**Work Paper Abstract**

**Fan Motor Assembly for Refrigerated Case Evaporators**

**Revision # 1.0**

**California Technical Forum**

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**High Efficiency Permanent Magnet Synchronous Fan Motor Assembly for Refrigerated Case Evaporators**

***Abstract***

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| WP Abstract Tracking Log |
| Task | **Date Issued** | **Due By** | **Version** | **Author Last Name** **(or primary editor)** |
| Submitted to TF Staff for review |  |  |  |  |
| TF Staff sent to TF Members for 10-day review |  |  |  |  |
| Abstract presented at meeting |  |  |  |  |
| Cal TF Staff summarizes comments, sends back to abstract developer |  |  |  |  |
| Abstract developer incorporates TF comments into abstract, sends back to TF Staff |  |  |  |  |
| Abstract presented to Subcommittee (if applicable) |  |  |  |  |
| TF Staff summarizes TF Subcommittee recommendations, sends back to abstract developer |  |  |  |  |
| Abstract developer incorporates TF Subcommittee comments into abstract, sends back to TF Staff |  |  |  |  |
| TF Staff sends abstract to Commission staff for 10-day review |  |  |  |  |
| Comments from Commission staff received (if applicable) |  |  |  |  |
| Cal TF summarizes comments |  |  |  |  |
| Abstract presented at Meeting; consensus decision-marking |  |  |  |  |
| Cal TF finalizes abstract; prepares comparison exhibit of non-consensus items |  |  |  |  |
| Abstract to TF Subcommittee |  |  |  |  |
| Abstract to TF Subcommittee |  |  |  |  |
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Table 1 Work Paper Abstract Snapshot

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| --- |
| Work Paper Abstract Snapshot |
| Item | **Details** | **Notes** |
| Measure name | High Efficiency Permanent Magnet Synchronous Fan Motor Assembly for Refrigerated Case Evaporators |  |
| Measure description | Evaporator fan/motor assembly retrofits for refrigerated cases that reduce demand, heat load, and improve power factor. |  |
| Sector (Res/Non-Res) | Non-Residential |  |
| Subsector (e.g. Ag) | Food retail | Supermarkets, convenience stores, gas stations, delis |
| Delivery Channel (e.g. Upstream) | Upstream/Downstream Prescriptive Rebate and Direct Install (DI) | Target supermarket customers for fan replacements |
| Measure Application Type (e.g. ROB) | Early Retirement and Replace on Burnout |  |
|  |  |  |
|  |  |  |

1. Measure Description & Key Terms

This abstract is the next natural step to a successful emerging technology study sponsored by the SDG&E ET group in which 173 fan motor assemblies for refrigerated case evaporators have been tested and showed high savings potential. As a result the abstract goal is to seek suggestion to include this technology in the energy efficiency programs.

Primary References:

Energy Savings of Permanent Magnet Synchronous Fan Motors Assembly for Refrigerated Case evaporators, ET15SDG1061, SDG&E Emerging Technologies, March 2016.

Q-Sync Motors in Commercial Refrigeration: Preliminary Test Results and Projected Benefits, Oak Ridge National Laboratory, September 2015.

Refrigerated cases in supermarkets, convenience stores, pharmacies, and other commercial customers with food retail operations rely on small fans that circulate air past evaporator coils to maintain case temperature setpoints. These fans operate 24/7 with the exception of brief, daily defrost periods in most freezer cases. Evaporator fans are powered by small motors, which are typically ECMs or shaded pole based on industry standard practice (although incumbent motors will occasionally be split capacitor type). The units are purchased and replaced as preassembled units of fan, coupling, electronics, and motor. These assemblies come in varying fractional horsepower sizes and can be categorized as 4-8W, 9-12W, or 38-50W. These sizes are typically used in small refrigerated cases, mid-size reach-in refrigeration or freezer cases, and walk-ins respectively. This workpaper focuses only on the mid-size 9-12W motors that are the most common and are employed in the majority of reach-in refrigeration or freezer cases.

The proposed measure is a new type of permanent magnet synchronous motor (PMSM) fan assembly that uses new technology to provide an affordable energy efficiency solution to ECM losses. The measure improves efficiency and power factor by by-passing supply power rectification during the vast majority of motor operation at synchronous speed. The AC to DC rectification, which is necessary for ECM control on a continuous basis, is turned off for the proposed technology when the motor speed is synchronous with the grid. When that happens the motor is directly connected to the grid without the electronics “in between.” The technology uses a Hall effect sensor to verify that the motor is turning at synchronous speed. The electronics are controlling the motor only during start up and when operating at lower then synchronous speed.

The high efficiency PMSM fan assemblies are easily installed as long as the right size fan is selected for the case frame. Retrofit installation can be performed easily by a refrigeration contractor in less than 10 minutes once the cases have been emptied of the food.

These motors are expected to have an effective useful lifespan of 15 years as the existing ECM (PG&E FSTC Report 5011.05.13 and other work paper and deemed measures).

There are no HVAC interactive effects with the store envelope as all the heat load of the motors is contained within the refrigeration system and rejected through the condensing units, which are outside.

Key Terms:

* High efficiency permanent magnet synchronous motors (PMSM): measure that improves upon existing PMSM technology
* Electrically commutated and shaded pole motors: baseline technology
* Refrigerated case: reach-in low and mid temperature food cases (includes freezers)
1. Program Implementation Method

The proposed program is an upstream or downstream deemed rebate and a direct install program for replace on burnout and early retirement of existing food retailer case fan assemblies.

The program goal would be to achieve early retirement of existing fan populations, make sure that replace on burnout do not re-install shaded pole or ECMs, and to incent stores to replace the entire fan base. Without an early retirement or replace on burnout utility program, the refrigeration technician would only replace the fan assembly when a motor fails and probably with the standard ECM or shaded pole technology rather than the proposed emerging technology. That is why it is proposed that even if the proposed technology has a very small incremental cost compared to ECM, an incentive is needed to move the market.

Although the measure should be applicable at any refrigerated case with standard fan sizes, supermarkets account for about 80% of the baseline fan energy consumption in California and could be specifically targeted for improved program success and market transformation. The rebate should be made available to any application, but supermarkets and grocery stores should be specifically targeted and offered direct install.

Since there are no interactive effects related to the evaporator fan motor assembly replacement and refrigerated case systems do not significantly vary across all statewide conditions, the program and measure implementation is fairly consistent across all climate zones. The savings due to the refrigeration cycle are less than 30% of the total savings related to the measure and the efficiency differences among different climate zones would be a fraction of that, thus too small in the overall savings to warrant an individualized climate zone approach. A detailed analysis could be done to validate this assumption.

The site where the test was conducted had a COP of 3.5 for the mid temp and 1.8 for low temp refrigerated cases. Other standardized values could be used in developing the savings, but the mentioned ones seem to be in line with many other average applications. Any potential variation between sites and cases is outweighed by the consistency of savings and poor returns of a more rigorous program design that includes tiered offerings or rebates that depend on largely inconsequential site variables (single stage, multistage, floating head pressure, sub cooling, air cooled or water cooled condenser, etc.). Because there is expected consistency among grocery stores regarding the number of mid tem versus low temp (approximately 57% vs 43%), we suggest a proportional blended savings between the two categories.

Aside from program evaluation reasons, no measurement of pre or post conditions would be required. The measure provides a nearly constant, dependable load reduction that lends itself well to a deemed, rebate program. The only unaccounted variables include differences in savings for the refrigeration COP among different systems that as explained above are minimal compared to the whole measure.

One possibility to improve program design and understanding would be to collect data on the ratios of low and mid temp cases and existing motor types during implementation. Although a single, blended savings value is recommended, these data could be collected to improve savings estimates and validate the workpaper assumptions. If the collected data suggest that the mid and low temp ratios or baseline type need adjustment after 1 year, the workpaper and deemed values can be revised.

1. Mixed Baseline

The emerging technology study, recently performed at a San Diego grocery store evaluated the replacement of 173 fan motor assemblies and 92% of the replaced fans were driven by ECM motors, while the remaining 8% by shaded pole motors. A September 2015 report by Oak Ridge National Labs claimed that supermarkets have about 65% shaded pole and 35% ECMs but cited no sources beyond industry partners and experience. As a result, it is initially assumed that this workpaper will take the conservative view that ECMs are ISP in California consistent with the Title 24 (Section120.6 (b) that refers to retail food stores with 8,000 sq. ft. of conditioned area and that utilized refrigerated display cases or freezers). Therefore, the baseline is a single, consistent baseline of ECM incumbent fan assemblies.

However if during the first year of program implementation utilities realized through information collection in the field that a sizable percentage is shaded pole motors the savings should be recalculated based on the ECM shaded pole mix found in the field. An alternative to this approach would be to first assume an ECM/shaded pole mix for this workpaper.

If large corporations with many sites selectively implement the technology on a trial basis, there should be no conflict with program support. However, if it becomes company policy or a company-wide initiative, it may be then fall under industry standard practice for that customer; therefore, bringing this product to customers before the industry as a whole realizes the benefit is in utilities’ and ratepayers’ best interests.

1. Measure Summary

Table 2 Measure Summary

|  |  |
| --- | --- |
| **Characteristic** | **Measure** |
| Baseline Technology or Mix | Constant speed ECM fan assembly |
| Measure Technology | Constant speed high efficiency PMSM fan assembly |
| Measure Application Type | NR (ER and ROB) |
| Delivery Mechanism | Upstream/Downstream rebate and DI |
| Impacted Markets | Commercial – food retail |
| Relevant Codes and Standards | No code for 9-12 watt refrigerated case motors |

1. Estimated Size of Offer (Number of Participants)

Since this is a brand new technology offering and only one company is currently producing the product, the market penetration and adoption rate are essentially 0%. Based on US Census data and estimates of installed fans per customer type, the following table lists the approximate baseline fan population in California. This includes about 8,800 supermarkets and grocery stores which will comprise the majority of the market.

Table 3 California market size (from United States Census Bureau and ORNL study)

|  |  |  |  |
| --- | --- | --- | --- |
| **Facility Type** | **# of CA Establishments** | **9-12 W motors per site** | **Total number of fans** |
| Supermarkets and other grocery stores | 8,805 | 216 | 1,748,323 |
| Convenience stores | 2,373 | 7 | 16,611 |
| Specialty food stores | 2,896 | 50 | 144,800 |
| Liquor stores | 3,815 | 2 | 7,630 |
| Drug stores | 4,435 | 8 | 35,480 |
| Gas stations with convenience stores | 6,089 | 2 | 12,178 |

The total potential energy savings in California is about 207 GWh/year if all the 9-12 watt fan assemblies were replaced. After program support, market adoption rate will improve, the market will transform, and when the technology becomes industry standard practice or free ridership is too great, the program will not provide any additional benefit. This will be the limiting factor on the number of participants.

The emerging technology study evaluated 173 9-12W fan motors and the above market estimates do not include savings from the smaller and larger fan categories (4-8W and 38-50W) which will soon become a market when the manufacturer releases their forthcoming smaller and bigger models. These could potentially be included in future program or workpaper updates.

1. Estimated Impact of the Measure on Statewide Energy Efficiency Savings.

Based on the emerging technology study:

Energy savings per fan assembly (mix of mid and low temp): 105.7 kWh/year

Demand reduction per fan assembly: 12.21 watts

Estimated 9-12 W fan market size in CA: 1,965,000

Total estimated energy savings potential (100% market penetration): 207 GWh/year

Total estimated demand reduction potential (100% market penetration): 24.0 MW

This savings potential is for the entire available California market. If reasonable, a cutoff point of market penetration when the technology becomes ISP could improve the estimated impact of the measure on statewide energy efficiency savings. For instance, assuming that the technology becomes ISP at 50% market uptake could provide a point that program support could end and thus reduce the estimated EE program savings potential.

These savings are estimates calculated in the Emerging Technologies field case study using various sources for market size figures. The savings potential would increase by 2-3 times if the smaller and larger fan sizes are included once the products become available.

1. Applicable DEER & CPUC Guidance

There are not relevant DEER measure that relate to evaporator fan motors. However, the DEER operating hours of equipment for refrigerated storage includes the 24/7/365 type operation that justify the 8,760 hours.

Title 24 2013 (Section120.6(b)) states that for refrigerated warehouses “single phase fan motors less than 1 hp and less than 460 Volts in newly installed evaporators shall be electronically commutated motors”. With this assumption and knowing the fact that in the real world there is still a percentage of shaded poles and permanent split capacitor motors, the energy savings will be slightly greater than used in program claims.

1. Proposed Measure Parameter Values, Methodology, and Data Sources

All energy savings, demand reduction, market potential, and measure cost figures were developed as part of an emerging technologies study. The energy savings and demand reduction were established by performing an M&V study at a supermarket that included baseline and post-implementation monitoring at 173 evaporator fan motor assemblies which were distributed roughly evenly between closed freezer cases and open mid-temp refrigerated cases. Due to the large number of fans and consistent savings across every instance, the confidence level for the energy metrics is high. The variance in savings across the fans was very low, resulting in high accuracy and reliability of savings estimates. This high level of confidence in a single average savings per fan suggests that a deemed rebate measure is appropriate. Additionally, these savings were validated by previous lab testing as reported by Oak Ridge National Labs in a separate study (September 2015). The workpaper will show the different values found in the ET and the ORNL results)

Table – ORNL study per unit findings (N=2, single store)

|  |  |
| --- | --- |
| **Motor type** | **Input power [W]** |
| Shaded pole | 60.0 |
| ECM, old | 22.6 |
| ECM, new | 18.2 |
| PMSM | 16.4 |

Table – ET study per unit findings (N=173, single store)

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Fan motor assemblies** | **Refrigeration mid temp** | **Refrigeration low temp** |
| Baseline on-peak power [W] | 23.0 | 6.6 | 13.1 |
| Post on-peak power [W] | 14.5 | 4.1 | 8.3 |
| On-peak demand reduction [W] | 8.5 | 2.4 | 4.8 |
| Baseline energy [kWh/yr] | 201.8 | 57.4 | 112.3 |
| Post energy [kWh/yr] | 127.3 | 36.2 | 70.9 |
| Energy savings [kWh/yr] | 74.4 | 21.2 | 41.4 |

The field test involved 1 month of baseline monitoring and 1 month of post-implementation monitoring of fan circuit demand at subpanels, a sample of case bulk air temperature and humidity, and spot measurements of airflow and power characteristics. Energy and demand savings were determined using real power measurements at the circuit breaker and supplemented by spot measurements of each fan. Demand was consistent across all conditions with only slight diurnal, periodic variation that depended on grid supply voltage. Thus, energy and demand savings were easily calculated by a simple comparison between pre and post data. Annualized values were calculated by extrapolating to 8,760 hours for the mid-temp cases and 8,575 hours for the freezers to account for daily 30 minute defrost cycles. Using site specific efficiency system kW/ton values, savings associated with the reduced fan heat load were also included.

The workpaper assumes an ECM baseline, similar freezer case defrost functions, and 24/7 cooling of the refrigerated cases. Installed cost per unit was taken from the project experience, vendor quotes, and refrigeration service provider rates. However, a range of unit costs was provided by the manufacturer and thus the respective confidence is medium. However, the range is relatively small and is not expected to reach levels that make the technology ineffective. Market size was determined using US Census data for food retail businesses in California. The number of fans at each type of business was defined by estimates in the reference Oak Ridge National Labs paper. Combining the ET study findings and this estimated market size allowed for total market potential energy savings and demand reduction.

Guidance sought from CalTF includes whether to see a blend of results from both the ET and ORNL studies and whether to consider having two different program offerings for freezer cases and mid-temp refrigerated cases. The field test used an almost exclusive ECM baseline while ORNL incorporated an assumed, mixed baseline and testing of only several fans in a lab setting. Refrigeration system COP is lower for freezer loads, thus increasing the per fan savings despite the half-hour of no run time per day due to defrost. This could be addressed by either using an average deemed savings for all fan applications or by having separate offerings.

Table 6 Proposed Measure Parameter Methods, Data, Assumptions and Sources

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Measure Parameter** | **Proposed Value (average of mid and low temp)** | **Methodology Description** | **Key Assumptions** | **Data Source Name and Description[[1]](#footnote-1)** | **Input Requested from TF** | **Confidence Level** **(High, Medium, Low)** |
| Baseline EnergykWh/yr | 286.4 | Emerging technologies field study | Field case study is representative of California market | [ET15SDG1061 Report](http://www.etcc-ca.com/reports/energy-savings-permanent-magnet-synchronous-motors-refrigerated-cases) |  | High |
| Measure EnergykWh/yr | 180.8 | Emerging technologies field study | Field case study is representative of California market | [ET15SDG1061 Report](http://www.etcc-ca.com/reports/energy-savings-permanent-magnet-synchronous-motors-refrigerated-cases) |  | High |
| Savings – kWh/yr | 105.6 | Emerging technologies field study | Field case study is representative of California market | [ET15SDG1061 Report](http://www.etcc-ca.com/reports/energy-savings-permanent-magnet-synchronous-motors-refrigerated-cases) |  | High |
| Baseline DemandkW | .0331 | Emerging technologies field study | Field case study is representative of California market | [ET15SDG1061 Report](http://www.etcc-ca.com/reports/energy-savings-permanent-magnet-synchronous-motors-refrigerated-cases) |  | High |
| Measure DemandkW | .0208 | Emerging technologies field study | Field case study is representative of California market | [ET15SDG1061 Report](http://www.etcc-ca.com/reports/energy-savings-permanent-magnet-synchronous-motors-refrigerated-cases) |  | High |
| Savings – kW | .0123 | Emerging technologies field study | Field case study is representative of California market | [ET15SDG1061 Report](http://www.etcc-ca.com/reports/energy-savings-permanent-magnet-synchronous-motors-refrigerated-cases) |  | High |
| Baseline EnergyTherms/yr | 0 |  |  |  |  | High |
| Measure EnergyTherms/Yr | 0 |  |  |  |  | High |
| Savings – therms/yr | 0 |  |  |  |  | High |
| EUL | 15 Years | Existing workpapers and studies  |  | Fisher Nickel, PG&E, SCE |  | Medium |
| MC | $95/unit | Manufacturer quotes and contractor info |  |  |  | Medium |
| NTG | 0.85 |  |  |  |  | Low |

1. Proposed Level of Complexity

Since this is a straightforward deemed rebate, drop-in retrofit with constant savings, a high level of confidence, and similar findings from AESC, Oak Ridge National Labs, and the manufacturer, we believe the level of complexity and risk are low.

1. Preliminary TRC Estimates

Table 7 Preliminary TRC Estimates and Parameters

|  |  |  |  |
| --- | --- | --- | --- |
| **TRC Parameter** | **Parameter Estimate or** **Required Parameter Value Threshold** (specify if estimate or threshold) | **Confidence Level** **(High, Medium, Low)** | **Comments** |
| UES |  |  |  |
| IMC | $96 |  |  |
| EUL | 15 |  |  |
| NTG | 0.95 |  |  |
| Incentive/unit | $20-60 |  |  |
| Number of units | Thousands |  |  |
| Installation Rate | 0.8 |  |  |
| Gross Realization Rate | 0.9 |  |  |
|  |  |  |  |
|  |  |  |  |
| ***TRC Value:***  | **Estimated 1.1 – 2.0** |

1. Literature Review

Small motors comprise a significant portion of grid demand and will not decrease in the foreseeable future without measures such as the one proposed here. This type of motor and low cost VFDs are the only expected technologies in the pipeline that could address this end-use. As far as the author’s know, the technology has not yet been granted program support in other jurisdictions due to its being a brand new available product.

References:

Fricke, B., & Becker, B. (2015). Q-Sync Motors in Commercial Refrigeration: Preliminary Test Results and Projected Benefits, ORNL/TM-2015/466. Oak Ridge National Laboratory.

* EM&V results, market size estimations, numbers of motors per establishment, proposed measure technology description

Karas, A. (2006). GE ECM Evaporator Fan Motor Energy Monitoring. Fisher-Nickel, Inc. and Pacific Gas & Electric.

* Evidence that motors run 24/7 in most establishments

NCI and PNNL. (2011). Preliminary Technical Support Document: Energy Conservation Program for Certain Commercial and Industrial Equipment: Commercial Refrigeration Equipment. Washington, D.C.: Building Technologies Program, Office of Energy Efficiency and Renewable Energy, US Department of Energy.

* Baseline motor efficiency

US Census Bureau. (2013). County Business Patterns (NAICS).

* Market size estimations

Valmiki, M M and Corradini, Antonio. (2016). Energy Savings of Permanent Magnet Synchronous Fan Motor Assembly in Refrigerated Case Evaporators. SDG&E Emerging Technologies, ET15SDG1061.

* Energy savings calculations, EM&V field study
1. Additional Research Needed

ORNL and ET reports are in good agreement with very consistent results. No additional information is needed for the workpaper at this time. As suggested above, data collected during program implementation for the first year could help revise case type blend or baseline motor types, if needed.

1. Questions for CPUC Staff on Applicability of DEER Values, Methods, Tools, Data, Etc.

1. Cal TF Comments on Proposed Measure Parameter Values, Methodology, and Data Sources

*Cal TF comments on proposed data and sources. Do data represent best available data? If not, what are alternate data/sources that should be considered?*

Table 8 Cal TF Comments on Measure Parameter Methods, Data, Assumptions, and Sources

|  |  |
| --- | --- |
| **Measure Parameter** | **Cal TF Comments / Recommendations** |
| Baseline EnergykWh/yr |  |
| Measure EnergykWh/yr |  |
| Savings – kWh/yr |  |
| Baseline DemandkW/yr |  |
| Measure DemandkW/yr |  |
| Savings – kW/yr |  |
| Baseline EnergyTherms/yr |  |
| Measure EnergyTherms/Yr |  |
| Savings – therms/yr |  |
| EUL or RUL |  |
| MC or IMC |  |
| NTG |  |

1. Cal TF Comments on Proposed Level of Complexity

*Cal TF comments on proposed level of complexity based on input from abstract developer and Cal TF discussion.*

1. Other Cal TF Comments
2. Commission Staff Review and Feedback

*Commission staff should provide feedback on proposed data and sources within 10 days of request.*

Table 9 Commission Staff Feedback on Proposed Data and Sources

|  |  |
| --- | --- |
| **Measure Parameter** | **Commission Staff Comments / Recommendations** |
| Baseline EnergykWh/yr |  |
| Measure EnergykWh/yr |  |
| Savings – kWh/yr |  |
| Baseline DemandkW/yr |  |
| Measure DemandkW/yr |  |
| Savings – kW/yr |  |
| Baseline EnergyTherms/yr |  |
| Measure EnergyTherms/Yr |  |
| Savings – therms/yr |  |
| EUL or RUL |  |
| MC or IMC |  |
| NTG |  |

# Appendix A – Sources

Primary Source: [ETCC Report](http://www.etcc-ca.com/reports/energy-savings-permanent-magnet-synchronous-motors-refrigerated-cases) (Calculations and M&V analysis can be provided on request)

Secondary Source: [ONRL Report](http://info.ornl.gov/sites/publications/files/Pub58600.pdf)

1. Provide a link to source or embed source in Appendix A of this document with page numbers specified. [↑](#footnote-ref-1)