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Power Drive System Retrofit Opportunities in the Northwest

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Memorandum

To: Northwest Energy Efficiency Alliance (NEEA)

From: Cadeo Group

Date: September 15, 2022

Re: Power Drive System (PDS) Product Research

The Northwest Energy Efficiency Alliance (NEEA) is interested in understanding the market and savings opportunities associated with the use of an adjustable speed motor—a Power Drive System (PDS)—in the Pacific Northwest. Already, NEEA's research has shown that there is significant PDS energy savings opportunity at the per-unit level in many commercial and industrial applications.[1] Existing research also shows that the adoption of PDSs remains limited—only 22% of all installed commercial and industrial motor horsepower in the United States is equipped with adjustable speed control. Given that motor-driven systems represent more than 50% of all commercial and industrial end-use electricity consumption in United States, there is significant opportunity to reduce electricity consumption by adopting more PDSs.[2]

Because they already have programs that focus on new construction sales, NEEA is interested in the applicability of retrofitting existing pumps and fans with PDSs. Although PDSs can be applied to a variety of motor-driven loads, most energy consumption and saving opportunity exists in centrifugal loads, such as pumps, fans, and compressors. Through previous research, NEEA determined that variable speed air compressors do not present a strong retrofit opportunity.[3] As part of that research, the research team demonstrated that there are 295 average megawatts (aMW) of retrofit PDS energy savings opportunity for pumps and fans in the Northwest commercial and industrial sectors. This is equivalent to approximately 30% of the energy efficiency resources the region needs to acquire by 2027 based on the 2021 Northwest Power Plan.[4]

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[1] Northwest Energy Efficiency Alliance (NEEA), *Power Drive Systems: Energy Savings and Non-Energy Benefits in Constant & Variable Load Applications*, by Cadeo Group, E20-313, Portland, Oregon: NEEA, 2020. https://neea.org/resources/power-drive-systems-energy-savings-and-non-energy-benefits-in-constant-variable-load-applications.

[2] Prakash Rao, Paul Sheaffer, Yuting Chen, Miriam L. Goldberg, Benjamin Jones, Jeff Cropp, and Jordan Hester, *U.S. Industrial and Commercial Motor System Market Assessment Report Volume 1: Characteristics of the Installed Base*, LBNL-20001382, Lawrence Berkeley National Laboratory: Berkeley, California, 2021. https://buildings.lbl.gov/publications/us-industrial-and-commercial-motor.

[3] Commercial & Industrial Air Compressor Market Characterization Memo prepared by Cadeo, August 2021.

[4] Northwest Power and Conservation Council, "2021 Power Plan Summary," https://www.nwcouncil.org/media/filer_public/45/b0/45b02281-e3da-4788-ad74-355e5c755a75/2022-2.pdf

This memo presents the findings from PDS market research in four sections:

- **1 | Power Drive System Overview:** This section provides context for what a PDS is and how it saves energy and affects power quality.
- **2 | Power Drive System Metrics:** This section describes the evolution of PDS metrics, including Power Index (PI), a metric that NEEA helped develop. This section reviews the benefits of a technology-agnostic approach to measuring PDS energy savings at various operating conditions.
- **3 | Market Characterization:** This section provides information about the PDS market: an estimate of the technical potential for drives in the Northwest, a discussion of how incentive programs currently influence drive adoption, and the PDS supply chain.
- **4 | Barriers and Strategies to Address:** This section explains barriers to the adoption of drives, as well as potential strategies to overcome these barriers.

Following these sections, the research team offers a PDS product definition that succinctly characterizes and differentiates safe and effective PDS with significant energy savings potential. Finally, the research team provides recommended next steps that NEEA can use to advance PDS to the next stage.

Power Drive System Overview

This section outlines concepts and terms that are necessary to understand the scope of a PDS, PDS energy savings, and PDS impacts on power quality. There are two main components of a PDS: (1) the motor and (2) the adjustable speed drive (ASD). A PDS **does not** include any transmission or end-use equipment. Figure 1 shows a diagram of these components.

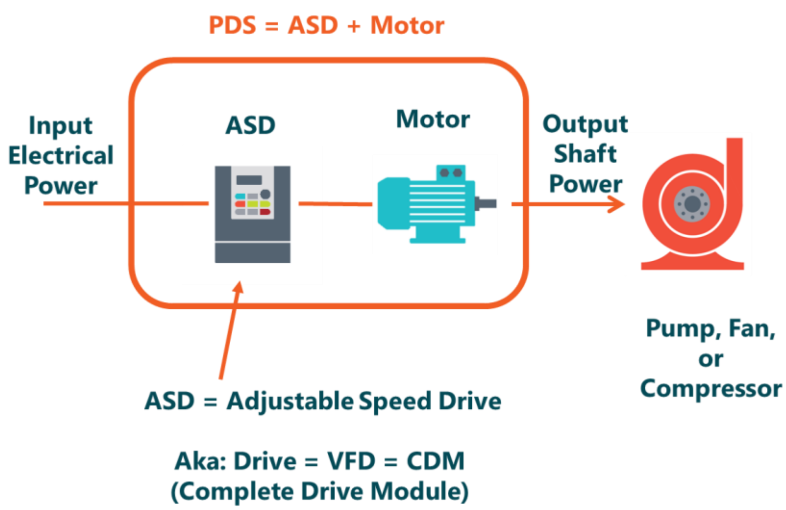

Figure 1: PDS Diagram

Motor: Motors serve to convert electrical energy to mechanical energy. A motor transfers this mechanical energy in the form of shaft rotation to the motor-driven equipment.

ASD: An ASD is a form of electronic control that allows the motor to rotate at different speeds by adjusting the input voltage and frequency. These are also referred to as "variable frequency drives" (VFDs), "complete drive modules," or simply "drives."

A PDS can include:

- a motor electrically connected to an ASD (i.e., drive on a wall).
- a motor physically connected to an ASD. These can either be a drive mounted on the motor housing or integrated motor/controls (e.g., electrically commutated motors [ECMs]).[5]

How a Power Drive System Saves Energy

By controlling the speed of a motor with a PDS, power consumption can be reduced. Power consumption reduction is more apparent in equipment like centrifugal fans, pumps, and compressors. This equipment follows the affinity laws: input power requirements are roughly proportional to the cube of speed. Figure 2 shows the idealized relationship between power and speed for centrifugal systems. Because of this relationship, even small reductions in speed can result in large reductions in power consumption. For example, if the speed is reduced to 80% of full speed, the electrical power required is reduced to 51% of full power.

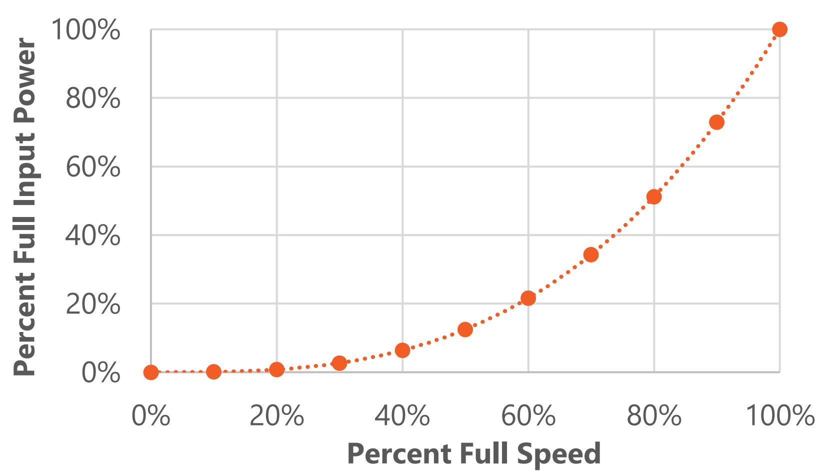

Figure 2: Affinity Law: Ideal Power/Speed Relationship for Centrifugal Systems

PDSs can be beneficial for both variable-load and constant-load systems (see Figure 3 for example load profiles). For variable load systems in which the required flow and pressure varies

[5] There are other types of integrated motor/controls (some permanent magnet motors, some synchronous reluctance motors) but these have very little market adoption and are generally used in niche applications. ECMs are currently sold and available in smaller sizes (generally fractional to 10hp) fans and pumps.

with time (e.g., a feedwater pump or a cooling tower fan), a PDS can replace mechanical flow-restricting equipment, such as a pump throttle valve or a fan damper, to match the changing needs of the system. PDSs save energy on constant-load systems (e.g., single-zone air handling unit, primary flow pumps through chillers) in a similar way, but rather then varying motor speed to match a changing load, the PDS right-sizes the system to match a steady design flow and pressure requirement. **Figure 4** shows the savings from replacing flow-restricting equipment with a PDS for various flow rates. The difference between the upper curve (throttle valve on a pump) and the lower curve (PDS) is the power savings. If a motor is oversized by 20%, power input reduces from 94% to 58% of full-flow power—an overall power savings of 36%. Although pumps commonly use mechanical flow-restricting devices, these devices are not as common for adjusting fan flow. Fans frequently use belts and sheaves to adjust the fan speed (and flow). Belts reduce the power required by fans nearly as much as a PDS, so a PDS is not applicable to all fan systems.

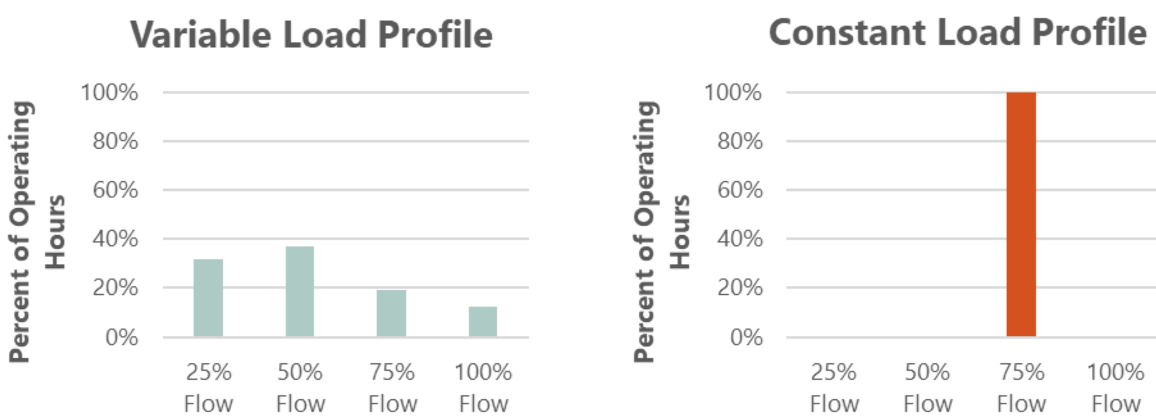

Figure 3: Example of a Variable-Load and a Constant-Load Profiles

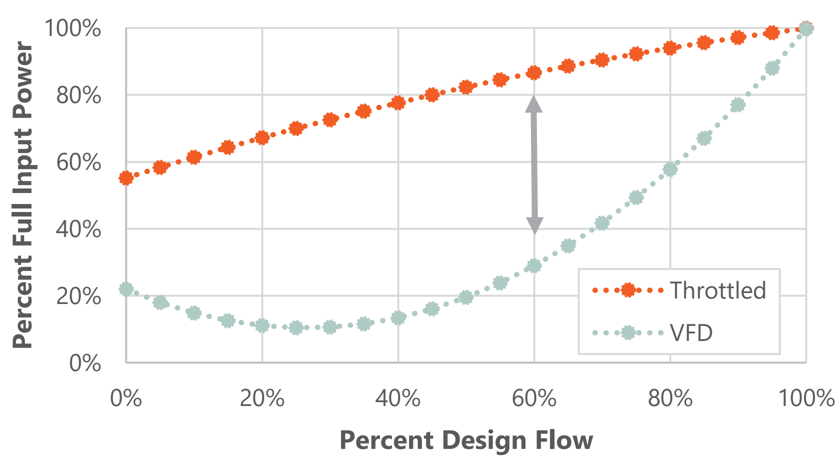

Figure 4: Typical Power Input Required for Pump Flow Control Methods (Throttle Valve vs. PDS)

Power Drive System Impacts on Power Quality

A known side-effect of PDS operation is the impact on power quality at the site and the local distribution network. Power quality is the degree to which the voltage, frequency, and waveform of a power supply conform to established specifications. Deviation from established standards can have detrimental effects on both electrical loads and power supply system architecture. PDSs, specifically the ASD component, inherently affect power quality because they are nonlinear loads, which means that their current consuming characteristics do not follow the fundament shape of the sinusoidal voltage waveform. The imbalance between power supply source waveform and load-drawn waveform from the ASD introduces harmonics into the power supply systems, a condition referred to as *harmonic distortion*. The impact of harmonic distortion on power quality is dependent on the size of PDS relative to the overall site load, the level of nonlinear loading already present at the site, and the relative sizing of the motor compared to the drive.

The Power Drive System Metrics section discusses metrics used to determine acceptable levels of harmonic distortion and the Barriers and Strategies to Address section discusses the consequence of this issue as it relates to PDS adoption and the mitigation strategies to reduce PDS-generated harmonic distortion.

Power Drive System Metrics

Motor and drive efficiency metrics have steadily evolved alongside the motor-driven systems they characterize. Historically, motor-driven system standards focused on rating the full-load efficiency of the motor. This worked because most motors ran at their nominal speed, so testing was only necessary at full load operating condition. Today, with the increased adoption of PDS, more motors operate at part-load operating conditions, requiring a shift in how motor-driven system efficiency and energy savings are calculated. The research team reviewed existing and forward-looking PDS efficiency metrics to understand the various ways to characterize PDS energy savings benefits and preserve acceptable power quality.

Full-load Component Efficiency Metrics

Currently, motor-driven system standards focus on rating the full-load efficiency of the motor and drive components separately. Full-load efficiency testing standards are straightforward and allow for a simple efficiency comparison between similar components; however, these standards do not capture the power savings of a PDS operating in the field. To capture PDS power savings, a new metric that accounts for the interaction between the ASD and motor at partial-speed operation is necessary.

The US Electric Motors Test Procedure, published September 20, 2022, recognizes the efficiency standards listed in Table 1. Institute of Electrical and Electronics Engineers (IEEE 112), IEEE 114, Canadian Standards Association (CSA) C390, CSA C747, and International Electrotechnical Commission (IEC) 60034-2-1 only apply to the electric motors and their test methods and data requirements are harmonized with one another. IEC 61800-9-2 is unique because it is the only standard that covers losses from the PDSs. Additionally, the test method compares a "real" PDS with a "reference" PDS at various part-torque and part-speed operating points. Although the US Department of Energy (DOE) requires use of this standard to define the full-load efficiency of inverter-only motors, inside the standard also serves as a framework to develop a weighted-average input power metric for PDS.

Table 1: Standards Referenced in the DOE's Electric Motors Test Procedure with Full-Load Efficiency Test Methods

Standard Name	Scope
IEEE 112-2017	Polyphase electric motors
IEEE 114-2010	Single-phase electric motors
CSA C390-10 (R2019)	Polyphase electric motors greater than 1 hp
CSA C747-09 (R2019)	Single-phase electric motors and polyphase electric motors less than 1 hp
IEC 60034-2- 1:2014	Single-phase and polyphase induction motors and synchronous motors
IEC 61800-9-2:2017	Electrical drives and inverter-fed electric motors that include an inverter

Power Index

NEEA and the National Electrical Manufacturers Association (NEMA) worked together to develop the PI rating system and metric based on the available data in IEC 61800-9-2.[6] This metric allows a streamlined method to evaluate the reduction in power, and associated energy savings, by controlling equipment speed with a PDS. PI ratings use data at several load points over the spectrum of speed/torque points and provides a way to compare the savings of adding a drive to a full-speed motor. The final PI rating is a number between 0 and 100 that represents the percent power savings over a baseline (NEMA Premium) constant speed motor. As such, higher numbers represent higher energy savings.

PI is a balance between engineering rigor and broad, data-driven assumptions that can be applied over a wide variety of motors. Though it does not calculate exact savings for a particular application, PI gives an estimate of savings similar to the miles-per-gallon ratings for cars. Like the city/highway mileage ratings, PI has separate ratings for variable ($PI_{,VL}$) and constant loads ($PI_{,CL}$). This will allow utility companies to calculate savings without having to perform costly measurements at each installation.

[6] National Electrical Manufacturers Association (NEMA), *NEMA MG 10011-2022: Power Index Calculation Procedure— Standard Rating Methodology for Power Drive Systems and Complete Drive Modules*, Rosslyn, Virginia: NEMA, https://www.nema.org/standards/view/power-index-calculation-procedure-standard-rating-methodology-for-power-drive-systems-and-complete-drive-modules.

The simplicity of PI will allow utilities to estimate savings without having to determine application specifics. To estimate savings, a utility would only need to know the type of load (variable or constant), the motor size, and the hours of use, which can be based on industry average data. This is especially valuable for smaller motors, where the energy and cost savings often do not justify the cost of data collection. Although PI provides for a simplified calculation, the load points and weightings used are based on rigorous engineering analyses. Authors of PI used data from the Motor System Market Assessment (MSMA), DOE rulemakings, utility company data, and NEEA research to determine typical load profiles and load points. NEMA industry experts and energy professionals vetted all data.

Power Quality Metrics

In addition to characterizing PDS efficiency, it is also worthwhile to characterize the PDSs' impact of power quality due to their introduction of harmonic distortion. While there is no national standard dictating harmonic distortion limits on systems, IEEE 519 provides recommended limits for acceptable harmonic distortion using the total harmonic distortion (THDi) metric. THDi represents harmonic content expressed as a percent of the fundamental 60-hertz grid frequency. The recommended limits in IEEE 519 apply to the point of common coupling (PCC), where the user's facility interfaces with the local distribution network. IEEE 519 states that the recommended limits should not be applied to individual pieces of equipment (such as a PDS) or at locations within a user's facility. This is because harmonic distortion may be significantly greater at these locations "due to the lack of diversity, cancellation, and other phenomena that tend to reduce the combined effects of multiple harmonic sources to levels below their algebraic summation." [7]

In interviews, subject matter experts agreed that having minimum THDi requirements for a PDS based on prescribed lab settings does not make sense because PDS harmonic distortion impacts are so interdependent on the site in which they are operating. This means that harmonic distortion impacts cannot be resolved easily with a metric. We discuss the ways to mitigate power quality issues for PDS in the absence of a metric in the Barriers and Strategies to Address section of this report.

Market Characterization

To understand the market for PDSs, the team looked at three items:

1 | Regional technical potential
2 | Regional program activity
3 | PDS supply chain

[7] IEEE-519 2014, https://standards.ieee.org/ieee/519/3710/

The regional technical potential provides an upper bound on the energy saving opportunity for the PDS market while the regional program activity quantifies the portion of the market that incentive programs have targeted. In addition to quantifying the size and savings opportunities associated with the PDS market, the team characterized the PDS supply chain to identify important market actors and uncover opportunities for market transformation.

Technical Potential

The research team conducted a detailed analysis to define the technical potential of retrofit PDS adoption in the Northwest. This technical potential relies on best available data from DOE's 2018 MSMA[8], NEEA's 2019 Commercial Building Stock Assessment (CBSA)[9], the Bonneville Power Administration's (BPA) ASD Market Model[10], and Regional Technical Forum (RTF) Unit Energy Savings Measures for commercial and industrial pumps[11] and fans[12]. This potential is only for retrofits: adding an ASD to an existing motor on an existing pump or fan or installing an integrated PDS (e.g., ECM) on an existing fan or pump. There are additional savings available (e.g., using a PDS to balance new construction pumps), but the research team calculated retrofit savings only at NEEA's direction.

The research team sought to characterize the technical potential of retrofit PDS for commercial and industrial pumps and fans. These equipment types represent the vast majority of retrofit PDS technical potential in the commercial and industrial sectors.[13] The regional retrofit PDS savings opportunity is dependent on the available stock, existing PDS saturation, and expected savings per retrofit. The analysis calculates regional energy savings from PDS retrofit measures using the equation shown below.

Equation 1: Technical Potential

$$Technical\ Potential = Stock * (1 - Saturation_{PDS}) * (UEC_{base} - UEC_{PDS})$$

Where:

- Stock = Total motor horsepower (hp) operating in the region 2021
- $Saturation_{PDS}$ = Saturation of PDS (%)

[8] U.S. Industrial and Commercial Motor System Market Assessment Report Volume 1: Characteristics of the Installed Base, https://buildings.lbl.gov/publications/us-industrial-and-commercial-motor

[9] NEEA 2019 Commercial Building Stock Assessment, https://neea.org/data/commercial-building-stock-assessments

[10] BPA Adjustable Speed Drives Market Research, https://www.bpa.gov/energy-and-services/efficiency/market-research-and-momentum-savings/adjustable-speed-drives-market-research

[11] Regional Technical Forum Efficient Pumps UES Measures, https://nwcouncil.app.box.com/v/ComIndAgPumps-v3-0

[1212] Regional Technical Forum Commercial and Industrial Fans UES Measures, https://nwcouncil.app.box.com/v/ComIndFans-v2-0

[13] Based on the 2018 MSMA, 46% of motor system electricity consumption in the commercial sector comes from pumps and fans, and 42% of motor system electricity consumption in the industrial sector comes from pumps and fans. Nearly all the remaining motor driven loads, with the exception of centrifugal compressors (7% of motor system electricity consumption in the commercial sector and 5% of motor system electricity consumption in the industrial sector), are constant-torque systems that would not provide as much energy savings through the adoption of a PDS.

- UEC_{Base} = Unit energy consumption of the motor with no PDS installed (kilowatt hour [kWh]/motor hp)
- UEC_{PDS} = Unit energy consumption of the motor with a PDS installed (kWh/motor hp)

Table 2 and Table 3 show the results of the technical potential analysis broken down by equipment type, sector, and load type. In total, the analysis identified 295 aMW of savings, finding that more than 50% of the saving are associated with commercial fans (173 aMW). Results from the analysis show significant savings opportunity in the industrial sector for both pumps (47 aMW) and fans (61 aMW) with noticeably less savings for commercial pumps (14 aMW). The rational for the technical potential values is described in the sections on PDS stock and unit energy savings below.

Table 2: Regional Retrofit PDS Potential for Pumps (aMW)

Load Type	Industrial	Commercial
Variable Load	21	5
Constant Load	27	9
Total	**47**	**14**

Table 3: Regional Retrofit PDS Potential for Fans (aMW)

Load Type	Industrial	Commercial
Variable Load	53	107
Constant Load	8	65
Total	**61**	**173**

The 2018 MSMA included its own energy savings opportunity assessment that provides nationwide estimates for VFD retrofit savings by equipment type and sector.[14] Table 4 shows a comparison between the 2018 MSMA values and the regional technical potential values described above. The regional technical potential of industrial pumps and fans and commercial pumps represents approximately 4% of the national technical potential, while the regional technical potential of commercial fans represents 8%.

Table 4: Technical Potential Comparison with 2018 MSMA

Sector and Equipment	National Savings from 2018 MSMA (aMW)	Regional Savings for NEEA Technical Potential (aMW)	Regional Percentage of National Savings (%)
Commercial Pumps	329	14	4.3%
Commercial Fans	2155	173	8.0%
Industrial Pumps	1182	47	4.0%
Industrial Fans	1567	61	3.9%

[14] U.S. Industrial and Commercial Motor System Market Assessment Report Volume 3: Energy Savings Opportunity, https://buildings.lbl.gov/publications/us-industrial-and-commercial-motor-1

Stock and Power Drive System Saturation Assessment

The research team characterized pump and fan stock and PDS saturation using separate data sources for the commercial and industrial sector. For the industrial sector, the research team relied on BPA's ASD Market Model data. For the commercial sector, the research team relied on NEEA's 2019 CBSA to define the total pump and fan stock and the 2018 MSMA to define the distribution of constant-load and variable-load systems as well as the PDS saturation. The 2019 CBSA also included data on PDS saturation; however, the research team concluded the portion of the pump and fan stock with control type data was too sparse and therefore not statistically reliable. For constant-load fans, the research team only considered the motor horsepower that is direct drive. Constant-load fans that are driven by belts have very small energy savings potential because the fans, when properly balanced by a belt, are slowed down and draw less power.

The results of the stock assessment for pumps and fans are shown in Table 5 and Table 6 by motor horsepower. There is over 1,000,000 horsepower of industrial pumps, industrial fans, and commercial fans, but only approximately 300,000 horsepower of commercial pumps. The lower commercial pump stock is the main reason that commercial pump savings are lower than the other equipment-sector categories. Variable load systems in both commercial and industrial already reflect relatively high PDS saturation. So, while there are significant energy savings associated with retrofitting variable load pumps and fans with PDS for the remaining 25% to 40% of systems without a PDS, most of the market opportunity exists in constant-load systems. This is especially true in the commercial sector, where PDS adoption on constant-load systems is less than 10% and constant-load systems outnumber their variable load counterparts.

Table 5: Regional Pump Stock and PDS Saturation

Load Type	Industrial		Commercial	
	Region Stock (motor hp)	PDS Saturation (%)	Region Stock (motor hp)	PDS Saturation (%)
Variable Load	605,978	75%	148,776	74%
Constant Load	592,692	40%	158,669	6%

Table 6: Regional Fan Stock and PDS Saturation

Load Type	Industrial		Commercial	
	Region Stock (motor hp)	PDS Saturation (%)	Region Stock (motor hp)[15]	PDS Saturation (%)
Variable Load	462,034	69%	504,759	59%
Constant Load	726,646	10%	1,202,015	2%

[15] The research team recognized that PDS retrofit energy savings will not apply to right-sized belt driven constant speed fans. The research team made a conservative assumption that all belt-driven constant speed fans are right-sized to match the load and therefore excluded these fans from the technical potential stock. The distribution of belt- to direct-drive fans is based on data from the DOE's Commercial and Industrial Fans NODA 3 LCC Analysis.

Unit Energy Savings

The research team used the unit energy savings (UES) equation developed for the BPA ASD Market Model to calculate yearly energy consumption of ASD controlled and non-ASD controlled pumps and fans. Since the ASD Market Model exclusively focuses on the industrial sector, modifications to operating hours and load factors were made to calculate the energy consumption of commercial pumps and fans. Then, UES were calculated by calculating the difference in energy consumption between a non-ASD controlled system and an ASD controlled system.[16]

Table 7 and Table 8 show the weighted-average UES for PDS retrofits on commercial and industrial pumps and fans. Weighted-average values are shown because UES vary slightly by motor nameplate horsepower (due to variation in oversize factors, motor efficiency, and drive efficiency).

Table 7: Regional Retrofit PDS UES for Pumps (kWh/hp)

Load Type	Industrial	Commercial
Variable Load	1,203	1,024
Constant Load	644	575

Table 8: Regional Retrofit PDS UES for Fans (kWh/hp)

Load Type	Industrial	Commercial
Variable Load	1,825	1,906
Constant Load	167	1,157

Program Activity

The previous sections describe the technical potential, but NEEA was also interested in understanding how much of that potential is already targeted by incentive programs. To answer this question, the research team reviewed existing and planned regional program activity to understand how incentive programs impact on PDS adoption.

Industrial Program Activity

For the industrial sector, the research team reviewed BPA's ASD Market Model Report, which included an in-depth analysis of program savings from industrial pumps and fans ASDs.[17] BPA identified that regional custom utility programs were the only source of industrial pumps and fans PDS program savings and that those custom utility programs tend to focus on high horsepower pumps and fans. BPA's research estimated that 94% of all industrial pump ASD program incented horsepower is attributable to motors greater than 50 horsepower and that

[16] This analysis does account natural replacement of non-ASD controlled equipment with ASD controlled equipment in the baseline.
[17] Bonneville Power Administration (BPA), *ASD Market Model Report*, https://www.bpa.gov/-/media/Aep/energy-efficiency/momentum-savings/2016-2021-industrial-asd-market-model-report.pdf.

68% of all industrial fan ASD program incented horsepower is attributable to motors greater than 50 horsepower. Between 2015 and 2021, ASD custom projects contributed between 0.9 and 2.7 aMW per year in regional savings. These savings are distributed between retrofit and new construction projects.

Commercial Program Activity

For the commercial sector, the research team reviewed NEEA's progress running a pilot midstream incentive program for pumps as part of their Extended Motor Products (XMP) program. The goal of the midstream incentive program is to influence the sale of high efficiency constant speed pumps as well as encourage the use of variable speed pumping—both through "traditional" variable speed pumps and "smart" pumps that have a PDS integrated into the pump design. This program does not distinguish new construction sales from retrofit sales.

NEEA is also developing a fans incentive as part of their XMP program. Currently, the intention is to focus on upstream influence: the manufacturing and sales of more efficient fans, which may or may not include a PDS.

Outside of NEEA's programs, there is a small amount of targeted drive activity in the region. The 2020 Regional Conservation Progress Report[18] reports 5.22 aMW of savings from PDS improvements and installation on pumps and fans in the commercial sector, as shown in Table 9 below. The research team did not review custom program savings in the commercial sector, as drive-specific data were not available, and a detailed analysis was beyond the scope of this research project. NEEA could pursue an analysis of custom commercial drives programs to get more insight on the sizes and types of projects that are currently being funded.

Table 9: 2020 Regional Conservation Progress Report Regional PDS Savings in the Commercial Sector

End Use	Category	TAP	Total Regional aMW @ Busbar
Motors/Drives	Motors/Drives Controls	Motors/Drives Control Improvements (VFD)	4.54
Motors/Drives	Pumps and Fans	Motors/Drives Installation on Fan System	0.20
Motors/Drives	Pumps and Fans	Motors/Drives Installation on Pump System	0.48

Supply Chain

The PDS supply chain is complex. Previous research from BPA's ASD Market Actor Interview Findings memo provide a comprehensive review of the PDS supply chain in both the commercial and industrial sectors as well as a supply chain flow diagram (see

[18] Regional Technical Forum, *2020 Regional Conservation Progress Report*, https://nwcouncil.app.box.com/v/2020RCPResults.

).[19] BPA's findings show that many manufacturers produce both motors and ASDs, but their internal organizations are structured in such a way that the ASD and motor divisions operate independently. A manufacturer may produce both motors and ASDs, but they rarely market or sell them paired together. One manufacturer did mention that in Europe, where energy conservation standards require an ASD on specific motor-driven equipment, manufacturers have started integrating the motor and ASD sides of their businesses. The research team expects that more manufacturers will seek to integrate the motor and ASD sides of their businesses as more program's incentivize PDS on motor-driven equipment.

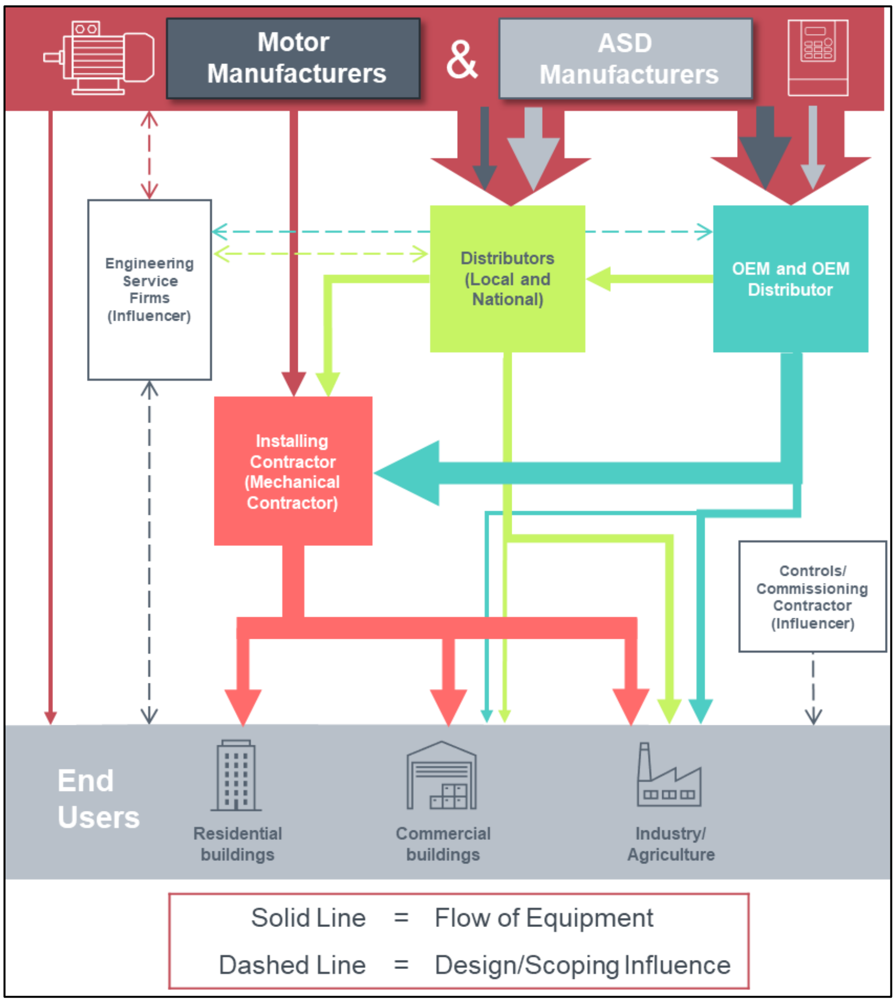

Figure 5. PDS Supply Chain[20]

[19] Cadeo Group, "Adjustable Speed Drives Market Actor Interview Findings," memo to BPA, March 26, 2021, https://www.bpa.gov/-/media/Aep/energy-efficiency/momentum-savings/2021-bpa-asd-market-actor-interview-findings.pdf.

[20] Arrow width shows relative size of product flows. PDS Supply Chain Map from Adjustable Speed Drives Market Actor Interview Findings memo.

Generally, motors and drives are paired downstream of the manufacturer. Most often, manufacturers sell ASDs to distributors to be paired with motors and equipment at installation (shown as the large light gray arrow from ASD manufacturers in

.) Motors are more typically sold to fan and pump original equipment manufacturers (dark gray arrow on the right in

.) Typically, engineering service firms engage in a consulting role, designing and specifying the system in the best interest of the end user. In the retrofit market, the installing contractor or facility owner would typically buy an ASD from a distributor and add it to the existing equipment.

Barriers and Strategies to Address

While the upfront cost of a PDS has fallen dramatically and PDS adoption continues to accelerate both regionally and nationally, the technical potential analysis shows that a large portion of the market for PDS remains untapped. There are several barriers related to the adoption of PDS and many strategies to overcome them. The research team reviewed BPA's recent ASD market research and interviewed multiple program implementors and PDS subject matter experts to determine four major barriers to PDS adoption: lack of industry-accepted PDS ratings, skepticism related to certain PDS applications, power quality issues, and lack of commissioning expertise.

Barrier #1: The PI rating system and metric is new, and manufacturers have not adopted it yet. Market actor interviews revealed that certain manufacturers are in the early stages of vetting the PI rating metric and marketing it on their products. To integrate the metric into a labeling requirement on their equipment, manufacturers identified the need for an industry consensus over appropriate PI standards.

To overcome this barrier, the research team recommends that NEEA work with NEMA to encourage members to rate their equipment with PI and advocate for codes and standards associations to consider the PI rating system. Additionally, NEEA should determine whether manufacturers can use the data they already report to the Air-Conditioning, Heating, and Refrigeration Institute (AHRI)[21] to calculate PI. This may show manufacturers that it is a simple calculation, and no further testing is required.

Barrier #2: Lack of understanding/ prioritization on the benefits of operating a PDS for certain applications. Although knowledge and appreciation of PDS is growing for variable load applications, end users remain skeptical and concerned about the high upfront costs. Also, many market actors dismiss the business case for PDS installations on constant-load and lower-horsepower motors, applications in which NEEA's previous PDS research has shown substantial benefit.

[21] Air-Conditioning, Heating, and Refrigeration Institute (AHRI), Directory, https://www.ahridirectory.org/Search/SearchHome?ReturnUrl=%2f.

In order to overcome this barrier, the research team recommends that NEEA understand and speak more to customer values like decreased maintenance, system control, process control and monitoring. Quantifying the non-energy benefits (NEBs) in life cycle cost (LCC) and payback calculations can help the business case for PDS retrofits. Additionally, displaying power savings through the PI metric can demonstrate simple payback period for energy savings, easing concerns associated with upfront costs. NEEA could consider developing an LCC calculator that incorporates the PI metric and NEBs to promote the business case for PDS. NEEA could also provide educational opportunities to manufacturers and distributors that showcase the benefits of PDS on portions of the market not traditionally considered viable for PDS.

Barrier #3: PDS impacts on Power Quality remains a significant concern to utilities. The increased use of solid-state devices, such as computer electronics, LEDs, programmable logic controllers, and PDS, are leading to more frequent power quality issues in the form of harmonic distortion on utilities distribution systems. This is not an issue specific to PDSs, but rather it represents the cumulative effect of increasing the number of nonlinear loads within a given building or facility. Market actors confirmed that utilities are concerned that introducing more PDSs may increase harmonic distortion to a point that it starts to negatively impact electrical equipment and that this concern is hindering PDS incentive programs.

To get a better understanding of the impact that PDS have on power quality, the research team interviewed subject matter experts and a PDS program implementor. All respondents agreed that harmonic distortion impacts are site dependent and become a bigger issue the larger the PDS is. A specific cut off point was difficult to determine because impacts are site dependent; however, respondents indicated that smaller electric motors (roughly smaller than 10 to 25 horsepower) should not cause significant power quality issues under that vast majority of circumstances. For larger motors, harmonic distortion impacts on power quality can be significant and respondents recommended incorporating harmonic distortion mitigation technology as a requirement for future PDS incentive programs where necessary. These requirements might also be site dependent, as certain facility types such as data centers have significantly higher penetration of nonlinear loads connected to the grid.

Fortunately, there are many ways to monitor and mitigate the effects of harmonic distortion. One such way is by including technological options, such as installing a filter (i.e., an alternating current (AC) line reactor) on a standard drive or purchasing a drive with built-in harmonic mitigation technologies. There are also certification options, such as working with an electrical engineer to certify that a site complies with IEEE 519 at the PCC; however, this route is likely more expensive then including harmonic distortion mitigation technology as part of the PDS installation.

To overcome this barrier, the research team recommends either including a requirement for inclusion of a line reactor in PDS incentive program or alternatively, requiring certification that installation won’t affect power quality. From our interviews, it appears that only larger motors like those found in the agricultural and industrial sectors are a concern, but this may also be true for sites with a large percentage of nonlinear loads already installed.

Barrier #4: Installation and commissioning PDS require expertise. The BPA ASD Market Actor Interview Findings Memo indicated there is a gap in knowledge around the likelihood of PDS being installed correctly. Some distributors, original equipment manufacturer distributors, and engineering service firms reported that they commission the systems they sold or specified and that 100% of systems receive proper commissioning. However, other market actors indicated that as low as 20% of equipment achieves proper commissioning. Most commonly, respondents estimated that proper commissioning occurs on 50% of systems. In addition, distributors noted that there has been recent and widespread reduction in employee training surrounding PDS commissioning to cut costs. This may indicate a shift toward outsourcing commissioning requirements from the distributor to engineering service firms or dedicated commissioning contractors, but it reinforces the idea that market actors are unclear about who is responsible for commissioning. The lack of accountability and diverging perspectives surrounding proper commissioning supports the need for targeted intervention related to PDS commissioning.

To overcome this barrier, the research team recommends that NEEA identify the most prevalent installation and operation issues/concerns and provide educational resources to market actors involved in PDS commissioning and operation. Additionally, NEEA could work with manufacturers to advocate for technology improvements that simplify drive installation, commissioning, and operating procedures for integrated equipment where possible.

Product Definition

The research team identified the following set of questions to help guide the development of the product definition for PDS.

- What efficiency metric(s) should be used to rate the PDS?
- What power range should be covered?
- What driven equipment should be covered?
- What operational requirements should the driven equipment meet?
- What power quality requirements should the PDS meet?
- What NEB requirements should the PDS meet?

Based on the research finding described above, we developed the following product definition:

A *qualified PDS* is either an external ASD or integrated power drive system (e.g., ECM) that

a) Meets minimum PI_{CL} and PI_{VL} values as shown in Table 10.

b) Has a nominal horsepower between 1 to 200 hp.[22]

[22] NEEA could consider further horsepower limitation in consultation with utilities to reduce overlap with custom programs.

c) Meets power quality requirements via either method:

   1. Prescriptive technology requirement: 3% AC line reactor or an active front end.
   2. Power Quality Assessment: <5% THDi or certified to meeting IEEE 519 at the PCC.

d) Includes centrifugal pumps and fans in both constant-load and variable-load systems. This does not include constant torque equipment.

Table 10: Recommended Minimum PI Values Based on Rated Motor Power

Rated Motor Power	PI Minimums	
hp	**PI_{CL} (Constant Load)**	**PI_{VL} (Variable Load)**
1	8	27
1.5	10	30
2	12	31
3	13	33
5	14	34
8	15	35
10	15	36
15	16	36
20	16	37
25	17	37
30	17	37
40	17	37
50	17	37
60	17	37
75	17	37
100	17	37
125	17	38
150	17	37
200	18	38
250	18	38
300	18	38
350	18	38
400	18	38
450	18	38
500	18	38

Conclusion

The market for PDSs is expanding rapidly, and this expansion is transforming motor-driven equipment into highly efficient and increasingly capable machines. However, the sheer scale of this market means that there is still significant opportunity to expand the reach of PDS. The market research and technical analysis conducted for this project suggests that now is the perfect time to take advantage of market transformation momentum already at play and promote PDSs in less well understood applications such as constant-load systems and lower-horsepower equipment. There is still massive technical potential available in both the commercial sector (187 aMW) and industrial sectors (105 aMW)—and that is only for the retrofit market for pumps and fans. A handful of incentive programs already exist in the region that cover PDSs, but they are patchworked and lack significant market coverage. Finally, the supply chain is ideally suited for downstream intervention assuming the proper instruments (such a PDS metric and proper education) are in place to enable these programs.

Despite all the forward momentum, the research team identified four main barriers: lack of industry-accepted PDS ratings, skepticism related to certain PDS applications, power quality issues, and lack of commissioning expertise. But NEEA can actualize several strategies to overcome these barriers and gain a deeper understanding of PDS market.

Next Steps

The research team recommends that NEEA work with manufacturers to rate equipment with PI. Getting manufacturers to adopt this PDS-specific metric will create a pathway for efficiency organizations to develop deemed measure incentive programs around qualifying PDSs. This should not be a burdensome activity for manufacturers, as the research team has strong reason to believe that most drive manufacturers already have the data available to calculate the PI metric for their equipment. One avenue NEEA could pursue is demonstrating to drive manufacturers that they can use the data they already report to AHRI to calculate PI.[23] This may show manufacturers that it is a simple calculation, and no further testing is required. NEEA should leverage their relationship with NEMA and advocate for minimum PI levels, such as those listed in Table 10—which are readily attainable by drive manufacturers, to ensure comprehensive market coverage.

In addition to working with manufacturers to get equipment rated with PI, NEEA should consider working with the RTF to revise the RTF variable speed drive UES measure set to be based on the PI metric rather than obscure load factors. The creation of RTF VSD measure set that uses PI to calculate savings should encourage manufacturers to have their equipment rated with PI.

[23] AHRI Directory. Air-Conditioning, Heating, and Refrigeration Institute (AHRI), Directory, https://www.ahridirectory.org/Search/SearchHome?ReturnUrl=%2f.

Outreach to drive manufacturers and drive subject matter experts answered many outstanding questions, but service contractors have the on-the-ground understanding of drive adoption that manufacturers lack. The research team recommends that NEEA conduct targeted market outreach to service contractors to understand their sales process and further understand the barriers for PDS adoption at the downstream level. These market actors can inform NEEA about remaining questions such as how often belt drives are installed on fans as an alternative to PDS or what constant speed and small horsepower applications could benefit from PDS retrofits. Service contractors will also be able to inform NEEA about how a downstream-deemed program would be implemented in the field and best practices for PDS commissioning.

Finally, the research team recommends that NEEA educate downstream market actors on the benefits of PDS on constant-load and lower- horsepower applications. NEEA could provide a summary of the NEBs and a simplified LCC calculator to demonstrate the business case for such PDS retrofits. This could also entail working with BPA or the Energy Trust of Oregon to educate strategic energy management implementation teams on benefits of PDS for these applications.