eTRM

best in class

HVAC

SOFTWARE-CONTROLLED SWITCH RELUCTANCE MOTOR

SWHC041-01

CONTENTS

MEASURE NAME

Software-Controlled Switch Reluctance Motor

STATEWIDE MEASURE ID

SWHC041-01

TECHNOLOGY SUMMARY

This measure is defined as a software-controlled switch reluctance motor (SRM) for a fan in a packaged HVAC system. SRMs have been used in industrial applications since the 1850s. The potential for wider use has been realized more recently with the increased availability of cheaper and reliable solid-state switching devices.

A SRM operates on the principle of minimizing the magnetic reluctance between the rotor pole and stator coil. The stator windings are switched ON and OFF by the controller to pull the rotor towards the next activated winding. This minimizes the magnetic reluctance and creates torque around the motor shaft. *High rotor pole SRMs* have non-traditional ratios of stator poles to rotor poles (6/10 versus 6/4). Using a non-traditional ratio will reduce rotational travel per excitation and will increase static torque production.

Additionally, SRMs are inherently variable-speed motors. Variable speed drives (VSDs) on induction motors have a small percentage of efficiency loss. A high rotor pole SRM packaged with an inverter and patented control system, which define a software-controlled SRM, will reduce the efficiency loss from VSD.

A SRM will outperform a National Electrical Manufacturers Association (NEMA) Premium ® motor at design and part loads. An induction motor is the most common type of NEMA premium-rated motor. The Southern California Edison (SCE) Emerging Products group tested and compared the SRM technology against a standard induction motor in both laboratory and field settings.[1] This study found that software-controlled SRM saves 11% energy compared to an Induction motor with VSD with a few assumed operating conditions. The results from this study were not directly used in this workpaper because the study was limited to one site and climate zone, whereas the savings from the fan system are highly dependent upon cooling loads which vary by climate zone and building type. Instead, the motor efficiencies published in SRM data sheets were used, along with DEER building prototypes for savings analysis in this workpaper

MEASURE CASE DESCRIPTION

The measure case is defined as the replacement of an existing supply fan induction motor and VFD controller with a software-controlled SRM in a HVAC packaged unit used in a commercial or industrial building. The measure is applicable to fan motors between 1 to 3 hp (nameplate).

[1] Southern California Edison (SCE), Emerging Products. 2018. *Software Controlled Switch Reluctance Motors.* Emerging Technologies Report ET15SCE1330. August.

BASE CASE DESCRIPTION

The base case is defined as an existing supply fan induction motor and VFD controller in a HVAC packaged unit that meets the California Building Energy Efficiency Standards (Title 24, see Code Requirements). The base case fan motor is an induction NEMA Premium® efficiency motor with variable speed controls.

Base, Standard, and Measure Cases

Case	Description of Typical Scenario
Measure	Software-controlled switch reluctance motor (SRM)
Existing Condition	NEMA Premium efficiency motor
Code/Standard	NEMA Premium efficiency motor
Industry Standard Practice (ISP)	NEMA Premium efficiency motor

CODE REQUIREMENTS

The equipment that is the subject of this measure is governed by federal code and California standards.

Applicable State and Federal Codes and Standards

Code	Applicable Code Reference	Effective Date
CA Appliance Efficiency Regulations – Title 20	None	n/a
CA Building Energy Efficiency Standards – Title 24 (2019)	Sections 140.4 (a) 5, 140.4 (c) 1, 140.4 (c) 3	January 1, 2020
Federal Standards (Title 10)	Subpart B 431.25 (h) Subpart X section 431.446 (a)	January 1, 2019

Title 10 of the Code for Federal Regulations, Subpart B 431.25 (h)[2] specifies the nominal full load efficiencies for NEMA Design A, Design B and Design C motors for motor power rating of 1 hp to 200 hp manufactured after June 1, 2016.

Design B motors account for most of the induction motors sold. A portion of Table 5 from CFR Title 10 Subpart B 431.25 (h) is provided below.

[2] Code of Federal Regulations at 10 CFR 431.25 (h).

Nominal Full-Load Efficiencies of NEMA Design A, NEMA Design B and IEC Design N Motors (Excluding Fire Pump Electric Motors) at 60 Hz[3]

Motor hp/standard kW equivalent	Nominal Full-Load Efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1/.75	77.0	77.0	85.5	85.5	82.5	82.5	75.5	75.5
1.5/1.1	84.0	84.0	86.5	86.5	87.5	86.5	78.5	77.0
2/1.5	85.5	85.5	86.5	86.5	88.5	87.5	84.0	86.5
3/2.2	86.5	86.5	89.5	89.5	89.5	88.5	85.5	87.5

Smaller motors less than 3hp and not under specific NEMA design are regulated by CFR Title 10 Subpart X section 431.446 (a).[4]

The 2019 California Building Energy Efficiency Standards (Title 24)[5] does not specify the motor efficiency but requires the following for fan systems:

> ***Section 140.9 (a) 5 – Fan Control.*** *Each unitary air conditioner with mechanical cooling capacity exceeding 60,000 Btu/hr and each chilled water fan system shall be designed to vary the airflow rate as a function of actual load and shall have controls and/or devices (such as two-speed or variable speed control) that will result in fan motor demand of no more than 50 percent of design wattage at 66 percent of design fan speed*
>
> ***Section 140.4 (c) 1 – Fan Power Limitation.*** *For Variable Volume Systems, either Option 1: Fan system motor nameplate hp <= cfm_S x 0.0015 or Option 2: Fan system bhp <= cfm_S x 0.0013 + A where A = sum of (Pressure Drop x cfm_D/4131)*
>
> ***Section 140.4 (c) 3*** *- HVAC motors for fans that are less than1 hp and 1/12 hp or greater shall be electronically-commutated motors or shall have a minimum motor efficiency of 70 percent when rated in accordance with NEMA Standard MG 1-2006 at full load rating conditions.*

NORMALIZING UNIT

Nominal horsepower (hp)

PROGRAM REQUIREMENTS

Measure Implementation Eligibility

All combinations of measure application type, delivery type, and sector that are established for this measure are specified below. Measure application type is a categorization based on the circumstances and timing of the measure installation; each measure application type is distinguished by its baseline determination, cost basis, eligibility, and documentation requirements. Delivery type is the broad categorization of the delivery channel through which the market intervention strategy (financial

[3] Code of Federal Regulations at 10 CFR 431.25 (h). Table 5.

[4] Code of Federal Regulations at 10 CFR 431.446 (a).

[5] California Energy Commission (CEC). 2018. *2019 Building Energy Efficiency Standards for Residential and Nonresidential Buildings.* CEC-400-2018-020-CMF.

incentives or other services) is targeted. This table also designates the broad market sector(s) that are applicable for this measure.

Note that some of the implementation combinations below may not be allowed for some measure offerings by all program administrators.

Implementation Eligibility

Measure Application Type	Delivery Type	Sector
Normal replacement	DnDeemDI	Com
Normal replacement	DnDeemed	Com
Normal replacement	UpDeemed	Com
Normal replacement	DnDeemDI	Ind
Normal replacement	DnDeemed	Ind
Normal replacement	UpDeemed	Ind

Eligible Products

This measure must replace the existing supply fan motors between 1 to <=3 hp in a packaged HVAC system in a commercial building type.

The new motor and controls must be UL Listed.

The installation of this measure shall meet all applicable regulations, including but not limited to the current California Building Energy Efficiency Standards (Title 24), federal code, and the National Electrical Code® (NEC).

Eligible Building Types and Vintages

This measure is applicable for all commercial and industrial building types of any vintage.

Eligible Climate Zones

This measure is applicable in all California climate zones.

PROGRAM EXCLUSIONS

This measure is not eligible for supply fan motors rated <1 hp and > 3 hp (nominal).

This measure is not eligible for other fans, such as the return fan or outdoor air fan of a packaged HVAC unit.

DATA COLLECTION REQUIREMENTS

In support of the next revision to this workpaper, additional data should to be gathered to determine if motors with horsepower ratings greater than 3 HP can be included as measure offerings. This includes the following:

- The application for software-controlled SRMs highlighted by the 2018 ET study is in air conditioning supply fans. Other applications may be studied for suitability.
- Based on the initially available set of datasheets, the 5 HP SRM falls below the NEMA Premium® rating of 89.5% for a 4-pole (1800 RPM) induction motor. As additional SRM products become available, efficiency rating tests (following the appropriate standard test procedures identified by the manufacturer) as well as data on full-load VSD losses for the comparable baseline equipment should be collected.

The existing measure cost analysis is considering data from only one manufacturer. In the future if more manufacturers are offering this product, the cost analysis has to be revised.

USE CATEGORY

HVAC

ELECTRIC SAVINGS (KWH)

The unit energy savings (UES) of this measure were derived as the difference of baseline and measure case unit energy consumption (UEC) derived from simulations with DOE-2.3/ eQUEST 3.65 energy modeling software.[6] Prototypes from the Database for Energy Efficient Resources (DEER) were utilized for the simulations. MASControl3, an updated version of the measure analysis software for DEER2020 was used to generate the energy savings values for all measure offerings

MASControl3 does not include a measure for switched controlled SRM. Hence, an existing measure was replicated and modified to increase the motor efficiency and modify other fan system characteristics to simulate switched controlled SRM performance.

MASControl3 includes the following measures for direct expansion (DX) packaged units that vary based on the system capacity:

DEER Energy Impact ID	Measure Description
NE-HVAC-airAC-SplitPkg-65to134kBtuh	Non-Residential Air-Cooled Packaged AC capacity between 65 and134kBtuh
NE-HVAC-airAC-SplitPkg-135to239kBtuh	Non-Residential Air-Cooled Packaged AC capacity between 135 and 239kBtuh
NE-HVAC-airAC-SplitPkg-240to759kBtuh	Non-Residential Air-Cooled Packaged AC capacity between 240 and 759kBtuh

For each of the above measures there are multiple standard systems that make up the total capacity range, as indicated in the measure ID. The capacity of the standard systems remains the same across the measures and only the total number of these standard systems vary. Because it is not easy to track the total cooling capacity of the packaged units in the buildings while implementing the measure, all three measures were simulated with the modifications explained below.

[6] Southern California Edison (SCE). 2019. "SWHC041-01 BES Files.zip."

The baseline and measure case fan system (that includes fan, motor, and controls) were specified with the keywords in DOE-2.3 as shown below.

Fan System Keywords in DOE-2.3 for Baseline and Measure Case Simulations

Keyword	Baseline		Measure	
	Design Value	Source	Design Value	Source
SUPPLY-KW/FLOW	Varies	DEER2020 prototypes default	SUPPLY-KW/FLOW[baseline] * adjustment factor	DEER2020 default adjusted for increased motor efficiency to 92.5% typical for 2 HP and 3 HP SRM. Southern California Edison (SCE). 2019. “SWHC041-01 SRM Datasheets.zip.” Southern California Edison (SCE), Emerging Products. 2018. *Software Controlled Switch Reluctance Motors.* Emerging Technologies Report ET15SCE1330. August.
SUPPLY-MTR CLASS or SUPPLY-MTR-EFF	PREMIUM	Code of Federal Regulations at 10 CFR 431.25 (h).	Same as Baseline	
SUPPLY-MECH-EFF	Varies	DEER2020 prototypes default	Same as Baseline	
FAN-CONTROL	Variable Speed Drive fPLR	California Energy Commission (CEC). 2018. *2019 Building Energy Efficiency Standards for Residential and Nonresidential Buildings.* CEC-400-2018-020-CMF.	Same as Baseline	

- SUPPLY-KW/FLOW – This includes the fan, motor and drive energy. While the California Building Energy Efficiency Standards (Title 24) Section 140.4 (c) 1 specifies a fan power requirement, it is function of pressure drop that is specific to a building. For the pressure drop value in the *Software Controlled Switch Reluctance Motors* emerging technology study (SRM ET study) the default in DEER2020 prototypes was more stringent than Title 24. Hence, the DEER2020 defaults were used for the baseline.
  For the measure case, since kW/flow includes motor efficiency, this value decreases in proportion with SRM efficiency. The proportion factor was calculated for the Office-Small (OfS) building type which represents larger building stock with packaged AC unit, for climate zone 9 and applied to all building types.
- SUPPLY-MTR CLASS/ SUPPLY-MTR-EFF – The baseline is premium efficiency motor that complies with federal code (see Code Requirements). The measure case was 92.5% based on software-controlled SRM specification sheets for 3-phase motors for less than 3 hp.
- SUPPLY-MECH-EFF – This includes fan and drive efficiency. Like supply-kW/flow, this was set to the DEER2020 default. Since this factor does not include motor efficiency, no adjustment was required for the measure case.

- **Fan Control** – Since Title 24 requires variable speed controls, the baseline fan control specifies variable speed controls. From the SRM ET study, using the w/acfm data at various flow rates and air flow resistance (Table 16 and Table 17), the % acfm and % watts were plotted for baseline (Induction + VFD) and software controlled SRM and compared with DOE-2.3 fan performance curve.[7] Within a small difference all three curves closely overlap. Hence, for the baseline and measure case, the DOE performance curve of a variable speed drive fPLR was used.

The selected DEER measures were run with the baseline case and measure case modifications shown in the table above for all building types and all California climate zones, and for the median vintage 2007.

Because of missing fan-control files in the DOE-2.2R library for Grocery and Refrigerated-warehouse building types, these building types could not be modeled. Therefore, the closest comparable building type in terms of HVAC operations were selected for these two building types. In particular, the Retail - Single-Story Large (RtL) building type was selected for Grocery, and the Office-Small (OfS) building type was selected for Refrigerated Warehouse to represent the office spaces served by HVAC systems in refrigerated warehouse.

MAScontrol3 generated the annual and hourly energy usage for each baseline and measure case model. Using the post processing scripts within MASControl3, the UES and unit peak demand reduction were determined for all three measure IDs. The UES adopted for this measure was calculated as the average of those values.[8]

PEAK ELECTRIC DEMAND REDUCTION (KW)

The average of 4-9 PM kW for the DEER peak days was generated using the post processing scripts in MASControl3 as explained in the above section.

GAS SAVINGS (THERMS)

Not applicable.

LIFE CYCLE

Effective useful life (EUL) is an estimate of the median number of years that a measure installed through a program is still in place and operable. Remaining useful life (RUL) is an estimate of the median number of years that a technology or piece of equipment replaced or altered by an energy efficiency program would have remained in service and operational had the program intervention not caused the replacement or alteration.

The EUL and RUL specified for this measure are presented below. Note that RUL is only applicable for add-on equipment and is not applicable for this measure.

[7] Southern California Edison (SCE). 2019. "SWHC041-01 Fan Curve Analysis.xlsx."

[8] Southern California Edison (SCE). 2019. "SWHC041-01 Energy Impact Calcs.xlsx

Effective Useful Life and Remaining Useful Life

Parameter	Value	Source
EUL (yrs)	15.0	California Public Utilities Commission (CPUC), Energy Division. 2014. "DEER2014-EUL-table-update_2014-02-05.xlsx"; EUL_ID: Motors-fan.
RUL (yrs)	n/a	-

BASE CASE MATERIAL COST ($/UNIT)

The base case material cost includes the cost of induction motor and variable frequency drive (VFD). The cost of the induction motor was derived as the average cost per horsepower of premium efficiency motors (230/460 V, 60 HZ) rated 1 hp to 3 hp obtained from RSMeans.[9] Because RSMeans only includes the cost of VFDs for 3 hp and higher, the cost of a 3-phase VFD 1 hp to 3 hp was derived from list prices obtained from three online equipment dealers. The material cost was calculated as the sum of the costs of an induction motor and the VFD; the base case material cost was calculated as the average material cost of the units in the analysis.[10]

MEASURE CASE MATERIAL COST ($/UNIT)

Currently, from author's knowledge there is only one manufacturer for software-controlled SRM. The manufacture provided the list prices for SRMs from 1 hp to 10 hp; only the cost for SRMs 1 hp to 3 hp were included in the cost analysis[11] and the measure case material cost was calculated as the average of list prices provided them.

BASE CASE LABOR COST ($/UNIT)

Since both base case and measure case involves the installation of a motor and variable speed controls, it is assumed that the labor cost will be the same for both cases.

The estimated labor hours were provided by the manufacturer of software-controlled SRM based on their experience, and the hourly labor rate was derived from RSMeans for motor installation. The per unit labor (per horsepower) was calculated as the total labor cost per motor (labor rate multiplied by labor hours) divided by the motor horsepower for each unit in the cost data provided by the manufacturer. The base case labor cost was then calculated as the average labor cost per hp across all units.[12]

---

[9] Gordian. 2019. *RSMeans Online*. Electrical Costs.

[10] Southern California Edison (SCE). 2019. "SWHC041-01 SRM Cost Analysis.xlsx."

[11] Southern California Edison (SCE). 2019. "SWHC041-01 SRM Cost Analysis.xlsx."

[12] Southern California Edison (SCE). 2019. "SWHC041-01 SRM Cost Analysis.xlsx."

Labor Cost Inputs

Parameter	Value	Source
Labor (hours)	3.0	Estimated by the manufacturer of software-controlled SRM
Labor Rate ($/hour)	$97.56	Gordian. 2019. *RSMeans Online.* Electrical Cost Data. Line # 267113200100.

MEASURE CASE LABOR COST ($/UNIT)

See Base Case Labor Cost.

NET-TO-GROSS (NTG)

The net-to-gross (NTG) ratio represents the portion of gross impacts that are determined to be directly attributed to a specific program intervention. The NTG value adopted for this measure is designated specifically for emerging technologies by the California Public Utilities Commission (CPUC).

Net-to-Gross Ratios

Parameter	Value	Source
NTG – emerging technology	0.85	California Public Utilities Commission (CPUC), Energy Division. 2013. *Energy Efficiency Policy Manual Version 5.* Page 21. California Public Utilities Commission (CPUC). 2012. *Decision 12-05-015 in the Order Instituting Rulemaking to Examine the Commission's Post-2008 Energy Efficiency Policies, Programs, Evaluation, Measurement, and Verification, and Related Issues (R.09-11-014).* Issued May 18, 2012. OP 14.

GROSS SAVINGS INSTALLATION ADJUSTMENT (GSIA)

The gross savings installation adjustment (GSIA) rate represents the ratio of the number of verified installations of the measure to the number of claimed installations reported by the utility. This factor varies by end use, sector, technology, application, and delivery method. This GSIA rate is the current "default" rate specified for measures for which an alternative GSIA has not been estimated and approved.

Gross Savings Installation Adjustment Rates

Parameter	GSIA	Source
GSIA	1.0	California Public Utilities Commission (CPUC), Energy Division. 2013. *Energy Efficiency Policy Manual Version 5*. Page 31.

NON-ENERGY IMPACTS

Non-energy benefits for this measure have not been quantified.

DEER DIFFERENCES ANALYSIS

This section provides a summary of Database for Energy Efficient Resources (DEER) -based inputs and methods, and the rationale for inputs and methods that are not DEER-based.

DEER Difference Summary

DEER Item	Comment / Used for Workpaper
Modified DEER methodology	No
Scaled DEER measure	No
DEER Base Case	Yes (DEER2020 prototypes)
DEER Measure Case	No
DEER Building Types	Yes
DEER Operating Hours	Yes
DEER eQUEST Prototypes	Yes
DEER Version	2020
Reason for Deviation from DEER	Measure does not exist in DEER
DEER Measure IDs Used	N/A
NTG	Source: DEER2019. The NTG of 0.85 is associated with NTG ID: *ET-Default*
GSIA	Source: DEER2011. The GSIA of 1.0 is associated with GSIA ID: *Def-GSIA*
EUL/RUL	Source: DEER2014. The value of 15 years is associated with *EUL_ID: Motors-fan*.

REVISION HISTORY

Measure Characterization Revision History

Revision Number	Revision Complete Date	Primary Author, Title, Organization	Revision Summary and Rationale for Revision Effective Date and Approved By
01	08/06/2019	Nicholas Fette and Akhilesh Reddy Endurthy/ Solaris-Technical, LLC.	New Workpaper
	08/21/2019	Jennifer Holmes, Cal TF Staff	Revisions for submittal of version 01
	05/15/2021	Kenny Liljestrom, SDG&E	Revised to add SDG&E implementations to EAD tables