

Table of Contents

Foreword	ix
Acknowledgements	x
About the Hydraulic Institute	xi
About Pump Systems Matter	xii

Chapter • One

An Introduction to Variable Frequency Drives (VFDs), 1

1.1 VFD System Architecture	2
1.1.1 Overview	2
1.1.2 VFD	2
1.1.3 Controls	3
1.1.4 Motor	4
1.1.5 Operating Principles	6

Chapter • Two

Application Considerations for VFDs, 9

2.1 Overview	9
2.2 Load Types and Control Functions	10
2.2.1 Pump/Motor Load Types	10
2.2.2 Application/Control Functions	14
2.3 Harmonics	15
2.3.1 Harmonic Origination	15
2.3.2 Harmonic Mitigation	16
2.3.3 Reactors	16
2.3.4 Drive Isolation Transformers (DITs)	18
2.3.5 Passive Harmonic Filters	18
2.3.6 Multipulse Front End Solutions	18
2.3.7 Active Front End Drives	19
2.3.8 Active Harmonic Filter (Injection Technology)	20
2.3.9 Broadband Filters	20
2.3.10 Single-Stage Tuned Trap and Tune Trap Systems	21
2.4 Motor and Other Considerations	21
2.5 Pump Dynamic Considerations When Applying a VFD	24
2.5.1 Rotor and Structural Resonance	24
2.5.2 Mechanical	25

Chapter • Three
Installation Considerations for VFDs, 27

3.1 Overview	27
3.2 Installation Considerations.....	27
3.2.1 Environment	27
3.2.2 Electrical System	30
3.2.3 Service Entrance Rating.....	40
3.2.4 Installation in Buildings.....	40
3.3 Helpful Installation Tips	41
3.4 Final Reminder.....	42

Chapter • Four
Troubleshooting VFD Problems, 43

4.1 Cautions and Overview	43
4.1.1 Caution.....	43
4.1.2 Overview	44
4.2 Hardware Troubleshooting.....	44
4.2.1 General Assessment	44
4.2.2 Recommended Grounding	45
4.2.3 Output Cable Length	46
4.2.4 Excessive Voltage Drop at Motor Terminals	47
4.2.5 VFD Overtemperature Fault.....	48
4.3 Troubleshooting with Fault Codes	48
4.3.1 Fault Codes (VFD Detection of External Faults)	48
4.3.2 Fault Reset.....	54
4.3.3 Monitoring.....	54
4.4 System Problems.....	55
4.4.1 Defining the System.....	55
4.4.2 Vibration.....	55
4.4.3 Water Hammer.....	56
4.5 Motor Issues	57
4.5.1 Windings.....	57
4.5.2 Bearings.....	58
4.6 Maintenance	59
4.6.1 Enclosure Filters.....	59
4.6.2 VFD Working Area	59
4.6.3 Hot Spots	60
4.6.4 Cable Lug Torque.....	60

Appendix A
Glossary for VFDs and Related Applications, 61

Appendix B
Index, 75

List of Figures

1.2	Basic VFD diagram	3
1.3	Typical operator interface	4
1.4	VFD input/output diagram (I/O)	5
1.5	Motor nameplate template	7
2.1	VFD output PWM (blue) waveform with corresponding sine wave (red)	10
2.2	Typical constant torque profile	11
2.3	Pump and load type classification	11
2.4	Centrifugal load affinity laws	12
2.5	Controlling the speed of a positive displacement pump	13
2.6	Typical constant horsepower load	14
2.7	VFD input power waveforms (voltage and current)	17
2.8	VFD input power current waveform	18
2.9	Front end solution with 12-pulse rectifier	19
2.10	Front end solution with 18-pulse rectifier	19
2.11	Active rectifier (front end) VFD	20
2.12	VFD input power waveforms (voltage and current)	20
2.13	Effectiveness of harmonic abatement	21
3.1	Low-impedance grounding strap	31
3.2	VFD input protection using a circuit breaker	32
3.3	VFD input protection using fuses	32
3.4	TECK cable	34
3.5	High-frequency ground current paths	36
3.6	Shielded cable with three symmetrical ground wires	36
3.7	Distributed inductance and capacitance over the motor cable	37
4.1	Multiple VFD grounding	45

4.2	VFD/motor grounding	46
4.3	Example of a pumping system	56

List of Tables

1.1	Typical 60-Hz motor speeds and corresponding pole numbers.	6
1.2	Typical 50-Hz motor speeds and corresponding pole numbers.	6