Evolution MOTION SOLUTIONS

YASKAWA

An Overview of Matrix Drive Technology

Matrix Drives Boost Power Quality and Energy Savings

Introduction

Variable Speed Drives (VSDs) are electronic devices used to regulate the speed of an ac induction motor. The key benefit is to provide new and improved process control, while also boosting power factor and overall system efficiency (energy savings). VSDs are used in a multitude of applications; from relatively simple applications like pumps and fans to more complicated applications like winders and dynamometers.

The evolution of VSD technology stems from the need to boost motor control performance and to provide clean, efficient use of line power. To that end, recent advancements in VSD technology have made way for a drive using Matrix technology. A Matrix Drive is an all-in-one solution for extremely low harmonics and/or full regeneration, and is the ultimate choice for power quality and energy savings. Additionally, a Matrix drive delivers high performance in a compact, easy to install and use design to meet a wide variety of application requirements.

What is a Matrix Drive?

A drive using Matrix technology is different than conventional drives. The difference lies within the Matrix technology itself. Unlike conventional drives, Matrix Drives 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. Matrix technology eliminates the need for a rectifying circuit and DC smoothing circuit found in conventional AC drive inverters. A Matrix drive incorporates a compact input PWM filter to mitigate the regenerative pwm waveform and provide a clean sine wave back onto the line.

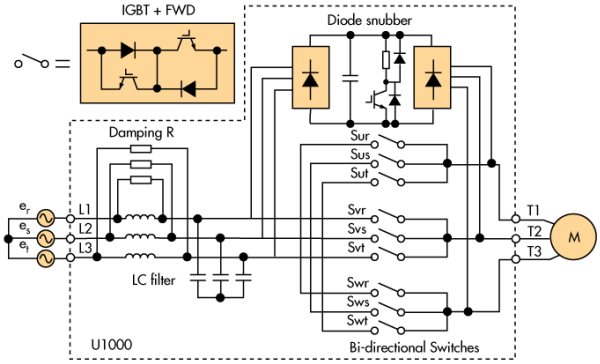


Figure 1: Matrix circuit diagram

The "Matrix" Behind Matrix Technology

A Matrix drive uses fast acting switches (IGBTs) configured in a matrix to generate an AC output voltage directly from three phase ac input power. Okay, but what is a matrix?

A matrix is a mathematical principal used to describe an arrangement of symbols, expressions, and/or numbers into rows and columns. The intent is to take a very complicated array of actions and describe and implement these actions in a clear and concise manner.

$$(T_1) = L_1 * S_1 + L_2 * S_2 + L_3 * S_3 = \begin{pmatrix} L_1 \\ L_2 \\ L_3 \end{pmatrix} * \begin{pmatrix} S_1 \\ S_2 \\ S_3 \end{pmatrix}$$

Complicated algebraic expression — Simplified matrix expression

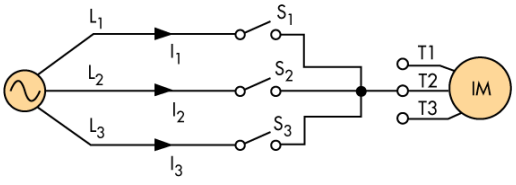


Figure 2: T1 motor phase circuit

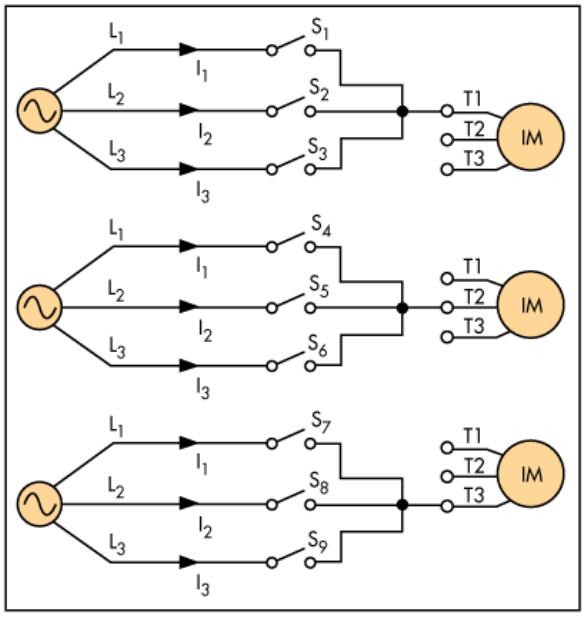
Breaking down the Matrix drive can help to better understand a matrix configuration. The Matrix drive can be described as using three sets of matrices. Each matrix describes the connection between the input power and one output phase. The matrix consists of three of the nine bi-directional IGBTs. Figure 2 is a representation of the mathematical and simplified electrical equivalent of one matrix set. The supply voltage is outputted to motor by closing one of the three bi-directional IGBTs. Therefore, no more than one IGBT can be turned ON at same time to prevent shorting the input power supply.

Analyzing all three phases using matricies can take a potentially complicated expression and present it in a simpler manner. Again, each of the matrices represents a connection to one output phase. Therefore, there are three sets of matrices, one for each output phase.

$$(T_1) = L_1 * S_1 + L_2 * S_2 + L_3 * S_3 = \begin{pmatrix} L_1 \\ L_2 \\ L_3 \end{pmatrix} * \begin{pmatrix} S_1 \\ S_2 \\ S_3 \end{pmatrix}$$

$$(T_2) = L_1 * S_4 + L_2 * S_5 + L_3 * S_6 = \begin{pmatrix} L_1 \\ L_2 \\ L_3 \end{pmatrix} * \begin{pmatrix} S_4 \\ S_5 \\ S_6 \end{pmatrix}$$

$$(T_3) = L_1 * S_7 + L_2 * S_8 + L_3 * S_9 = \begin{pmatrix} L_1 \\ L_2 \\ L_3 \end{pmatrix} * \begin{pmatrix} S_7 \\ S_8 \\ S_9 \end{pmatrix}$$



Since the power source is identical to all three matrices, each input phase can be connected at a common point to simplify the overall circuit. Each motor phase has independent access to the line. Turning on and off one of its switches will dictate what voltage is sent to each motor phase. Figure 4 shows the final configuration. A LC input line filter is added before the IGBTs to turn the regenerative waveform to a clean sine wave.

$$\begin{pmatrix} T_1 \\ T_2 \\ T_3 \end{pmatrix} = \begin{pmatrix} L_1 * S_7 + L_2 * S_8 + L_3 * S_9 + \\ L_1 * S_4 + L_2 * S_5 + L_3 * S_6 + \\ L_1 * S_7 + L_2 * S_8 + L_3 * S_9 \end{pmatrix} = \begin{pmatrix} L_1 \\ L_2 \\ L_3 \end{pmatrix} * \begin{pmatrix} S_1 & S_1 & S_1 \\ S_2 & S_2 & S_2 \\ S_3 & S_3 & S_3 \end{pmatrix}$$

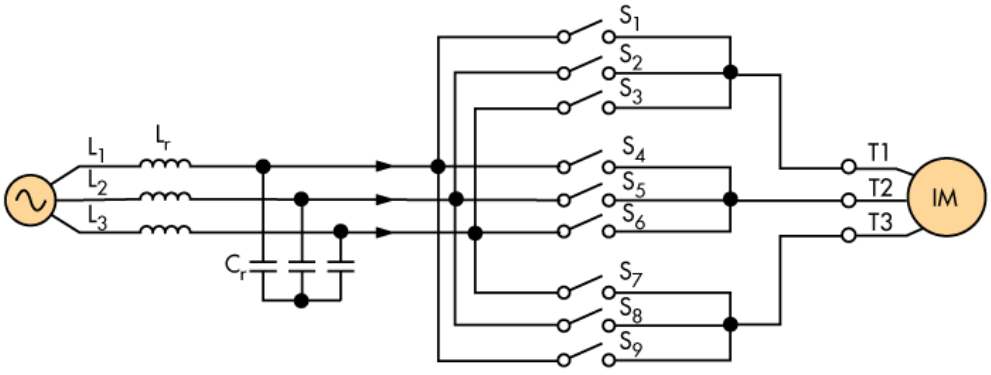


Figure 4: Simplified combined matrix

Matrix Drive Motor Control

To understand how a matrix drive converts AC input voltage directly into an AC output voltage to control a motor it is best to first understand how a conventional drive generates its output voltage.

Conventional drives operate by converting AC to DC and then back to AC. Conventional drives convert AC to DC using diodes. Diodes only conduct when the voltage at the anode (AC side) is greater than the cathode (DC side).

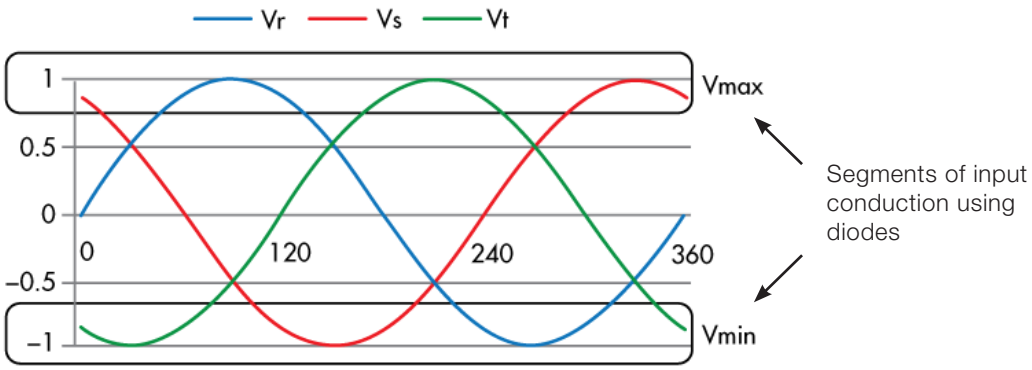


Figure 5; Diode rectification region

However, the DC supply (DC bus) generated from diode rectification is not uniform because only the peaks of the AC input voltages is higher than the DC supply. Thus, a DC bus ripple from the electric conversion process occurs. Conventional drives use large amounts of electrolytic capacitors to smooth out the DC bus ripple.

Once a stable DC bus is generated, the drive can utilize the smoothed DC bus voltage to generate an output voltage waveform to control a motor at the requested voltage and frequency. The voltage is generated by outputted DC pulses in a waveform known as pulse width modulation (PWM).

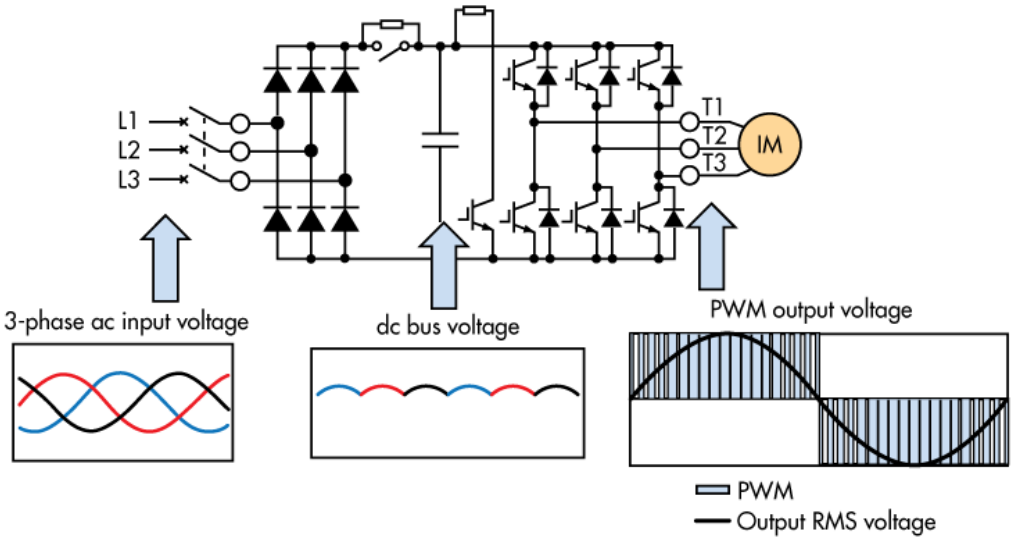


Figure 6: Pulse width modulation

Conventional Drive Pulsing

PWM waveforms, as the name indicates, are generated using pulses of varying thicknesses (widths). For a conventional drive, each pulse is generated by turning on and off an IGBT (switch) that allows the DC bus voltage to reach the motor. Therefore, each pulse resembles a square wave. The time the DC bus is supplied to the motor compared to the overall total time period equates to the average voltage for a specified segment of time.

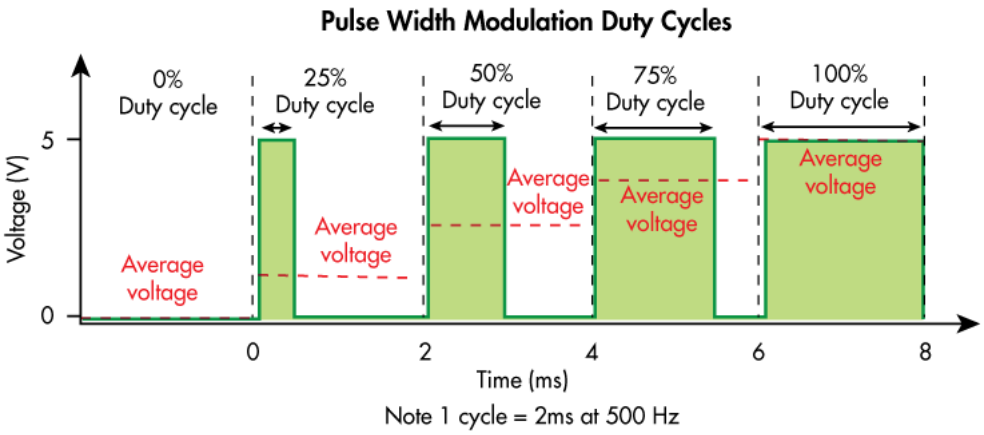


Figure 7: PWM duty cycles

One method of determining when and for how long the drive needs to generate a pulse is referred to as sine-triangle pulse width modulation. The technique requires a reference voltage waveform (waveform needed to operate the motor) and a waveform that determines the sample rate (in this case a triangular wave set to the frequency of the drive's carrier frequency). The PWM technique has the sampling waveform overlaid on top of the reference waveform. The drive's IGBTs turn ON and stay on whenever the reference voltage waveform is greater than the triangular carrier frequency waveform, i.e. Blue > Red = ON.

The RMS output voltage of these pulses determines the voltage being sent to the motor. The period of positive and negative pulses determines the fundamental frequency of the waveform. The pulses are filtered by the impedance of the motor, allowing it to react to the PWM voltage as if it were purely sinusoidal. The resulting sinusoidal current waveform is a direct indication that the motor is reacting to only the fundamental voltage (RMS voltage) of the PWM waveform.

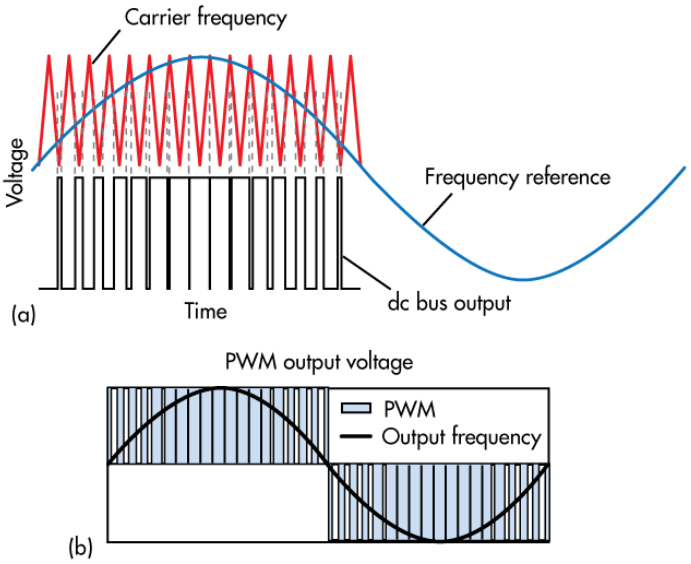


Figure 8: Sine triangle PWM

Matrix Drive Pulsing

A Matrix Drive's technique for generating its output voltage waveform is near identical to that of a conventional drive. The only difference lies with how the matrix drive generates its output pulses.

A matrix drive has no DC bus smoothing capacitors, thus no DC bus to generate pulses for its PWM waveform. Instead AC voltage is directly applied to the motor to generate its PWM waveform pulses using bi-directional IGBTs.

Matrix Drive Pulse Generation

At any given moment in time the matrix drive has access to any input phase. Each of these voltages presents a different voltage potential that can be sent to any motor phase. Therefore, the drive has the ability to send three distinct line to line voltages to any two phases at any given time.

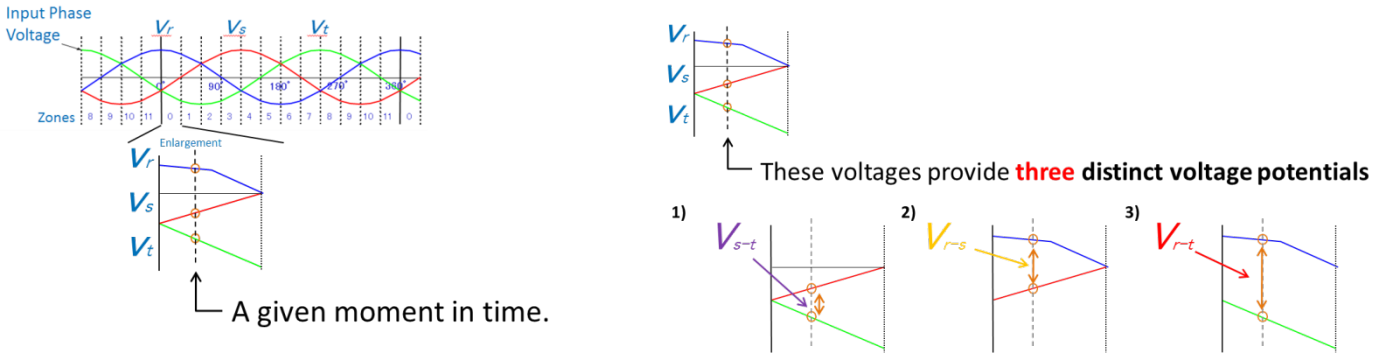


Figure 9: Three distinct voltage potentials can be sent to any motor phase

To generate a pulse equivalent to that of a conventional drive's DC bus, the matrix drive would need to send pulses with the potential of Vr-t above. However, the matrix drive has access to two additional pulses. Therefore, instead of outputting Vr and Vt across two phases the matrix drive takes two steps in generating each pulse.

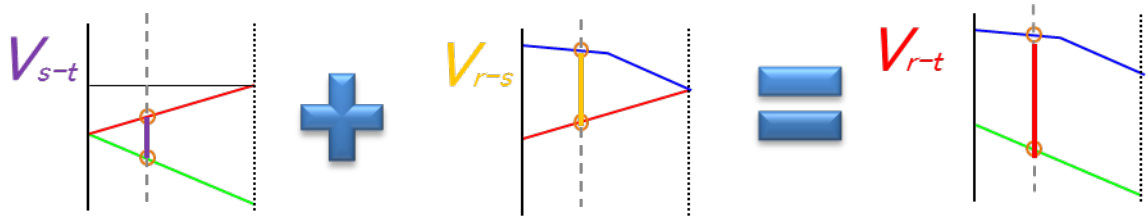


Figure 10: Matrix generation of pulses

Therefore, each individual pulse would be accomplished by using three distinct switching patterns to generate the full pulse. The pattern creates a three level output pulse.

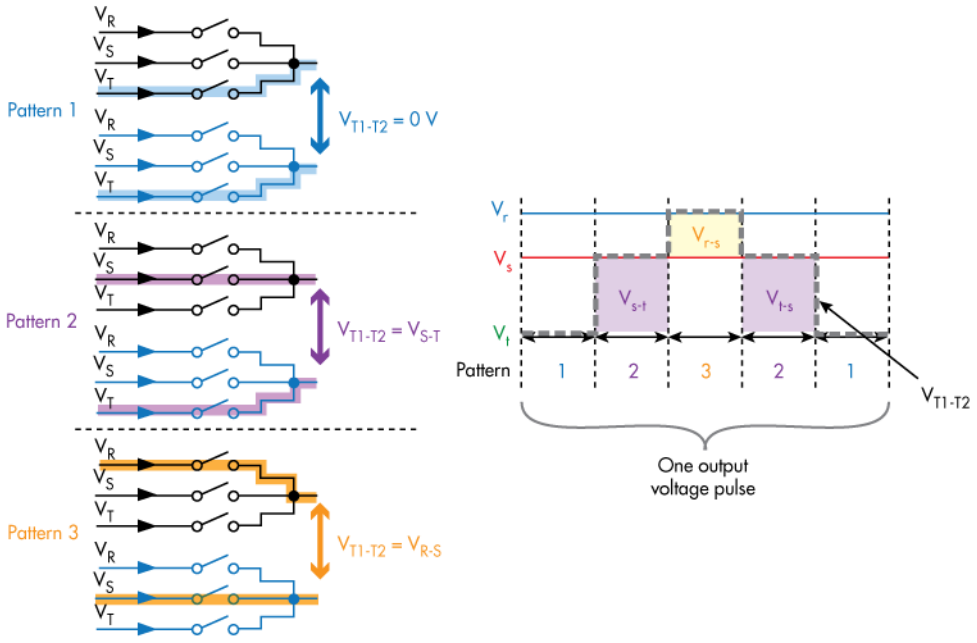


Figure 11: Generation of three-level output pulse

Generating a Waveform

The Matrix drive implements the steps above continuously as the input voltage changes. The only difference in the pulse pattern is the level being pulsed to the motor. As you see in Figure 12, for the same period of time the minimum and maximum voltages do not change. The mid voltage (Vr) changes, thus providing a pulses output using a variable three level control.

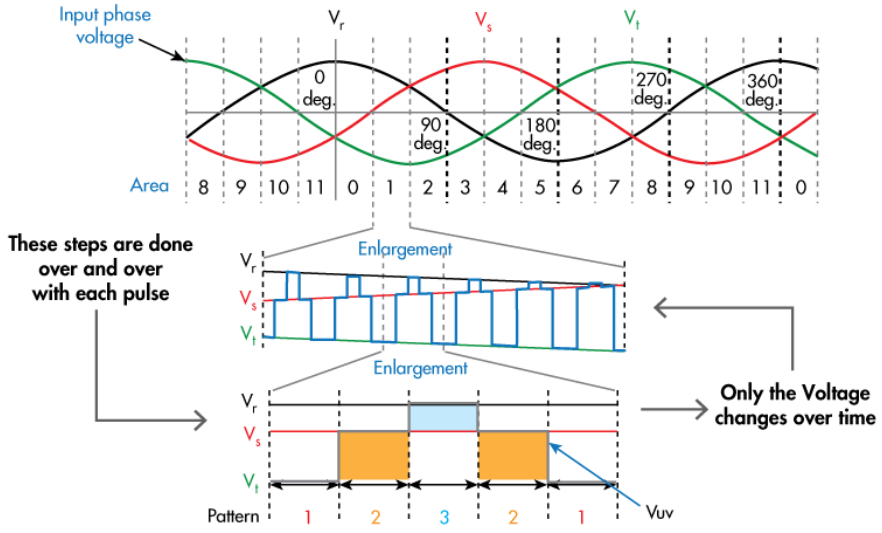


Figure 12: Waveform generation

The beauty of the way the matrix drive generates its output waveform is the resulting current draw. Unlike other low input harmonic current solutions the matrix drive does not force current into the drive to reduce harmonics. The matrix drive draws current with low harmonic content naturally. Each time the drive generates a pulse to the motor using the input voltage a corresponding current draw occurs. The current draw is taking from the line during each step of the generation of the variable three level output. The result of generating a full PWM output voltage waveform to control the motor naturally results in an input current waveform that is sinusoidal with low harmonic currents. The matrix drive can operate at rated power with less than 5% iTHD at the input of the drive with near unit power factor (0.98 or better).

IEEE-519 provides recommended practice and requirements for harmonic control in electric power systems. The recommendations of IEEE-519 apply to an entire system not to one specific device. However, the matrix drive's natural ability to draw current with less than 5% iTHD means that the matrix drive can meet the most stringent requirements of IEEE-519 at the input of the drive. The performance of the matrix drive means that you can add a matrix drive to your system or it could be the sole load on a power supply and be confident it will not exceed the most stringent requirements of IEEE-519.

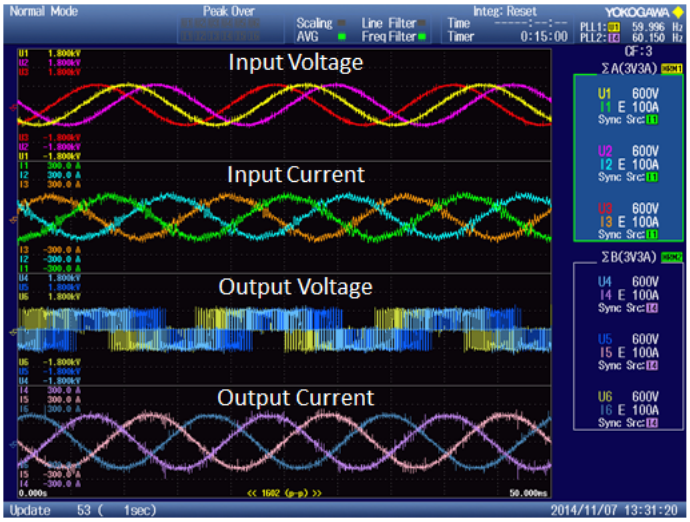


Figure 13: Sample waveform

Key Advantage of Matrix Drives

- Near Unity Power Factor
- Low Harmonics
- Full Continuous Regeneration
- Compact Size
- High Efficiency
- Induction Motor and Permanent Magnet Motor Control

Applications Suited for the Benefits of Matrix Drives

- Centrifuges
- Downhill Conveyors
- Escalators/Moving Walkways
- Extruders
- Fans
- Feeders
- Industrial Washers
- Lumber Industry
- Metal Working
- Mixers
- Pumps
- Pumpjacks
- Punch/Ram Presses
- Steel Grinders
- Test Dynamometers
- Winders

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