YASKAWA

Application Note: Matrix Drive Applications Test Stands & Dynamometers

The U1000 Industrial Matrix Drive is a compact, all-in-one solution for ultra-low harmonics and/or full regeneration, and is the ultimate choice for power quality and energy savings.

Engine Load Dynamometer

Application Overview:

Test Stands and Dynamometers are used to test and characterize rotating equipment. Gasoline and diesel engine manufacturers, automotive companies, racecar builders, performance shops, tractor and forklift manufacturers, and lawn and farm equipment manufacturers all use load dynes. Basically, load dynes are used by any business that makes, incorporates, or modifies engines and other rotating systems. Engine size can range from about 5 Hp for lawn mower engines to more than 1500 Hp for large diesel engines.

An *engine Load dynamometer* (often called *Absorber* or *Load Dyne*) typically uses an electric motor and AC Drive to simulate a mechanical load on gasoline and diesel engines. Endurance testing requires that the engine be run under load continuously for days, weeks or months to determine component life and establish preventive maintenance schedules or to 'break-in' a new or re-built engine.

A load dynamometer absorbs a large amount of energy from the engine. Historically, load dynes used an eddy-current brake, fluid (water) brake, or friction brake to load the engine. While eddy-current and fluid brakes produce relatively consistent load torque, these older methods wasted power produced by the engine. Furthermore, these brakes typically require external means to start the engine. It makes good sense to regenerate the wasted energy back to the power line and recover some of the cost of the fuel.

Other types of test dynamometers, which require fast accelerations and/or decelerations, can also find benefits from regenerative systems. Longer deceleration times are required to prevent regenerative energy from being produced or resistors are used to burn off the extra energy when trying to achieve a desired deceleration or cycle time. Instead of wasting the energy generated by rapidly decelerating the load, the wasted energy can be redirected back to the power line and recover the energy that would otherwise be burnt off in a resistor. Power sent back onto the line is redistributed to other loads lowering the overall power used from the utility.

Application Challenges:

- The Drives and motors must be extremely durable and capable of running for months unattended without breaking down or interrupting the test.
- The Drive should be capable of repeatable torque control through the entire speed range.
- The Drive must function in a system containing very sensitive sensing equipment without causing interference to low-level sensor signals.
- The load dyne system should be capable of regenerating the absorbed mechanical energy back to the power line to recover some the lost fuel cost.
- The load dyne system should be cost effective.

Application Details:

Figure 1 illustrates the basic components of an engine dynamometer:

1. Engine under test
2. The dyne motor
3. Dyne motor control
4. Data logger

The operation begins with the dyne motor control in speed mode and ramps the motor up to the *starting speed* of the engine. Fuel is applied to the engine. When the engine is running on its own, the dyne motor control switches to torque control mode. Actual testing begins as the regenerative (braking) unit and AC Drive regulates load on the engine.

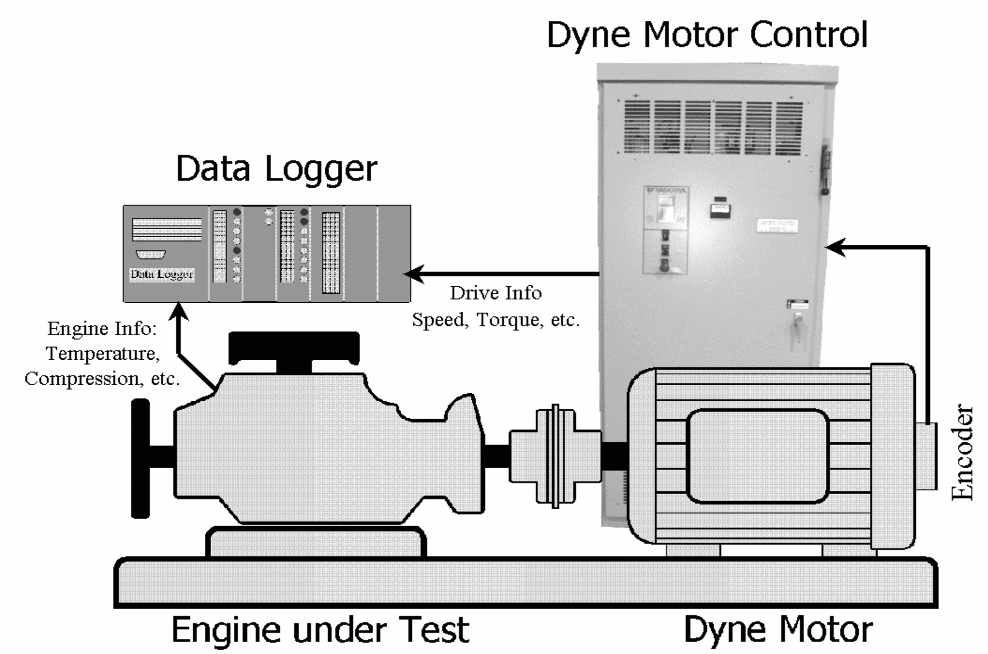


Figure 1

Yaskawa Solution:

The dyne motor is an induction motor with a shaft-mounted encoder for speed feedback. The dyne motor control consists of a **Yaskawa Flux Vector Drive** (A1000, G7, A1000 HHP) and the line regeneration module (R1000, D1000).

A load dyne using an induction motor controlled by a Yaskawa Drive (A1000, G7, A1000HHP) provides very reliable load torque control and a means of starting the engine. Yaskawa line regeneration modules (R1000, D1000) regenerate engine power back to the electrical power line. The R1000 is a fundamental front end (FFT) that provides regenerative capabilities with adequate harmonic performance (~40% iTHD). The D1000 is an active front end (AFE) that provides regenerative capabilities with low harmonic performance (< 5% iTHD).

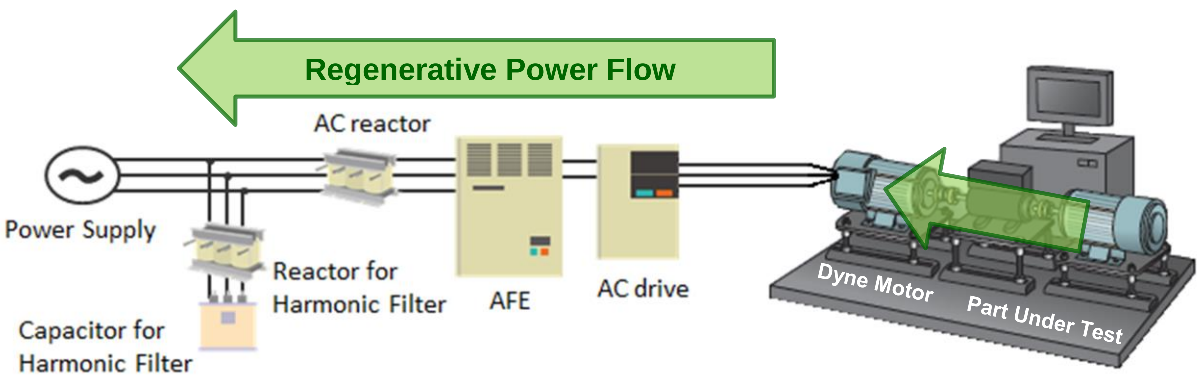


Figure 2

Figure 2 illustrates a typical engine load dynamometer using an AC Drive with an AFE. The power flow during operation (regeneration) is indicated in Green. The dyne motor acting as a brake absorbs power generated by the engine under test. The AC Drive transfers the power from the motor to the Drive's DC Bus. The active front end (AFE) line regeneration unit converts DC to AC at the power line voltage and frequency. The capabilities of the AFE combined with the input PWM filter allows for low harmonic performance during regeneration (< 5% iTHD).

Yaskawa Solution Products:

Products	Product Feature	Benefits
A1000	Ratings from 0.75 HP to 1000 HP	Covers the range of most gasoline and small diesel engines.
	Cost effective vector control	Multiple methods of load torque control available through full speed range.
		Full range speed control including 0.0 RPM.
	Six programmable control inputs available	For mode switching and selection
	RS485/422 communications standard	For data logging and control.
	Closed Loop Flux Vector Control	High reliability and endurance.
G7	Ratings from 0.5 HP to 500 HP	Covers the range of most gasoline and small diesel engines.
	G7's 3-level output switching scheme	Extends motor life by reducing shaft and bearing current.
	High performance vector control	Multiple methods of load torque control available through full speed range.
		Full range speed control including 0.0 RPM.
	Ten programmable control inputs available	For mode switching and selection.
	RS485/422 communications standard	For data logging and control.
A1000HHP	Ratings from 400 HP to 1800 HP	Covers the range of most diesel and large gasoline engines.
	Modular construction	Flexibility - up to five 400 amp inverters can be operated in parallel to supply one motor.
	Closed Loop Flux Vector Control	Two methods of load torque control available through full speed range.
R1000	6-step line regeneration option	Cost effective, simple, and reliable.
D1000	4-Quadrant sinusoidal current power converter	IEEE519 compatible for both motoring and regenerating.
		Very low total harmonic distortion.

Next Generation Solution:

U1000 Industrial Matrix Drive

The U1000 Industrial Matrix Drive is a compact, all-in-one solution for ultra-low harmonics and/or full regeneration, and is the ultimate choice for power quality and energy savings. Additionally, the U1000 delivers high flexibility and motor control performance to meet a wide variety of application requirements.

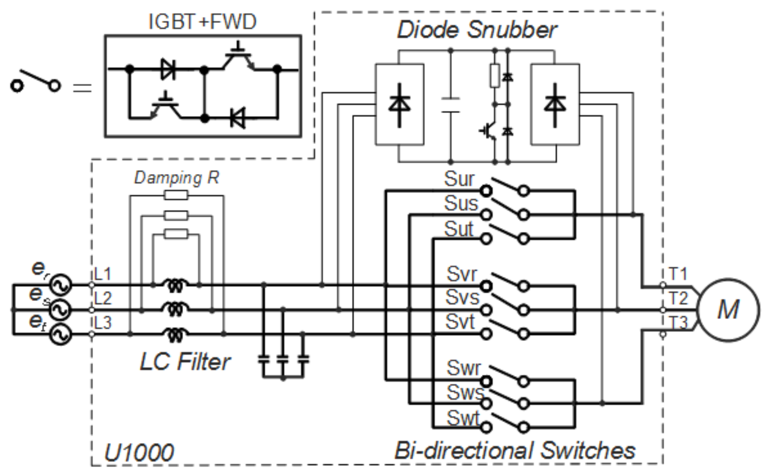


Fig.1 U1000 circuit diagram

Matrix Topology:

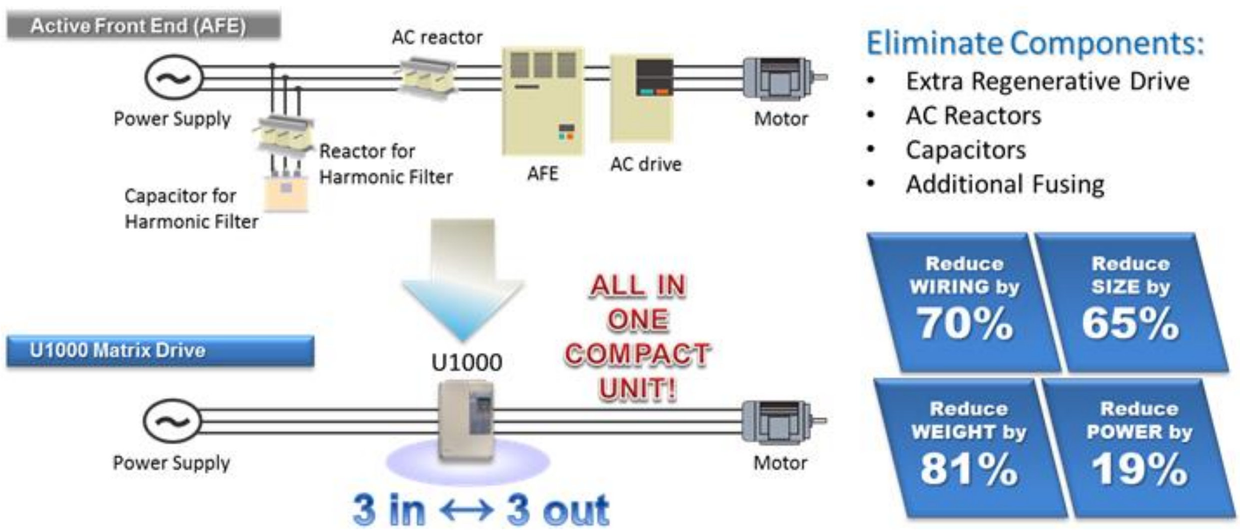
A Drive using Matrix technology is different than conventional Drives. The difference lies within the Matrix Technology itself. Unlike conventional Drives, Yaskawa's Matrix technology employs a system of nine bi-directional switches arranged in a matrix to convert a three-phase AC input voltage directly into a three-phase AC output voltage. This eliminates the need for a rectifying circuit and DC smoothing circuit found in conventional AC Drive inverters.

Matrix Drive Attributes:

- Low Harmonics (<5% iTHD at input of drive)
- Near Unity True Power Factor (0.98 or better)
- Power Regeneration (Full 4-Quadrant Control)
- Expanded Motor Control (Permanent Magnet Motor Control)
- High Efficiency
- Compact Size

Title: Matrix Drive Applications: Test Stands & Dynamometers	
Product(s): U1000 Industrial Matrix Drive	**Doc. No.** AN.U1000.01

Matrix Drive Solution:



Compared to Yaskawa's classical solution (AC Drive with a regenerative front end), the U1000 Industrial Matrix Drive provides the same motor performance with these additional benefits:

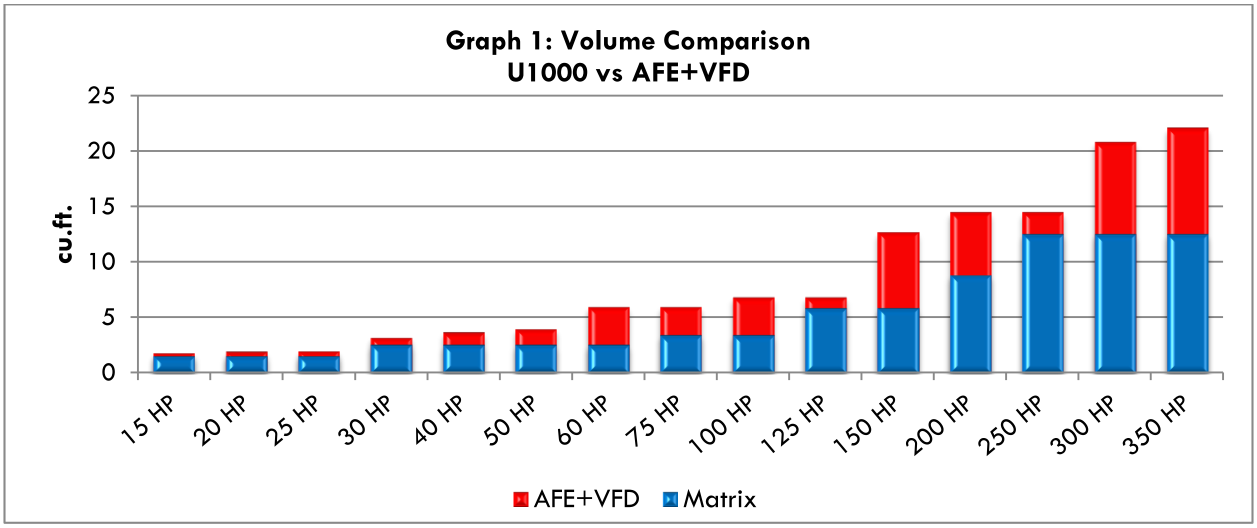
- Less Wiring & Reduced System Complexity
- Space Savings
- Greater Efficiency
- Lower Input Harmonics
- System Payback

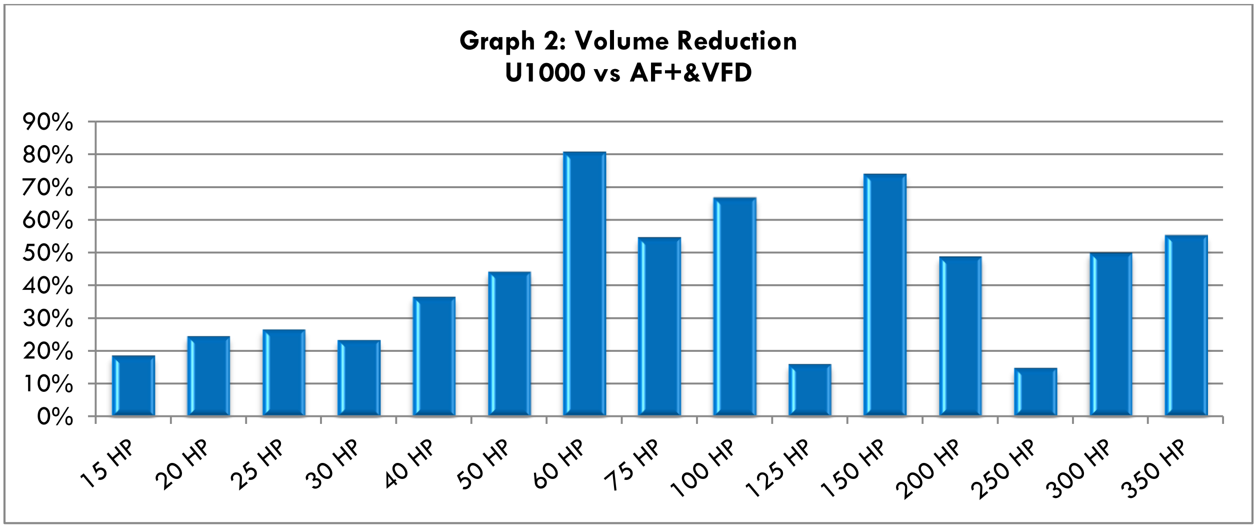
Less Wiring & Reduced System Complexity:

The Matrix Drive is an all-in-one compact solution for low harmonics and/or full regeneration eliminates the need for an additional regenerative Drive, AC reactor(s), capacitors and wiring. The reduction in components eliminates wiring and simplifies installation to a simple 3 wires in and 3 wires out power wiring configuration.

Space Savings:

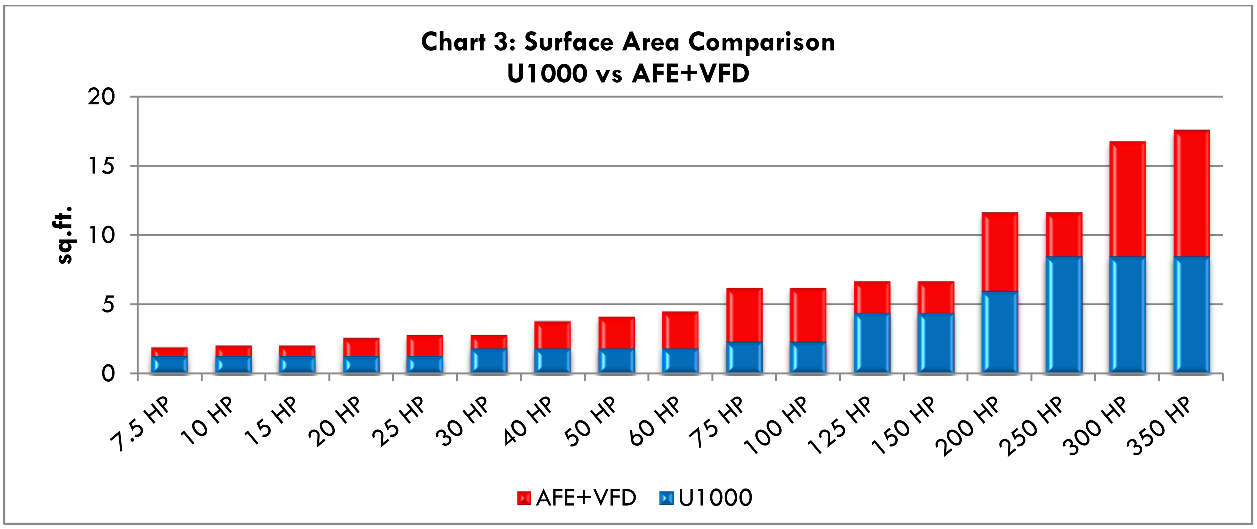
A Matrix Drive will be between 14% and 80% smaller than an AFE+VFD package between 15 HP and 350 HP. On average, the matrix Drive will be over 37% smaller than an equivalent AFE and VFD package. The average space savings of 37% only accounts for the size of each component. There will be additional space savings due to clearance, panel layout availability, and wiring requirements needed in an AFE+VFD solution.

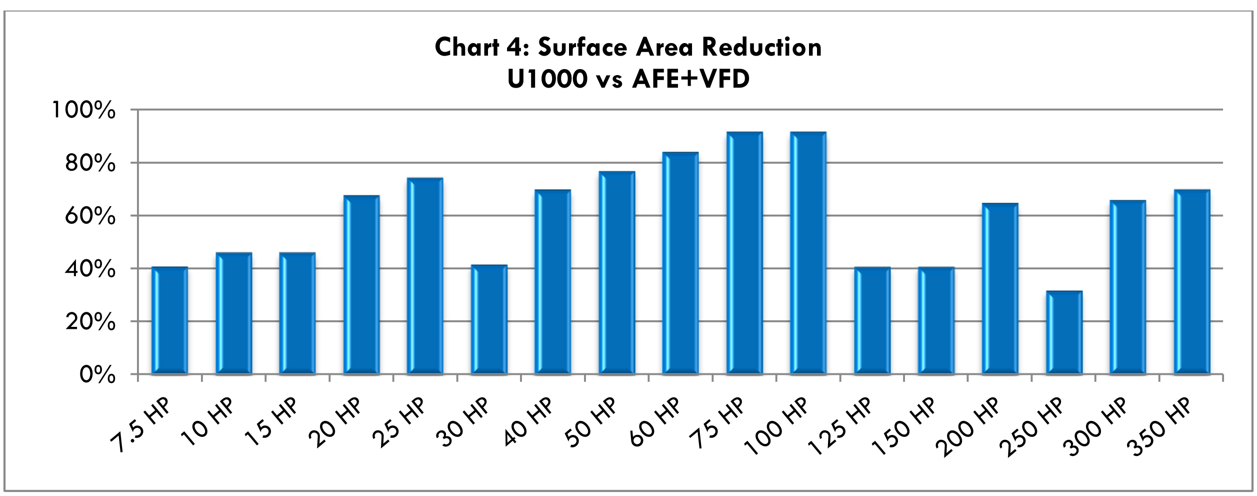




Depth of a product is not always a concern when configuring a panel. Mounting space in a panel or on a wall is more a factor of surface area. In other words the height and width of a package will often determine space savings.

The U1000 Matrix Drive will have a surface area between 30% and 90% smaller than an AFE+VFD package between 15 HP and 350 HP. On average, the matrix Drive will be over 60% smaller than an equivalent AFE and VFD package. The surface area reduction in using a Matrix Drive does not include the additional space savings due to clearance, panel layout availability, and wiring requirements needed in an AFE+VFD solution.





Volume and Surface Area Tables:

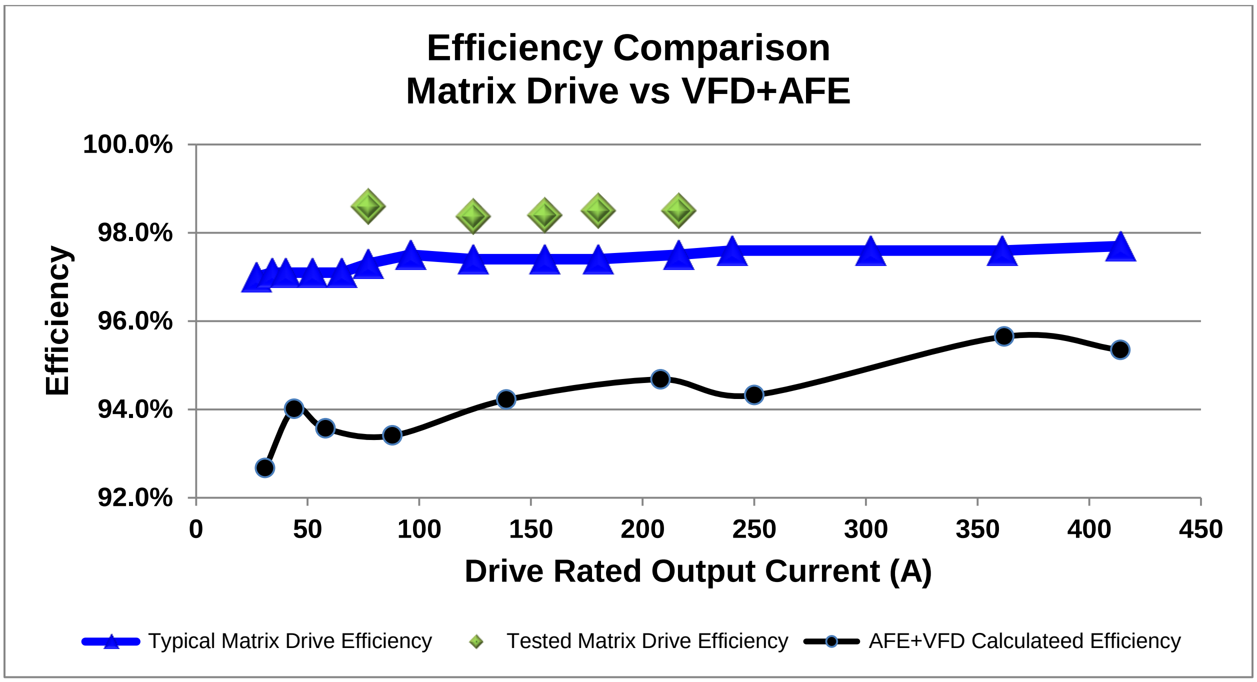
<table>
<tr><th rowspan="2">Motor HP</th><th colspan="3">Volume (cu.ft.)</th></tr>
<tr><th>U1000</th><th>AFE+VFD</th><th>% Diff</th></tr>
<tr><td>15 HP</td><td rowspan="3">1.52</td><td>1.84</td><td>-18.62%</td></tr>
<tr><td>20 HP</td><td>1.95</td><td>-24.54%</td></tr>
<tr><td>25 HP</td><td>1.99</td><td>-26.71%</td></tr>
<tr><td>30 HP</td><td rowspan="4">2.54</td><td>3.22</td><td>-23.47%</td></tr>
<tr><td>40 HP</td><td>3.68</td><td>-36.62%</td></tr>
<tr><td>50 HP</td><td>3.99</td><td>-44.29%</td></tr>
<tr><td>60 HP</td><td>5.99</td><td>-80.79%</td></tr>
<tr><td>75 HP</td><td rowspan="2">3.42</td><td>5.99</td><td>-54.66%</td></tr>
<tr><td>100 HP</td><td>6.86</td><td>-66.97%</td></tr>
<tr><td>125 HP</td><td rowspan="2">5.84</td><td>6.86</td><td>-16.10%</td></tr>
<tr><td>150 HP</td><td>12.71</td><td>-74.03%</td></tr>
<tr><td>200 HP</td><td>8.81</td><td>14.50</td><td>-48.81%</td></tr>
<tr><td>250 HP</td><td rowspan="3">12.49</td><td>14.50</td><td>-14.84%</td></tr>
<tr><td>300 HP</td><td>20.83</td><td>-50.02%</td></tr>
<tr><td>350 HP</td><td>22.09</td><td>-55.49%</td></tr>
</table>

<table>
<tr><th rowspan="2">Motor HP</th><th colspan="3">Surface Area (sq.ft.)</th></tr>
<tr><th>U1000</th><th>AFE+VFD</th><th>% Diff</th></tr>
<tr><td>15 HP</td><td rowspan="3">1.29</td><td>2.07</td><td>-46.14%</td></tr>
<tr><td>20 HP</td><td>2.61</td><td>-67.65%</td></tr>
<tr><td>25 HP</td><td rowspan="2">2.82</td><td>-74.33%</td></tr>
<tr><td>30 HP</td><td rowspan="4">1.85</td><td>-41.61%</td></tr>
<tr><td>40 HP</td><td>3.83</td><td>-69.78%</td></tr>
<tr><td>50 HP</td><td>4.15</td><td>-76.82%</td></tr>
<tr><td>60 HP</td><td>4.52</td><td>-83.91%</td></tr>
<tr><td>75 HP</td><td rowspan="2">2.32</td><td rowspan="2">6.23</td><td>-91.58%</td></tr>
<tr><td>100 HP</td><td>-91.58%</td></tr>
<tr><td>125 HP</td><td rowspan="2">4.42</td><td rowspan="2">6.68</td><td>-40.76%</td></tr>
<tr><td>150 HP</td><td>-40.76%</td></tr>
<tr><td>200 HP</td><td>5.97</td><td rowspan="2">11.67</td><td>-64.63%</td></tr>
<tr><td>250 HP</td><td rowspan="3">8.47</td><td>-31.81%</td></tr>
<tr><td>300 HP</td><td>16.79</td><td>-65.92%</td></tr>
<tr><td>350 HP</td><td>17.60</td><td>-70.07%</td></tr>
</table>

Matrix Efficiency:

The Matrix Drive's typical calculated efficiency is 96.7% on average between 20 HP and 250 HP, while testing consistently shows true operating efficiencies are in excess of 98%. Higher efficiency operation is achieved by maintaining near unity input power factor and low input current harmonics, which drives down the input current requirement at rated output power conditions. Lower input current requirement drives down losses and increases efficiency.

Classical solutions, like a VFD with AFE, can expect to see efficiencies between 92% and 96% between 20 HP and 350 HP; averaging about 94% efficient operation. The matrix drive can boost drive system efficiency by 4% on average.



Efficiency Table:

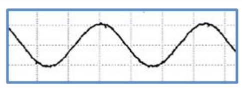
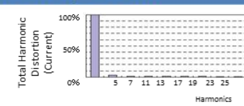
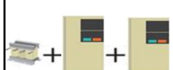
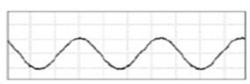
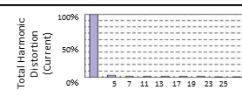
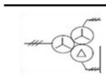
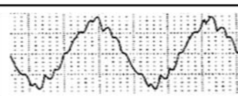
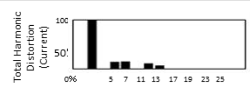
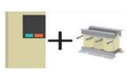
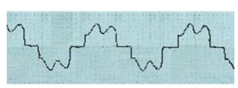
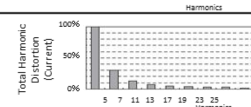
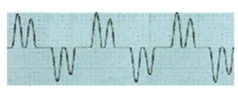
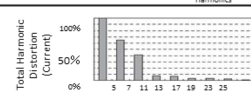
Motor	Watt Loss			Calculated Efficiency			Tested Results	
HP	U1000*	AFE+VFD	% Diff	U1000*	AFE+VFD	% Diff	U1000	% Diff
20	554	1094	-49.4%	96.3%	92.7%	3.9%	--	--
25	705	1160	-39.2%	96.2%	93.8%	2.6%	--	--
30	827	1340	-38.3%	96.2%	94.0%	2.3%	--	--
40	1088	1427	-23.8%	96.4%	95.2%	1.2%	--	--
50	1377	2104	-34.6%	96.3%	94.4%	2.1%	--	--
60	1502	2952	-49.1%	96.7%	93.4%	3.5%	98.60%	5.20%
75	1745	3164	-44.8%	96.8%	94.3%	2.6%	--	--
100	2389	4315	-44.6%	96.8%	94.2%	2.7%	98.40%	4.18%
125	2999	4790	-37.4%	96.7%	94.9%	1.9%	98.40%	3.54%
150	3511	5954	-41.0%	96.8%	94.7%	2.2%	98.50%	3.82%
200	4203	8473	-50.4%	97.2%	94.3%	3.1%	--	--
250	5404	8644	-37.5%	97.1%	95.4%	1.8%	--	--
300	6557	9742	-32.7%	97.0%	95.7%	1.4%	--	--
350	7191	10182	-29.4%	97.2%	96.1%	1.1%	--	--

* Calculated Results based specific conditions: 460 VAC input line, 0.98 input power factor, NEMA minimum Efficiency for 4 pole Open motors, and Marathon BlueMax TEFC Motor expected Power Factor.

Matrix Input Current Harmonics:

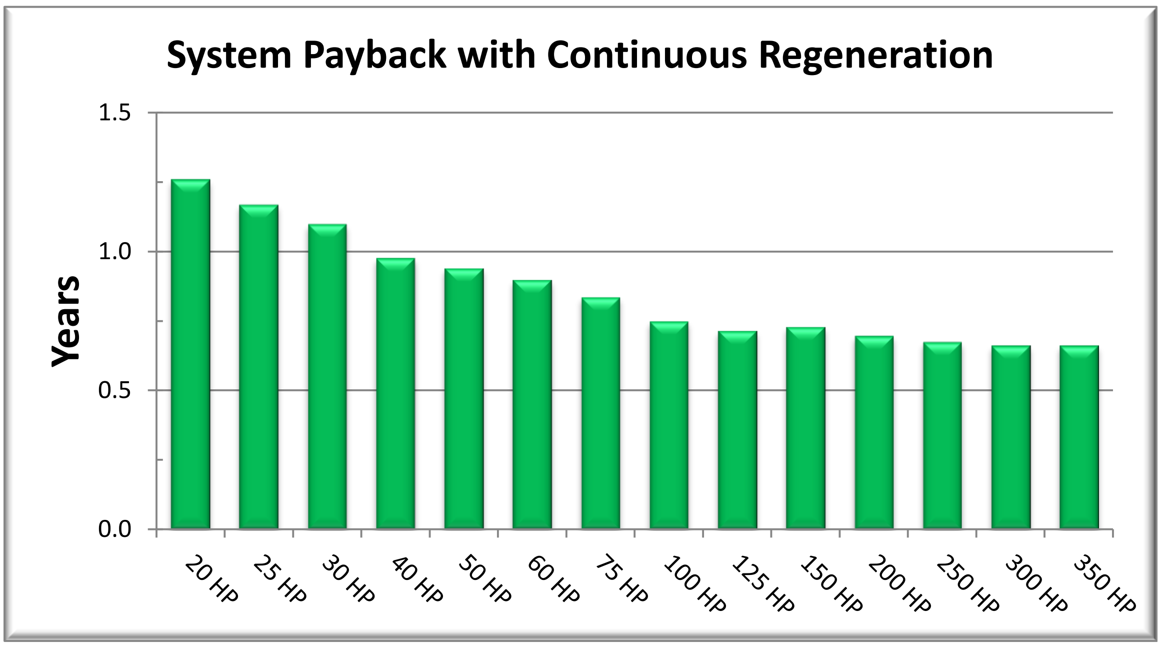
The U1000 can achieve near unity power factor (0.98 or better) and conforms to IEEE-519's most stringent input current harmonic requirements without the need for additional peripheral components. Typical input current harmonics at rated power are less than 5% iTHD.

Lower input current harmonics reduces interference with other electrical devices sharing the same power source. Also, the high input power factor and low input current harmonics reduces heating in the supply transformer and other upstream equipment. Reduced harmonic content allows for downsizing in the supply transformer and wiring or frees up existing transformers for new loads.

Configuration		Current Waveform	Current Spectrum	iTHD
	U1000 Matrix			≤ 5%
	AC drive with AFE			≤ 5%
	AC drive with multi-pulse			6 - 12%
	AC drive with DC reactor			~ 40%
	AC drive without reactor			~ 80%

Payback:

Applications like test stands and engine dynes requiring heavy to continuous duty cycle regeneration can see a quick return on the initial investment of the total drive system. The U1000 operating in continuous regeneration will typically pay the cost of purchasing the drive back in under a year when compared to using braking resistors to dissipate the energy.



The study based on a machine operating in continuous regeneration operating at rated horsepower for two 8 hours shifts, 5 days a week, 52 weeks a year. Price is based on competitive end user pricing through a distributor.

100 HP Comparison Example: VFD+AFE vs Matrix Drive

Space Savings:

A 100 HP Matrix Drive will use over 91% less panel space (area) than an equivalent VFD and AFE package and over 67% smaller in total volume. This does not include clearances required to properly mount, wire, and ventilate components.

Surface Area (sq.ft.)		
U1000	AFE+VFD	% Diff
2.32	6.23	-91.6%

Volume (cu.ft.)		
U1000	AFE+VFD	% Diff
3.42	6.86	-66.97%

Efficiency Improvement:

A 100 HP Matrix Drive is 2.47% more efficient than an equivalent VFD and AFE package. Therefore, a Matrix Drive will be able to save an additional 1.757 kW when regenerating 100 Hp. At 11.5 cents/kWh the Matrix Drive will save an additional $840 when compared to an equivalent VFD and AFE configuration. The cost of a 100 HP Matrix Drive will see a return on its investment in energy saving in under 7.5 months.

Watt Loss			Calculated Efficiency			Tested Efficiency	
U1000	AFE+VFD	% Diff	U1000	AFE+VFD	% Diff	U1000	% Diff
2558	4315	-44.6%	96.6%	94.2%	2.47%	98.4%	4.18%

Note: Payback Calculations use two 8 hours shifts, 5 days a week, 52 weeks a year operating at continuous 100 HP regenerative condition.

Title: Matrix Drive Applications: Test Stands & Dynamometers	
Product(s): U1000 Industrial Matrix Drive	**Doc. No.** AN.U1000.01

Revision History

REVISION	COMMENT / MODIFICATION	DATE
—	**ORIGINAL**	**06/08/2017**