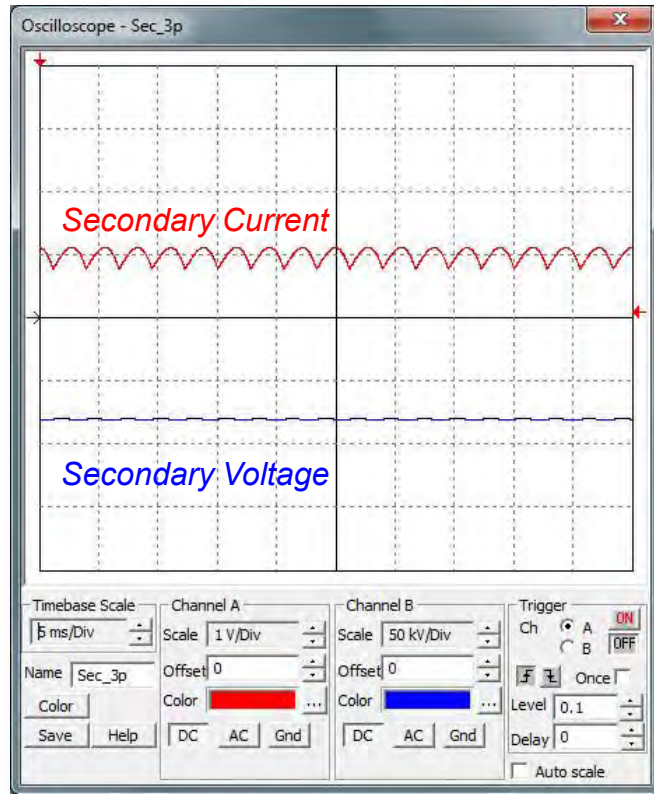
Single-Phase



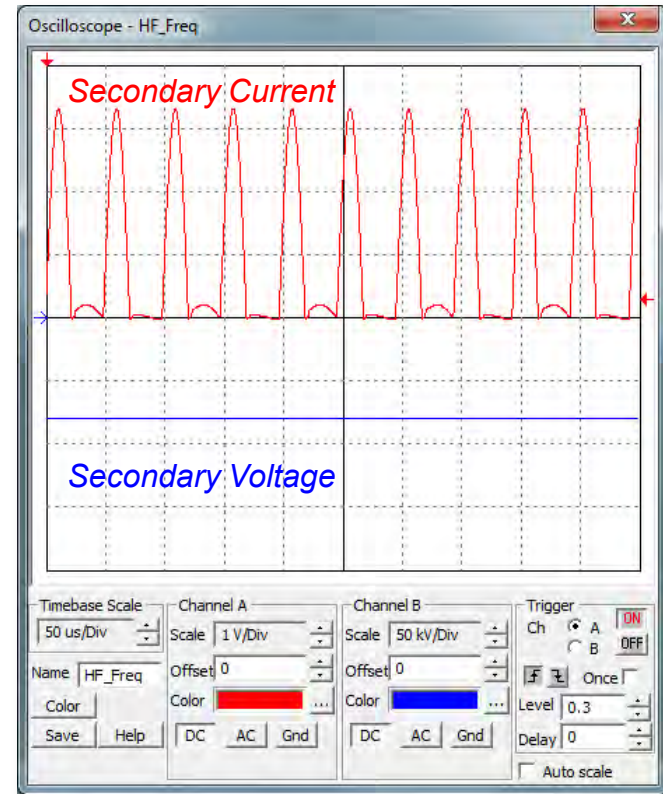
- ▶ Secondary voltage ripple (in blue) is significantly reduced in the 3-phase
- ▶ Secondary current ripple (in red) is also reduced

Two Different Low Ripple Options

3-Phase



High Frequency

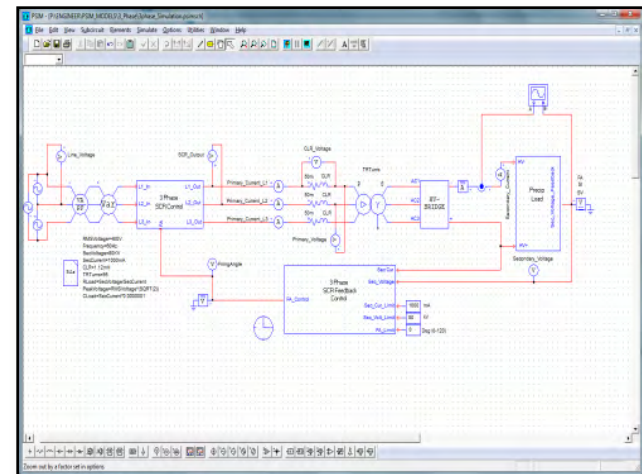


- ▶ The voltage ripple (in blue) is nearly identical
- ▶ Secondary current ripple (in red) is greater with the high frequency supply

Power Supply Comparison Results

▶ Our comparison showed that:

- The 3-phase performed equal to the switch mode in providing a low ripple voltage output
 - The 3-phase is the only power supply with a 3-phase output from the transformer. This, combined with the capacitive nature of the precipitator field produces a low ripple output
 - Most of the energy (>99.9%) dissipated by a spark comes from the energy stored in the capacitance of the field, not the power supply
- ✓ The 3-phase is an extension of the single-phase in design and reliability
- ✓ The controls for the 3-phase can be located in a remote, environmentally friendly area



Power Supply Comparison Results

▶ Our comparison also showed that:

- ✓ **The 3-phase is the lowest cost solution for low ripple power supplies**
- **The 3-phase is larger than the other three power supplies**
- **The 3-phase is heavier than the other three power supplies**

Precipitator Power Supply Cost, Size, and Weight Comparison¹

Power Supply	Cost Comparison ²	Volume (Cu Ft)	Volume Comparison ³	Weight (Lbs)	Weight Comparison ³
SMPS(1) 21 KW	1.49	77	1.04	1,050	0.56
SMPS(2) 20 KW	1.78	25	0.34	528	0.28
3 Phase 24 KW	1.16	128	1.73	3,527	1.88
Single Phase 24 KW	1.00	74	1.00	1,874	1.00
SMPS(1) 35 KW	1.89	81	1.09	1,200	0.64
SMPS(2) 28 KW	1.76	25	0.34	528	0.28
3 Phase 32 KW	1.16	128	1.73	3,638	1.94
Single Phase 32 KW	1.00	74	1.00	1,874	1.00
SMPS(1) 70 KW	2.31	101	0.95	1,300	0.46
SMPS(2) 60 KW	1.70	25	0.24	528	0.19
3 Phase 72 KW	1.17	139	1.31	3,968	1.41
Single Phase 72 KW	1.00	106	1.00	2,822	1.00
SMPS(1) 120 KW	2.31	152	1.23	2,300	0.65
SMPS(2) 120 KW	2.22	47	0.38	1,100	0.31
3 Phase 120 KW	1.12	193	1.56	5,071	1.44
Single Phase 120 KW	1.00	124	1.00	3,527	1.00

¹ Four power supply ratings are compared. Within each rating, the cost, size, and weight are compared to single phase.

² For Single Phase and 3-Phase: external control cabinet cost is included.

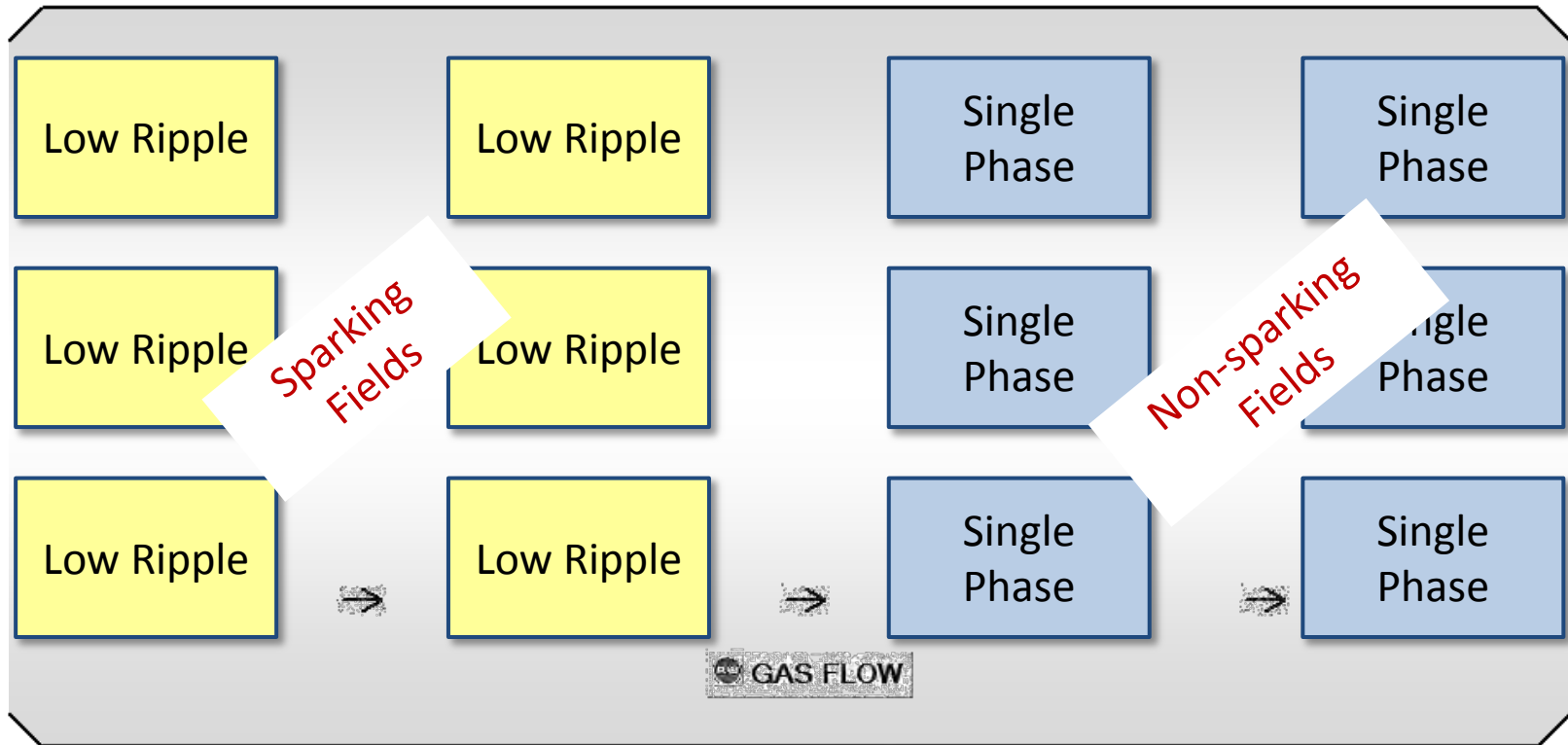
³ For Single Phase and 3-Phase: CLR(s) are included in the T/R set, volume and weight specified are for T/R Set only, external control cabinet not included.

Upgrade Path to Low Ripple

- ▶ Replacing power supplies can be an expensive upgrade
- ▶ For improved performance, where is the money best spent?
- ▶ Maybe it's not necessary to replace all of the existing single-phase power supplies



Upgrade Path to Low Ripple

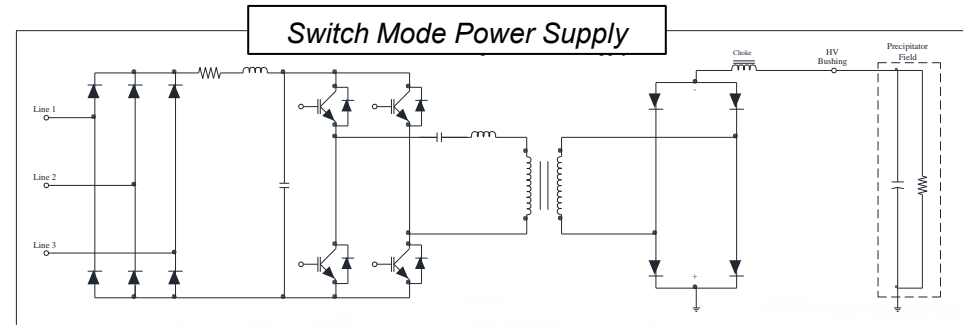
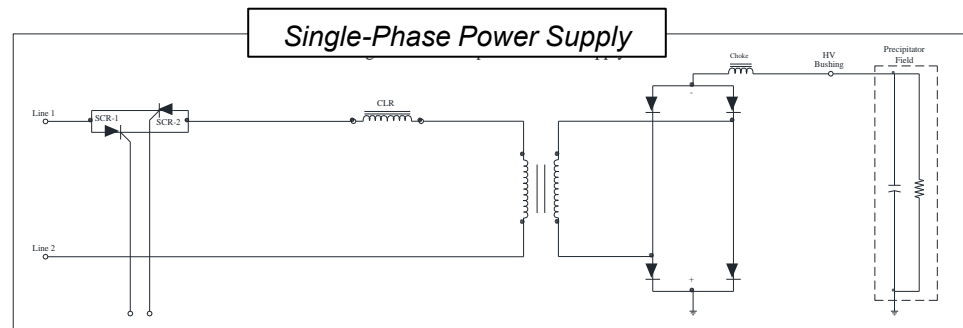


- ▶ **This is a common upgrade path**
- ▶ **Installing low ripple power supplies on the spark-limited fields may achieve significant performance improvements**

Upgrade Path to Low Ripple

- ▶ Possible drawbacks to this approach:
 - Different power supply control systems (potentially from different manufacturers)
 - Increased requirements for spare parts inventory
 - Multiple interfaces with the plant's control system

- ▶ What if there was a single control system that could operate both a low ripple and a conventional, single-phase power supply?

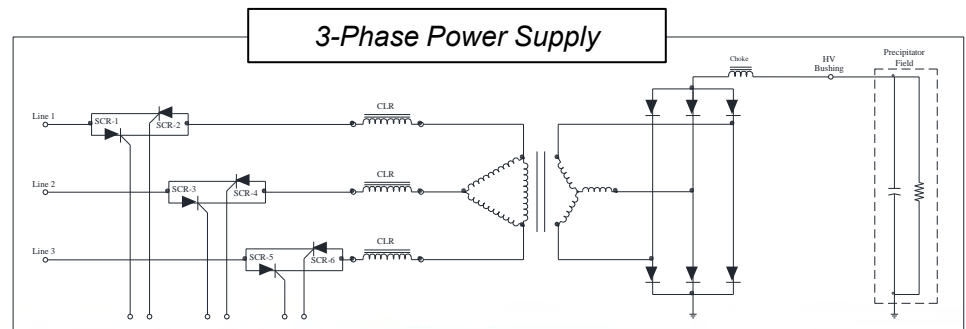
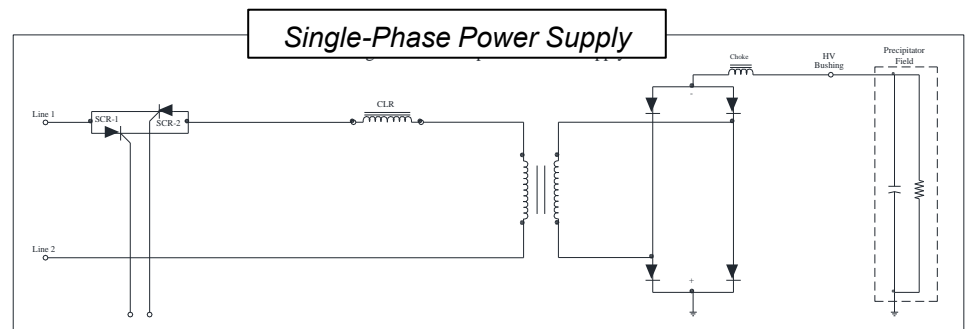


A Natural Progression

▶ Common Characteristics

- Single-phase and 3-phase are born from the same design
- Both use SCRs for power control
- Neither requires an active cooling system
- Both provide dramatic cost benefits
- Both exhibit high reliability
- Control-wise, they're nearly equal

▶ Why not combine the two?

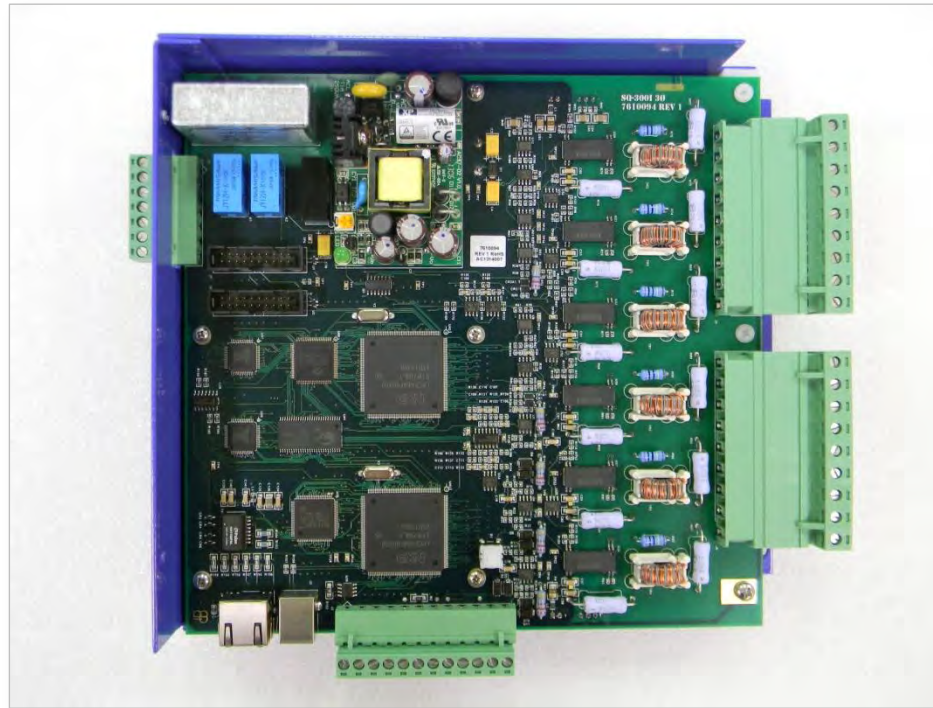


The Hybrid Controller



- ✓ **A single package solution for 3-phase low ripple and conventional single-phase power supplies**
- ▶ **High reliability at low cost**

The Hybrid Controller

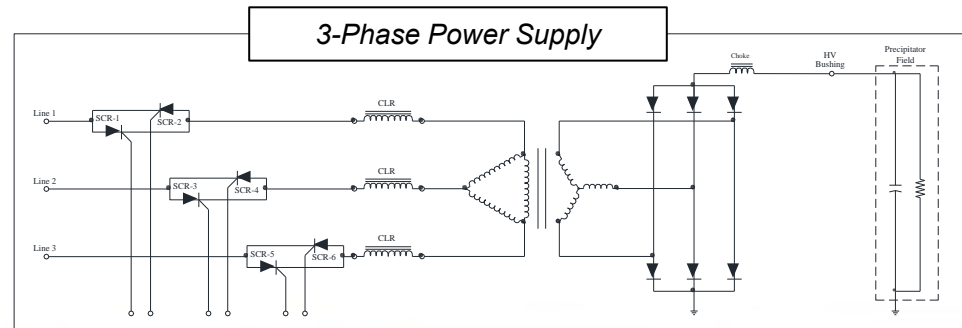
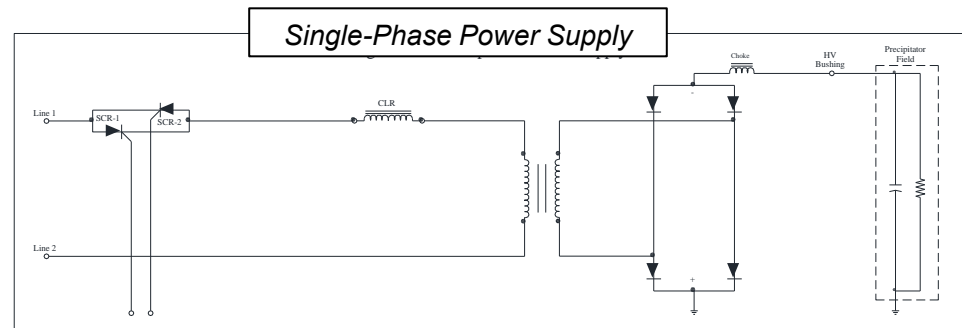


- ▶ **Control size and complexity are significantly reduced through the use of modern, large-scale integration components and assemblies**

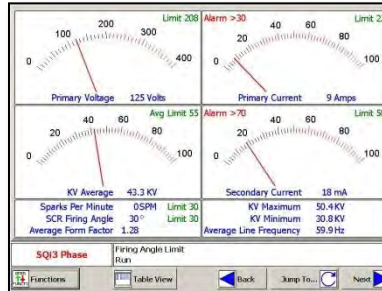
The Hybrid Controller

► **Benefits of the single package solution include:**

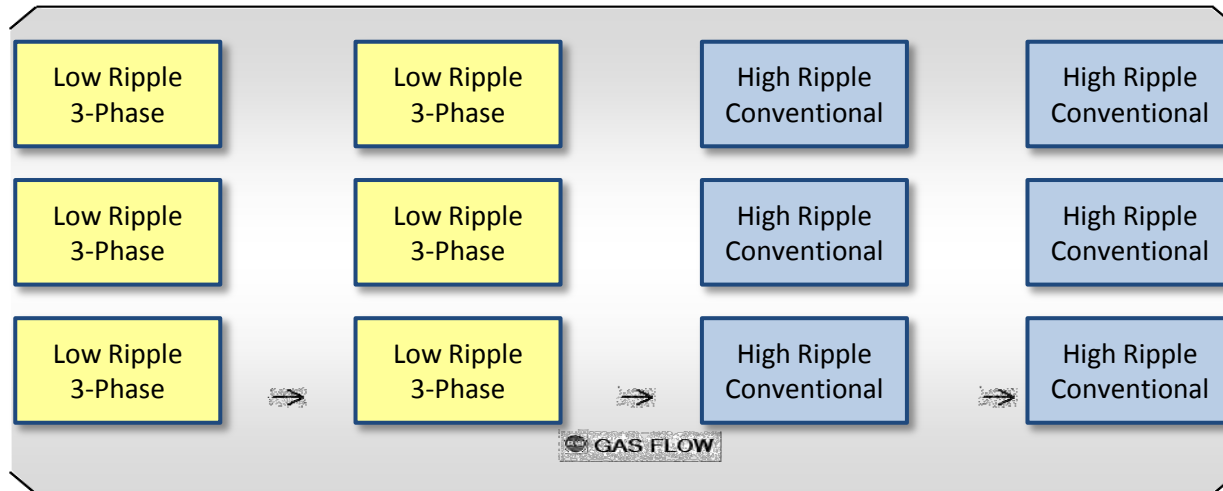
- Simplified operation using one power supply control system
- Reduced requirements for spare parts inventory
- One global interface with the plant's control system
- Leveraged design and control principles developed over 30 years of experience with conventional single-phase power supply



Upgrade Path to Low Ripple



One common operator interface



- ▶ The same type of controller is used for all power supplies
- ▶ All controllers use the same interface to communicate with the plant control system

Summary:

- ▶ **The reliability of existing low ripple power supplies does not match that of the single-phase conventional supply**
 - ✓ **Solution: A low ripple, 3-phase power supply is now available that matches the reliability of the high ripple, conventional single-phase**
- ▶ **Controls for the low ripple power supply are integrated into the transformer and may be located and serviced in a harsh environment**
 - ✓ **Solution: The controls for the low ripple, 3-phase power supply can be located in a remote, environmentally controlled area**
- ▶ **The cost of existing low ripple power supplies is significantly higher than conventional power supplies**
 - ✓ **Solution: Low ripple, 3-phase power supplies cost much less than the low ripple, high frequency options (especially in larger sizes)**
- ▶ **Mixing low ripple and conventional power supplies on the same precipitator often requires two different control systems and software interface**
 - ✓ **Solution: Applying a combination of low ripple and conventional power supplies is now possible using one control system**





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Thank You. Questions?

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