**Work Paper PGECOHVC106**

**VFDs for HVAC Fans**

**Revision # 4**

**Pacific Gas & Electric Company**

**Customer Energy Solutions**

**Variable Frequency Drives (VFDs) for HVAC Fans**

**Measure Code H148**

# At-a-Glance Summary

|  |  |
| --- | --- |
| **Applicable Measure Codes:** | H148 |
| **Measure Description:** | Install a variable frequency drive and associated controls on an existing constant speed HVAC supply or return fan. |
| **Energy Impact Common Units:** | Per fan motor hp |
| **Base Case Description:** | Source: DEER2014, Legacy Measure ID: D03-051  The baseline fans are simulated as forward curved fans with discharge dampers. [[1]](#endnote-1) |
| **Base Case Energy Consumption:** | Source: DEER2014, Legacy Measure ID: D03-051  Varies with building type, building vintage, and climate zone. |
| **Measure Energy Consumption:** | Not explicitly stated in DEER documentation. |
| **Energy Savings**  **(Base Case – Measure):** | Source: DEER2014, Legacy Measure ID: D03-051  Varies with building type, building vintage, and climate zone. [[2]](#endnote-2) |
| **Costs Common Units:** | Per rated fan motor hp |
| **Base Case Equipment Cost ($/unit):** | Source: DEER2014 – D03-051 and DEER 2008 for 09-11 Planning/Reporting  $0.00 [[3]](#endnote-3),[[4]](#endnote-4),[[5]](#endnote-5),6 |
| **Measure Equipment Cost ($/unit):** | Source: DEER2014 – D03-051 and DEER 2008 for 09-11 Planning and Reporting (Measure equipment cost varies by climate zone) 3,4,5,[[6]](#endnote-6) |
| **Gross Measure Cost ($/unit)** | Source: DEER2014 – D03-051 and DEER 2008 for 09-11 Planning and Reporting (Measure equipment cost varies by climate zone) 3,4,5, [[7]](#endnote-7) |
| **Measure Incremental Cost ($/unit):** | Source: DEER2014 – D03-051 and DEER 2008 for 09-11 Planning and Reporting (Measure equipment cost varies by climate zone) 3,4,5, [[8]](#endnote-8) |
| **Effective Useful Life (years):** | Source: EUL Values from DEER2014  15 years[[9]](#endnote-9) |
| **Measure Application Type:** | Retrofit Add On (REA) |
| **Net-to-Gross Ratios:** | Source: DEER 2014, READI version 1.0.5  NTG = 0.60[[10]](#endnote-10) Com-Default>2yrs index 47 |
| **Important Comments:** |  |

# Work Paper Approvals

The following Manager(s) approved this workpaper through the PG&E Electronic Data Routing System under Routing Requisition # \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

|  |
| --- |
|  |
| **Grant Brohard**  Manager, Technical Product Support |
| **Carolyn Weiner**  Manager, Core Products |

# Document Revision History

|  |  |  |  |
| --- | --- | --- | --- |
| **Revision #** | **Revision Date** | **Section-by-Section Description of Revisions** | **Author (Company)** |
| **Revision 0** | **04/11/08** | **Original work paper:**  **VFDs for HVAC Fans PGECOHVC106 R0.doc** | **Sean Harleman (kW Engineering)** |
| **Revision 1** | **05/01/09** | **VFDs for HVAC Fans PGECOHVC106 R1.doc** | **Tim Conroy (PG&E)** |
| **Revision 2** | **03/10/10** | **VFDs for HVAC Fans PGECOHVC106 R2.doc** | **Tim Conroy (PG&E)** |
| **Revision 3** | **06/15/2012** | **VFDs for HVAC Fans PGECOHVC106 R3.doc Updated Catalog Description and References.** | **Judith Jennings, (PG&E)**  **Jon Aldrich (kW Engineering)** |
| **Revision 3** | **8/29/2012** | **Revise nomenclature per ED request. Added OTR explanation in two places. Set GRRs to 1, and implementation method to I. Revised dates on cover and footer.** | **Judith Jennings (PG&E)** |
| **Revision 4** | **5/08/2014** | **Revised with new workpaper template. Updated references to DEER2014. Added midstream/direct install distribution channel.** | **Jia Huang (PG&E)** |

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# Section 1. General Measure & Baseline Data

## 1.1 Product Measure Description & Background

***Catalog Description –***

This measure requires the installation of a variable frequency drive and associated controls on a motor driving a ventilation fan.

***Requirements:***

* Installation address must have a commercial electric account with PG&E.
* Drives must be applied to existing HVAC supply or return air fans only.
* Eligible for a rebate only if throttling devices, such as inlet vanes or bypass dampers and throttling valves, are removed or permanently disabled.

***Program Restrictions and Guidelines***

***Terms and Conditions:***

***Exclusions***

* Fans of size greater than 100 horsepower (hp) are not eligible for this rebate.
* Replacement Multiple-Speed or Variable Speed Motor (VSM) are not eligible for a rebate. See applicable VSM rebate.
* VFDs on cooling towers fans are not eligible for this rebate.

***Market Applicability:***

This measure applies to most commercial and industrial facilities, including but not limited to offices, retail, schools, colleges, hotels, motels, and hospital facilities. The measure application type is retrofit add on. The incentive will be provided through downstream and midstream/direct install distribution channels.

## 1.2 Product Technical Description

Energy usage in constant-speed HVAC systems can be reduced by installing electronic VFDs on ventilation fans. VFDs are a far more efficient method of regulating speed or torque than throttling valves, inlet vanes and fan dampers. Installing a VFD on the fan motor will enable the fan to slow down more efficiently whenever the building load allows it, saving fan energy. Due to the fan affinity laws, a small reduction in fan speed results in significant energy savings.

## 1.3 Measure Application Type

The DEER Measure Cost Data Users Guide found on [www.deeresources.com](http://www.deeresources.com) under *DEER2011 Database Format* hyperlink, DEER2011 for 13-14, spreadsheet *SPTdata\_format-V0.97.xls*, defines the terms as follows:

Table 1 Measure Application Type[[11]](#endnote-11)

*Identifies the measure application type in the Measure Implementation table in DEER2014.*

|  |  |  |
| --- | --- | --- |
| **Code** | **Description** | **Comment** |
| ER | Early retirement | *Measure is more efficient than code/std; Dual baseline, full measure costs required* |
| ROB | Replace on Burnout | *Single baseline (above code), incremental or full costs* |
| NC | New Construction | *Single baseline (above code), incremental or full costs* |
| REA | Retrofit Add On | *Single baseline (above pre-existing), full measure costs required* |

This measure is identified as REA, or retrofit add on.

## 1.4 Product Base Case and Measure Case Data

## 1.4.1 DEER Base Case and Measure Case Information

The DEER data (Measure ID: D03-051) include electric demand savings, electric energy savings, and equipment unit costs for installation of VFDs on HVAC fans. The energy savings in this work paper are taken directly from DEER Measure ID D03-051. No changes were made to measure code D03-051 under the DEER2014, DEER2011 or the DEER2008 updates and therefore DEER2005 values were used to estimate the savings in the DEER2014 database.

* The DEER 2014 data includes: demand, electric, and gas energy savings with interactive effects, labor costs, equipment useful life, and Net to Gross of this measure.
* The DEER 2008 data includes: equipment unit costs for this measure.



**Net-to-Gross Assumption:**

Table 2 below summarizes all applicable DEER based Net-to-Gross ratios for programs that may be used by this measure.

Table 2 DEER Net-to-Gross Ratios

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | **DEER Spreadsheet** | |
| Program Approach | NTG | File name | Cell Number |
| Com-Default>2yrs:  All other EEMs with no evaluated NTGR; existing EEM in programs with same delivery mechanism for more than 2 years | 0.6 | SupportTable\_NTGR.csv9 | D52 |

**Effective Useful Life:**

The measure equipment effective useful life (EUL) is given by DEER2014 as 15 years8.

## 1.4.2 Codes & Standards Requirements Base Case and Measure Information

***Title 20:*** This measure does not fall under Title 20 of the California Energy Regulations.

***Title 24:*** This measure falls under Title 24 of the California Energy Regulations. Under this regulation, the following is required to meet prescriptive compliance:

1. DX [>=75,000 Btu/hr] and chilled water [>=1 HP] cooling systems that control the capacity of the mechanical cooling directly based on occupied space temperature shall (i) have a minimum of 2 stages of fan control with no more than 66 percent speed when operating on stage 1; and (ii) draw no more than 40 percent of the fan power at full fan speed, when operating at 66 percent speed.
2. All other systems, including but not limited to DX cooling systems and chilled water systems that control the space temperature by modulating the airflow to the space, shall have proportional fan control such that at 50 percent air flow the power draw is no more than 30 percent of the fan power at full fan speed.
3. Systems that include an air side economizer to meet 140.4(e)1 shall have a minimum of two speeds of fan control during economizer operation.

However, installing a VFD is not required to meet performance compliance of the 2013 Title 24 regulations, nor is it a mandatory measure.

***Federal Standards:*** This measure does not fall under Federal DOE or EPA Energy Regulations.

## 1.4.3 EM&V, Market Potential, and Other Studies – Base Case and Measure Case Information

There are no M&V or other studies which apply to these measures.

## 1.4.4 Assumptions and Calculations from other sources—Base and Measure Cases

There are no further data or calculations provided for the support of the measures in this workpaper.

***1.4.5 Time-of-Use Adjustment Factor***

We are required by CPUC decision 06-06-063 dated June 29, 2006 to apply time-of-use (TOU) adjustment factors on residential A/C and commercial A/C (packaged and split-system direct-expansion cooling) measures only. Since this is not an A/C measure, the TOU adjustment factor is 0.

The specific values and results are summarized in Table 6.

Table 6 TOU Adjustment Factors

|  |  |  |  |
| --- | --- | --- | --- |
| **Measure** | ***kWAC*** | ***kWTotal*** | **%** |
| VFD | 0 | 0 | 0 |

***1.5 Summary of Inputs for Savings Calculations***

The following table provides references to sections that document the inputs for calculation:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Input Variable** | **Variations** | **Base Case Average Value** | **Measure Case Average Value** | | **Reference Section** | |
| **Electric Savings** | CZ, BT, BV | Varies | Varies | | Section 1.4.1 | |
| **Gas Savings** | CZ, BT, BV, IE | Varies | Varies | | Section 2.3 | |
| **Hours of operation** | CZ, BT, BV | N/A | N/A | | N/A | |
| **Full Cost** | REA | Varies | Varies | | Section 4.3.1 | |
| **Incremental Cost** | REA | Varies | Varies | | Section 4.3.2 | |
| **EUL /RUL** | REA | 15 | 15 | | Section 1.4.1 | |
| **NTG** | One | - | 0.60 | | Section 1.4.1 | |
| **ISR** | Applies -- No | N/A | N/A | | N/A | |
| **TOU Factor** | *A/C projects only* | N/A | N/A | N/A | |  | |

# 

# Section 2. Calculation Methods

Table 7 Baseline by Measure Application Type

|  |  |  |  |
| --- | --- | --- | --- |
| ****Measure Application Type**** | ****Measure Life Basis**** | ****First Baseline Period: Energy Savings Baseline**** | ****Second Baseline Period: Energy Savings Baseline**** |
| ***ER* (early retirement)** | **EUL** | Customer Average Baseline | Code Baseline |
| ***ROB* (replace-on-burnout)** | **EUL** | Code Baseline | N/A |
| ***NC* (new construction)** | **RUL/EUL-RUL** | Code Baseline | N/A |
| ***REA (retrofit add on)*** | **EUL** | Code Baseline | N/A |

Notes:

* For ROB and REA measures, First Baseline is the baseline for the full EUL. There is no second baseline.
* For ER measures, First Baseline Period is the period for the RUL(remaining useful life),defined by the CPUC as RUL=1/3 EUL. Second baseline period for ER is Code baseline for the period EUL-RUL.

## 

## 2.1 Electric Energy Savings Estimation Methodologies

Electric energy savings depend on climate zone, building type, and building vintage. This information is gathered from program applications to determine unique savings estimates for each installation. Deemed savings values are taken directly from DEER2014 (Measure ID: D03-051), which provides kW and kWh savings per horsepower of the installed VFD. No changes were made to measure code D03-051 under the DEER2014, DEER2011, or DEER2008 updates and therefore DEER2005 values were used in the DEER2014 database to estimate the savings. The savings values listed for Measure ID D03-051 were determined by using the DOE2 modeling program. Details regarding the DOE2 modeling approach and specific assumptions are given in the DEER documentation.1

## 2.2. Demand Reduction Estimation Methodologies

Electric demand savings depend on climate zone, building type, and building vintage. The demand savings for this measure were developed along with the energy savings as described in the section above.

## 2.3. Gas Energy Savings Estimation Methodologies

There are no gas energy savings associated with this measure.

# *Section 3. Load Shapes*

Load Shapes are an important part of the life-cycle cost analysis of any energy efficiency program portfolio. The net benefits associated with a measure are based on the amount of energy saved and the avoided cost per unit of energy saved. For electricity, the avoided cost varies hourly over an entire year. Thus, the net benefits calculation for a measure requires both the total annual energy savings (kWh) of the measure and the distribution of that savings over the year. The distribution of savings over the year is represented by the measure’s load shape. The measure’s load shape indicates what fraction of annual energy savings occurs in each time period of the year. An hourly load shape indicates what fraction of annual savings occurs for each hour of the year. A Time-of-Use (TOU) load shape indicates what fraction occurs within five or six broad time-of-use periods, typically defined by a specific utility rate tariff. Formally, a load shape is a set of fractions summing to unity, one fraction for each hour or for each TOU period. Multiplying the measure load shape with the hourly avoided cost stream determines the average avoided cost per kWh for use in the life cycle cost analysis that determines a measure’s Total Resource Cost (TRC) benefit.

## 3.1 Base Case Load Shapes

The base case load shape would be expected to follow a typical non-residential HVAC ventilation-fan end use load shape (E3 code = VENT).

## 3.2 Measure Load Shapes

For purposes of the net benefits estimates in the E3 calculator, what is required is the load shape that ideally represents the *difference* between the base equipment and the installed energy efficiency measure. This *difference* load profile is what is called the Measure Load Shape and would be the preferred load shape for use in the net benefits calculations.

The measure load shape would be expected to follow a typical non-residential HVAC ventilation-fan end use load shape (E3 code = VENT).

# Section 4. Base Case & Measure Costs

|  |  |  |  |
| --- | --- | --- | --- |
| **Measure Application Type** | **Measure Life Basis** | **First Baseline Period Full Measure Cost (RUL)** | **Second Baseline Period Full Measure Cost (EUL – RUL)** |
| ***NC (new construction)*** | EUL | Calculated as Incremental Measure Cost | N/A |
| ***ROB(replace on burnout)*** | EUL | Calculated as Incremental Measure Cost | N/A |
| ***ER (early retirement)*** | RUL/  EUL-RUL | Calculated as Full Gross Measure Cost | Calculated as Negative Full Gross Base Case Cost |
| ***REA (retrofit add on)*** | EUL | Calculated as Full Gross Measure Cost | N/A |

## 4.1 Base Case(s) Costs

The base case for this measure is a “do-nothing” alternative, i.e. not install a VFD. If no VFD is installed, then the base case cost for this measure is zero. The base case cost is the same for both ER and NC projects.

## 4.2 Measure Case Costs

The measure cost is the sum of the equipment cost and the labor cost. Because the nominal equipment costs have not changed in the DEER2014 Updates, the nominal equipment cost was referenced from DEER2008 for 09-11 Planning/Reporting. The nominal equipment cost for both ER and NEW projects is $176.68.6

The per-hour labor rates were updated in DEER2011. Under table name “LaborRate” in the DEER2014 database, the hourly labor rate for the installation of HVAC equipment is $67.88.3 However, the labor cost needed to be normalized to a cost per horsepower (hp) value. The average labor hours per VFD hp was estimated using the total labor hours by VFD hp size provided in 2014 RS Means Mechanical Cost Data.5 By multiplying the average labor hours/hp by the labor cost/hour, the normalized labor cost/ VFD hp is $84.94. Climate zone specific cost adjustment factors from the DEER2014 database are applied to the labor and equipment cost.

However, the DEER2014 database includes cost adjustment factors for the DEER2008 values by climate zone.4 All 16 climate zones in California have individual equipment and labor cost adjustment factors. The appropriate cost adjustment factors were applied to the equipment and labor costs described above.

The following Measure Application Type is appropriate to this measure. The Measure Case Costs are:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| ***Measure Code*** | **Measure Application Type** | **Baseline** | **Equipment Cost** | **Labor / Installation Cost** | **Maintenance / Other Cost** | **Total Measure Case Cost** |
| H148 | REA | Code | $176.68 (Varies by climate zone) | $84.94 (Varies by climate zone) | $0.00 | $261.62 (Varies by climate zone) |

*All costs are noted as $ per VFD hp.*

## 4.3 Incremental & Full Measure Costs

|  |  |  |  |
| --- | --- | --- | --- |
| **Measure Application Type** | **Full Measure Cost**  **(RUL Period/First Baseline)** | **Full Measure Cost**  **(EUL-RUL Period/ Second Baseline)** | **Incremental Measure Cost** |
| ER | Measure Equipment Cost  +Measure Labor Cost | (-1)x(Base Equipment Cost  + Base Labor Cost) | Measure Equipment Cost  – Base Case Equipment Cost |
| ROB | Measure Equipment Cost  – Base Case Equipment Cost | N/A | Measure Equipment Cost  – Base Case Equipment Cost |
| NC | Measure Equipment Cost  – Base Case Equipment Cost | N/A | Measure Equipment Cost  – Base Case Equipment Cost |
| REA | Measure Equipment Cost  – Base Case Equipment Cost | N/A | Measure Equipment Cost  – Base Case Equipment Cost |

# *4.3.1 Full Measure Cost*

Gross Measure Cost is the cost to install an energy efficient measure per the CPUC calculators. This definition implies a different meaning depending on the Measure Application type. Due to the climate zone cost adjustment factors listed in the DEER2014 database, the full measure cost fluctuates for each climate zone.

# *4.3.2 Incremental Measure Costs*

Incremental Measure Cost is the premium cost to install an energy efficient measure over a standard efficiency measure or code baseline measure. Due to the climate zone cost adjustment factors listed in the DEER2014 database, the incremental measure cost fluctuates for each climate zone.

**Summary Table for Section 4**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Measure ID** | **Measure Application Types** | **Base Case Total Cost** | **Measure Case Total Cost[[12]](#endnote-12)** | **Full Measure Case Cost** | **Incremental Measure Cost** |
| H148 | REA | $0.00 | $261.62 (Varies by climate zone) | $261.62 (Varies by climate zone) | $261.62 (Varies by climate zone) |

*All costs are noted as $ per VFD hp.*

# References

1. 2004-2005 DEER Update Final Report, page 7-35, VSD Supply Fan Measure, [www.deeresources.com](http://www.deerresources.com) under *DEER2005, DEER 2005 Final Report (Itron – December 2005)* hyperlink at the bottom of the page, PDF file DEER2005UpdateFinalReport\_ItronVerion.pdf. [↑](#endnote-ref-1)
2. California Public Utilities Commission (CPUC), Database for Energy Efficient Resources (DEER) v. 2014, *Measure ID: D03-051*, extracted from READI\_v1.0.5.zip, downloaded from [www.deeresources.com](http://www.deeresources.com). [↑](#endnote-ref-2)
3. California Public Utilities Commission (CPUC), Database for Energy Efficient Resources (DEER) v. 2014, *Table Name: LaborRate*, *Table Code: NR-HVAC-AC*, extracted from READI\_v1.0.5.zip, downloaded from [www.deeresources.com](http://www.deeresources.com). [↑](#endnote-ref-3)
4. California Public Utilities Commission (CPUC), Database for Energy Efficient Resources (DEER) v. 2014, *Table Name: CostAdjust*, *Table Code: HVAC50 (all 16 climate zones)*, extracted from READI\_v1.0.5.zip, downloaded from [www.deeresources.com](http://www.deeresources.com). [↑](#endnote-ref-4)
5. 2014 RS Means Mechanical Cost Data, 37rd Annual Edition, Mossman, Melville J., *Section 26 29 23.10 Variable Frequency Drives/Adj. Frequency Drives*, pg. 429-430. [↑](#endnote-ref-5)
6. Updated 2008 DEER Measure Costs for 09-11 Planning/Reporting, [www.deeresources.com](http://www.deeresources.com) under DEER2008 for 09-11 Planning/Reporting, *Cost Values and Summary Documentation (updated 6/2/2008 – NR linear fluorescent labor costs typo)* hyperlink under Technology and Measure Cost Data, spreadsheet *Revised DEER Measure Cost Summary (05\_30\_2008) Revised (06\_02\_2008).xls*, NR-Misc Tab, Row 26. [↑](#endnote-ref-6)
7. Updated 2008 DEER Measure Costs for 09-11 Planning/Reporting, [www.deeresources.com](http://www.deeresources.com) under DEER2008 for 09-11 Planning/Reporting, *Cost Values and Summary Documentation (updated 6/2/2008 – NR linear fluorescent labor costs typo)* hyperlink under Technology and Measure Cost Data, spreadsheet *Revised DEER Measure Cost Summary (05\_30\_2008) Revised (06\_02\_2008).xls*, NR-Misc Tab, Row 26. [↑](#endnote-ref-7)
8. Updated 2008 DEER Measure Costs for 09-11 Planning/Reporting, [www.deeresources.com](http://www.deeresources.com) under DEER2008 for 09-11 Planning/Reporting, *Cost Values and Summary Documentation (updated 6/2/2008 – NR linear fluorescent labor costs typo)* hyperlink under Technology and Measure Cost Data, spreadsheet *Revised DEER Measure Cost Summary (05\_30\_2008) Revised (06\_02\_2008).xls*, NR-Misc Tab, Row 26. [↑](#endnote-ref-8)
9. California Public Utilities Commission (CPUC), Database for Energy Efficient Resources (DEER) v. 2014, *Table Name: EUL*, *EUL\_ID: HVAC-VSDSupFan*, extracted from READI\_v1.0.5.zip, downloaded from [www.deeresources.com](http://www.deeresources.com). [↑](#endnote-ref-9)
10. California Public Utilities Commission (CPUC), Database for Energy Efficient Resources (DEER) v. 2014, Table Name: *NTGR*, NTG\_ID: *Com-Default>2yrs*, extracted from READI\_v1.0.5.zip, downloaded from [www.deeresources.com](http://www.deeresources.com). [↑](#endnote-ref-10)
11. The DEER Measure Cost Data Users Guide found on [www.deeresources.com](http://www.deeresources.com) under *DEER2011 Database Format* hyperlink, DEER2011 for 13-14, spreadsheet *SPTdata\_format-V0.97.xls.* [↑](#endnote-ref-11)
12. SCE, Measure Cost Revision 5 revised for PG&E by S.L. Blanc 2012

     [↑](#endnote-ref-12)