Inverters & Variable Frequency Drives

NREL / NWTC 5 MW Dynamometer

INTERGRID

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About the Presenter..

- Renewable Energy since 1982
- Codes and Standards
- Power Electronics & Inverters
- Chairing NEC & IEEE WGs on Microgrids

NREL - Silicon Carbide-Based Inverters for Intermediate Wind Applications

Single & Three Phase Inverters 20-50 kW for Wind and Storage. Variable Speed Drives (VFD) as active front-end.

Acknowledgement & Thanks
NREL Subcontract - NFC-5-52012-03

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NREL NATIONAL RENEWABLE ENERGY LABORATORY CIP Program

What is a VFD (Variable Frequency Drive)?

A variable-frequency drive (VFD) (also termed adjustable-frequency drive, variable-speed drive, AC drive, micro drive or inverter drive) is a type of adjustable-speed drive used in electro-mechanical drive systems to control AC motor speed and torque by varying motor input frequency and voltage.
https://en.wikipedia.org/wiki/Variable-frequency_drive

ABB (Finland)

Hitachi (Japan)

Yaskawa (Japan)
Owns Solectria USA

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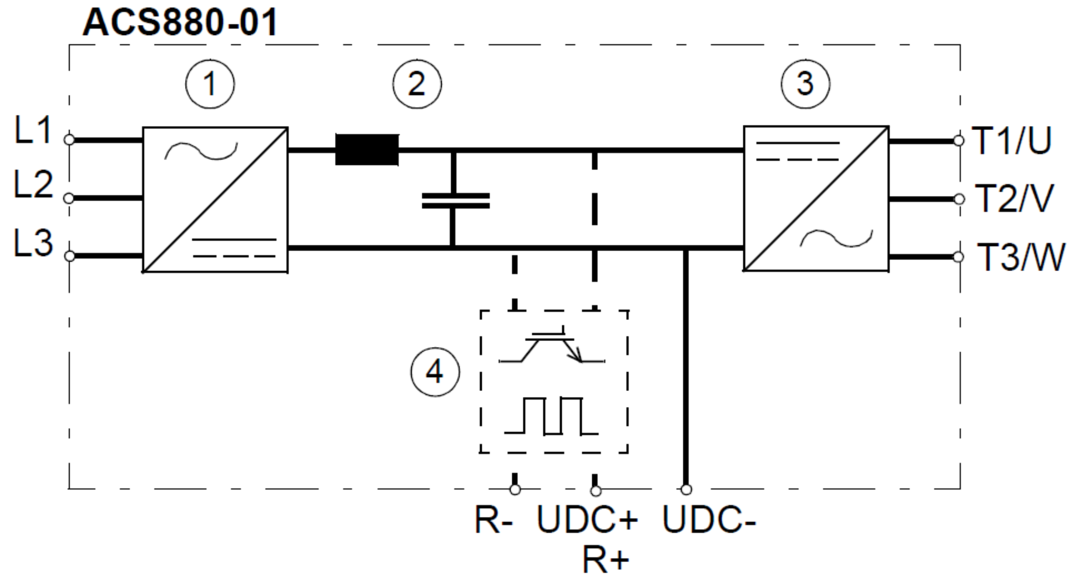
What is a VFD (Variable Frequency Drive)?



1	Rectifier. Converts alternating current and voltage to direct current and voltage.
2	DC link. DC circuit between rectifier and inverter.
3	Inverter. Converts direct current and voltage to alternating current and voltage.
4	Brake chopper. Conducts the surplus energy from the intermediate DC circuit of the drive to the brake resistor when necessary. The chopper operates when the DC link voltage exceeds a certain maximum limit. The voltage rise is typically caused by deceleration (braking) of a high inertia motor. User obtains and installs the brake resistor when needed.

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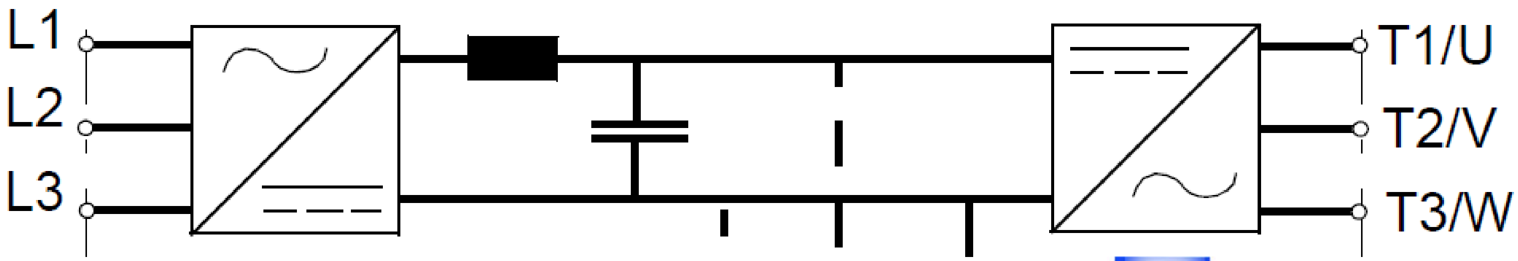
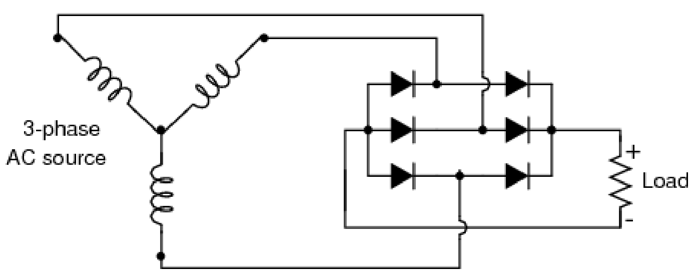
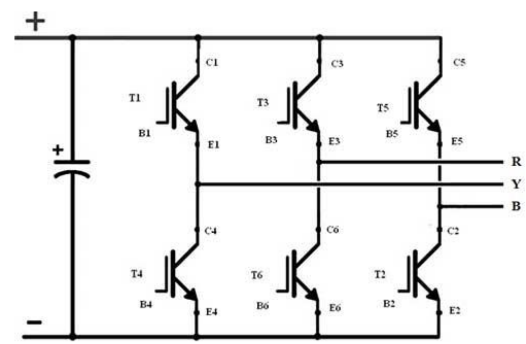
What is a VFD (Variable Frequency Drive)?



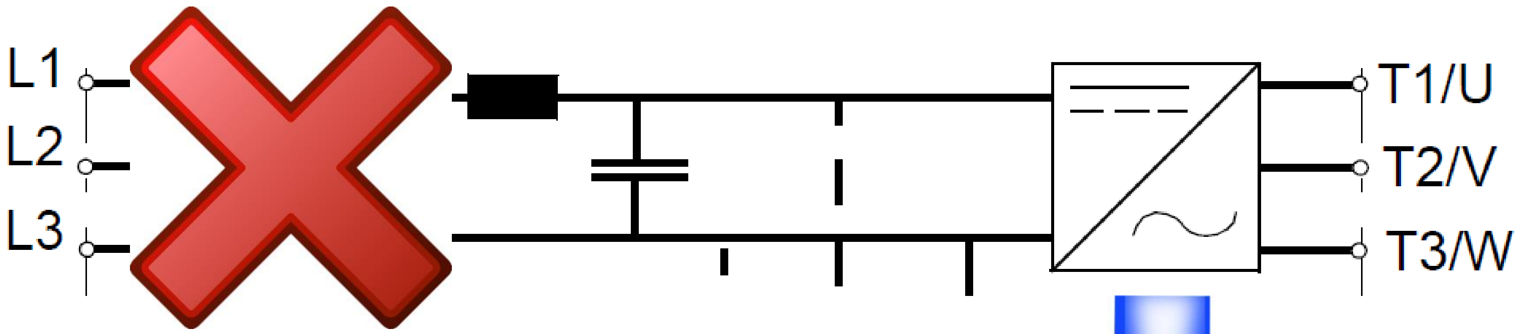


Three Phase Rectifier

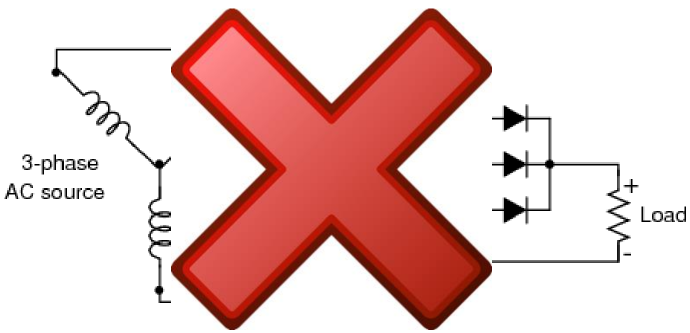


Three Phase Inverter

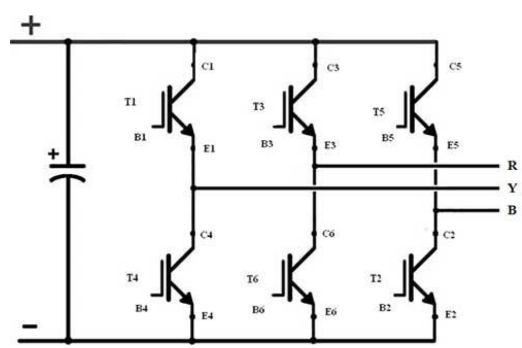
What is a VFD (Variable Frequency Drive)?



We use the VFD output inverter as an active PFC rectifier



Three Phase Rectifier



Three Phase Inverter

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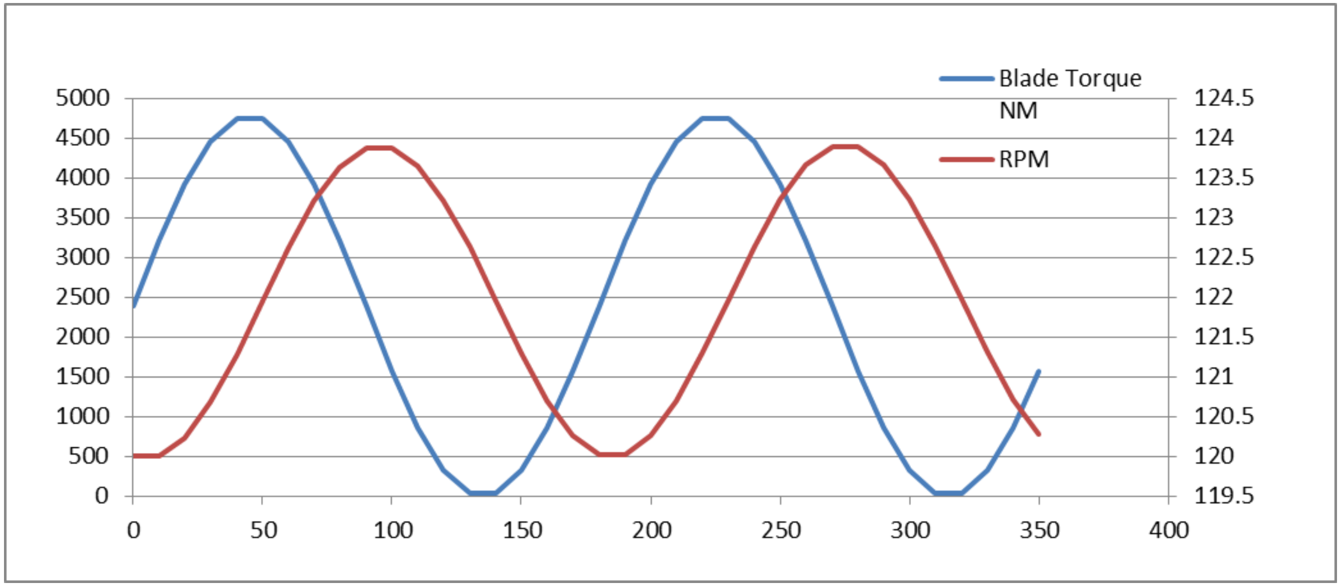
Why Use VFDs for The Wind Drive Train?

1. Torque Control



Torque control is essential for VAWTs

Rotor inertia smooths out torque ripple in hub and drive

Torque control benefits stall controlled HAWTs

Provides more accurate speed control

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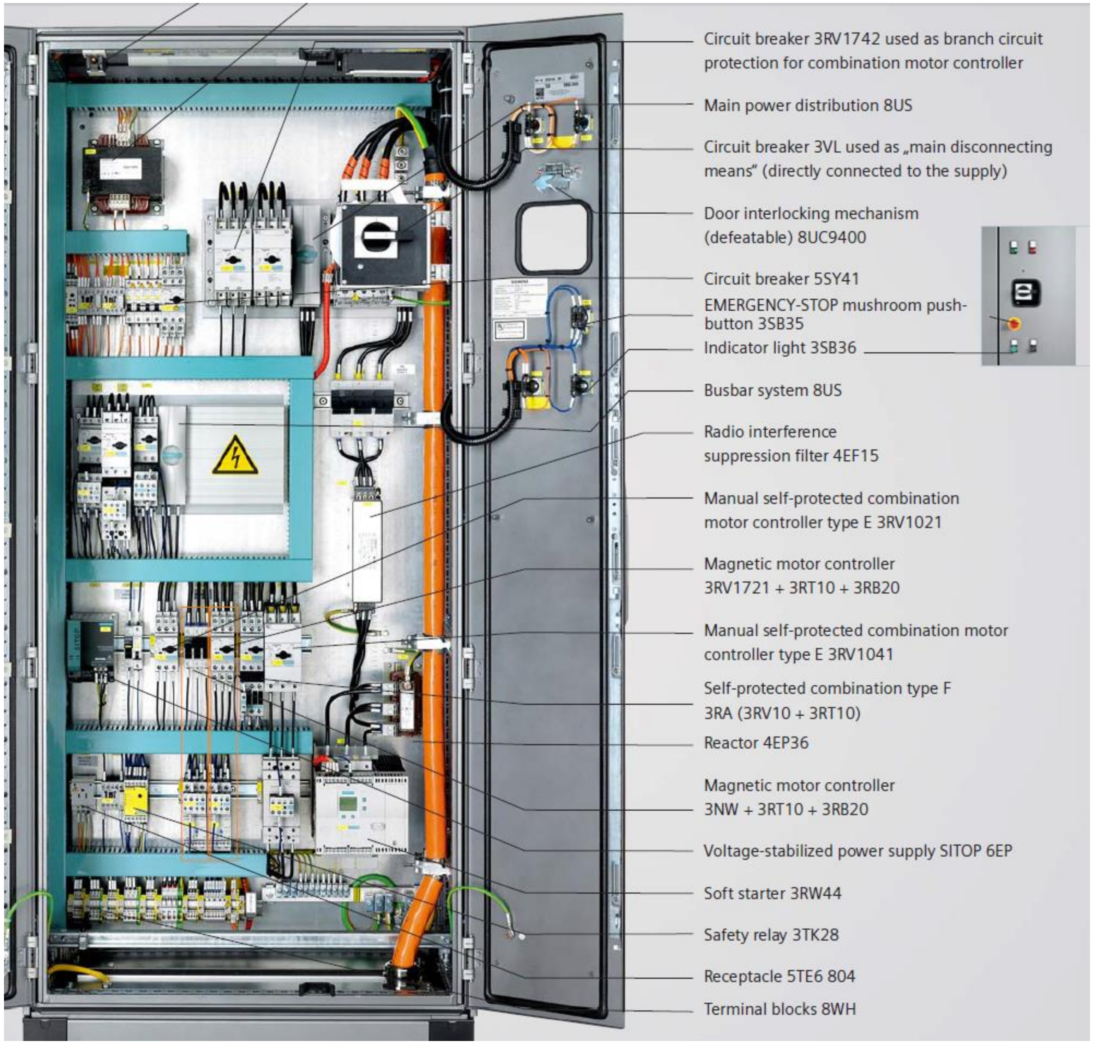
Why Use VFDs?

2. UL Listed Turbine Front End & Assemblies

- VFDs: UL 508C ->
  UL 61800-5-1 (2012)
- Assemblies: UL508
- UL 508 Certified Assemblers

IEC 61800-5-1 specifies requirements for adjustable speed power drive systems, or their elements, with respect to electrical, thermal and energy safety considerations. It does not cover the driven equipment except for interface requirements.



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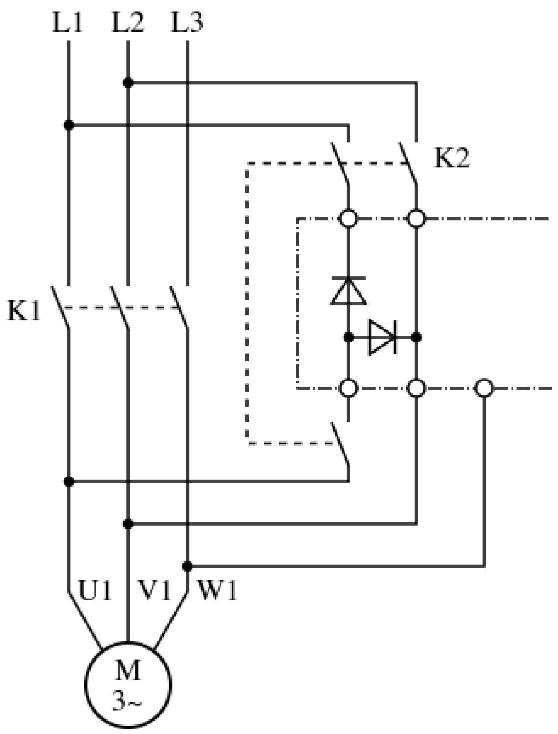
Why Use VFDs?

3. DC Injection Braking



DC Injection Braking may eliminate the need for a diversion load

http://machinedesign.com/mechanical-drives/three-phase-induction-motors-put-brakes

Why Use VFDs?

4. Ability to use Induction Generators

Motor Performance Data (460 Volt)														
Part Number	HP	F.L. rpm	F.L. Amps @460V	N.L. Amps @460V	F.L. Torque (lb-ft)	B.D. Torque (lb-ft)	F.L. Effic. (%)	F.L. Power Factor	Rotor Inertia (lb-ft^2)	Ohms/Ph - Equiv. Wye Circuit (460 VAC) (at rated operating temp. in 40° C ambient)				
										R1	R2	X1	X2	XM
E205	15	1775	19	8	44.5	126.4	92.4	81	2.4	0.376	0.238	1.351	1.777	32.508
E206	20	1775	24	8	59.5	144.6	93.0	84	3.2	0.267	0.207	0.990	1.491	28.4
E207	25	1775	31	14	74	215	93.6	81	4.2	0.150	0.154	0.852	1.066	20.064
E208	30	1773	36	15	89	245	94.1	82	4.5	0.125	0.136	0.724	0.937	17.785
E209	40	1780	48	18	118	304	94.1	83	8.5	0.082	0.066	0.597	0.798	13.514
E210	50	1775	60	24	148	340	94.5	82	9.2	0.068	0.062	0.483	0.648	11.068
E211	60	1780	69	22	177	449	95.0	86	16	0.065	0.047	0.412	0.473	11.447
E212	75	1780	86	28	221	574	95.4	86	18	0.048	0.037	0.319	0.386	9.238
E213	100	1780	113	28	295	773	95.4	87	28	0.034	0.028	0.307	0.287	8.920

* Maximum Constant HP RPM is for direct coupled loads.

- *Off The Shelf (OTS)*
- *Lower Cost*
- *Higher Efficiency - Lower Iron Losses (B ~ Torque)*
- *Simple Construction*
- *No Magnet Thermal Issues*
- *No Cogging*
- *VFD supplies required reactive power excitation*

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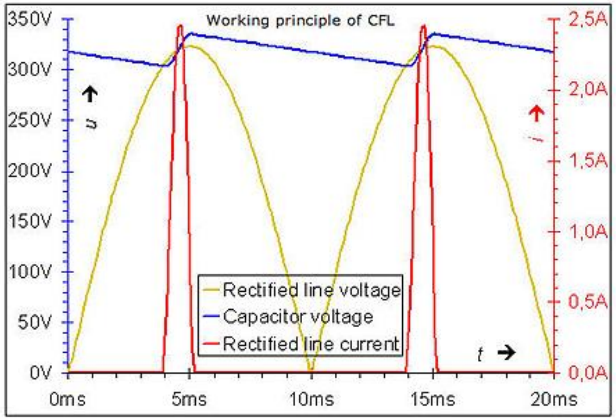
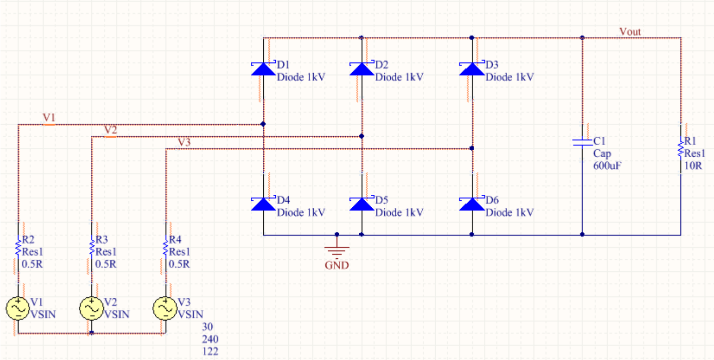
Why Use VFDs?

5. Increased Efficiency





Non-Sinusoidal Current causes Higher generator and wiring losses ($P = I^2R$)
Improvements of a few % to 10% possible with long cables

Also, 460V class generators and drives can be used (700V output).
Reduces currents and wire size

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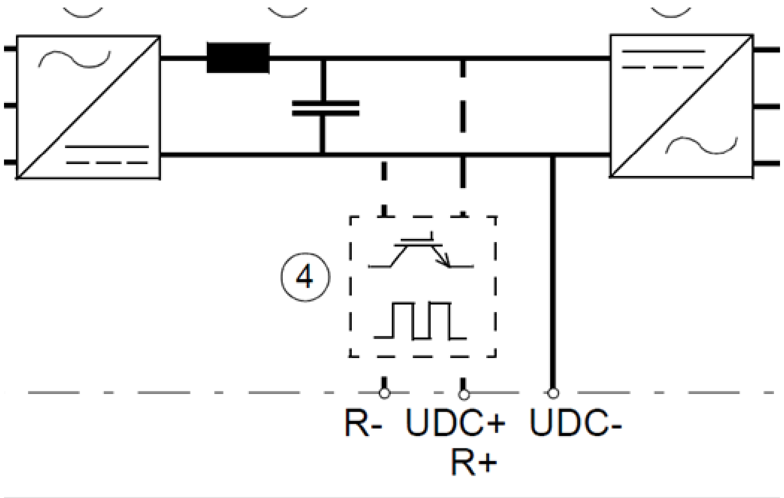
Why Use VFDs?

6. Integral or Optional Diversion Load Control



Considering development costs, a VFD is likely less expensive than a custom rectifier and diversion load controller

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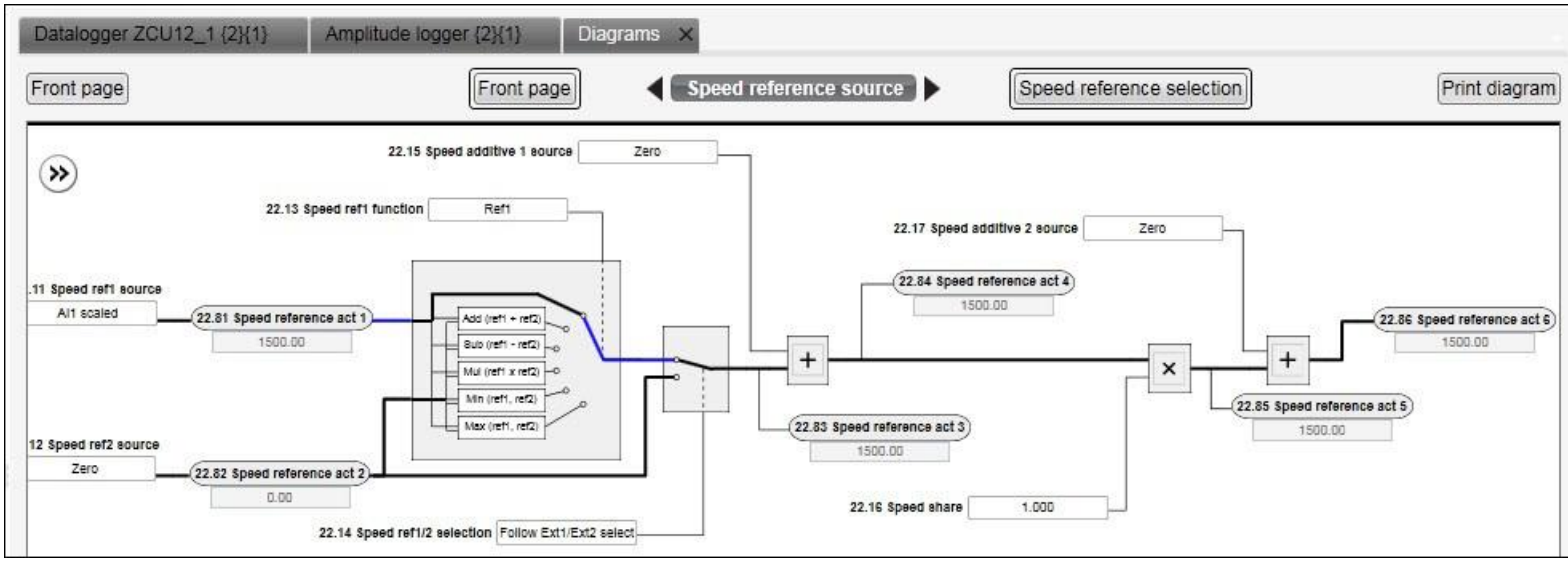
Why Use VFDs?

7. Internal Programming



Complex control programs can be embedded in the VFD.
For example, startup and shutdown sequences,
Torque curve programming (T ~ RPM^2)

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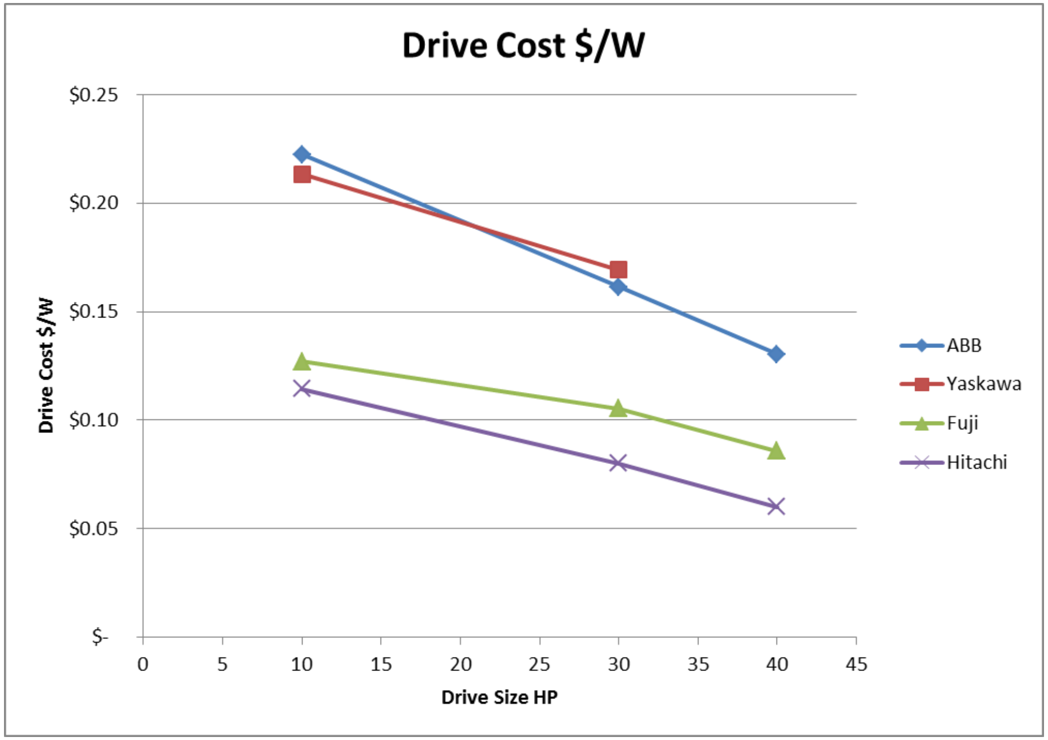
Why Use VFDs?

8. Cost



Considering development costs, a VFD is likely less expensive than a custom rectifier and diversion load controller

What’s the Downside?

- VFD flexibility means lots of setup parameters, complexity and a significant learning curve (500 page software manual)
- Manufacturers show little interest in low-volume non-traditional applications
- Field support staff require education ☺

Group	Contents	Page
45 Energy efficiency	Settings for the energy saving calculators.	307
46 Monitoring/scaling settings	Speed supervision settings; actual signal filtering; general scaling settings.	310
47 Data storage	Data storage parameters that can be written to and read from using other parameters’ source and target settings.	313
49 Panel port communication	Communication settings for the control panel port on the drive.	316
50 Fieldbus adapter (FBA)	Fieldbus communication configuration.	318
51 FBA A settings	Fieldbus adapter A configuration.	326
52 FBA A data in	Selection of data to be transferred from drive to fieldbus controller through fieldbus adapter A.	327
53 FBA A data out	Selection of data to be transferred from fieldbus controller to drive through fieldbus adapter A.	328
54 FBA B settings	Fieldbus adapter B configuration.	328
55 FBA B data in	Selection of data to be transferred from drive to fieldbus controller through fieldbus adapter B.	329
56 FBA B data out	Selection of data to be transferred from fieldbus controller to drive through fieldbus adapter B.	330
58 Embedded fieldbus	Configuration of the embedded fieldbus (EFB) interface.	330
60 DDCS communication	DDCS communication configuration.	338
61 D2D and DDCS transmit data	Defines the data sent to the DDCS link.	351
62 D2D and DDCS receive data	Mapping of data received through the DDCS link.	355
90 Feedback selection	Motor and load feedback configuration.	363
91 Encoder module settings	Configuration of encoder interface modules.	371
92 Encoder 1 configuration	Settings for encoder 1.	374
93 Encoder 2 configuration	Settings for encoder 2.	380
94 LSU control	Control of the supply unit of the drive, such as DC voltage and reactive power reference.	380
95 HW configuration	Various hardware-related settings.	384
96 System	Language selection; access levels; macro selection; parameter save and restore; control unit reboot; user parameter sets; unit selection.	388
97 Motor control	Motor model settings.	395
98 User motor parameters	Motor values supplied by the user that are used in the motor model.	398
99 Motor data	Motor configuration settings.	400
200 Safety	FSO-xx settings.	406

Summary of parameter groups

Group	Contents	Page
01 Actual values	Basic signals for monitoring the drive.	111
03 Input references	Values of references received from various sources.	114
04 Warnings and faults	Information on warnings and faults that occurred last.	115
05 Diagnostics	Various run-time-type counters and measurements related to drive maintenance.	122
06 Control and status words	Drive control and status words.	123
07 System info	Drive hardware and firmware information.	135
10 Standard DI, RO	Configuration of digital inputs and relay outputs.	137
11 Standard DIO, FI, FO	Configuration of digital input/outputs and frequency inputs/outputs.	144
12 Standard AI	Configuration of standard analog inputs.	149
13 Standard AO	Configuration of standard analog outputs.	153
14 I/O extension module 1	Configuration of I/O extension module 1.	157
15 I/O extension module 2	Configuration of I/O extension module 2.	178
16 I/O extension module 3	Configuration of I/O extension module 3.	181
19 Operation mode	Selection of local and external control location sources and operating modes.	185
20 Start/stop/direction	Start/stop/direction and run/start/jog enable signal source selection; positive/negative reference enable signal source selection.	187
21 Start/stop mode	Start and stop modes; emergency stop mode and signal source selection; DC magnetization settings; autophasing mode selection.	196
22 Speed reference selection	Speed reference selection; motor potentiometer settings.	203
23 Speed reference ramp	Speed reference ramp settings (programming of the acceleration and deceleration rates for the drive).	211
24 Speed reference conditioning	Speed error calculation; speed error window control configuration; speed error step.	217
25 Speed control	Speed controller settings.	220
26 Torque reference chain	Settings for the torque reference chain.	231
28 Frequency reference chain	Settings for the frequency reference chain.	237
30 Limits	Drive operation limits.	246
31 Fault functions	Configuration of external events; selection of behavior of the drive upon fault situations.	252
32 Supervision	Configuration of signal supervision functions 1…3.	261
33 Generic timer & counter	Configuration of maintenance timers/counters.	265
35 Motor thermal protection	Motor thermal protection settings such as temperature measurement configuration, load curve definition and motor fan control configuration.	273
36 Load analyzer	Peak value and amplitude logger settings.	283
40 Process PID set 1	Parameter values for process PID control.	287
41 Process PID set 2	A second set of parameter values for process PID control.	299
43 Brake chopper	Settings for the internal brake chopper.	301
44 Mechanical brake control	Configuration of mechanical brake control.	303

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Regenerative VFDs

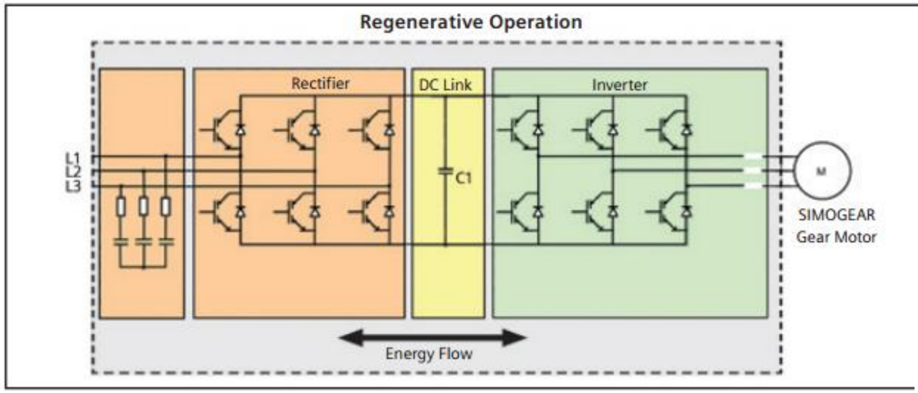

ABB industrial drives
ACS800, regenerative drives, 5.5 to 5200 kW

Currently, Siemens is the only MFR with a UL1741 listed regen drive. (120 kW three phase). No interest in single phase.

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Using A Separate Inverter

- Inverter runs with constant input bus voltage
- VFD rectifies and boosts input alternator voltage to bus voltage
- Power output is proportional to VFD torque command
- No VFD-to-Inverter comm. needed.

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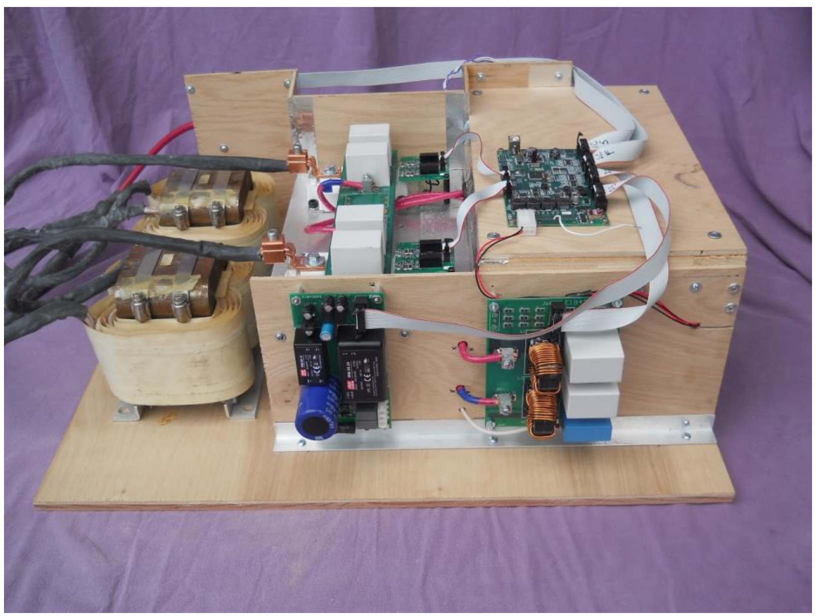
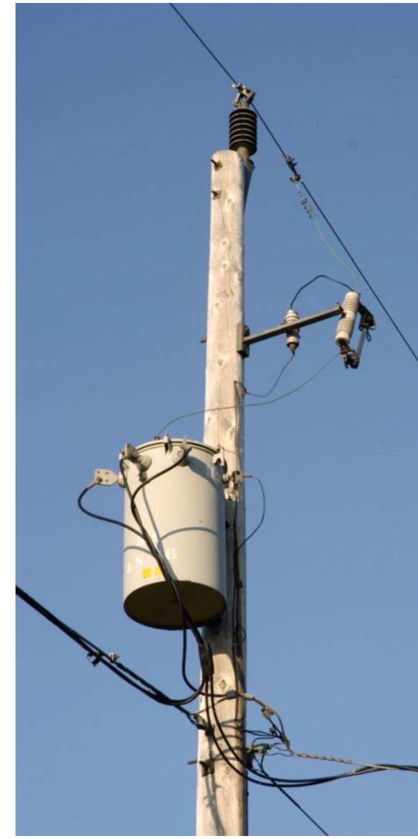
Intergrid SiC Inverter Development

- **Addressing 25 – 40 kW Single Phase Market (120/240V)**
- **Up to 100 kW 480V three phase**
- **Suitable for Battery Energy Storage**
- **High Rate LiTi Diversion Load**



CREE SIC FET

"Breadboard" Prototype



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Christmas is coming..

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PortandStarboard.com