AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
1791 Tullie Circle, N.E./Atlanta, GA 30329
404-636-8400

TC/TG/MTG/TRG MINUTES COVER SHEET

(Minutes of all Meetings are to be distributed to all persons listed below within 60 days following the meeting.)

TC/TG/MTG/TRG No. TC – 5.1 DATE 6/27/2016

TC/TG/MTG/TRG TITLE Fans
DATE OF MEETING 6/27/2016 LOCATION St. Louis, MO

MEMBERS PRESENT	YEAR APPTD	MEMBERS ABSENT	YEAR APPTD	EX-OFFICIO MEMBERS AND ADDITIONAL ATTENDANCE
Patrick Chinoda	2014	John Murphy	2012	
Franco Cincotti	2014	Mike Brendel	2012	
Asesh Raychaudhuri	2012	John Cermak	2014	
Harold Dubensky	2015	Chuck Coward	2014	
Armin Hauer	2015	Tim Kuski	2014	
Eric Tngloff	2014	David Rasmussen	2012	
Greg Wagner	2012	Craig Wray	2014	

DISTRIBUTION

All Members of TC/TG/MTG/TRG plus the following:	
TAC Section Head:	Kenneth Peet
TAC Chair:	Thomas Lawrence
All Committee Liaisons As Shown On TC/TG/MTG/TRG Rosters:	Cameron Labunski Jamesd Arnold Annette Dwyer David John Dr. Arsen Melikov
Manager Of Standards Manager Of Research & Technical Services	Stephanie Reiniche Mike Vaughn

Other corresponding Members and guests attending TC 5.1 Meeting:

Brian Reynolds
Joe Brooks
Zhiping Wang
Jay Eldridge
Kim Osborn
Rich Stauter
Brent Fullerton
Seve Liescheidt
Jeremy Smith
Robert Pope
Lauren Zelinski
Sanaee Iyama
Diane Jakobs
Koosha Kiamehr
Igor Maewski
Ken Kuntz
Gang Wang
Michel Feuser

ASHRAE TC 5.1 Meeting
Monday, 27 Jun 2016

Americas Convention Center Complex **Room 264**
St. Louis, MO

Minutes

1. Call to Order

The Chair, Patrick Chinoda, called the meeting to order at 4:15 pm.

2. Roll Call

The following TC 5.1 voting members were present:

Patrick Chinoda – Chair
Franco Cincotti – Vice Chair
Asesh Raychaudhuri – Program S/C Chair
Harold Dubensky
Armin Hauer
Eric Tingloff
Greg Wagner

The following TC 5.1 voting members were unable to be present:

John Murphy – Standard S/C Chair
Mike Brendel
John Cermak
Chuck Coward
Tim Kuski
David Rasmussen
Craig Wray

A quorum was not present.

3. Adoption of Agenda

The agenda was adopted by consensus

4. Approval of the Minutes

The last meeting of this committee was held on 25 January, 2016 in Orlando, FL. Since there was no quorum the approval of those minutes was postponed until next meeting.

5. Items of business

5.1 ASHRAE Code of Ethics

The code of conduct, which can be found at http://www.ashrae.org/codeofethics was reviewed.

5.2 Chairman's report

Items of interest reported by the chair:

- For programs submitted but not accepted by ASHRAE, ASHRAE will inform the TC within two weeks of submittal, TC can then present at the TC meeting and time and topics will be listed in program.
- Web meeting tools can be used to aid in attendance at TC meetings. This should make it easier to obtain a quorum.
- ASHRAE is promoting subcommittee meetings outside of the Winter/Annual meeting time periods.

5.3 TC 5.0 Section Head/Liaison Reports

Item of interest reported by the section head included:

- Seminars/Forum program requests due Monday, August 8, if not accepted, TC will know within two weeks after, it could then be presented at the TC meeting.
- ASHRAE will have a dedicated collaboration site called google Base Camp. It should be ready shortly after the annual meeting. Members urged to look at it.

5.4 DOE Fan Regulation Status

It was reported that there has been no change in the status of the DOE Fan Regulation.

5.5 Old business

No old business was brought to the floor.

6. Subcommittee reports

6.1 Standards subcommittee

6.1.1 ASHRAE Standard 149-2013

The recommendation from the last meeting of TC 5.1 was to withdraw this standard. The form that is required to be filled out needs to include a justification. Although not present, it was requested that John Murphy draft a justification and then the Secretary will send out a letter ballot to the voting members.

6.1.3 ASHRAE 68/AMCA 330

Patrick Chinoda volunteered to contact SRS to determine what action is needed for ASRHAE 68.

6.1.4 ASHRAE 51/AMCA 210

Joe Brooks reported on the status of the approval of this standard. It was currently awaiting ASHRAE Board approval which is needed prior to sending to ANSI for approval as an American National Standard.

6.2 Handbook subcommittee – Zhiping Wang

The handbook subcommittee report was discussed and is attached.

6.3 Research subcommittee – Brian Reynolds

The research subcommittee report was discussed and is attached.

6.4. Program subcommittee – Asesh Raychaudhuri
Some ideas for future programs were discussed:

- Fan system/Energy Performance (Mike Brendel/Tim Mathson, Craig Wray declined as a presenter due to lack of approval of this by ASHRAE in the past) – This will be submitted as a program and if not accepted, it will be given as a hot topic during the winter meeting,
- Fan Selection – it ws thought this may be a possibility
- Circulating Fans (Jay Fizer as presenter),
- Fan systems – have a fan, motor, and driver manufacturers talk. Dutin Meredith will provide some names.

The hot topic from this was thought to be very good. The presentation slides are attached.

7. Website Report – Harold Dubensky

This TC website analytics were discussed and are attached.

8. New Business

There was no new business.

9. Time and Place of Next Meeting

The next meeting of this TC will be in Las Vegas at the Winter Meeting.

10. Adjournment

The meeting adjourned at 6:00 pm.

Noted recorded by,

Joe Brooks
ASHRAE TC 5.1 Secretary

Attachments:
1) Hanbook Subcommittee Report
2) Research Subcommittee Report
3) AMCA 207: Standardized Fan System Energy Calculations, slide deck
4) TC 5.1 Website Analytics

TC 5.1 Handbook Subcommittee Notes (06/26/2016)

By Zhiping Wang

- 2016 Handbook volume was published and sent out to members in May. At that point, we formally completed our 2016 revision cycle. Again, I want to thank all of our members for your time, efforts, and contributions. Specifically, I want to thank Armin Hauer for doing the proof read of our chapter in March.
- ASHRAE is "rolling out a brand new way to make revising your handbook chapters easier". I will follow up on that.
- Two outside reviewers agreed to review our chapter and provide comments and suggestions for our next revision. The chapter content will be forwarded to them after this meeting.
- We will formally start the next revision cycle in early 2017. Right now, we are still open for ideas, suggestions, and Handbook Online stuff.
- The ASHRAE Terminology was briefly reviewed and discussed in the subcommittee meeting. We decided to take a few terms that are not accurate on the current website and try to work with TC1.6 and/or ASHRAE staff to have them corrected. Assume we go through this exercise successfully, we will then do a more thorough review and also compare with AMCA 99 and ISO13349?

List of Potential Topics for 2020 Version of the Fan Chapter

- **Fan Efficiency – New section to define and discuss total efficiency vs. static efficiency**
  - **Examples of proper fan selection to save energy**
  - **Fan Selection (Total pressure based vs. Static pressure based)**

  Actions: Wait after DOE publishes the new regulation on fans?
- **Fan Drive System – Direct Drive vs. Belt Drive, VFD, VSD, etc.**
  Actions: 05/23/14 – Greg S., Chuck, and Zhiping will draft up the content. Craig suggested Chpt.18 (9th ed.) of Fan Engineering covers information about motors and drives. AMCA 203 also has good information. AMCA 207 maybe, too.
- **Fan Part Load?**

Actions: 05/23/14 – Good topic but Committee decided to put it on the parking lots for now. Maybe for next revision cycle after we collect enough information.

- **Airflow measurement by means of instrumented fan inlet rings (Armin Hauer)**
  Actions: 03/21/16 – Armin submitted the material after AMCA published the Publication 600-06. We now need to create the right content/format for the chapter.
- **Fan Stall (Greg Sanchez wrote some content during our last revision cycle and will investigate further)?**
  Actions: 05/23/14 - Greg will send out information before the Seattle meeting for the committee members to review.
  06/29/14 - Greg Sanchez will have the information ready by mid. July. 01/25/15 – No content yet. Will push back for next revision cycle.
- **Fan Noise (Greg S., predicting fan noise – AMCA 301, or aerodynamic noise?)**
  Actions: 05/23/14 - Good topic. Committed decided to put it on the parking lots for now. Maybe for next revision cycle. Reference Bill Cory's book and the Fan Engineering.
- **Fan Law Applications and System Curves** – Craig Wray already sent the revised content last year. Need to review the content.
- **Handbook Online** - Some ideas came out from our last HB meeting.
  - 3D models of different types of fans and interactive performance curves within Table 1;
  - Interactive curves to demonstrate the fan laws;
  - Interactive contents to show the stall/surge;
- ~~**Outside Reviewers** – Let me know if you know somebody who could be a potential reviewer for us.~~
- ~~**ASHRAE Terminology** – We will dedicate some time to review those terms associated with fans.~~

TC 5.1 (Fans) Research Committee Meeting
June 27, 2016 (St. Louis)

Research Chair breakfast notes

1. RAC reviewed 9 RTAR's in St. Louis
    - 1 accepted with comments, 4 conditionally accepted with comments, 4 rejected

    10 work statements were considered
    - 6 conditionally accepted, 4 returned
2. Research Database on line electronically – about 250 projects currently on line with more to follow (eventual total around 1000)

Link to access the new online research database mentioned during the research subcommittee breakfast this morning.

Public: Http://research.ashrae.org

3. Co-sponsoring TC's need to participate in RTAR and WS creation, including committee votes to approve.
4. New - Project milestones and stage funding to evaluate each project phase for continued funding.
5. Curt Eichelberger (curtis.eichelberger@jci.com) and 10 year Research Chair for TC 2.6 is on RAC now. He offered to help TC's to write RTAR's and WS's that will be effective for RAC consideration.

TC 5.1 Research Subcommittee meeting summary (6-26-16)

- TC 5.1 currently has no active research projects and no work statements at this time.
- There are 2 RTAR's in process and another proposed RTAR.

1. RTAR 1769 - Experimental Evaluation of Efficiency of V-Belt Drives used on Fans – (authors Tim Mathson and Craig Wray)
    - RAC negative vote in Atlanta, authors addressed comments in a revised RTAR.
    - RAC approved with comments in St. Louis. Our liaison (David John) was very helpful in representing the RTAR at RAC.
    - We will receive the official comments following the conference. David John provided comments from one of the RAC members. These comments were reviewed at the Research sub-committee meeting yesterday.
    - Prior to St. Louis I had a call with the AHRI Research Director to address questions and confirm AHRI as a co-sponsor.
    - Craig and Tim will proceed with writing the Work Statement. The goal is to have a liaison review and TC letter ballot prior to Las Vegas.

Comments received from one reviewer

a) It is surprising that such data is not available in other industries, for example, automotive industry.
b) Authors are strongly recommended to include detailed literature survey from other industries into the work statement. It is also recommended to develop a first project just for literature review before conducting any experiments. We have done literature search, there is no information as stated in the RTAR. RMA concurs. AMCA info is only at full load.

Brian Reynolds

c) I don't feel that they presented existing available formulas and other information (tables/graphs) that can currently be used to calculate belt efficiency. Not typically included in RTAR's or Work Statements.
d) I don't feel they established the need or the level of benefit. It would be impossible to predict tension for a given application so this is at best a rough estimate no matter how many other variables are considered. It would be beneficial if data was presented to indicate just how much variation in efficiency (generally assumed to be 3%-5%) there is expected to be. V-belt drive efficiency falls off dramatically as part load, as mentioned in the RTAR and illustrated by the chart.
e) At its heart this seems to be about market position competition between fan walls and large centrifugal fans for air handlers. Thus, it is more in the interest of the incumbents than the challengers (fan walls). 80% of large centrifugal fans are still belt drive. The installed base is still predominantly belt drive fans.
f) Firm commitment for substantial co-funding by AHRI and/or AMCA.
g) Better understanding from available data of the fraction of energy lost to belts at part load, such as might be inferred from the graphs in the RTAR.

I will contact the two main commenters from RAC to see if I can resolve their concerns in addition to making sure the WS addresses the official RAC comment list. *(Per suggestion of the liaison.)*

2. RTAR - "Inlet and Outlet Air and Sound system effects on multiple plenum fans (parallel arrangement)"
   - Authors – Dustin Meredith & Patrick Chinoda
   - Extension of RP 1420 (single DDP system effects)
   - Dustin went through the RTAR with the committee.
   - Initial liaison review comments
     a) Need to clarify task list
     b) Use 'plenum fan array' description

   The goal is to complete the liaison review and TC letter ballot prior to Las Vegas. Or try for fall RAC meeting review. Dustin will work with Kim Osborn.

<u>New RTAR (Dustin Meredith)</u>

Research to improve the wire-to-air models; specifically inverters and motors in the absence of certified test data (e.g., AHRI Standard 1210).
- Many variables and combinations.
- AHRI has some data collected for 1210. But doesn't represent how real systems work.

Dustin can prepare RTAR draft for committee review, possibly in a conference call meeting before Las Vegas.

<u>RAC dates</u>

- RAC meets 3 times per year to review RTAR's (May 15, August 15, and December 15). Submit RTAR's and WS's to RAC one month prior to dates.

Brian Reynolds

- There is also a spring conference call meeting around March 15. RTAR's are typically <u>not</u> reviewed at the spring meeting but a special request can be made for a review. Very important to have no negative votes or letter ballot abstentions.
- Our liaison (David John) is our voice at the RAC meeting so it is important for him to understand what the RTAR is about.

<u>Other research topics list</u>

- The list was distributed prior to the Orlando meeting
- The list was scrolled through at the 6-26 Research sub-committee meeting.
- There are not any actionable items from the list at this time (no champions or authors).
- One possible topic was added to the list in Orlando - EC motor fans. Fan/motor/drive systems. How does air & sound compare with traditional fan with induction motor & inverter? (Rad)

  Send suggestions fan research topic suggestions to Brian Reynolds (breynolds@trane.com)

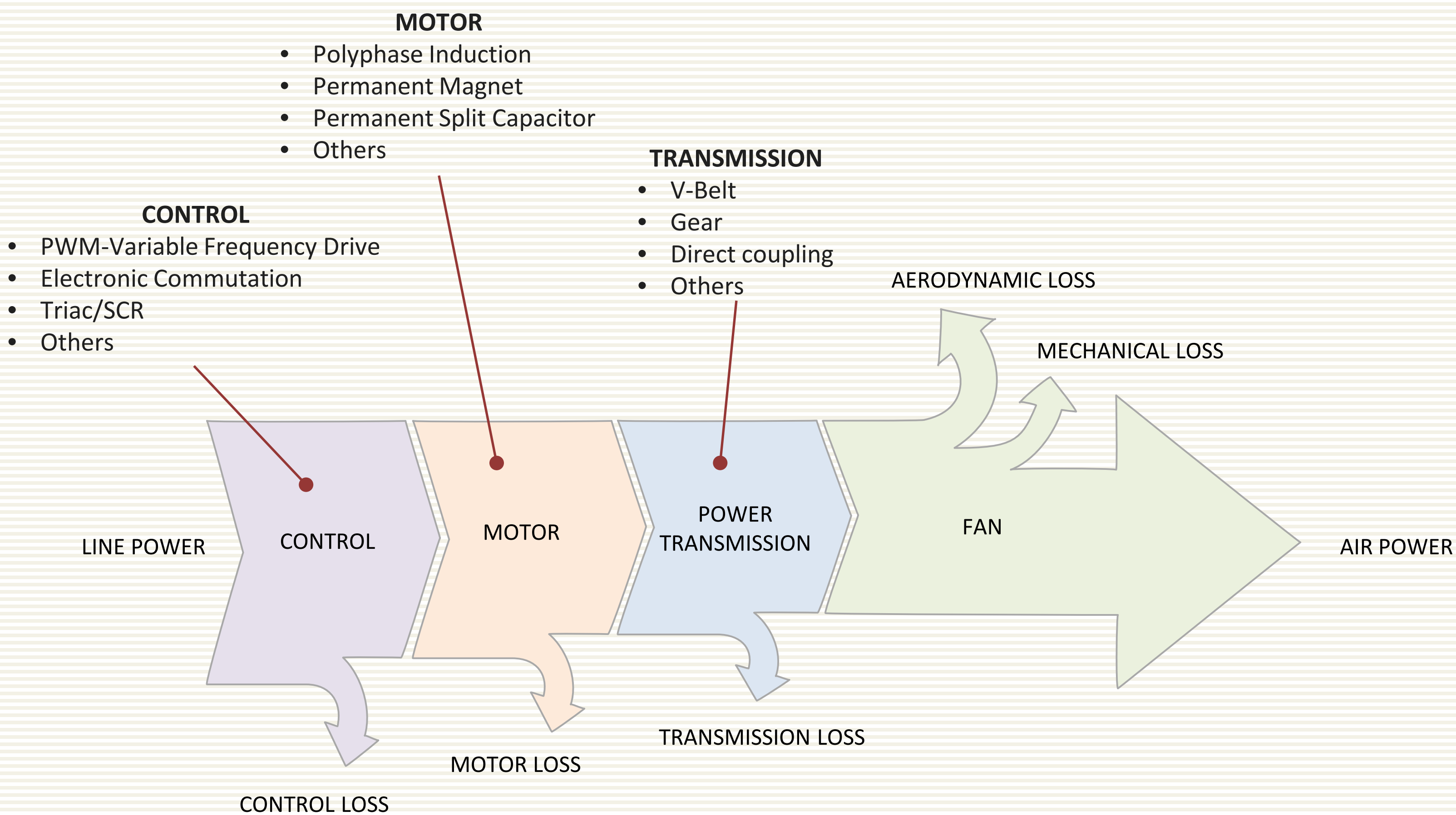
Brian Reynolds

AMCA 207: Standardized Fan System Energy Calculations

Outline

- Background
- Calculation Model
  - Power Transmission
  - Polyphase AC Induction Motor
  - PWM – Variable Frequency Drive
- Examples

Background



Extended Fan System

Background

Test Standards

- AMCA 210-07 *Laboratory Methods of Testing Fans for Certified Aerodynamic Performance Rating*
- ISO 5801:2007 *Industrial fans -- Performance Testing Using Standardized Airways*

Practical Issues

- Too many combinations of motor, drives, and controls creates testing burden
- No established affinity laws for extended fan systems
- Part load operation important in many applications

Current State

- Ad hoc calculations – inconsistent, unreliable, untraceable, *smoke and mirrors* approach
- ISO 12759 – no provision for part load performance

Opportunity

- Create a *standardized* method for calculating extended fan performance
- Permit part-load performance
- Offer repeatable and consistent comparison of fan system configurations
- Provide a benchmark for system performance

AMCA 207: *Fan System Efficiency and Fan System Input Power Calculation*

Objective

Standardized calculation for extended fan system

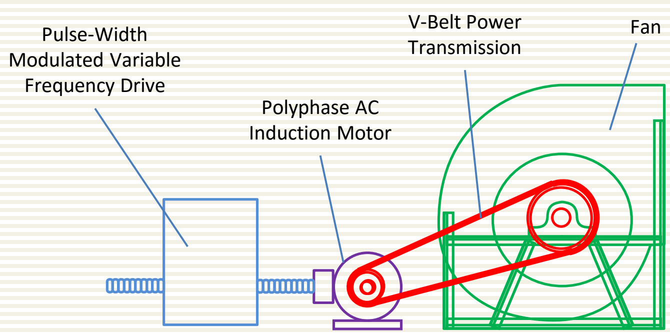
- *Input power*
- *Wire-to-air efficiency*

Given:

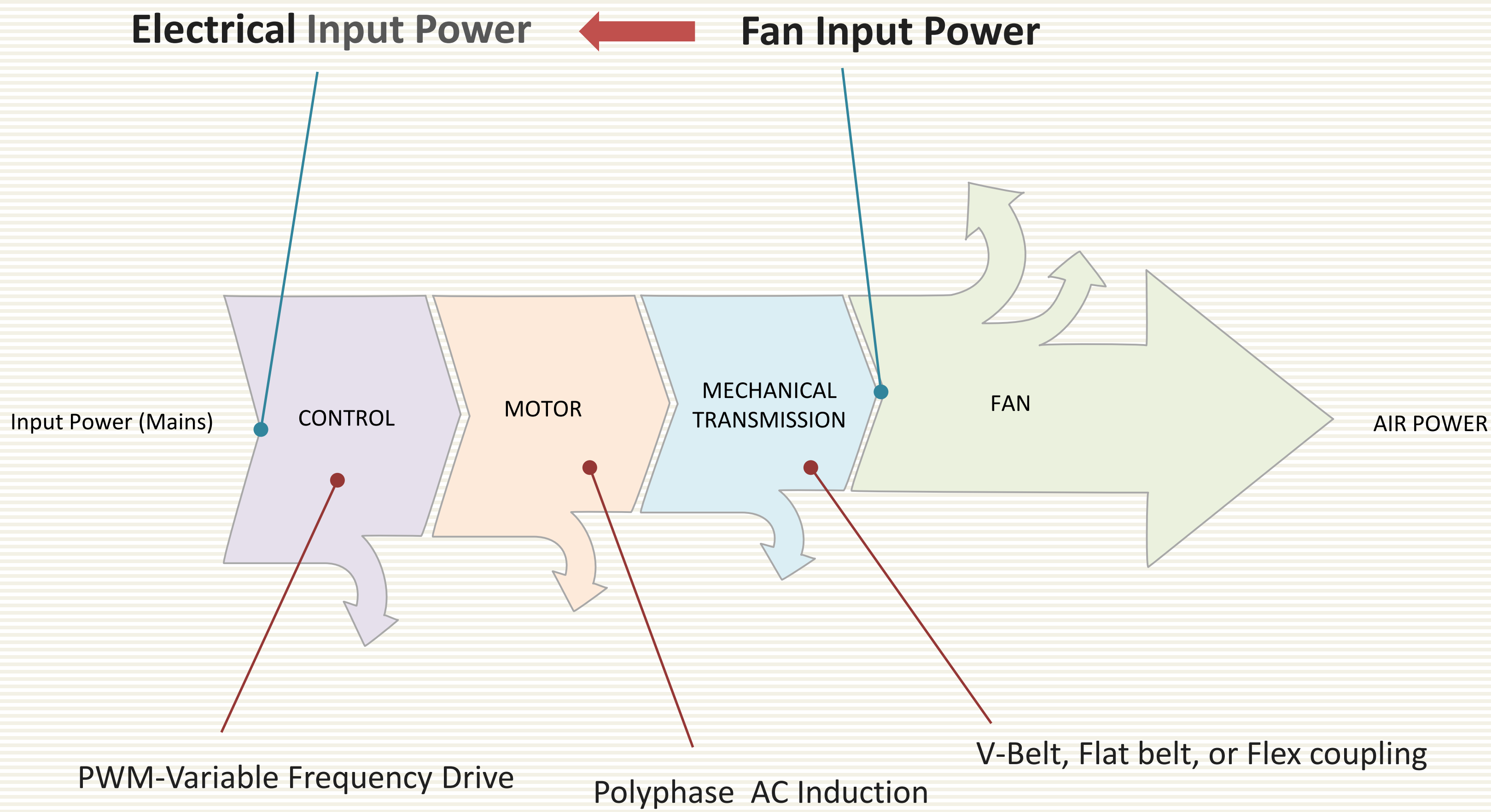
- Tested fan performance – *scaled using fan laws if necessary*
- Fan system operating condition(s)

Specified:

- Polyphase AC induction motor (Regulated)
- Power transmission (v-belt, flat belt, flex coupling)
- PWM-variable frequency drive



Scope



Electrical Input Power
Fan Input Power
Input Power (Mains)
CONTROL
MOTOR
MECHANICAL
TRANSMISSION
FAN
AIR POWER
PWM-Variable Frequency Drive
Polyphase AC Induction
V-Belt, Flat belt, or Flex coupling

General Nomenclature

Calculation proceeds *upstream* from the fan:

Transmission Output Power ≡ Fan Shaft Power (H_i)

Motor Output Power ≡ Transmission Input Power (H_m) ≡ $\frac{H_i}{\eta_B}$

Control Output Power ≡ Motor Input Power (W_m) ≡ $\frac{H_m}{\eta_m}$

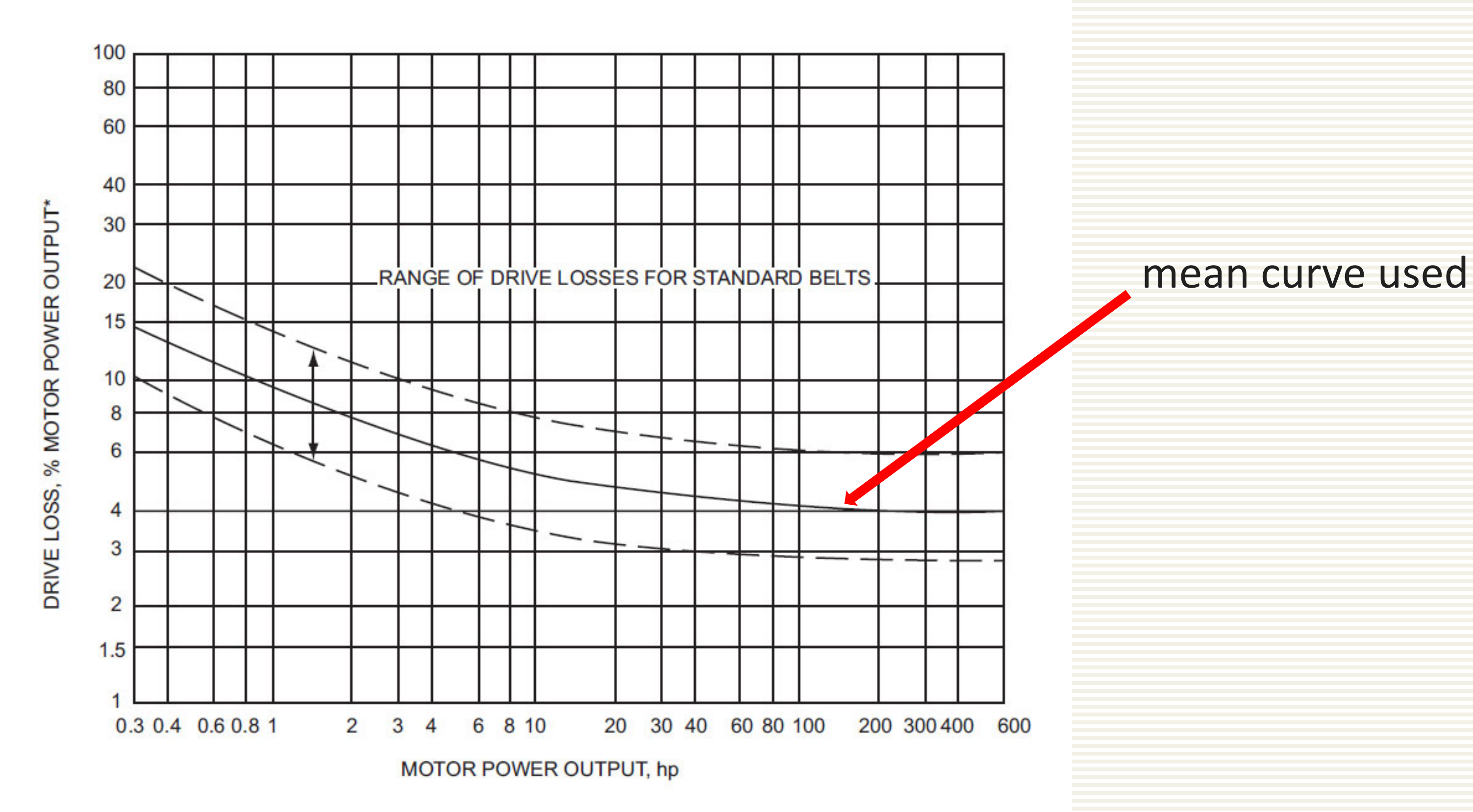
Mains Power ≡ Control Input Power (W_c) ≡ $\frac{W_m}{\eta_c}$ ≡ $\frac{H_i}{\eta_B \eta_m \eta_c}$

Wire-to-air efficiency = $\eta_w = \eta\ \eta_B\ \eta_m\ \eta_c = \frac{H_o}{W_c}$

V-Belt Power Transmission

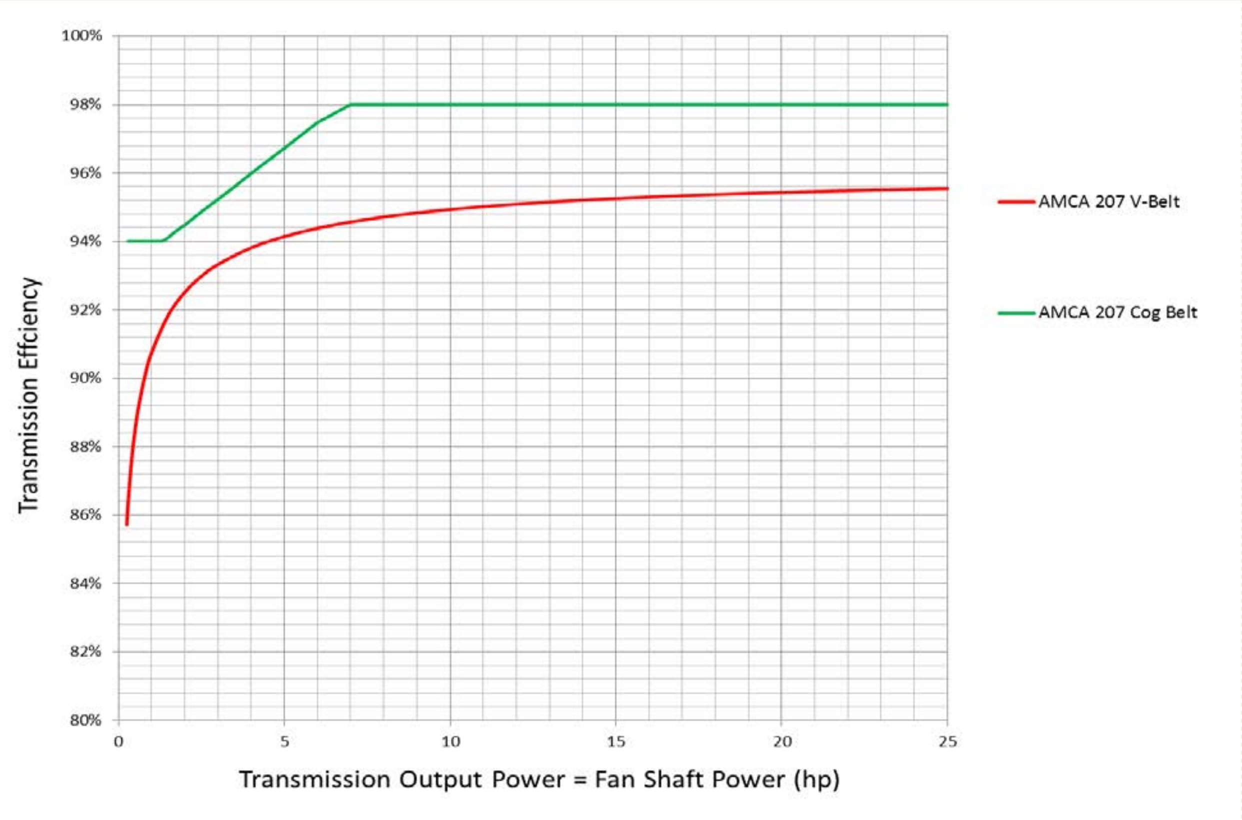
V-Belt Power Transmission

- Efficiency depends on: tension, geometry, flexure, alignment, sheave diameters, belts speed,…
- Efficiency model from AMCA 203-90 (R2007) *Field Performance Measurement of Fan Systems*
- Adjusted for fan shaft power instead of motor output power



Standard V-Belt Loss Model

V-Belt Power Transmission



$$\eta_B = 0.96 \left(\frac{H_i}{H_i + 2.2}\right)^{0.05} \qquad (0.25 \text{ hp} \leq H_i \leq 590 \text{ hp}) \quad [IP]$$

$$\eta_B = 0.96 \left(\frac{H_i}{H_i + 1.64}\right)^{0.05} \qquad (0.19 \text{ kW} \leq H_i \leq 440 \text{ kW}) \quad [SI]$$

* Final version will include flat belts (cog) and flexible couplings

Polyphase AC Induction Motor

Polyphase AC Induction Motor

Based on AEDM simulations provided by Nidec Motor Corporation
DOL (Direct On Line) and VF (variable frequency, constant V/Hz)

Model accounts for 5 motor losses:

- Stator Loss (i.e. I^2R losses)
- Rotor Loss
- Core Loss
- Stray Loss
- Windage/Friction Loss (cooling fan, bearings)

Motor Simulation Matrix

Operation	Rating (hp)	Voltage	#Poles	Enclosure	Load Ratios (% full load)
DOL	1, 5, 20, 50, 100, 200	460	2P, 4P, 6P	ODP, TEFC	3, 6, 13, 22, 34, 51, 73, 100, 115, 120, 130, 140, 150
VF	1, 5, 20, 50, 100, 200	Constant V/Hz 460V max	2P, 4P, 6P	ODP, TEFC	3, 6, 13, 22, 34, 51, 73, 100

Polyphase AC Induction Motor

Simulation Data Example (4P ODP 20HP)

20 hp 4P ODP DOL												
H_m (hp)	E (V)	f (Hz)	η_M	N (rpm)	W_s (W)	W_r (W)	W_c (W)	W_l (W)	W_f (W)	Total (W)	L_m	η_N
20.00	460	60	93.0	1775	508	212	209	111	73	1113	100.0%	100.0%
14.58	460	60	93.7	1784	277	103	209	68	73	730	72.9%	100.8%
10.24	460	60	93.4	1789	160	48	209	44	73	534	51.2%	100.4%
6.86	460	60	92.1	1793	103	22	209	32	73	439	34.3%	99.0%
4.32	460	60	89.1	1795	74	9	209	26	73	391	21.6%	95.8%
2.50	460	60	83.4	1797	62	3	209	24	73	371	12.5%	89.7%
1.28	460	60	72.7	1798	57	1	209	23	73	363	6.4%	78.2%
0.54	460	60	50.9	1799	56	0	209	22	73	360	2.7%	54.7%

stator loss

core loss

friction loss

Constant V/Hz VFD Output

rotor loss

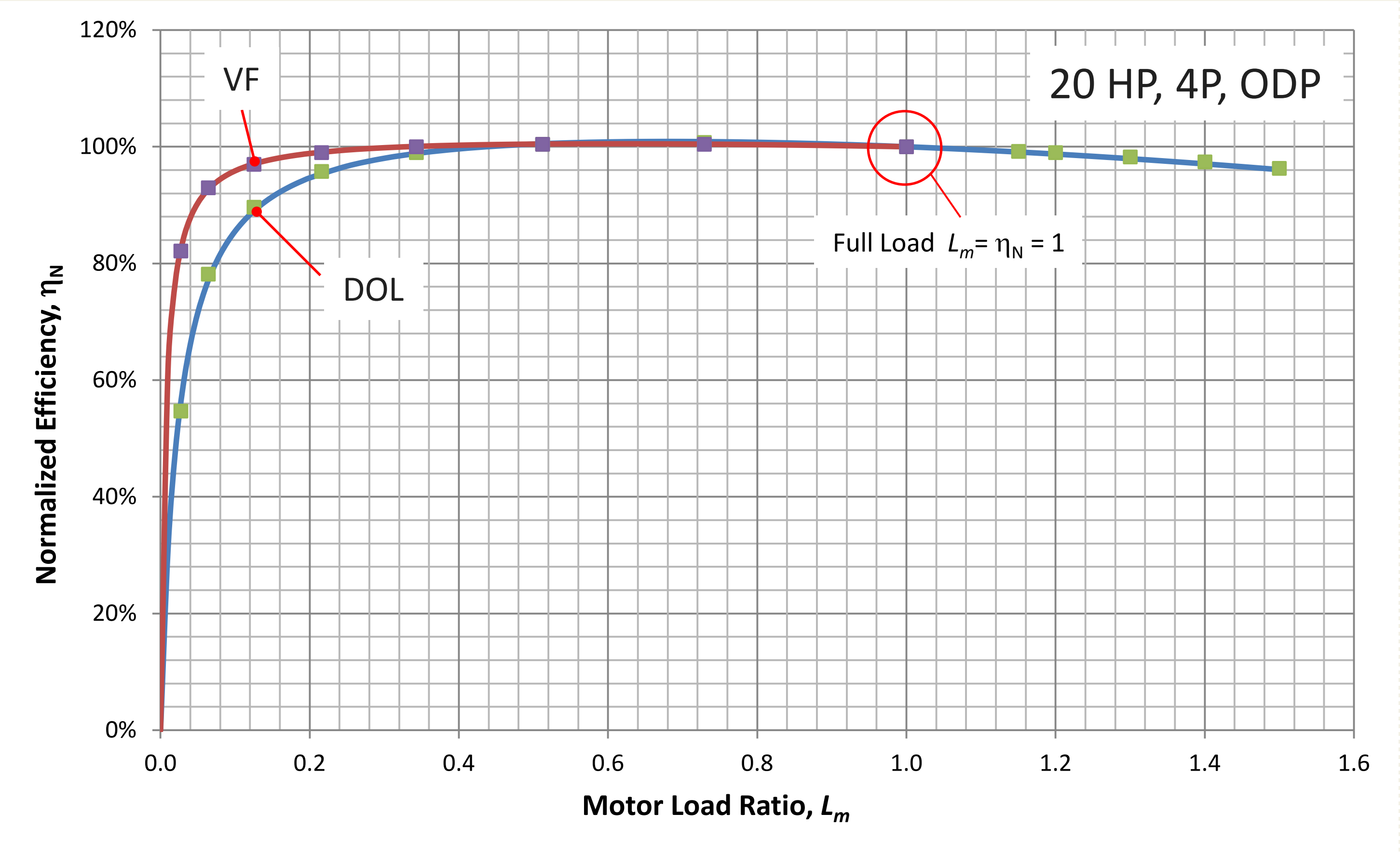
stray loss

Normalized load and efficiency

20 hp 4P ODP VF												
H_m (hp)	E (V)	f (Hz)	η_M	N (rpm)	W_s (W)	W_r (W)	W_c (W)	W_l (W)	W_f (W)	Total (W)	L_m	η_N
20.00	460	60	93.0	1775	508	212	209	111	73	1113	100.0%	100.0%
14.58	414	54	93.4	1601	335	131	181	69	58	774	72.9%	100.4%
10.24	368	48	93.4	1426	221	77	154	43	45	540	51.2%	100.4%
6.86	322	42	93.0	1249	151	45	129	38	34	397	34.3%	100.0%
4.32	276	36	92.1	1072	104	24	106	18	24	276	21.6%	99.0%
2.50	230	30	90.2	895	77	12	84	13	16	202	12.5%	97.0%
1.28	184	24	86.5	717	63	5	64	9	10	151	6.4%	93.0%
0.54	138	18	76.4	538	56	1	46	6	6	115	2.7%	82.2%

- Absolute load and efficiency are normalized (100% load)
- Variable frequency load follows fan law

Polyphase AC Induction Motor



$$\eta_N = \frac{aL_m}{(b + L_m)} + cL_m^2 \qquad c = 1 - \frac{a}{(b+1)}$$

Polyphase AC Induction Motor

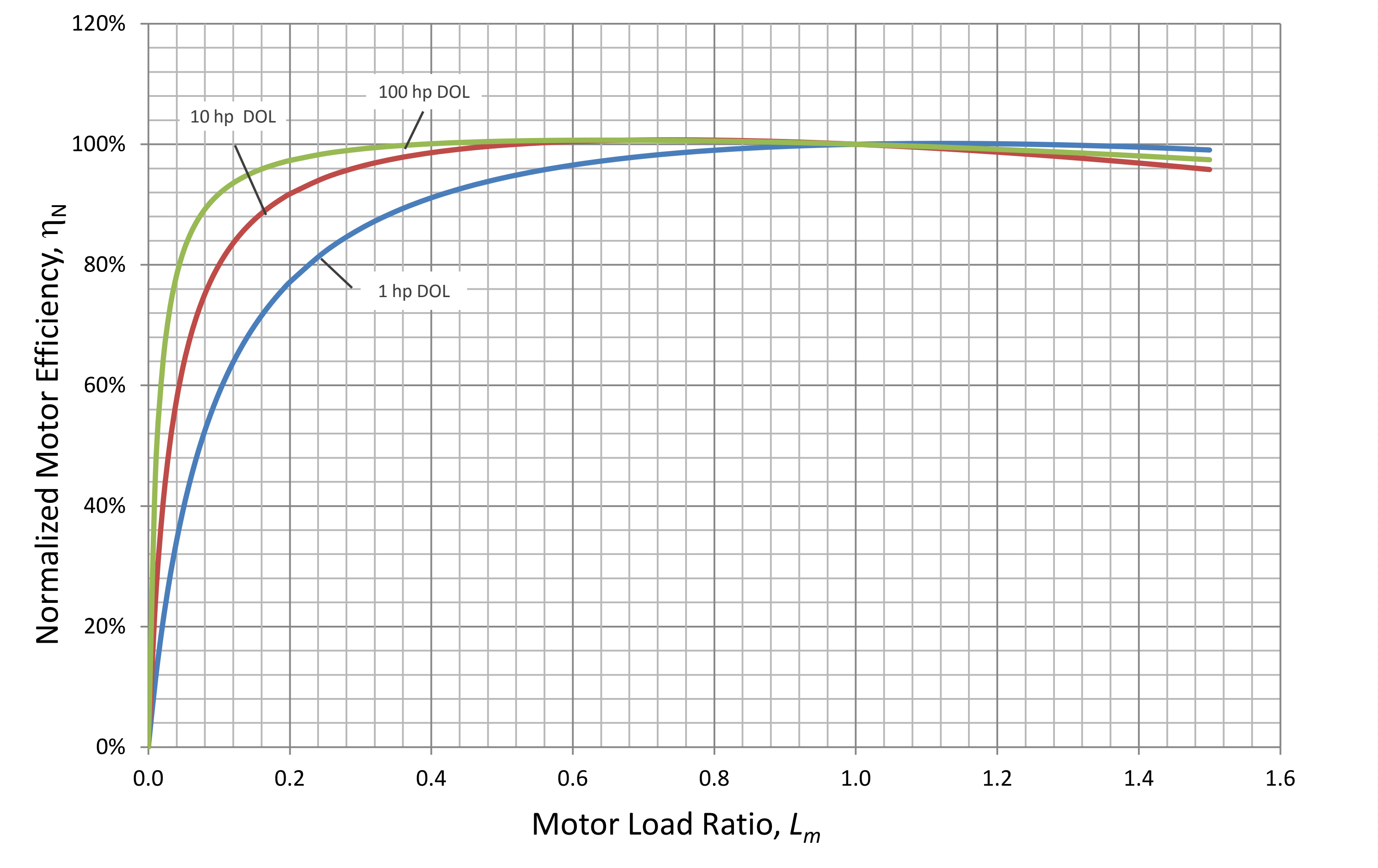
Motor Coefficient Table*

VF COEFFICIENTS (using ODP)										DOL COEFFICIENTS (using ODP)									
	2 POLE			4 POLE			6 POLE				2 POLE			4 POLE			6 POLE		
Power (hp)	a	b	c	a	b	c	a	b	c	**Power (hp)**	a	b	c	a	b	c	a	b	c
1	1.01420	0.01593	0.00170	0.99919	0.02949	0.02943	1.05239	0.05851	0.00578	**1**	1.13460	0.08674	-0.04404	1.12541	0.09132	-0.03124	1.16873	0.11466	-0.04850
1.5	1.01487	0.01504	0.00017	1.00253	0.02765	0.02444	1.04917	0.05355	0.00416	**1.5**	1.12932	0.08114	-0.04456	1.12067	0.08492	-0.03295	1.15895	0.10606	-0.04781
2	1.01554	0.01415	-0.00137	1.00587	0.02581	0.01944	1.04594	0.04859	0.00252	**2**	1.12405	0.07555	-0.04510	1.11592	0.07851	-0.03468	1.14917	0.09747	-0.04711
3	1.01688	0.01236	-0.00446	1.01254	0.02214	0.00939	1.03950	0.03867	-0.00080	**3**	1.11350	0.06436	-0.04618	1.10643	0.06571	-0.03821	1.12962	0.08027	-0.04568
5	1.01956	0.00880	-0.01067	1.02589	0.01478	-0.01095	1.02661	0.01883	-0.00764	**5**	1.09241	0.04197	-0.04840	1.08745	0.04009	-0.04553	1.09051	0.04588	-0.04267
7.5	1.01897	0.00803	-0.01085	1.02513	0.01341	-0.01157	1.02562	0.01672	-0.00875	**7.5**	1.08883	0.03990	-0.04706	1.08340	0.03745	-0.04429	1.08579	0.04217	-0.04185
10	1.01838	0.00727	-0.01103	1.02437	0.01203	-0.01220	1.02462	0.01460	-0.00987	**10**	1.08526	0.03783	-0.04571	1.07936	0.03481	-0.04305	1.08107	0.03846	-0.04103
15	1.01720	0.00574	-0.01140	1.02285	0.00927	-0.01345	1.02263	0.01038	-0.01212	**15**	1.07811	0.03368	-0.04299	1.07127	0.02953	-0.04054	1.07163	0.03104	-0.03936
20	1.01602	0.00421	-0.01176	1.02132	0.00651	-0.01472	1.02063	0.00616	-0.01439	**20**	1.07096	0.02953	-0.04024	1.06318	0.02425	-0.03800	1.06218	0.02362	-0.03767
25	1.01532	0.00423	-0.01104	1.02007	0.00598	-0.01401	1.01929	0.00571	-0.01351	**25**	1.06949	0.02923	-0.03912	1.06033	0.02291	-0.03659	1.05966	0.02257	-0.03627
30	1.01462	0.00426	-0.01032	1.01882	0.00546	-0.01329	1.01796	0.00526	-0.01263	**30**	1.06802	0.02892	-0.03800	1.05749	0.02157	-0.03516	1.05713	0.02152	-0.03486
40	1.01322	0.00430	-0.00888	1.01632	0.00440	-0.01187	1.01528	0.00436	-0.01087	**40**	1.06508	0.02831	-0.03576	1.05180	0.01889	-0.03231	1.05208	0.01942	-0.03204
50	1.01181	0.00434	-0.00744	1.01382	0.00334	-0.01044	1.01261	0.00346	-0.00911	**50**	1.06214	0.02769	-0.03351	1.04612	0.01621	-0.02944	1.04703	0.01732	-0.02921
60	1.01215	0.00402	-0.00810	1.01324	0.00316	-0.01005	1.01228	0.00361	-0.00864	**60**	1.05946	0.02585	-0.03276	1.04436	0.01556	-0.02836	1.04553	0.01691	-0.02814
75	1.01266	0.00354	-0.00909	1.01237	0.00287	-0.00947	1.01179	0.00383	-0.00793	**75**	1.05544	0.02309	-0.03162	1.04172	0.01459	-0.02674	1.04328	0.01631	-0.02654
100	1.01351	0.00274	-0.01074	1.01092	0.00240	-0.00850	1.01097	0.00420	-0.00674	**100**	1.04874	0.01849	-0.02970	1.03732	0.01298	-0.02403	1.03954	0.01530	-0.02387
125	1.01277	0.00268	-0.01006	1.01097	0.00259	-0.00836	1.01180	0.00422	-0.00754	**125**	1.04713	0.01813	-0.02848	1.03731	0.01332	-0.02367	1.03948	0.01463	-0.02449
150	1.01203	0.00263	-0.00938	1.01101	0.00277	-0.00822	1.01263	0.00425	-0.00835	**150**	1.04553	0.01778	-0.02726	1.03729	0.01365	-0.02332	1.03942	0.01396	-0.02511
200	1.01054	0.00251	-0.00801	1.01111	0.00314	-0.00794	1.01430	0.00431	-0.00995	**200**	1.04231	0.01707	-0.02482	1.03726	0.01432	-0.02262	1.03931	0.01262	-0.02636
250	1.01054	0.00251	-0.00801	1.01111	0.00314	-0.00794	1.01430	0.00431	-0.00995	**250**	1.04231	0.01707	-0.02482	1.03726	0.01432	-0.02262	1.03931	0.01262	-0.02636
300	1.01054	0.00251	-0.00801	1.01111	0.00314	-0.00794	1.01430	0.00431	-0.00995	**300**	1.04231	0.01707	-0.02482	1.03726	0.01432	-0.02262	1.03931	0.01262	-0.02636
350	1.01054	0.00251	-0.00801	1.01111	0.00314	-0.00794	1.01430	0.00431	-0.00995	**350**	1.04231	0.01707	-0.02482	1.03726	0.01432	-0.02262	1.03931	0.01262	-0.02636
400	1.01054	0.00251	-0.00801	1.01111	0.00314	-0.00794	1.01430	0.00431	-0.00995	**400**	1.04231	0.01707	-0.02482	1.03726	0.01432	-0.02262	1.03931	0.01262	-0.02636
450	1.01054	0.00251	-0.00801	1.01111	0.00314	-0.00794	1.01430	0.00431	-0.00995	**450**	1.04231	0.01707	-0.02482	1.03726	0.01432	-0.02262	1.03931	0.01262	-0.02636
500	1.01054	0.00251	-0.00801	1.01111	0.00314	-0.00794	1.01430	0.00431	-0.00995	**500**	1.04231	0.01707	-0.02482	1.03726	0.01432	-0.02262	1.03931	0.01262	-0.02636

*coefficients presented are for illustration purposes only

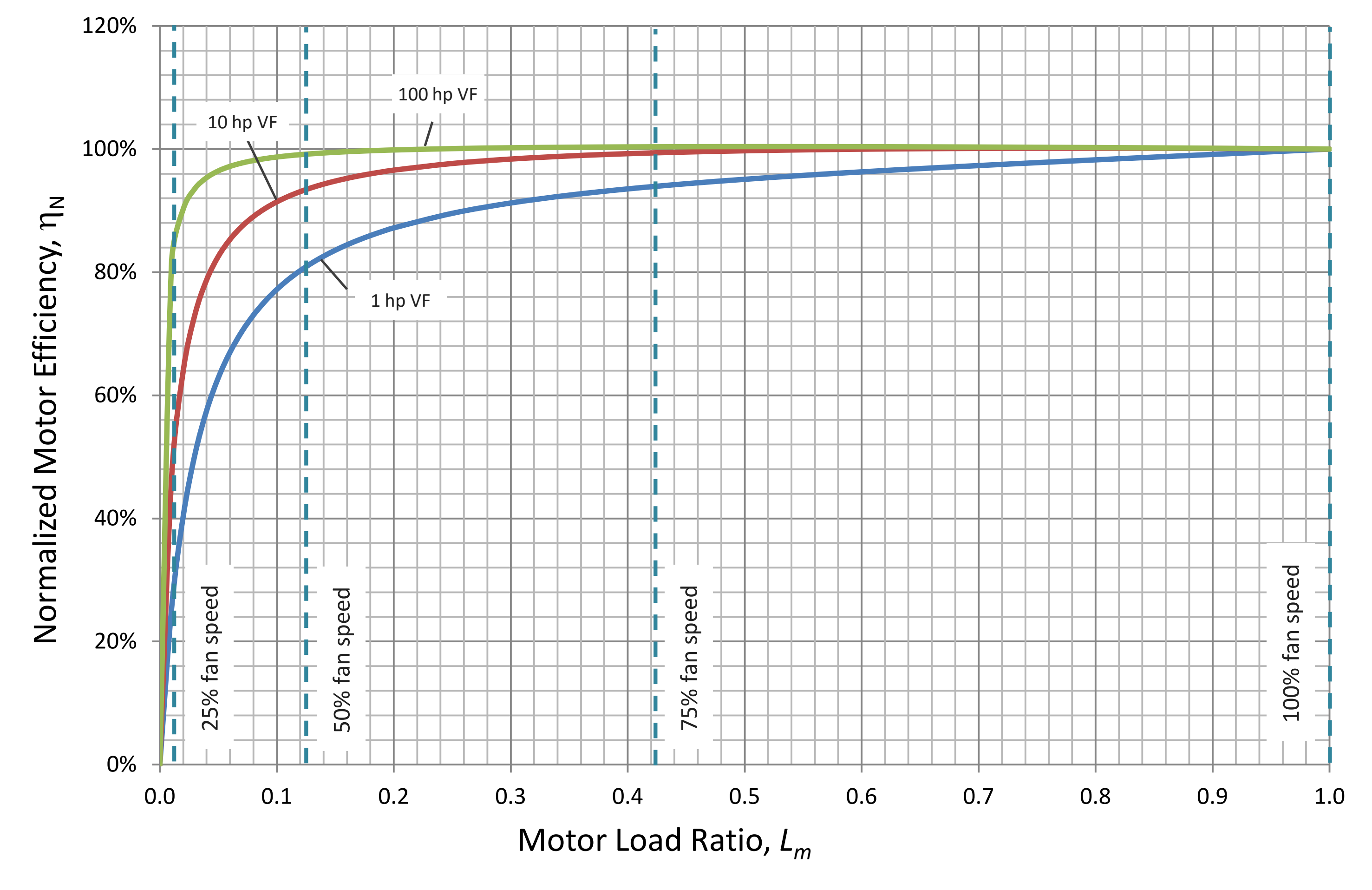
Polyphase AC Induction Motor

DOL Motor Load Curves (4P, ODP)



Polyphase AC Induction Motor

Variable Frequency Motor Load Curves (4P, ODP)



Polyphase AC Induction Motor

NEMA MG-1 Table 12-12 Nominal Motor Efficiency, η_R

NEMA OPEN FULL LOAD EFFICIENCY (η_R)								
	2 POLE		4 POLE		6 POLE		8 POLE	
HP	**Nom**	**Min**	**Nom**	**Min**	**Nom**	**Min**	**Nom**	**Min**
1	77.0	74.0	85.5	82.5	82.5	80.0	75.5	72.0
1.5	84.0	81.5	86.5	84.0	86.5	84.0	77.0	74.0
2	85.5	82.5	86.5	84.0	87.5	85.5	86.5	84.0
3	85.5	82.5	89.5	87.5	88.5	86.5	87.5	85.5
5	86.5	84.0	89.5	87.5	89.5	87.5	88.5	86.5
7.5	88.5	86.5	91.0	89.5	90.2	88.5	89.5	87.5
10	89.5	87.5	91.7	90.2	91.7	90.2	90.2	88.5
15	90.2	88.5	93.0	91.7	91.7	90.2	90.2	88.5
20	91.0	89.5	93.0	91.7	92.4	91.0	91.0	89.5
25	91.7	90.2	93.6	92.4	93.0	91.7	91.0	89.5
30	91.7	90.2	94.1	93.0	93.6	92.4	91.7	90.2
40	92.4	91.0	94.1	93.0	94.1	93.0	91.7	90.2
50	93.0	91.7	94.5	93.6	94.1	93.0	92.4	91.0
60	93.6	92.4	95.0	94.1	94.5	93.6	93.0	91.7
75	93.6	92.4	95.0	94.1	94.5	93.6	94.1	93.0
100	93.6	92.4	95.4	94.5	95.0	94.1	94.1	93.0
125	94.1	93.0	95.4	94.5	95.0	94.1	94.1	93.0
150	94.1	93.0	95.8	95.0	95.4	94.5	94.1	93.0
200	95.0	94.1	95.8	95.0	95.4	94.5	94.1	93.0
250	95.0	94.1	95.8	95.0	95.4	94.5	95.0	94.1
300	95.4	94.5	95.8	95.0				
350	95.4	94.5	95.8	95.0				
400	95.8	95.0	95.8	95.0				
450	95.8	95.0	96.2	95.4				
500	95.8	95.0	96.2	95.4				

NEMA ENCLOSED FULL LOAD EFFICIENCY (η_R)								
	2 POLE		4 POLE		6 POLE		8 POLE	
HP	**Nom**	**Min**	**Nom**	**Min**	**Nom**	**Min**	**Nom**	**Min**
1	77.0	74.0	85.5	82.5	82.5	80.0	75.5	72.0
1.5	84.0	81.5	86.5	84.0	87.5	85.5	78.5	75.5
2	85.5	82.5	86.5	84.0	88.5	86.5	84.0	81.5
3	86.5	84.0	89.5	87.5	89.5	87.5	85.5	82.5
5	88.5	86.5	89.5	87.5	89.5	87.5	86.5	84.0
7.5	89.5	87.5	91.7	90.2	91.0	89.5	86.5	84.0
10	90.2	88.5	91.7	90.2	91.0	89.5	89.5	87.5
15	91.0	89.5	92.4	91.0	91.7	90.2	89.5	87.5
20	91.0	89.5	93.0	91.7	91.7	90.2	90.2	88.5
25	91.7	90.2	93.6	92.4	93.0	91.7	90.2	88.5
30	91.7	90.2	93.6	92.4	93.0	91.7	91.7	90.2
40	92.4	91.0	94.1	93.0	94.1	93.0	91.7	90.2
50	93.0	91.7	94.5	93.6	94.1	93.0	92.4	91.0
60	93.6	92.4	95.0	94.1	94.5	93.6	92.4	91.0
75	93.6	92.4	95.4	94.5	94.5	93.6	93.6	92.4
100	94.1	93.0	95.4	94.5	95.0	94.1	93.6	92.4
125	95.0	94.1	95.4	94.5	95.0	94.1	94.1	93.0
150	95.0	94.1	95.8	95.0	95.8	95.0	94.1	93.0
200	95.4	94.5	96.2	95.4	95.8	95.0	94.5	93.6
250	95.8	95.0	96.2	95.4	95.8	95.0	95.0	94.1
300	95.8	95.0	96.2	95.4				
350	95.8	95.0	96.2	95.4				
400	95.8	95.0	96.2	95.4				
450	95.8	95.0	96.2	95.4				
500	95.8	95.0	96.2	95.4				

use nominal values

$$\eta_m = \eta_R\left(\frac{aL_m}{(b+L_m)} + cL_m^2\right)$$

Polyphase AC Induction Motor

For motor sizes not simulated (e.g. 10 hp)

- Linear interpolation of coefficients *a* and *b*, calculate *c*

Motor Slip

- Not considered – motor speed assumed synchronous DOL and VF

Operation at f = 50Hz

- Assume same normalized load curve as 60Hz
- Linear interpolation used to establish standard kW motor coefficients

Operation at L_m > 100%

- Simulations to 150% DOL applications (*service factor*) – disclaimers apply
- VF operation TBD

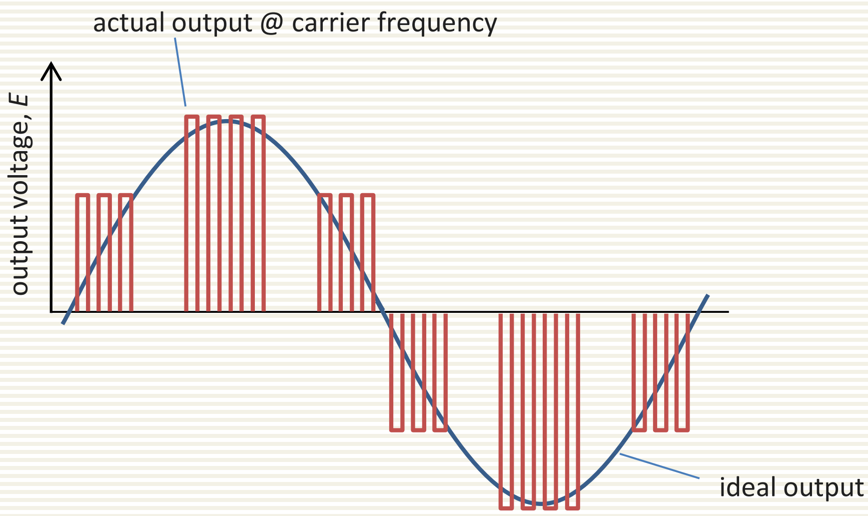
TEAO Motors

- Currently no credible test standard = not subject to regulation
- Many fan applications provide self cooling
- Same as ODP/TEFC without windage loss?

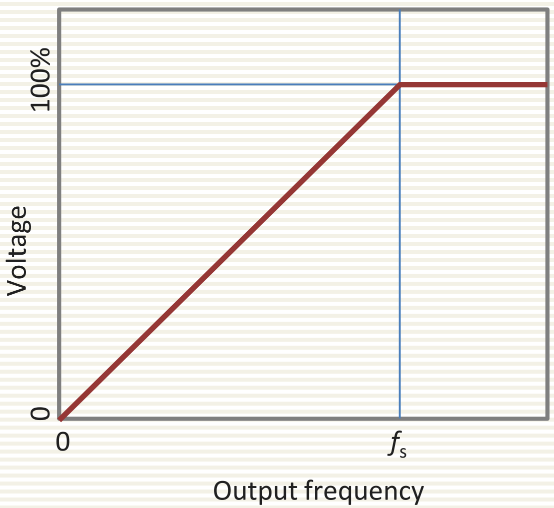
PWM Variable Frequency Drive

Variable Frequency Drive

- Increased usage – lower costs, direct drive, VAV
- AHRI 1210 *Performance Rating of Variable Frequency Drives*
- Limited data available
- VFD/Motor combinations – extensive test burden



$E \alpha f \rightarrow$ constant V/Hz



Variable Frequency Drive

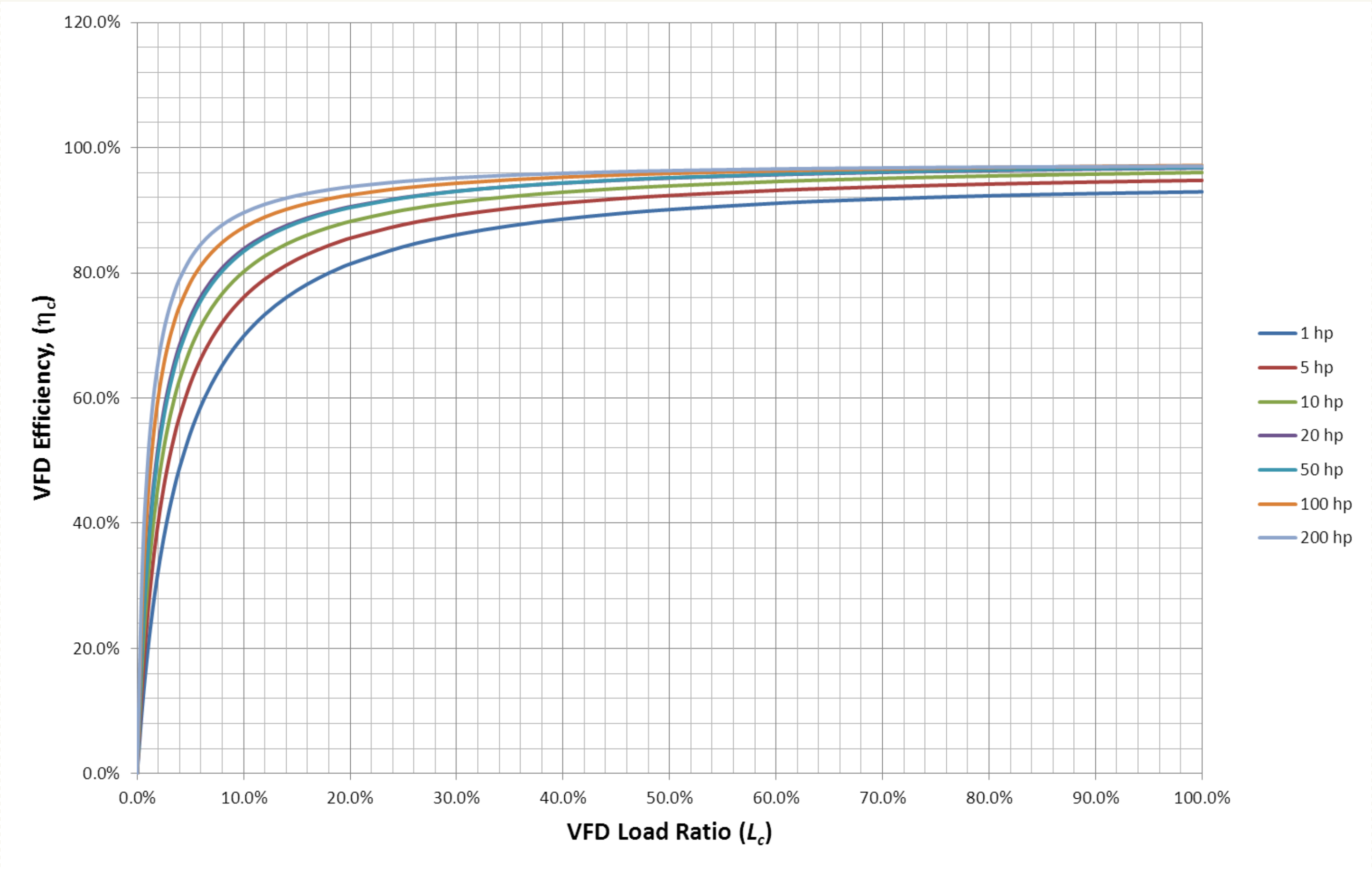
Manufacturer	Parameter	VFD Rated Power Output (hp)	Input Voltage (V)	a	b	c
DOE	Percent of Rated VFD Output Power	3	Unknown	0.9789	0.0342	–0.0079
DOE	Percent of Rated VFD Output Power	5	Unknown	0.9775	0.0284	–0.0027
DOE	Percent of Rated VFD Output Power	10	Unknown	0.9787	0.0222	0.0019
DOE	Percent of Rated VFD Output Power	20	Unknown	0.9850	0.0175	–0.0005
DOE	Percent of Rated VFD Output Power	30	Unknown	0.9874	0.0155	–0.0059
DOE	Percent of Rated VFD Output Power	50	Unknown	0.9879	0.0184	–0.0017
DOE	Percent of Rated VFD Output Power	60	Unknown	0.9719	0.0145	0.0118
DOE	Percent of Rated VFD Output Power	75	Unknown	0.9919	0.0179	–0.0013
DOE	Percent of Rated VFD Output Power	100	Unknown	0.9824	0.0126	0.0014
DOE	Percent of Rated VFD Output Power	200 to 400	Unknown	0.9845	0.0098	–0.0046
A	Percent of Full Speed	50	Unknown	2.7500	0.7430	–0.6430
B	Percent of Full Speed	50	480	1.1300	0.0783	–0.0689
B	Percent of Full Speed	50	480	1.1100	0.0783	–0.0676
B	Percent of Full Speed	50	240	1.1200	0.0790	–0.0693
B	Percent of Full Speed	50	240	1.1000	0.0791	–0.0679
C	Percent of Rated VFD Output Power	50	480	1.0200	0.0089	–0.0321
C	Percent of Rated VFD Output Power	50	240	1.0300	0.0144	–0.0519

Krukowski, A. and C. P. Wray 2013 *Standardizing Data for VFD Efficiency* ASHRAE Journal.

* Other HP coefficients by linear interpolation/extrapolation

$$\eta_c = \frac{aL_c}{(b + L_c)} + cL_c \qquad (0 \leq L_c \leq 1)$$

Variable Frequency Drive



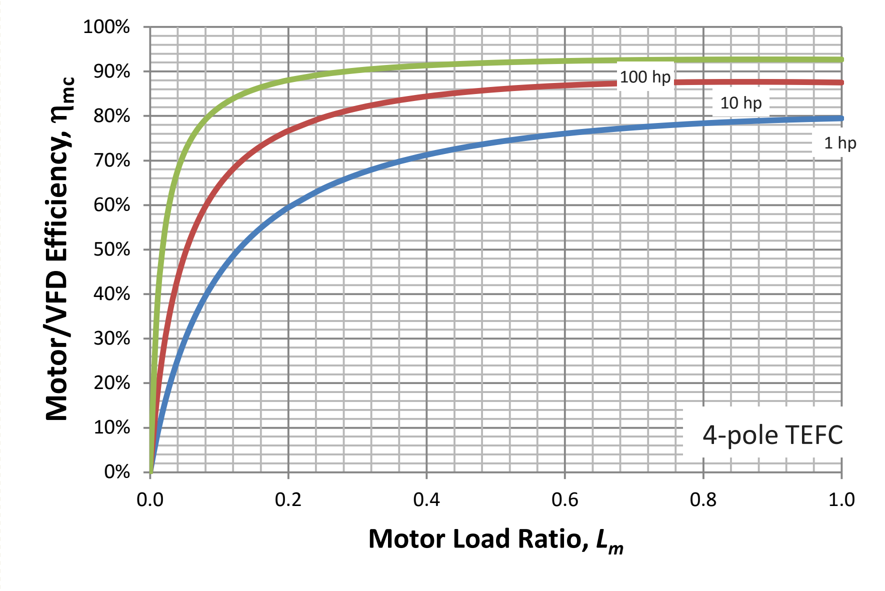
* VFD curves are absolute efficiency

Variable Frequency Drive

Practical considerations

- Separate treatment of VFD
- L_c = VFD load ratio
- Assume $L_c = L_m$ when VFD capacity is matched to given motor
- VFD's generally rated for output kVA – not motor power
- Combine VFD and motor load curves

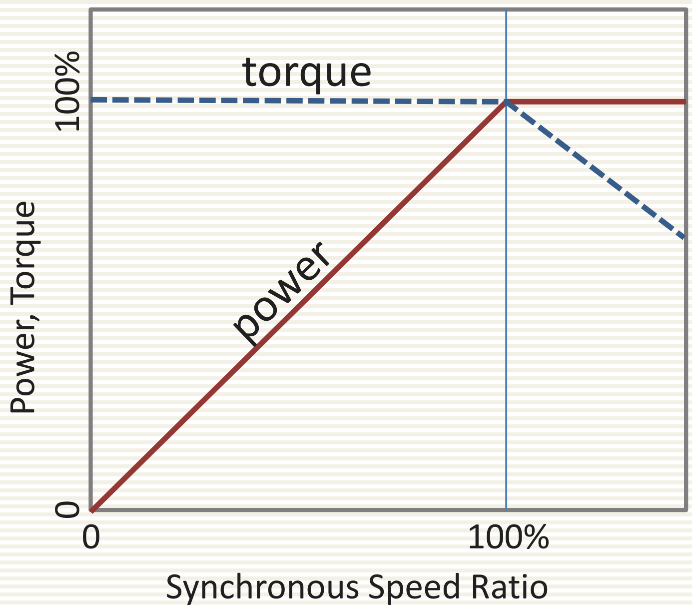
$$\eta_{mc} = \eta_R \left(\frac{aL_m}{(b + L_m)} + cL_m^2 \right) \left(\frac{dL_c}{(e + L_c)} + fL_c \right)$$



Variable Frequency Drive

Super-synchronous VFD frequency (i.e. f = 70 Hz)?

- Load must not exceed motor capacity.
- Use motor load ratio independent of frequency – first approximation



Implications of constant V/Hz

- Max power increases linearly $f < f_s$
- Max power is constant $f > f_s$
- Max torque is constant $f < f_s$
- Max torque decreases $f > f_s$

Examples

Examples

Given: Q, P, H_i

Adjust with fan laws as necessary

→ Transmission Efficiency

→ Motor or VFD/Motor Efficiency

→ Result: W_c

Examples

Example 1

Fan: Q = 12,000 cfm, FTP = 6 in-wg, N=1700 rpm, H_i = 16.2 hp
Transmission: V-Belt
Motor: 20 HP, 2P, ODP

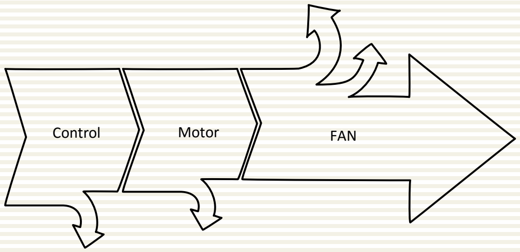
Find: Input power, W_c, and wire-to-air efficiency, η_w

1) Calculate belt efficiency

$$\eta_B = 0.96 \left(\frac{16.2}{16.2 + 2.2}\right)^{0.05} = 0.954$$

2) Calculate motor output power, H_t

$$H_m = \frac{H_i}{\eta_B} = \frac{16.2}{0.954} = 17.0 \text{ hp}$$



3) Calculate motor load ratio

$$L_m = \frac{actual\ load}{full\ load} = \frac{17.0}{20} = 0.85$$

Examples

4) Find regulated motor efficiency, η_R

NEMA-MG1 ODP			
	2 POLE	4 POLE	6 POLE
HP	Nom	Nom	Nom
1	77.0	85.5	82.5
1.5	84.0	86.5	86.5
2	85.5	86.5	87.5
3	85.5	89.5	88.5
5	86.5	89.5	89.5
7.5	88.5	91.0	90.2
10	89.5	91.7	91.7
15	90.2	93.0	91.7
20	**91.0**	93.0	92.4
25	91.7	93.6	93.0

5) Find motor curve coefficients, *a*, *b* ,*c*

	2 POLE DOL		
HP	a	b	c
1	1.13460	0.08674	-0.04404
1.5	1.12932	0.08114	-0.04456
2	1.12405	0.07555	-0.04510
3	1.11350	0.06436	-0.04618
5	1.09241	0.04197	-0.04840
7.5	1.08883	0.03990	-0.04706
10	1.08526	0.03783	-0.04571
15	1.07811	0.03368	-0.04299
20	**1.07096**	**0.02953**	**-0.04024**
25	1.06949	0.02923	-0.03912

6) Calculate motor efficiency, η_m

$$\eta_m = \eta_R\left(\frac{aL_m}{(b+L_m)} + cL_m^2\right) = 0.910\left(\frac{(1.07096)(0.85)}{(0.02953+0.85)} + (-0.04024)(0.85)^2\right) = 0.915$$

Examples

7) Find input power

$$W_c = W_m = \frac{H_m}{\eta_m} = \frac{17}{0.915} = 18.6 \text{ hp} = 13.9 \text{ kW}$$

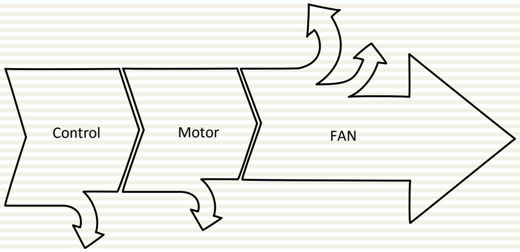
8) Calculate overall wire-to-air efficiency

$$\eta_w = \eta\, \eta_B\, \eta_m = (0.70)(0.953)(0.915) = 61\%$$

Examples

Example 2

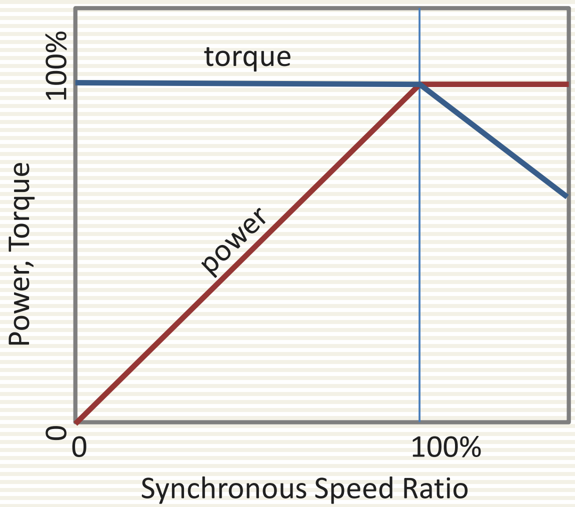
Fan: Q = 12,000 cfm, FTP = 6 in-wg, N = 1700 rpm, H_i = 16.2 hp
Transmission : No belt = direct drive, η_t = 1.0
Motor: 20 HP, 4P, ODP
VFD: 20 HP



Find: W_c, 1700 rpm and 850 rpm, Wire-to-Air Efficiency

1) Test VFD/Motor capacity output (approximate)

4-Pole, N_s = 1800
Motor speed ratio = 1700/N_s = 0.944
Motor capacity = 0.944 x 20 hp = 18.19 hp
This is greater than the 16.2 hp required – go to next step.



2) Calculated motor load ratio

$$L_m = L_c = \frac{actual\ load}{full\ load} = \frac{16.2}{20} = 0.81$$

Examples

3) Find regulated motor efficiency, η_R

NEMA-MG1 ODP			
	2 POLE	4 POLE	6 POLE
HP	Nom	Nom	Nom
1	77.0	85.5	82.5
1.5	84.0	86.5	86.5
2	85.5	86.5	87.5
3	85.5	89.5	88.5
5	86.5	89.5	89.5
7.5	88.5	91.0	90.2
10	89.5	91.7	91.7
15	90.2	93.0	91.7
20	91.0	**93.0**	92.4
25	91.7	93.6	93.0

4) Find motor curve coefficients, *a*, *b*, c

	4 POLE Variable Speed		
HP	**a**	**b**	**c**
	1.03744	0.03337	-0.00394
1.5	1.03812	0.03120	-0.00672
2	1.03880	0.02902	-0.00951
3	1.04016	0.02467	-0.01512
5	1.04288	0.01596	-0.02649
7.5	1.04077	0.01446	-0.02593
10	1.03866	0.01296	-0.02536
15	1.03443	0.00996	-0.02423
20	1.03021	0.00696	-0.02308
25	1.02882	0.00642	-0.02225

5) Find VFD coefficients, *d*,*e*,*f*

VFD Coefficients			
HP	**d**	**e**	**f**
1	0.9803	0.0400	-0.0131
1.5	0.9800	0.0386	-0.0118
2	0.9796	0.0371	-0.0105
3	0.9789	0.0342	-0.0079
5	0.9775	0.0284	-0.0027
7.5	0.9781	0.0253	-0.0004
10	0.9787	0.0222	0.0019
15	0.9819	0.0199	0.0007
20	0.9850	0.0175	-0.0005
25	0.9862	0.0165	-0.0032

6) Calculate combined VFD/motor efficiency

$$\eta_{mc} = 0.930\left(\frac{(1.03021)(0.81)}{(0.00696+0.81)} + (-0.02308)(0.81)^2\right)\left(\frac{(0.9850)(0.81)}{(0.0175+0.81)} + (-0.0005)(0.81)\right) = 0.902$$

7) Calculate input power, W_c (full speed)

$$W_c = \frac{H_i}{\eta_{mc}} = \frac{16.2}{0.902} = 18.0\ \text{hp} = 13.4\ \text{kW}$$

8) Calculate overall wire-to-air efficiency

$$\eta_w = \eta\,\eta_B\,\eta_{mc} = (0.70)(1.0)(0.902) = 63.1\%$$

Examples

9) 850 rpm – use fan laws to get new fan power, H_i = 2.03 hp

$$L_m = \frac{actual\ load}{full\ load} = \frac{2.03}{20} = 0.102$$

10) Calculate combined VFD/motor efficiency

$$\eta_{mc} = 0.930\left(\frac{(1.03021)(0.102)}{(0.00696+0.102)} + (-0.02308)(0.102)^2\right)\left(\frac{(0.9850)(0.102)}{(0.0175+0.102)} + (-0.0005)(0.102)\right) = 0.754$$

11) Calculate input power, W_c (full speed)

$$W_c = \frac{H_i}{\eta_{mc}} = \frac{2.03}{0.754} = 2.7\ \text{hp} = 2.0\ \text{kW}$$

12) Calculate overall wire-to-air efficiency

$$\eta_w = \eta\,\eta_B\,\eta_{mc} = (0.70)(1.0)(0.754) = 52.8\%$$

Examples

Example 3

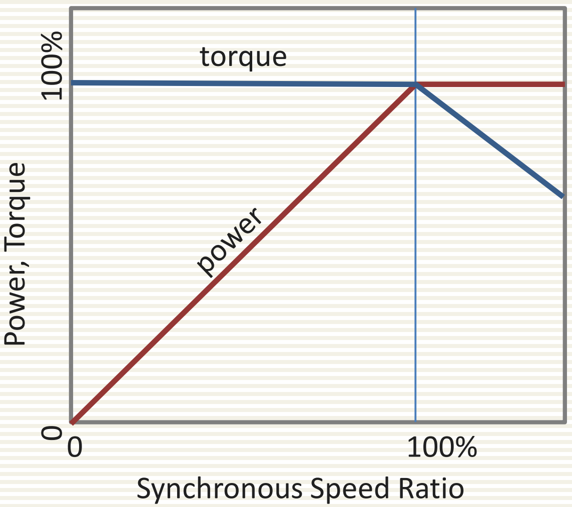
Fan: Q = 12,000 cfm, FTP = 6 in-wg, N = 1700 rpm, H_i = 16.2 hp
Transmission : No belt = direct drive , $\eta_t = 1.0$
Motor: 20 HP, **2P**, ODP
VFD: 20 HP

Find: W_c, 1700 rpm and 850 rpm, Wire-to-Air Efficiency

1) Test VFD/Motor capacity output (approximate)

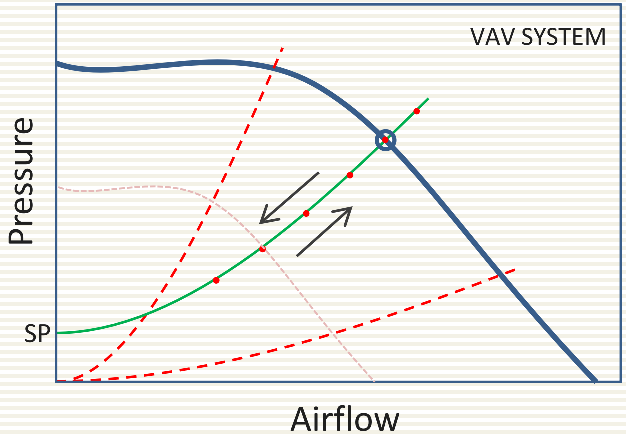
2-Pole, $N_s = 3600$
Motor speed ratio = 1700/N_s = power ratio = 0.472
Motor capacity = 0.472 x 20 hp = 9.44 hp < 16.2 hp required.

Test Fails – Motor can not produced required power with constant V/Hz VFD control. Need to choose a 2P 40 hp motor, or a 4P 20 hp motor.



Examples

Belt Drive Plenum
20 hp, 4P, ODP Motor
20 hp VFD
0.12 $/kWh
24/7 operation



VAV SYSTEM				
Q (cfm)	***FSP* (in-wg)**	***H* (hp)**	*N* (rpm)	L_f
12500	6.0	16.4	1385	5%
12000	5.6	14.7	1336	20%
11000	5.0	12.1	1253	20%
10000	4.2	9.2	1147	20%
9000	3.6	7.2	1062	20%
8000	3.0	5.3	958	10%
6000	2.2	2.9	806	5%

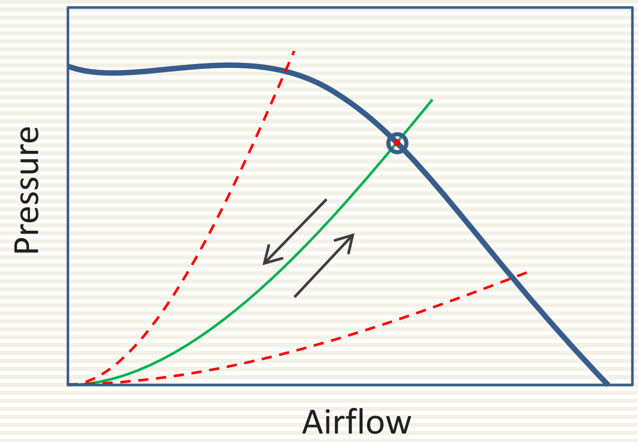
* L_f is the duty profile fraction

f (Hz)	N (rpm)	Q (cfm)	L_f	L_m	η_B	η_{mc}	η_c	W_c (kW)	E_a (kWh)	Cost
60	1385	12500	5%	82.2%	95.3%	88.9%	61.1%	14.4	6324	$759
58	1336	12000	20%	73.6%	95.2%	88.9%	61.0%	13.0	22730	$2,728
54	1253	11000	20%	60.3%	95.1%	88.7%	60.3%	10.7	18703	$2,244
50	1147	10000	20%	46.1%	94.9%	87.9%	59.9%	8.2	14449	$1,734
46	1062	9000	20%	36.1%	94.6%	86.8%	58.5%	6.6	11495	$1,379
42	958	8000	10%	26.6%	94.2%	84.9%	56.5%	5.0	4348	$522
35	806	6000	5%	14.7%	94.2%	84.9%	55.5%	2.7	1203	$144

Energy consumed: 79252 kWh, Net annual electrical cost: **$9510**

Examples

Belt Driven PRV
3500 cfm, 1.3 (in-wg), 1.35 hp, 1800 rpm
2 hp, 4P, TEFC Motor
2 hp VFD



f (Hz)	N	Q (cfm)	FSP (in-wg)	H_i	H_{mc}	L_m	η_B	η_{mc}	η_w	W_c
60	1800	3500	1.30	1.35	1.47	73.7%	91.6%	79.5%	38.7%	1.4
54	1620	3150	1.05	0.98	1.08	54.2%	90.7%	77.0%	37.1%	1.1
48	1440	2800	0.83	0.69	0.77	38.6%	89.6%	73.1%	34.8%	0.79
42	1260	2450	0.64	0.46	0.52	26.2%	88.2%	67.3%	31.5%	0.58
36	1080	2100	0.47	0.29	0.34	16.9%	86.4%	59.0%	27.1%	0.43
30	900	1750	0.33	0.17	0.20	10.1%	83.9%	47.7%	21.3%	0.31
24	720	1400	0.21	0.09	0.11	5.4%	80.5%	33.7%	14.4%	0.24
18	540	1050	0.12	0.04	0.05	2.4%	75.6%	19.1%	7.7%	0.19

Summary

Extended Fan System Performance Calculation = AMCA 207

- Limited to common configuration – AC induction motor, V-Belt, VFD
- Accommodates part load performance
- Designed for machine computations – lookup tables and continuous formulas
- Motor model backed by regulatory AEDM
- Provides benchmark to compare extended systems

Future Consideration

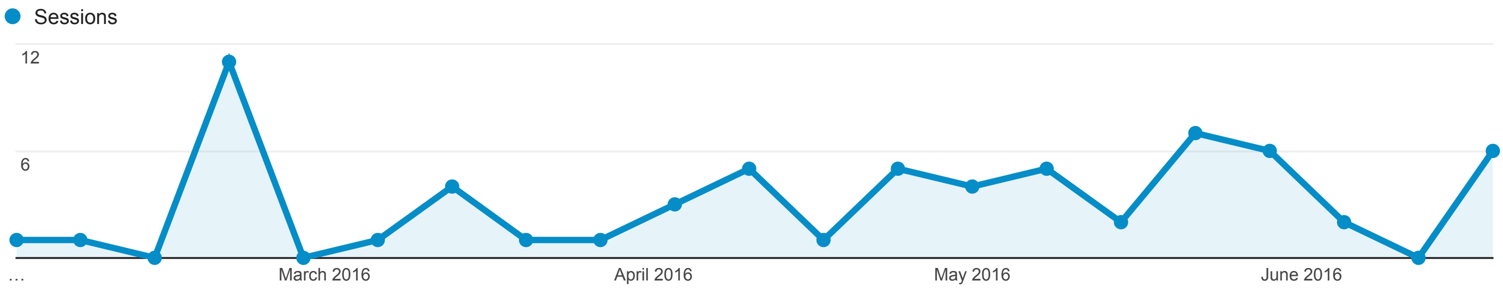
- Incorporating tested component performance
- Refined belt and VFD models as data become available
- Other motor/control technologies

Audience Overview

Feb 1, 2016 - Jun 25, 2016

All Users
100.00% Sessions

Overview



Sessions
66

Users
51

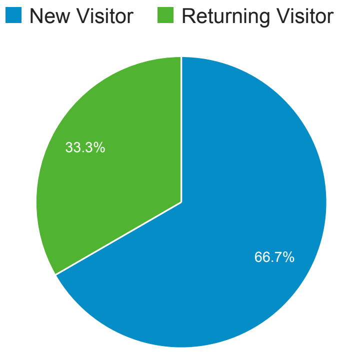
Pageviews
158

Pages / Session
2.39

Avg. Session Duration
00:02:12

Bounce Rate
65.15%

% New Sessions
66.67%



	Country	Sessions	% Sessions
1.	United States	42	63.64%
2.	Russia	3	4.55%
3.	Australia	2	3.03%
4.	Canada	2	3.03%
5.	China	2	3.03%
6.	India	2	3.03%
7.	Portugal	2	3.03%
8.	United Arab Emirates	1	1.52%
9.	Argentina	1	1.52%
10.	Brazil	1	1.52%