Grundfos Technical Institute

Raising the bar above NEMA Premium

Efficient Pumping using Permanent Magnet Motor Technology

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Grundfos in brief

By the numbers

- Founded in 1945 by Poul Due Jensen
- Annual production of more than 16 million pumps
- Represented by more than 80 companies in more than 55 countries
- Over 19,000 employees worldwide
- Over 1,400 North American employees
- The world's largest manufacturer of pumps and pump systems

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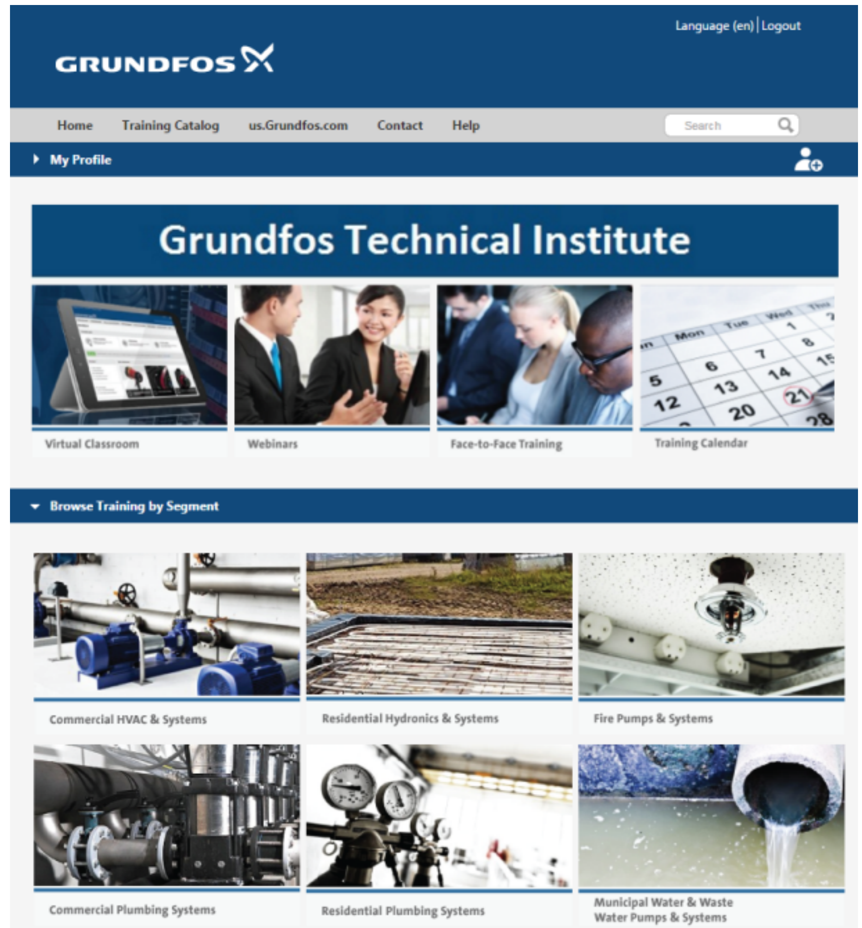


Learning Objectives

- The difference between a permanent magnet and standard (induction) motor
- Key advantages (namely improved efficiency) of permanent magnet motors
- How permanent magnet motors exceed NEMA Premium motor efficiency levels
- How this new efficiency level translates to pump system energy savings

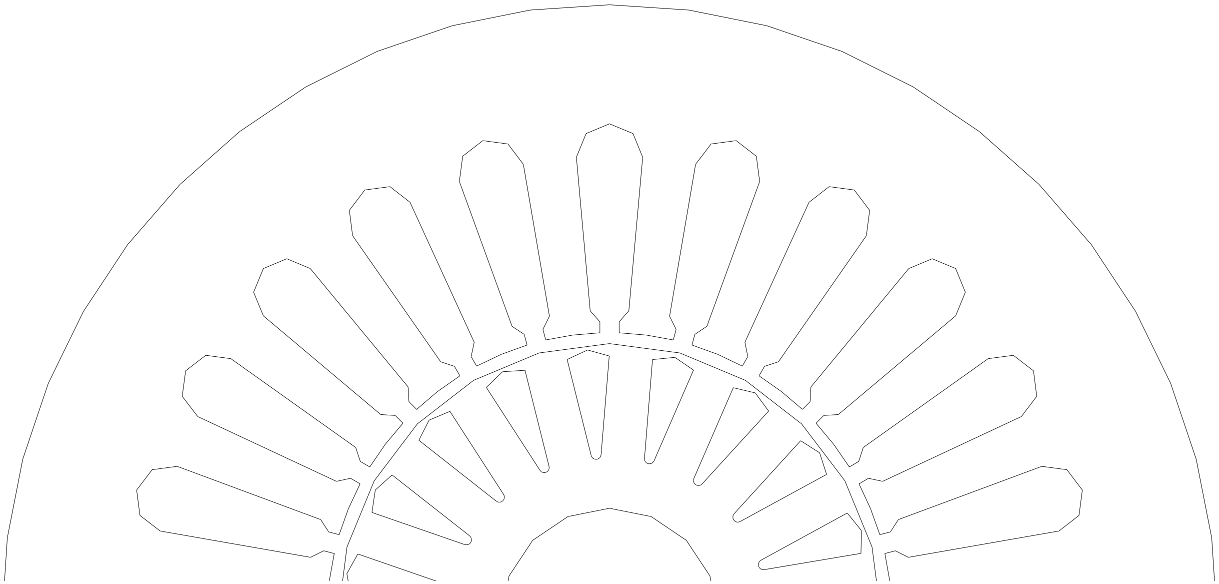
Motor Technologies

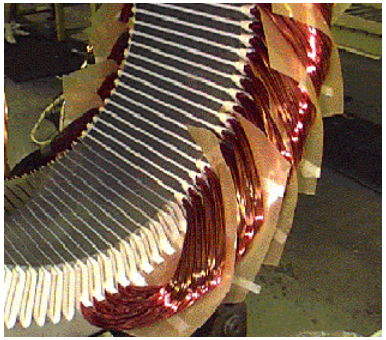
Motor technologies

- Induction motor
- Reluctance type motor
  - Switched Reluctance
  - Synchronous Reluctance
- Permanent Magnet motor
  - Brushless DC
  - Line Start PM
  - Synchronous (PMSM)
- Hybrids

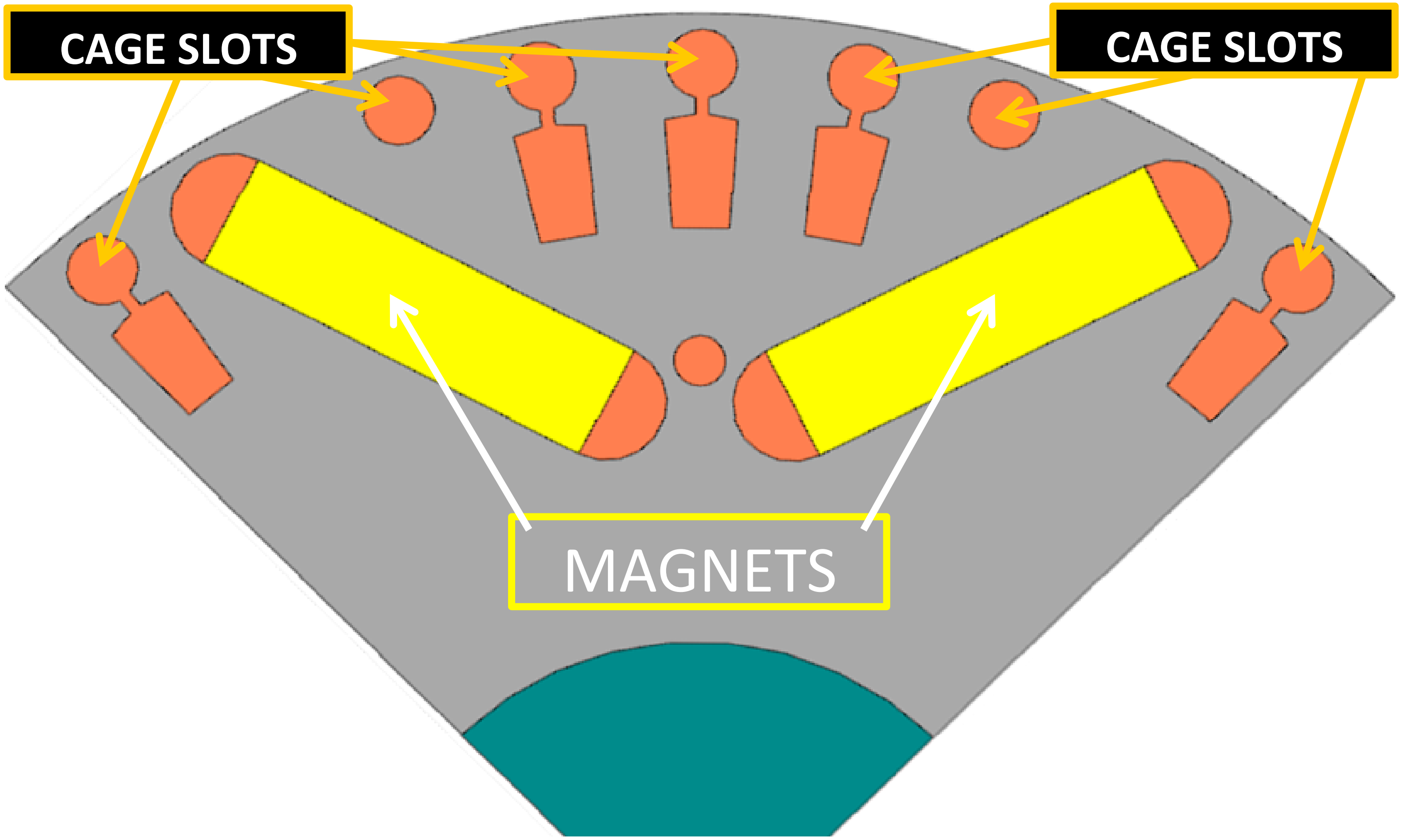
Current Technology: Induction Motors (IM)

- Distributed stator lamination slots and winding
- Stator is fixed in a cast iron or aluminum motor frame
- Squirrel cage rotor (cast or fabricated) with Al or Cu.



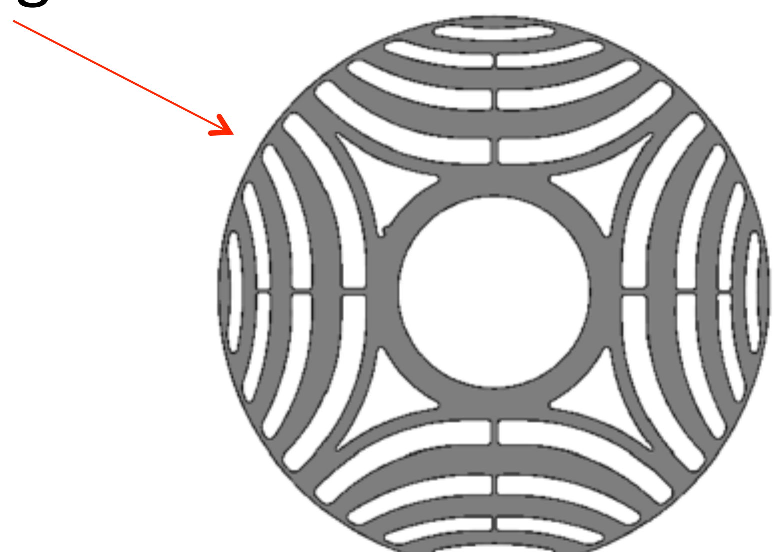


Line Start PM Motors (LSPM)



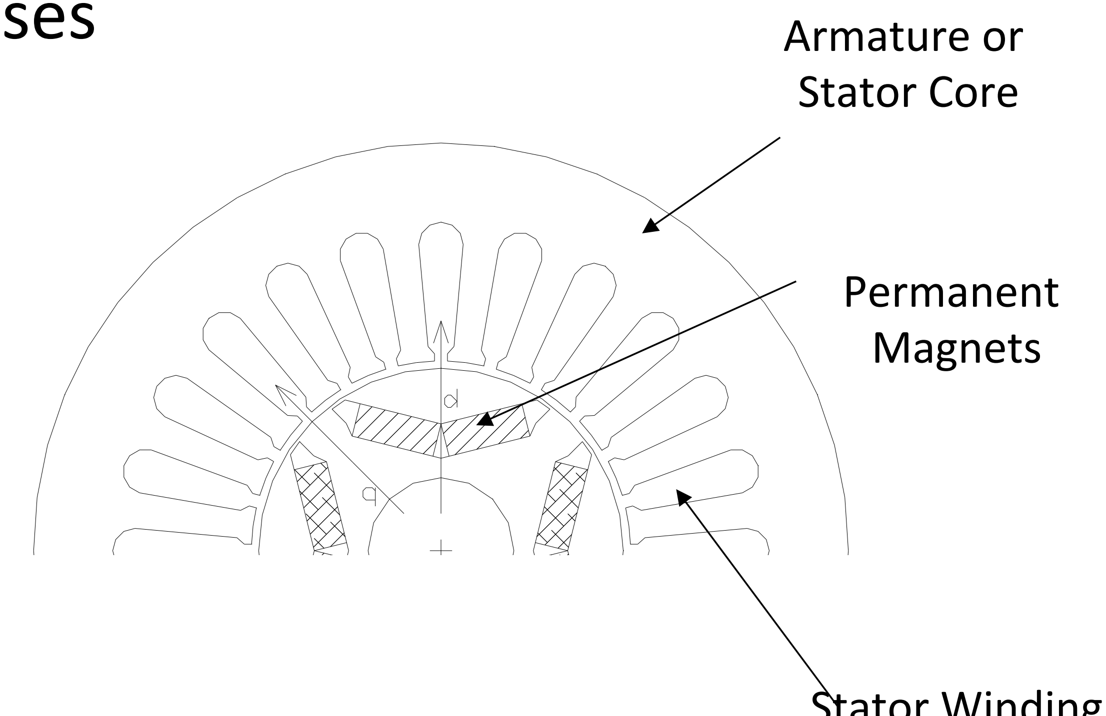
Synchronous Reluctance (SR)

- Distributed, symmetric stator lamination and winding (same as induction motor)
- Rotor is simple design, no magnets or cage
- Designed to create areas of high reluctance



Interior Permanent Magnet (PM) Motors

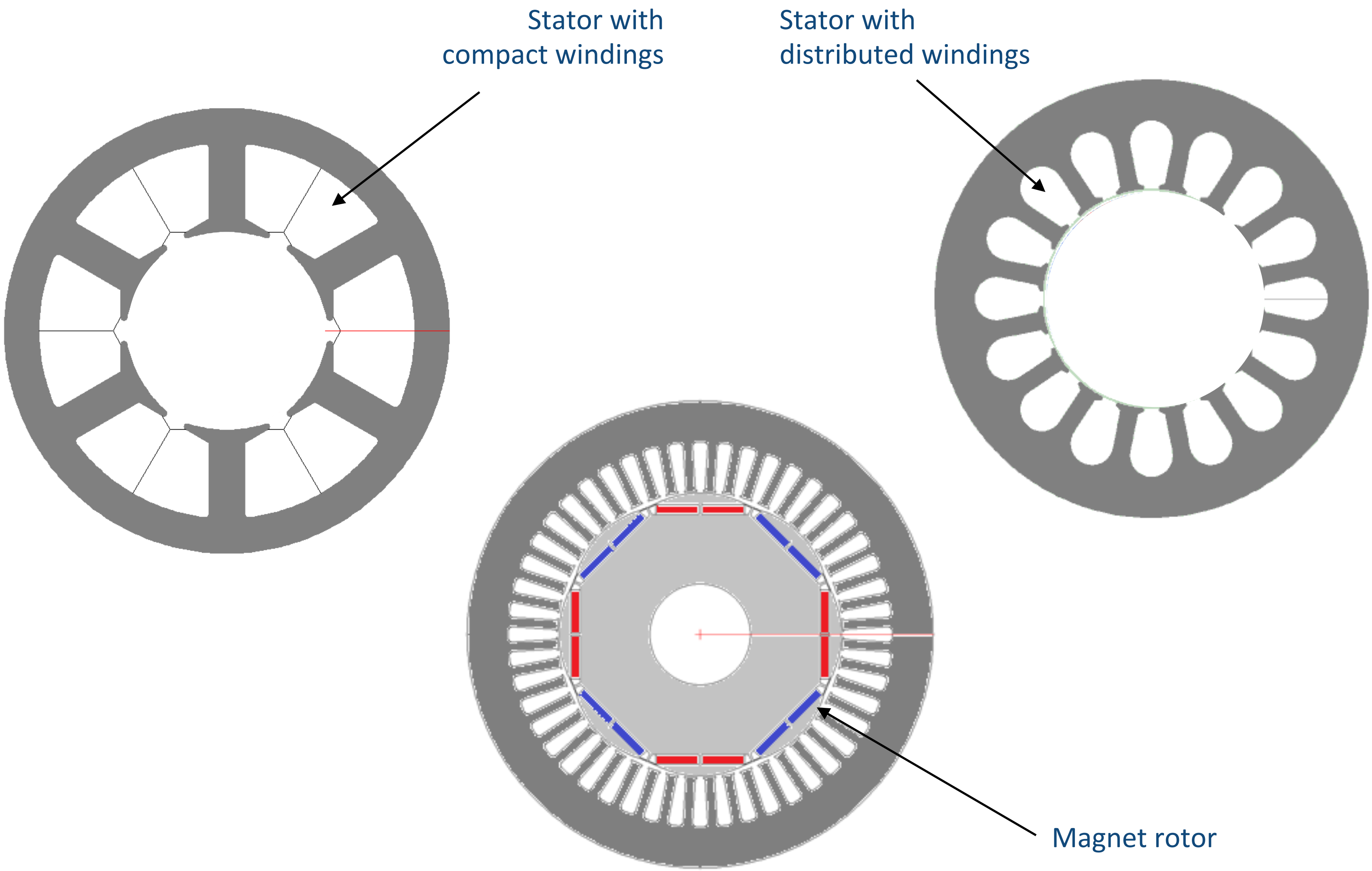
- Typical Interior Magnet PM AC Motor cross section
- Rotor field from permanent magnets
- No slip (synchronous)
- Very low rotor losses
- Requires VFD



Motor technology comparison

	Induction Motor (IM)	Line start PM (LSPM)	Synchronous Reluctance (SR)	Perm. Mag. (PMSM)
Scope	IEC 60034-30-1	IEC 60034-30-1	IEC 60034-30-2	IEC 60034-30-2
Stator construction	Proven technology	Proven technology	Proven technology	Proven technology or segmented
Rotor construction	Proven technology	New technology	New technology	New/known technology
Power density by same efficiency	Known/accepted level	A little higher than IM	Higher than IM	Much higher than IM
Magnets	None	Yes	None	Yes
Rotors losses	Yes	None significant	None significant	None significant
VFD	Not needed but possible	Not needed but possible	Always needed	Always needed
VFD type	Standard	Standard	Not supported by all VFD types	Not supported by all VFD types
Power factor	Known/accepted level	As Induction Motor or slightly higher	Lower than IM	Higher than IM
IE4 efficiency level	Difficult reachable	Reachable	Reachable	Easy reachable
IE5 efficiency level	Not considered possible and outside scope	Not considered possible and outside scope	Might be possible	Reachable
Comments	**Industry standard**	**Torque ripple / special start condition**	**Low power factor might call for oversize VFD**	**Potential for highest efficiency**

Example: PMSM technologies



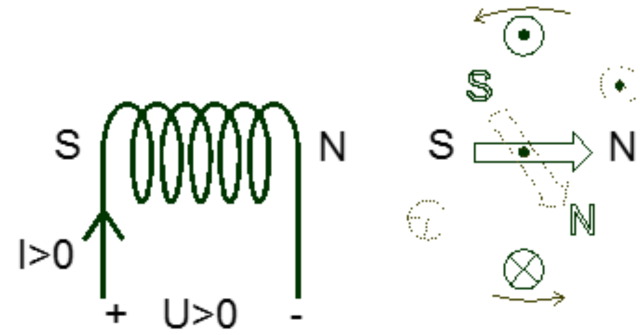
Torque types

A motor’s torque is created by an interaction between the stator and the rotor

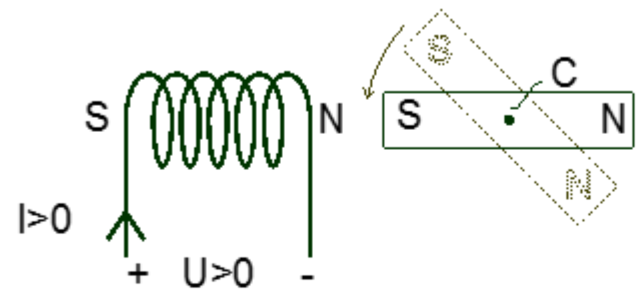
Rotors rotate due to a magnetic rotating stator field (symbolized with a coil on the sketches)

The rotating stator field is created by the applied current and by correct placements of the windings in the stator

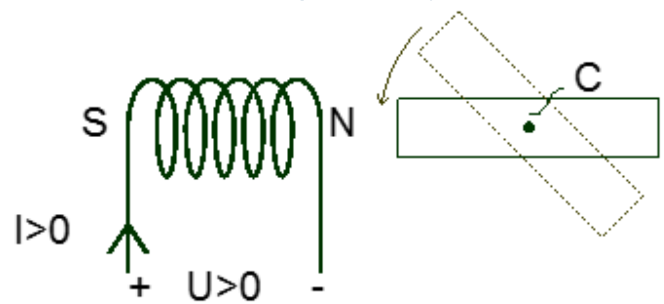
The basic difference in the motors is the rotor design and whether they require a control or not



Slip torque (coil and closed coil)

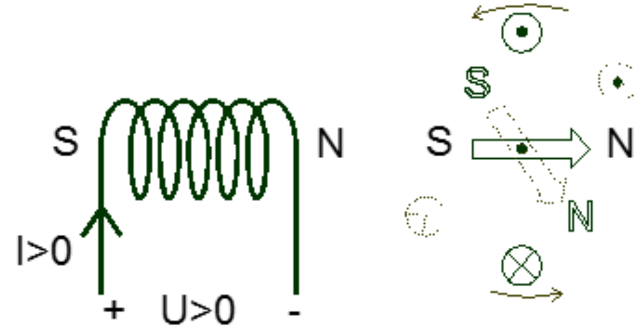


Permanent magnet torque (coil and magnet)

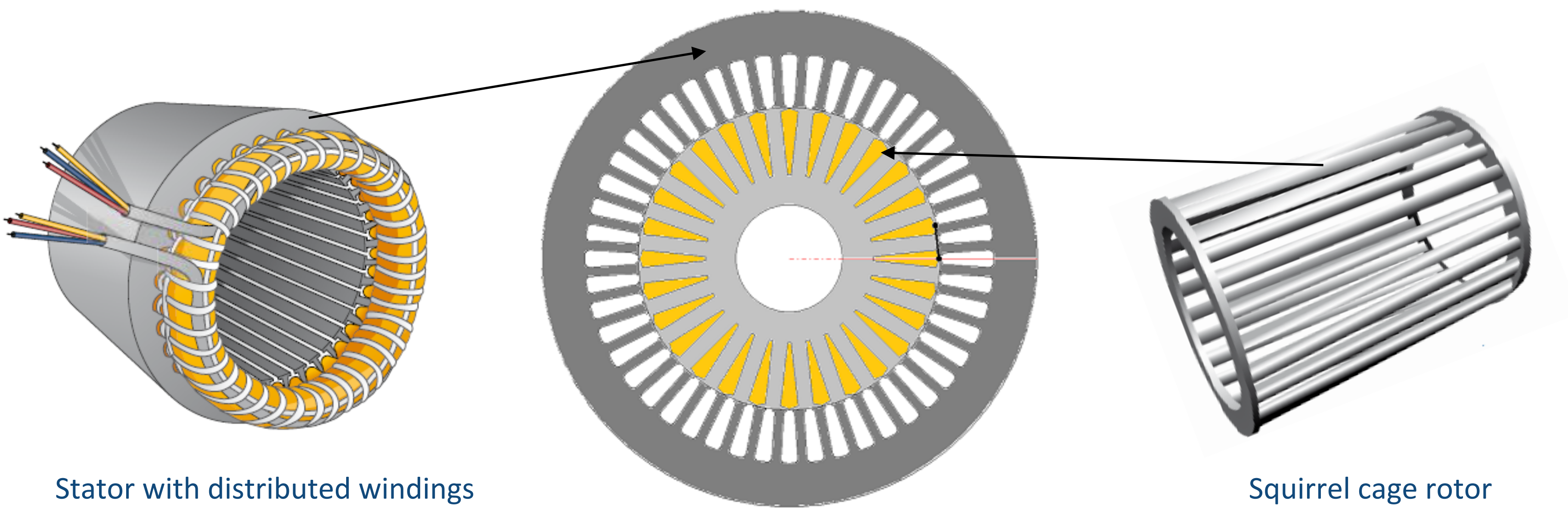


Reluctance torque (coil and magnetic iron)

Slip torque



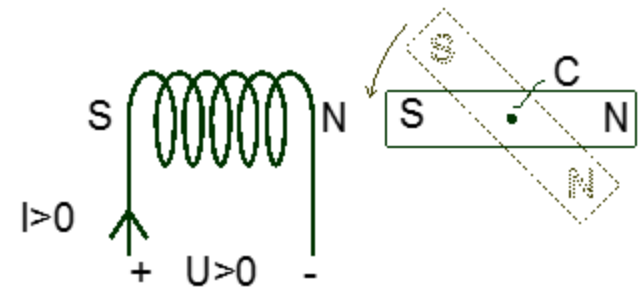
This type of torque is present in the Induction Motor (IM)
The stator is made with distributed winding and the rotor is a closed coil also called a ”squirrel cage”
This motor type does not require a control unit to function



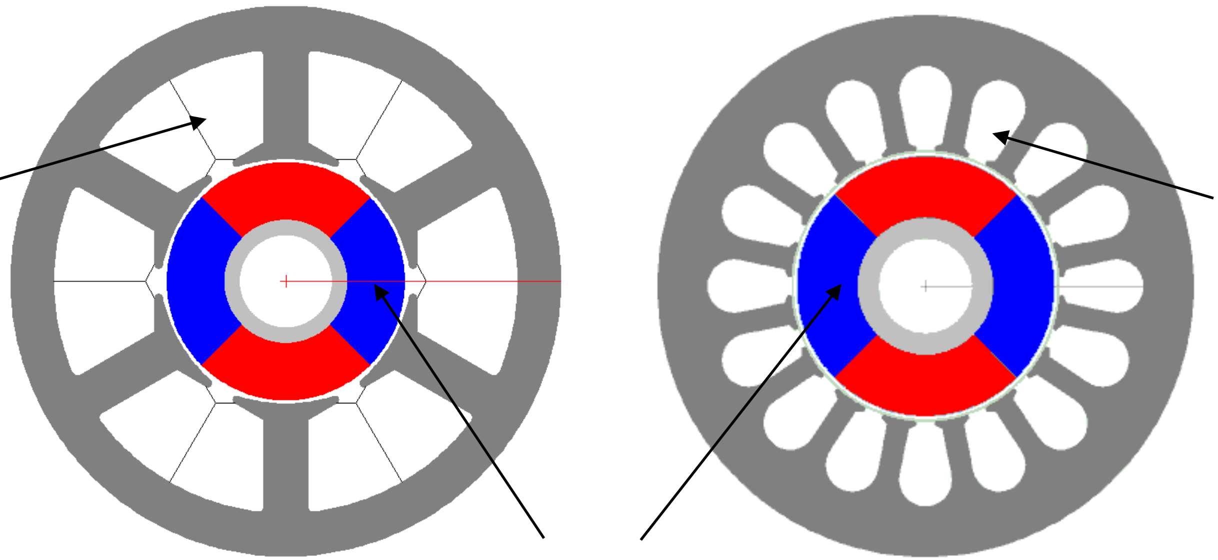
Stator with distributed windings

Squirrel cage rotor

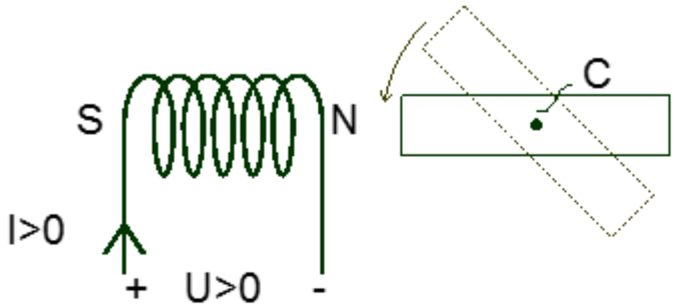
Permanent magnet torque



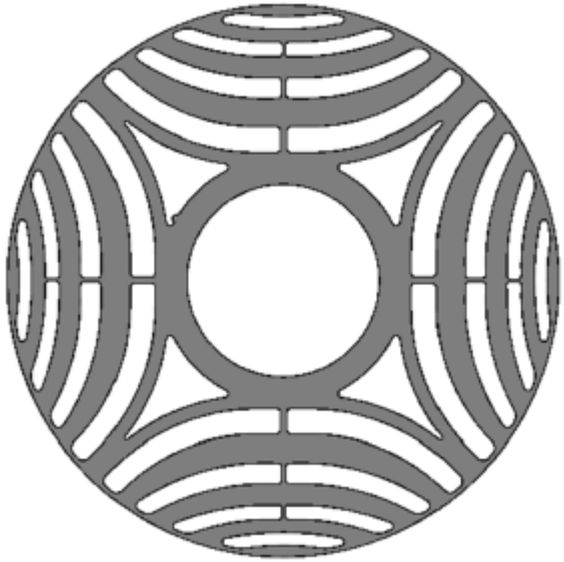
This type of torque is present in Permanent Magnet Synchronous Motors (PMSM)
The stator can be made with a distributed winding or a compact winding
This motor type requires a control



Reluctance torque



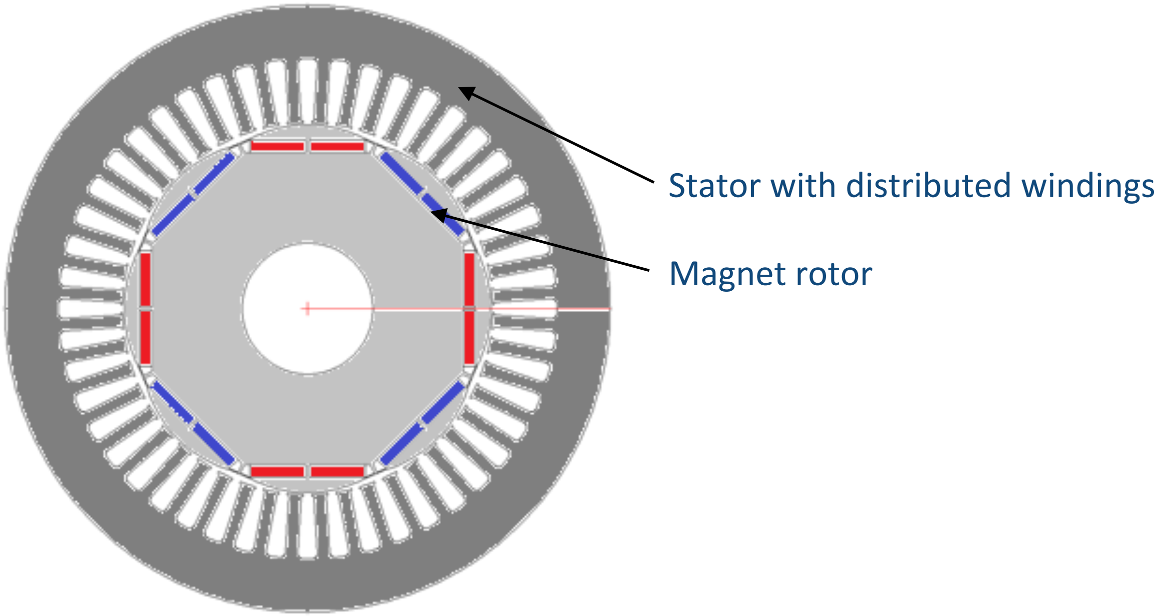
This type of torque is present in Synchronous Reluctance Motors (SyncR)
The stator can be made with a distributed winding or a compact winding
This motor type requires a control



Reluctance rotor

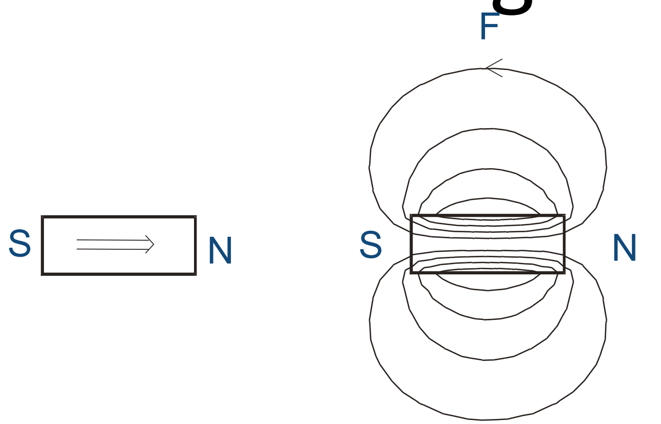
Example of a Hybrid

There is a lot of motor types that are combinations of torque types
One of these is the Interior Permanent Magnet Motor (IPM) which develops a combination of permanent magnet torque and reluctance torque.
The stator can be made with a distributed winding or a compact winding
This motor type requires a control

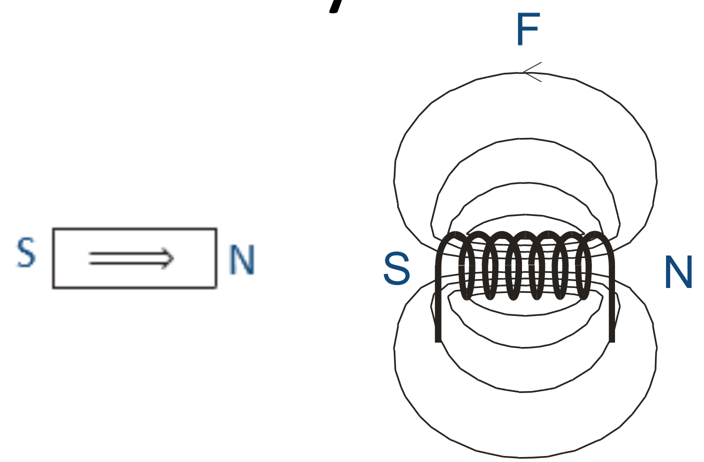


Operation principles in induction motor (IM) and Permanent Magnet Synchronous Motor (PMSM)

Making a magnet field by use of coil



Magnets with opposite poles attract each other



A magnet field can also be created by sending a current through a coil

The part containing the coils in a motor is named the stator (the stationary part)

The part that rotates is named the rotor (the rotating part)

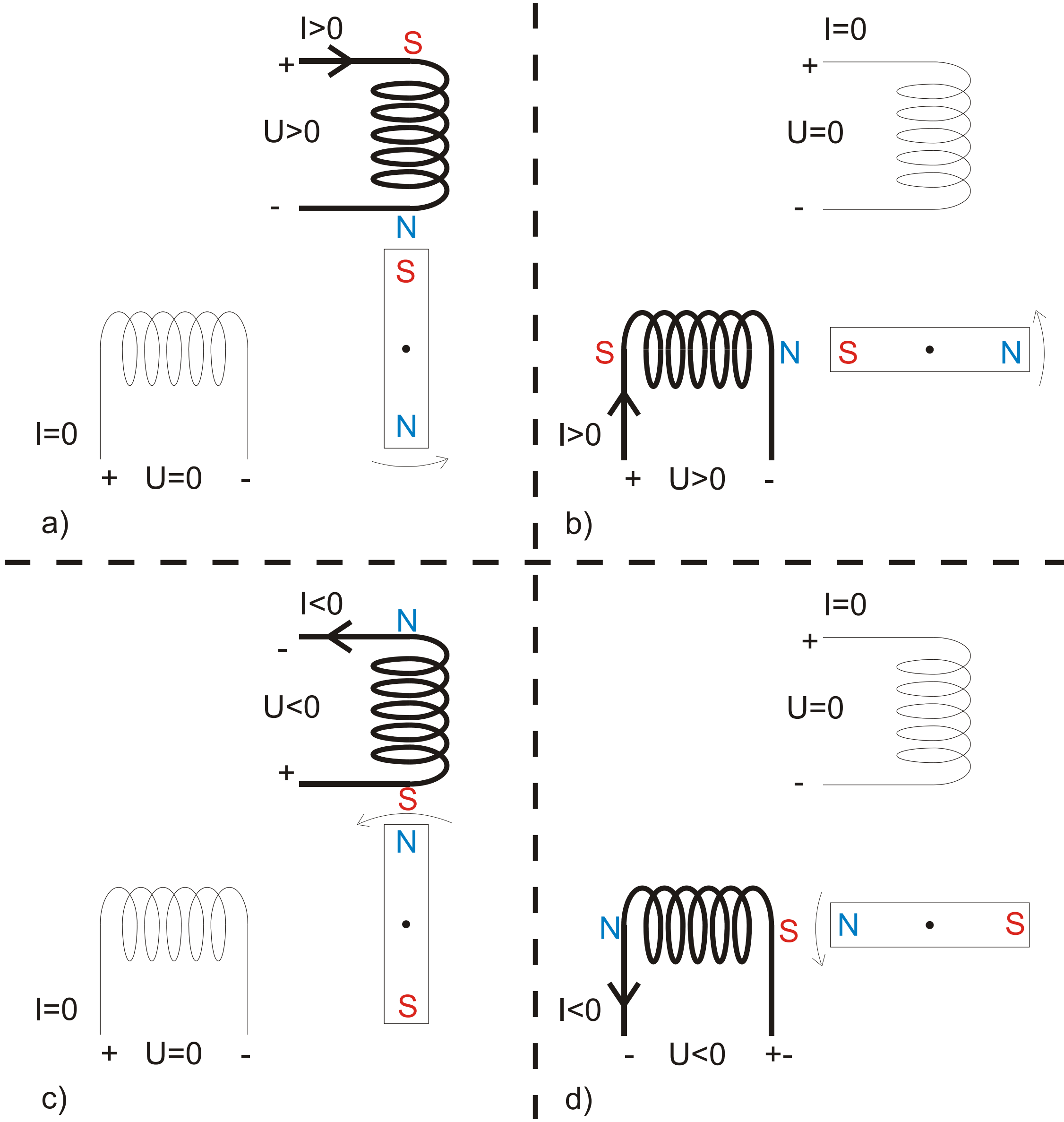
PMSM-motor

(synchronous motor)

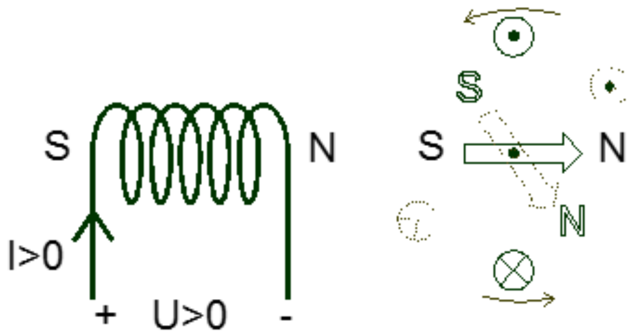
In the figure to the right it can be seen that by adding current to the different coils at specific times and in different directions – the magnet will follow (a-b-c-d)

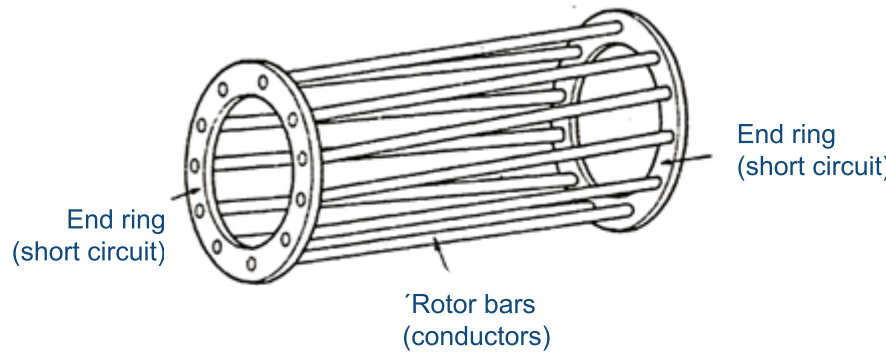
This is a permanent magnet motor (PMSM)

The rotor has magnets which automatically will follow the magnetic field which is created by the coils in the stator.
Therefore the rotor is running at the same speed as (synchronous with) the stator field



IM-motor
(asynchronous motor)





The induction motor has a rotor containing of short-circuited conductors.
When the magnet field is changing around a conductor, a voltage will be induced.
If the conductor is short-circuited (as in the rotor) a current will flow in the conductor

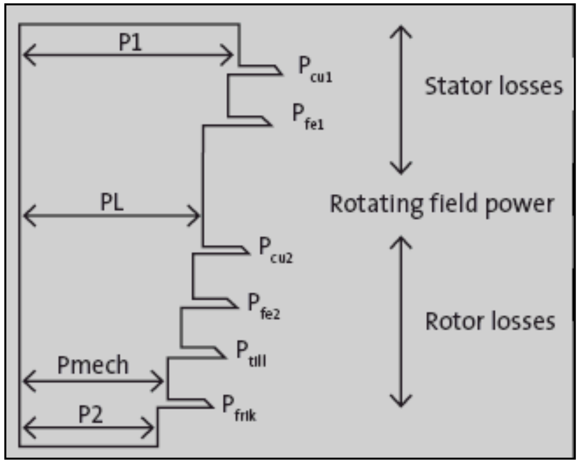
This current will make a magnet field from the rotor. The stator field and the rotor field will influence on each other

The rotor will run slower than the stator field. The rotor has to ”discover” a change in the stator field before it self can be magnetic. Therefore it is lagging behind the stator field

It’s running asynchronous and has a ”slip”

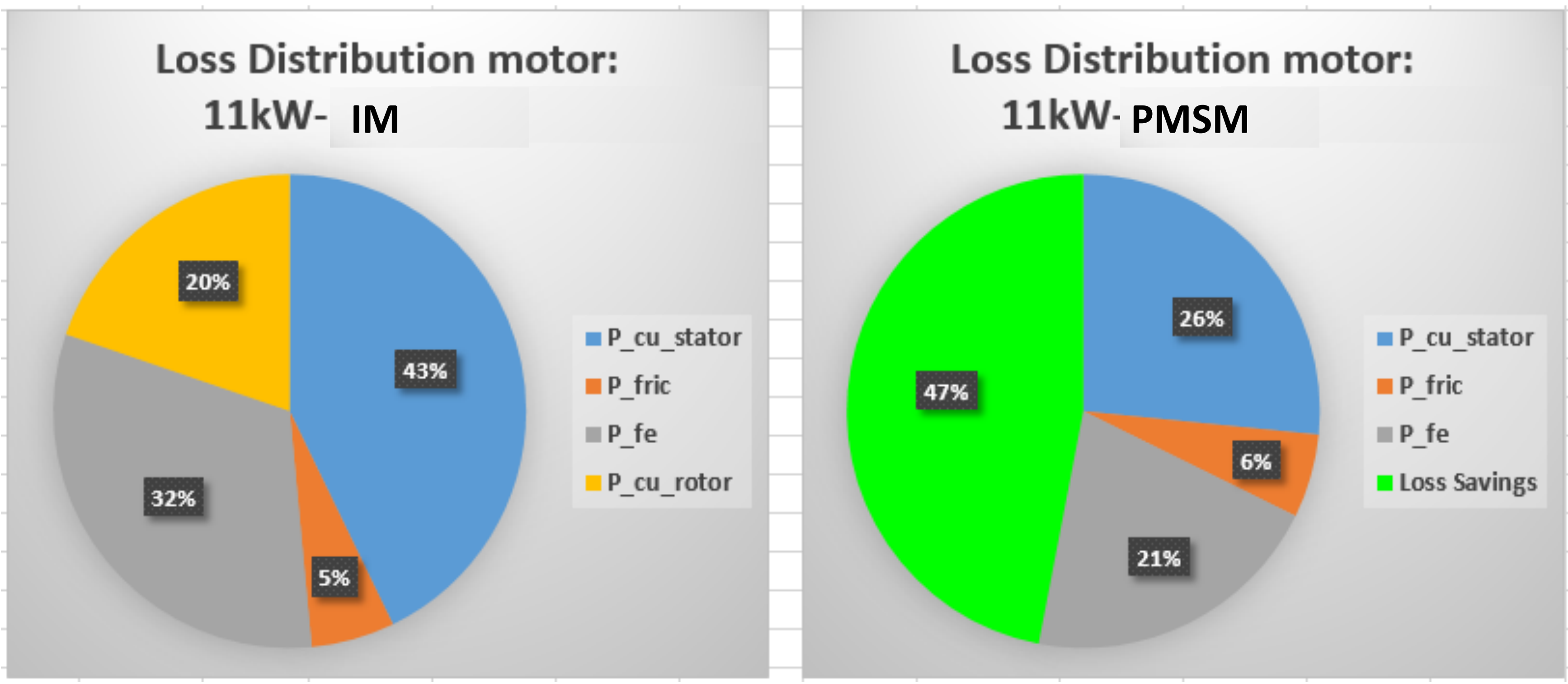
Comparison of (IM) and (IPM)

- Moving to PMSM-motor technology enables a reduction of the losses in the motor
- As the induction motor has a ”slip” there will be losses on the rotor side (Pcu2) Some of these losses are transferred to the bearing via the shaft
- As the induction rotor is not magnetic itself, some energy (current) is used to create the magnetic flux. This results in extra losses



Losses in motor

Comparison of IM and PMSM
Loss distribution (motor)



Advantages of PMSM

Higher full & variable speed efficiency

Flatter efficiency curve

Cooler operating temperatures

Higher torque at low speeds

Increased power density

Rare-earth permanent magnets produce more flux (and resultant torque) for their physical size than induction types.

Reliability:

Lower operating temperatures reduces wear and tear, maintenance

- Extends bearing and insulation life
- Robust construction for years of trouble-free operation in harsh environments.

More on Efficiency

Motor Efficiency Standards

- NEMA – National Electric Manufactures Association
  - NEMA MG-1-2016 – Standard for Motors and Generators
    Table 12-12 define NEMA Premium Eff. Levels for 60Hz motors

- IEC – International Electrotechnical Commission
  - IEC 60034-30-1 – March 2014, extended IEC 60034-30 efficiency level from IE1-3 to IE4
  - **IEC 60034-30-2** Energy Efficiency classification of variable speed motor as a component and extended **motor efficiency level to IE5**

- MEPS legislation (Minimum Energy Performance Standards) – mandates minimum efficiency levels for motors sold in the USA, EU, and most of ROW
  - DOE EISA 2007 standards as of **June 1, 2016**, includes most types of motors used in water industry applications and requires **NEMA Premium efficiency motors for USA market.**

Electric Motor Efficiency Standards

NEMA Motor Efficiency	Similar IEC Designation
Below Energy Efficient	IE1
Energy Efficient	IE2
NEMA Premium	**IE3**
"Super" Premium (not officially defined)	IE4
????	IE5

- The highest defined **MEPS** for motor efficiency today is **NEMA Premium in the USA and IE3 for much of ROW.**

Electric Motor Efficiency Standards

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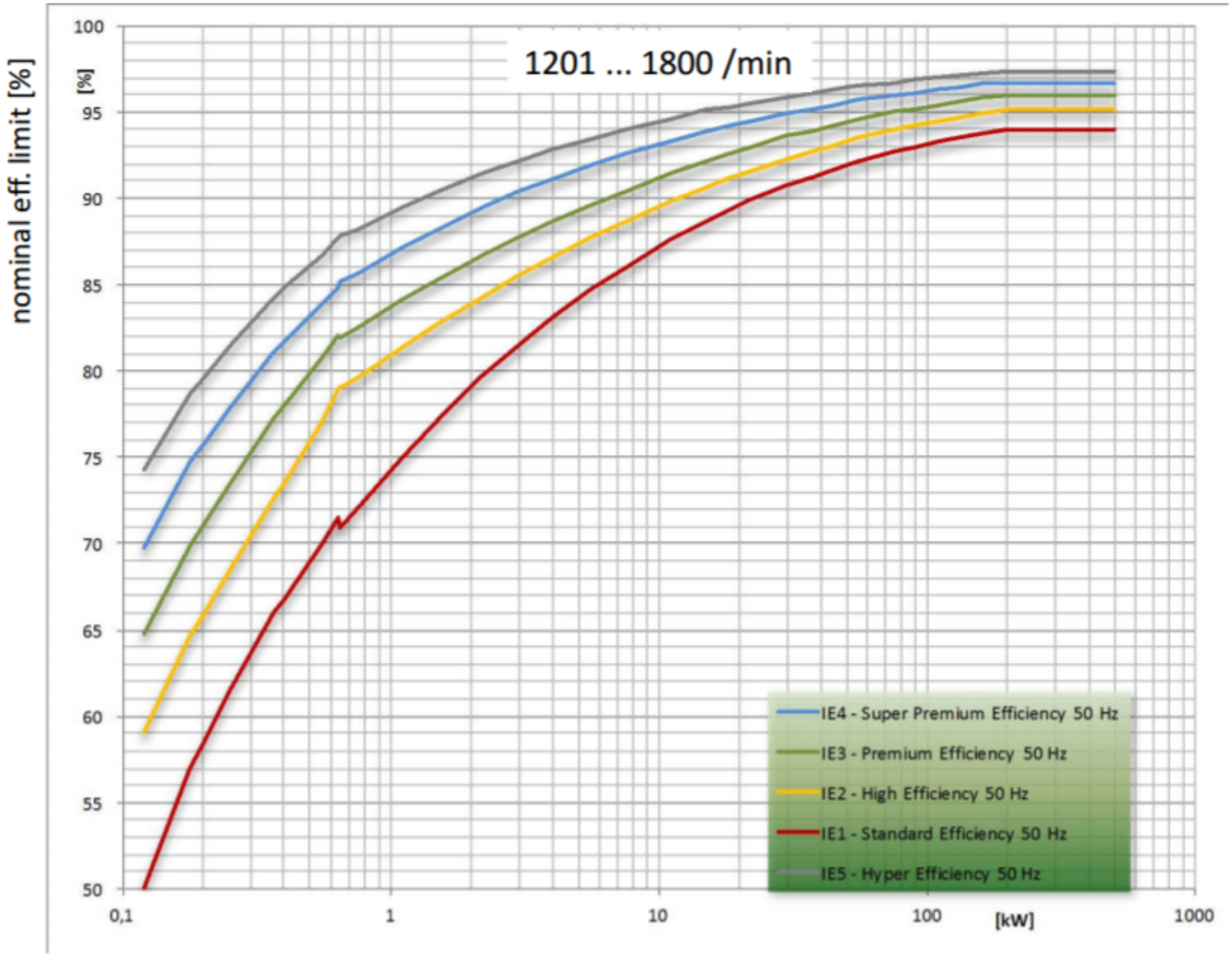
Motor Efficiency Comparison

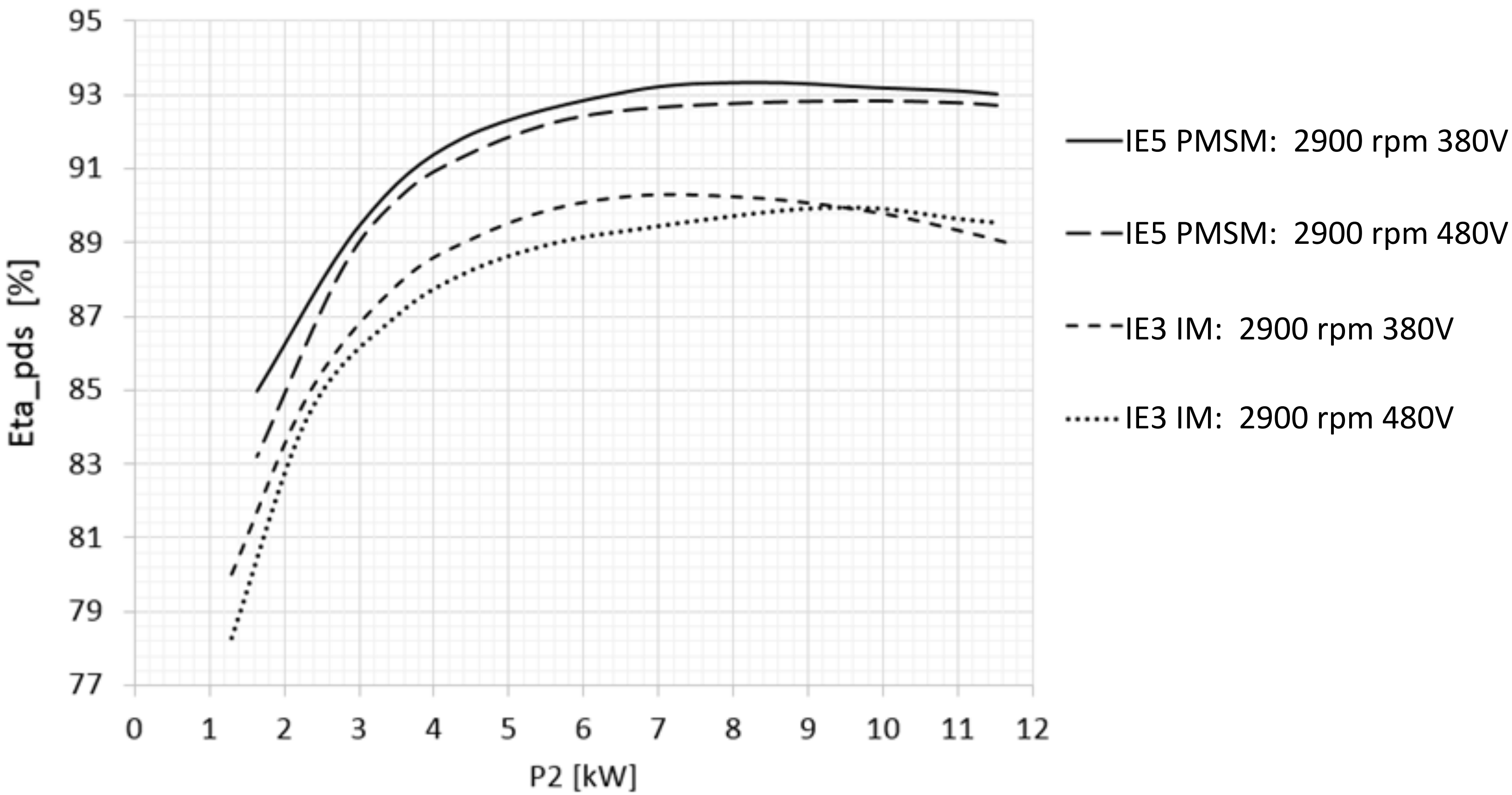


Motor Efficiency Comparison
(1800 RPM - Enclosed)

HP	IE3/ NEMA Premium	IE4 "Super" Premium	IE5
2	86.5	88.5	90.2
3	89.5	91.0	92.4
5	89.5	91.0	92.4
7.5	91.7	92.4	93.6
10	91.7	92.4	93.6
15	92.4	93.6	94.5

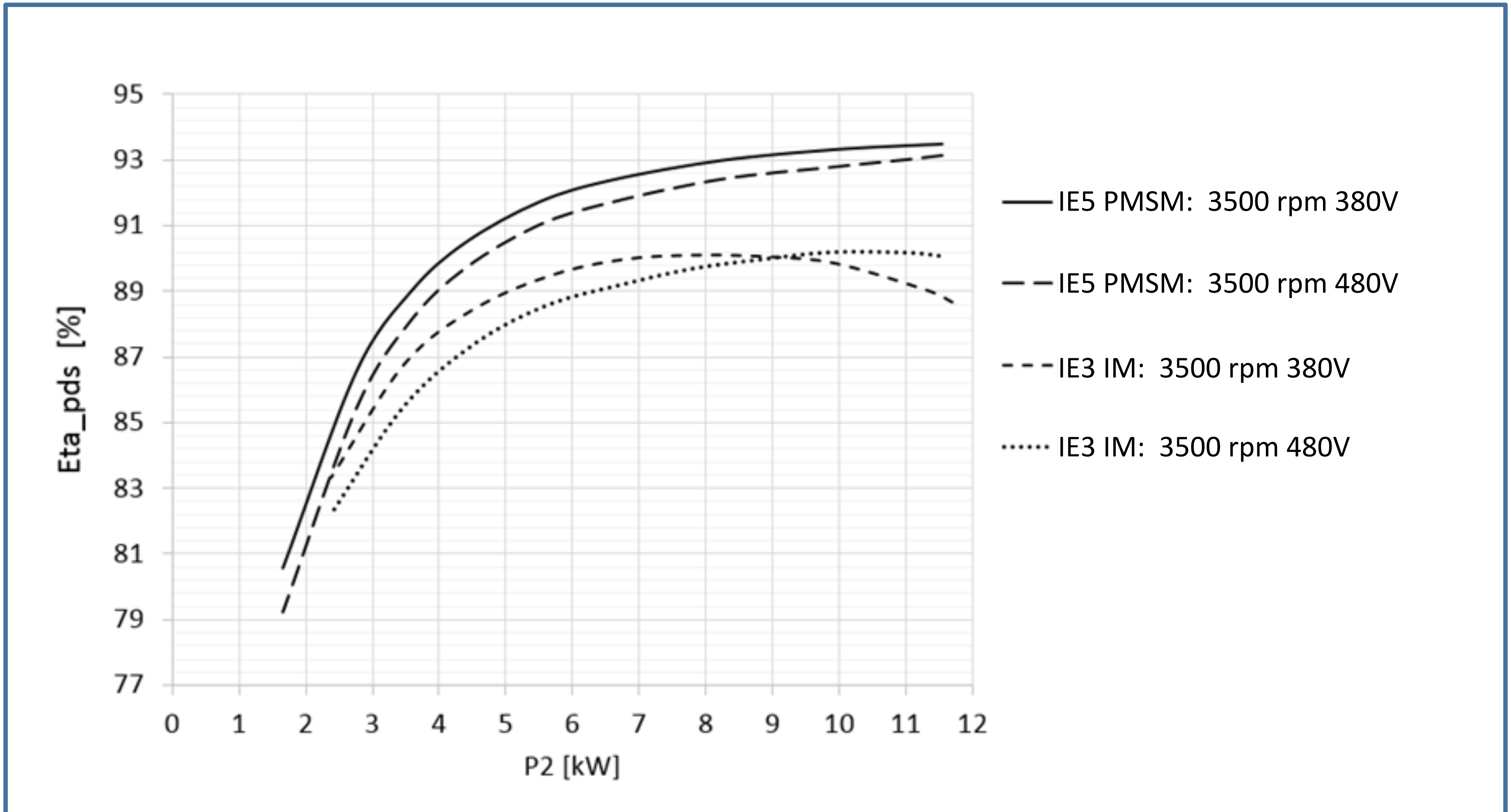
Comparison of “old” and new motors at 2900 rpm

Efficiency for product/system (motor + drive)



Comparison of “old” and new motors at 3500 rpm

Efficiency for product/system (motor + drive)



Some energy savings examples

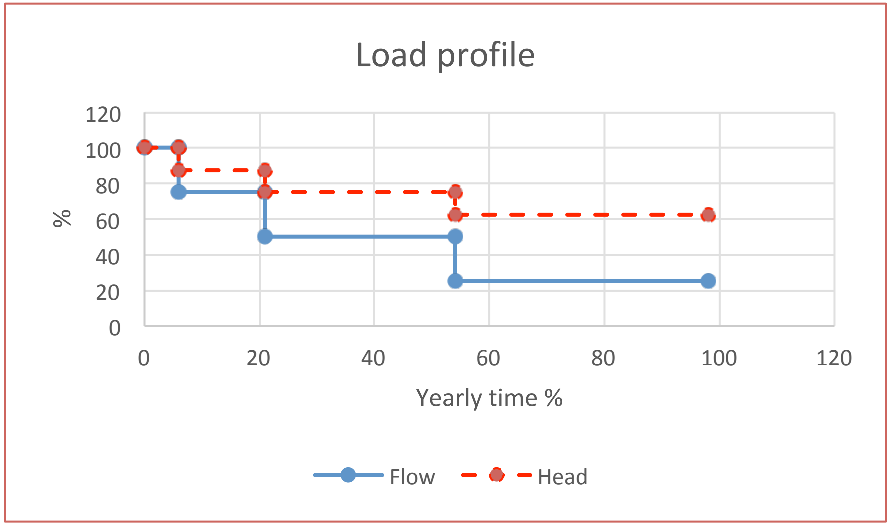
Circulator pump in a heating system

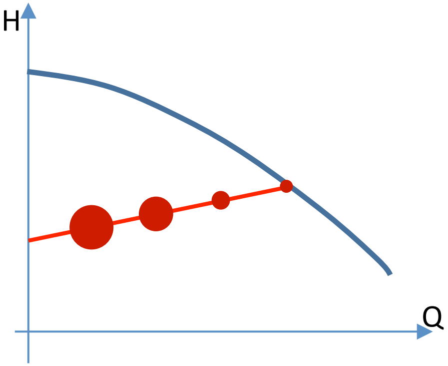
Example:
We will compare the yearly energy consumption of three different pumps in a heating system, with a Load profile as shown here.

The load profile is defined by EUROPUMP as ”The European part load profile”

We will compare the following three pumps:

1. Pump with IE3 Motor
2. Pump with IE3 Motor and drive
3. Pump with IE5 Motor and drive

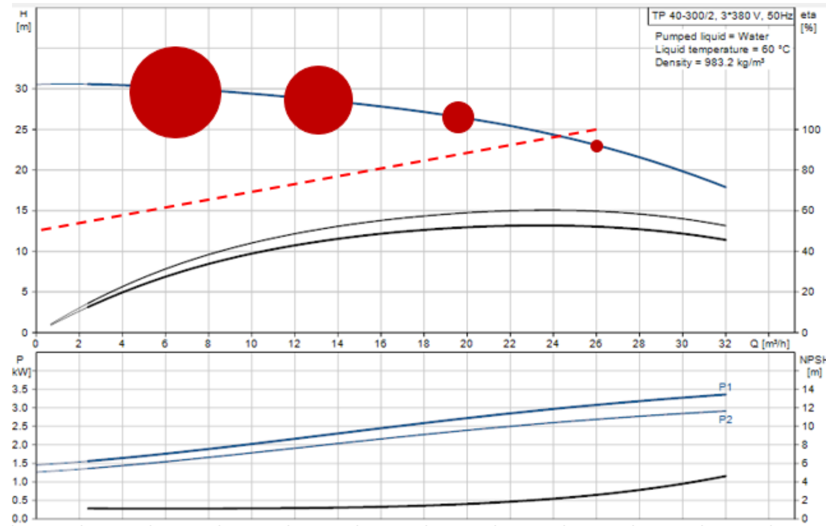




Time %	Flow %	Head %
6	100	100
15	75	87,5
33	50	75
44	25	62,5

Pump with IE3 Motor

The pump runs fixed full speed ≈ 2900 rpm. Only the flow can follow the load profile, meaning that the head will follow the performance curve.



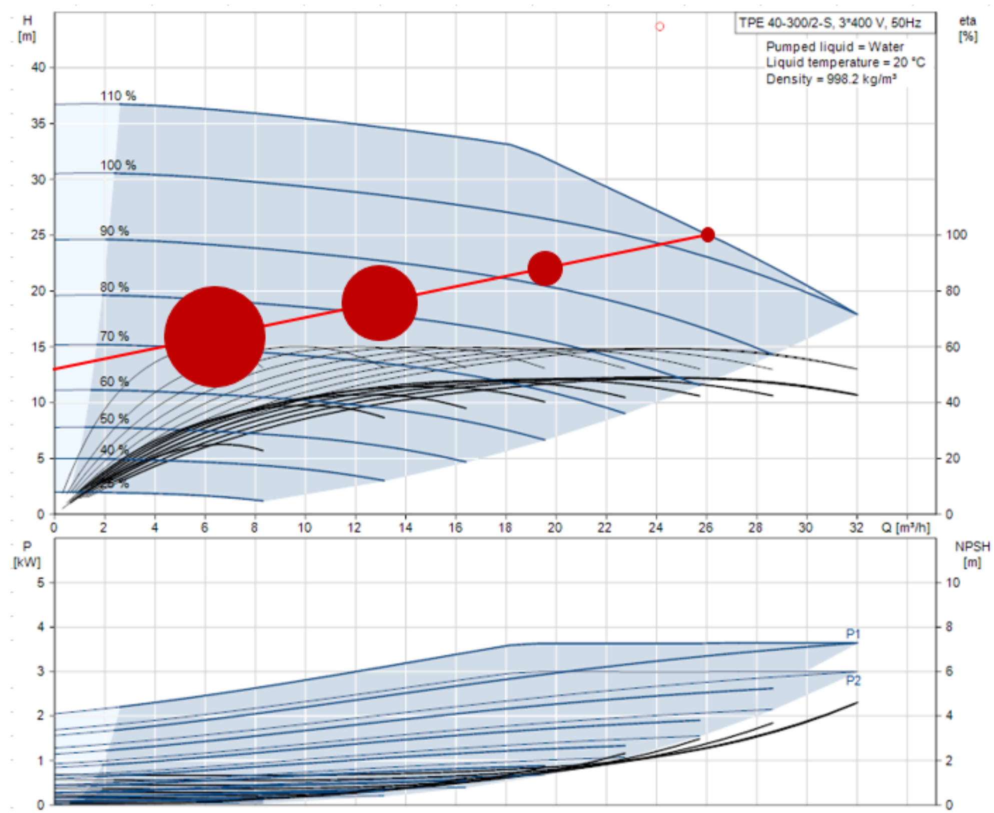
Yearly energy consumption = 18528 kWh

Flow		Head		Time		P1	P2	n	eta(P)	eta(M+P)	eta(M)	Energy
%	m3/h	%	m	%	hours	kW	kW	rpm	%	%	%	kWh
100	26	100	23,1	6	526	3,08	2,69	2914	0,597	0,522	0,87	1.619
75	19,5	115	26,6	15	1314	2,69	2,37	2928	0,587	0,516	0,88	3.535
50	13	124	28,7	33	2891	2,24	1,98	2953	0,507	0,448	0,88	6.475
25	6,5	130	30,1	44	3854	1,79	1,57	2957	0,333	0,293	0,88	6.899

Pump with IE3 Motor and Drive

The pump runs Proportional pressure and follows the load profile curve as shown. The pump will reduce the head by reduced flow.

Yearly energy consumption = 12680 kWh

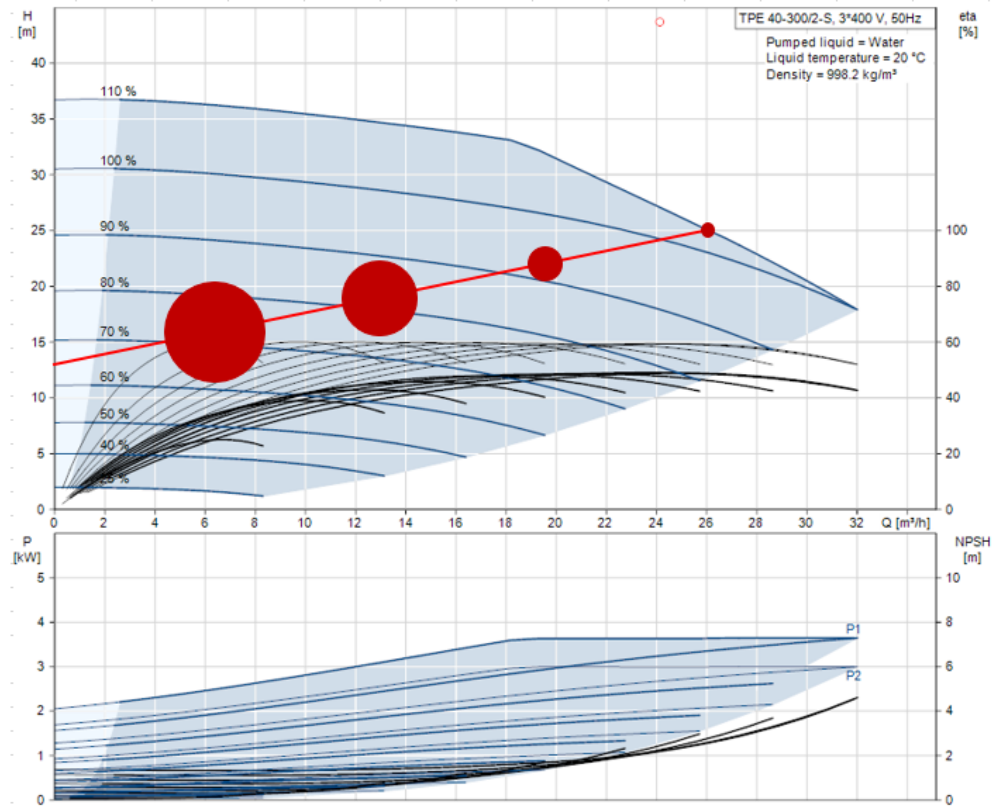


Flow		Head		Time		P1	P2	n	eta(P)	eta(M+P)	eta(M)	Energy
%	m3/h	%	m	%	hours	kW	kW	rpm	%	%	%	kWh
100	26	100	25	6	526	3,64	2,99	3009	0,59	0,49	0,82	1.912
75	19,5	87,5	21,9	15	1314	2,40	1,97	2689	0,588	0,483	0,82	3.154
50	13	75	18,8	33	2891	1,49	1,21	2406	0,544	0,442	0,81	4.319
25	6,5	62,5	15,6	44	3854	0,86	0,67	2141	0,411	0,323	0,79	3.296

Pump with IE5 Motor and Drive

The pump runs Proportional pressure and follows the load curve as shown. The pump will reduce the head by reduced flow.

Yearly energy consumption = 11447 kWh

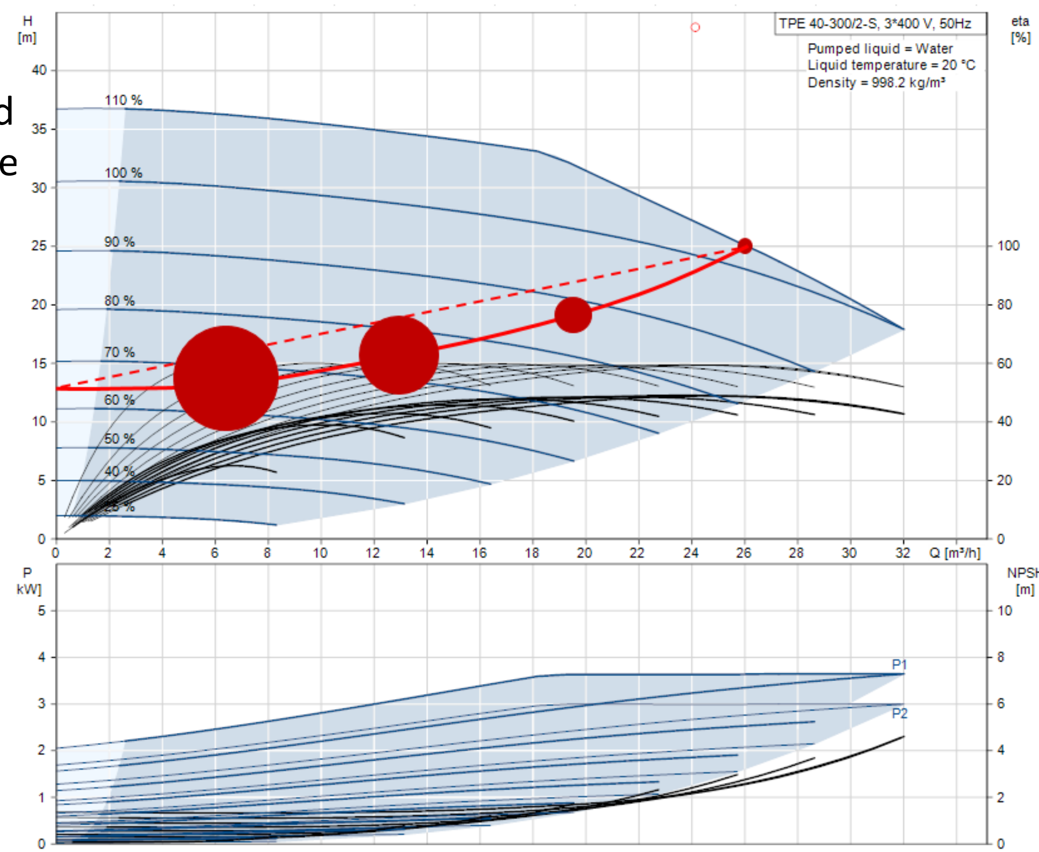


Flow		Head		Time		P1	P2	n	eta(P)	eta(M+P)	eta(M)	Energi
%	m3/h	%	m	%	hours	kW	kW	rpm	%	%	%	kWh
100	26	100	25,0	6	526	3,30	2,99	3009	0,593	0,538	0,908	1.733
75	19,5	87,5	21,9	15	1314	2,18	1,97	2689	0,588	0,532	0,905	2.860
50	13	75	18,8	33	2891	1,35	1,21	2406	0,544	0,489	0,898	3.905
25	6,5	62,5	15,6	44	3854	0,77	0,67	2141	0,411	0,360	0,877	2.949

Pump with IE5 Motor and Drive

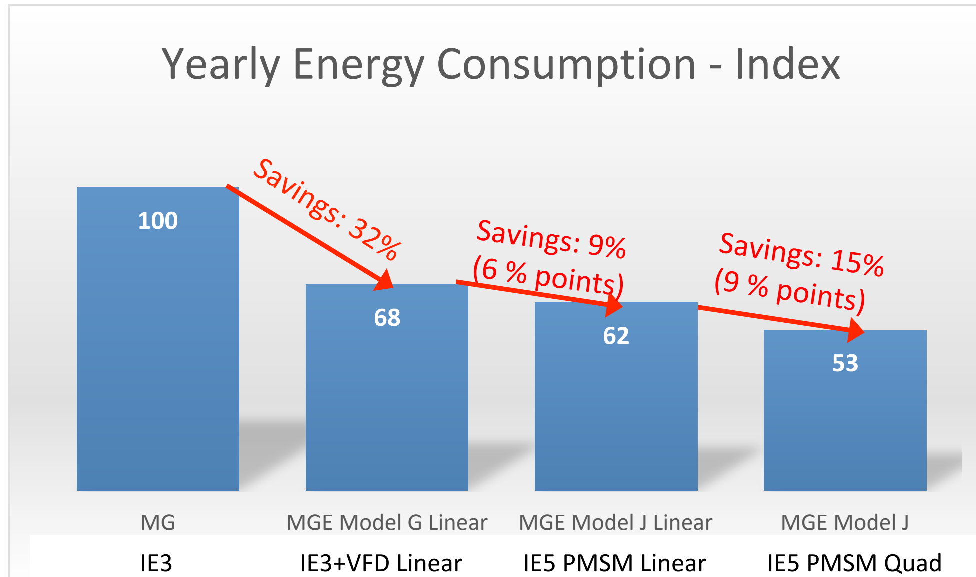
The pump runs Proportional pressure **with quadratic characteristic** and follows the load curve as shown. The pump will reduce the he even more by reduced flow.

Yearly energy consumption = 9890 kWh



Flow		Head		Time		P1	P2	n	eta(P)	eta(M+P)	eta(M)	Energi
%	m3/h	%	m	%	hours	kW	kW	rpm	%	%	%	kWh
100	26	100	25,0	6	526	3,30	2,99	3009	0,593	0,538	0,908	1.733
75	19,5	78,13	19,5	15	1314	1,92	1,74	2565	0,592	0,537	0,907	2.524
50	13	62,5	15,6	33	2891	1,10	0,99	2215	0,562	0,504	0,896	3.184
25	6,5	53,13	13,3	44	3854	0,64	0,55	1986	0,429	0,371	0,864	2.449

The comparison



	IE3	IE3 + VFD Linear	IE5 PMSM Linear	IE5 PMSM Quadratic
kWh:	18.528	12.680	11.447	**9.890**
Index:	100	68	62	53

Energy Savings Example

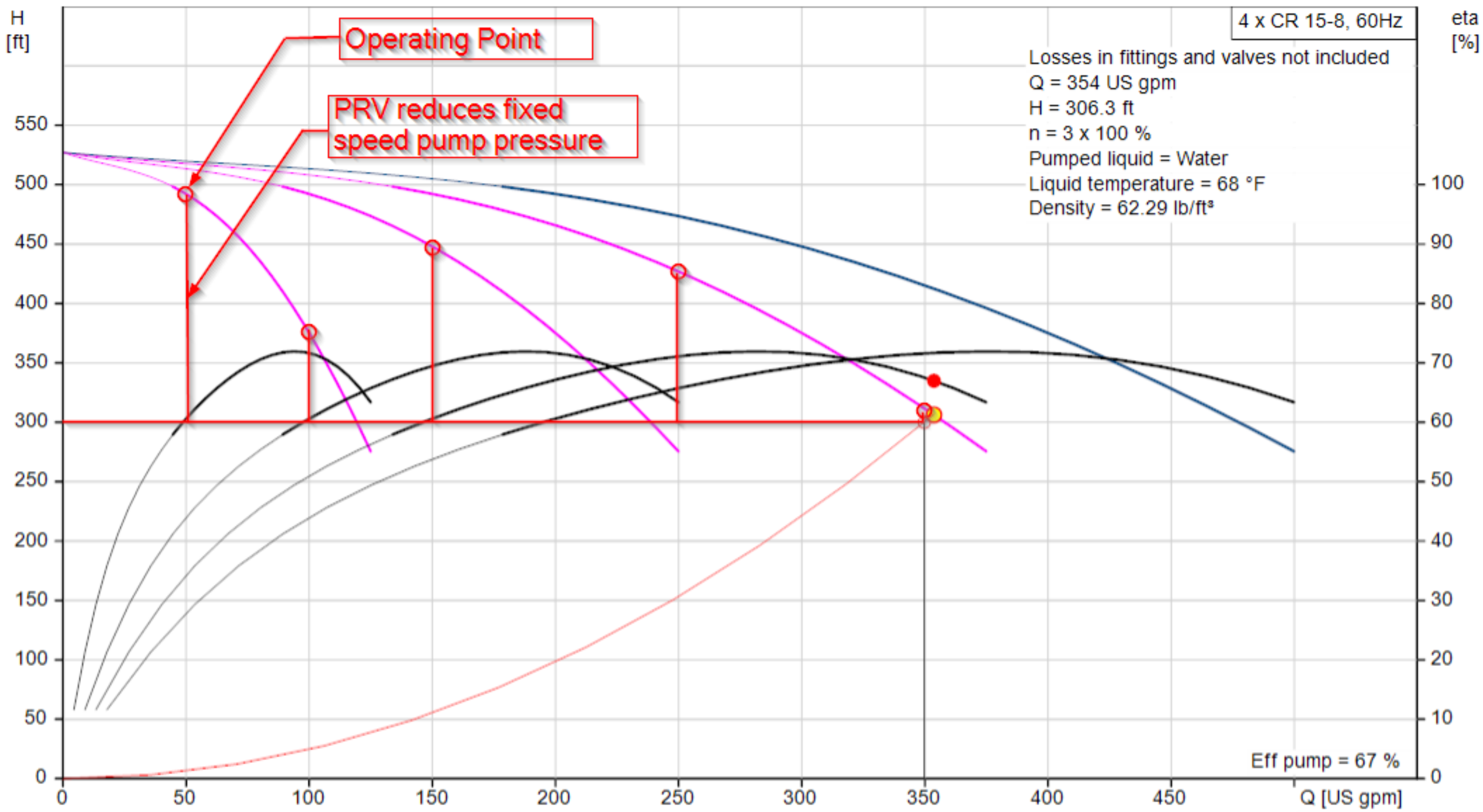
Flow (GPM)	Required TDH, feet	Hours per Day	Hours per Yr	% Time
0.0	300	2.4	876	10%
50.0	300	10.8	3,942	45%
150.0	300	4.8	1,752	20%
250.0	300	3.6	1,314	15%
350.0	300	2.4	876	10%
		24	8,760	

Example: High Rise Building **Domestic Water Pressure Boosting**

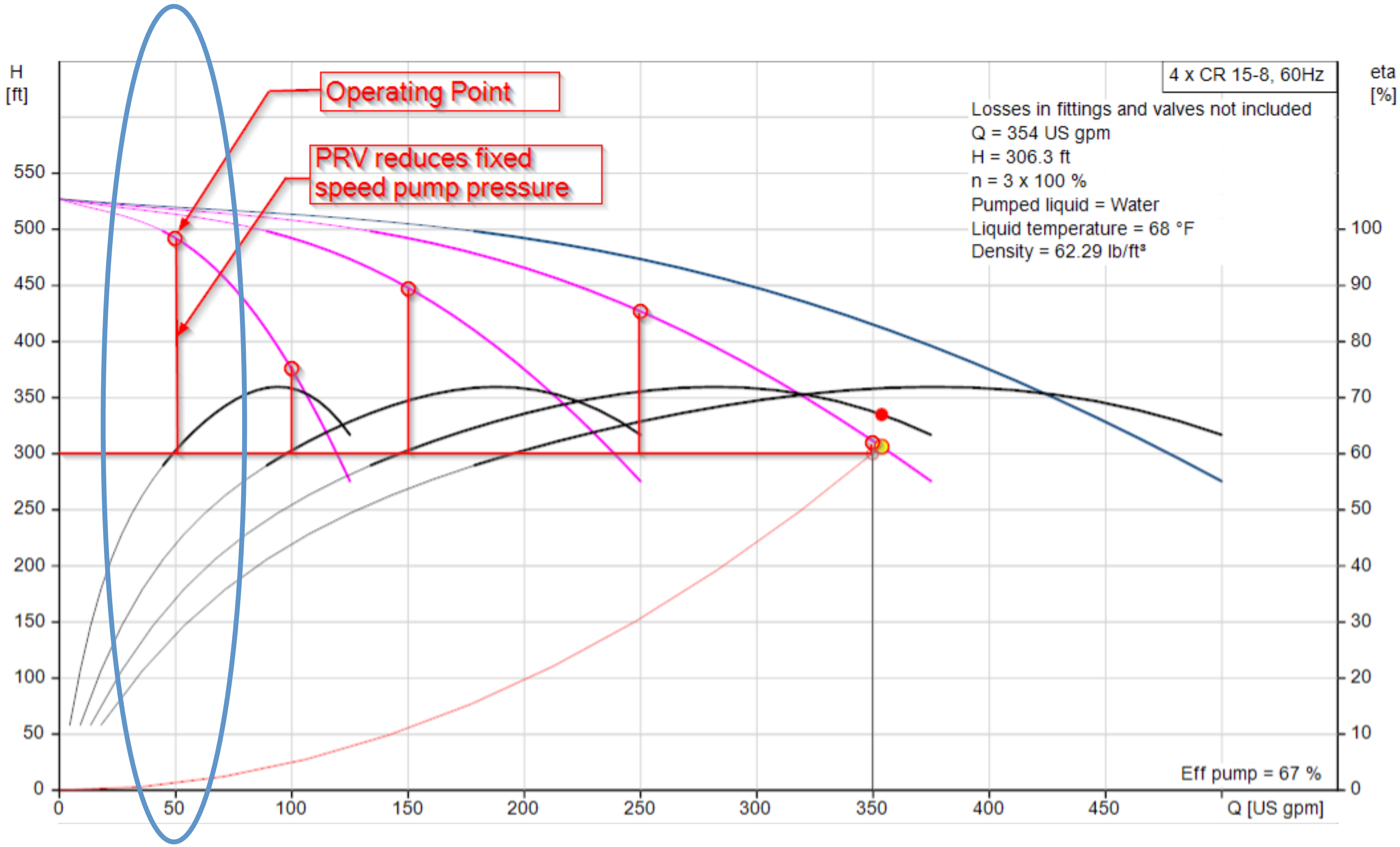
Design Condition: **350 gpm @ 130 psi (300 ft.) TDH**; (4) - 33% pumps, with one redundant pump

1. 4-Pump Fixed-Speed 15HP 3x460V
   – All Fixed Speed Premium Eff. Motors pumping against PRV - Constant Pressure
2. 4-Pump All VFD controlled 15HP 3x460V
   – All VFD and Premium Eff. Motors – Constant Pressure
3. 4-Pump All VFD controlled 15HP 3x460V
   – All VFD IE5 PM Motors – Constant Pressure
4. 4-Pump All VFD controlled 15HP 3x460V
   – All VFD IE5 PM Motors – Proportional Pressure

Fixed Speed Pumping Against PRV - Constant Pressure

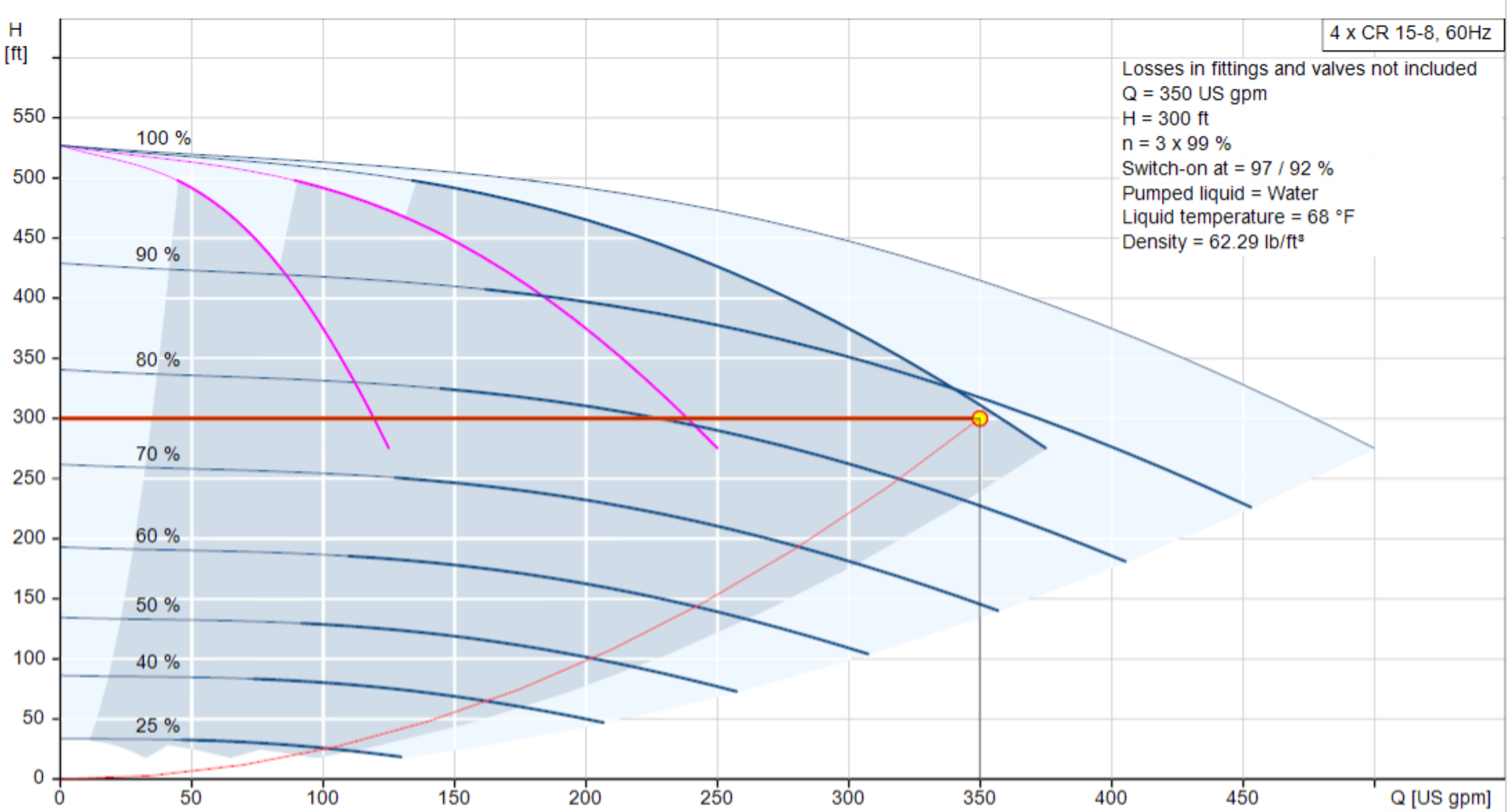


Fixed Speed Pumping Against PRV - Constant Pressure



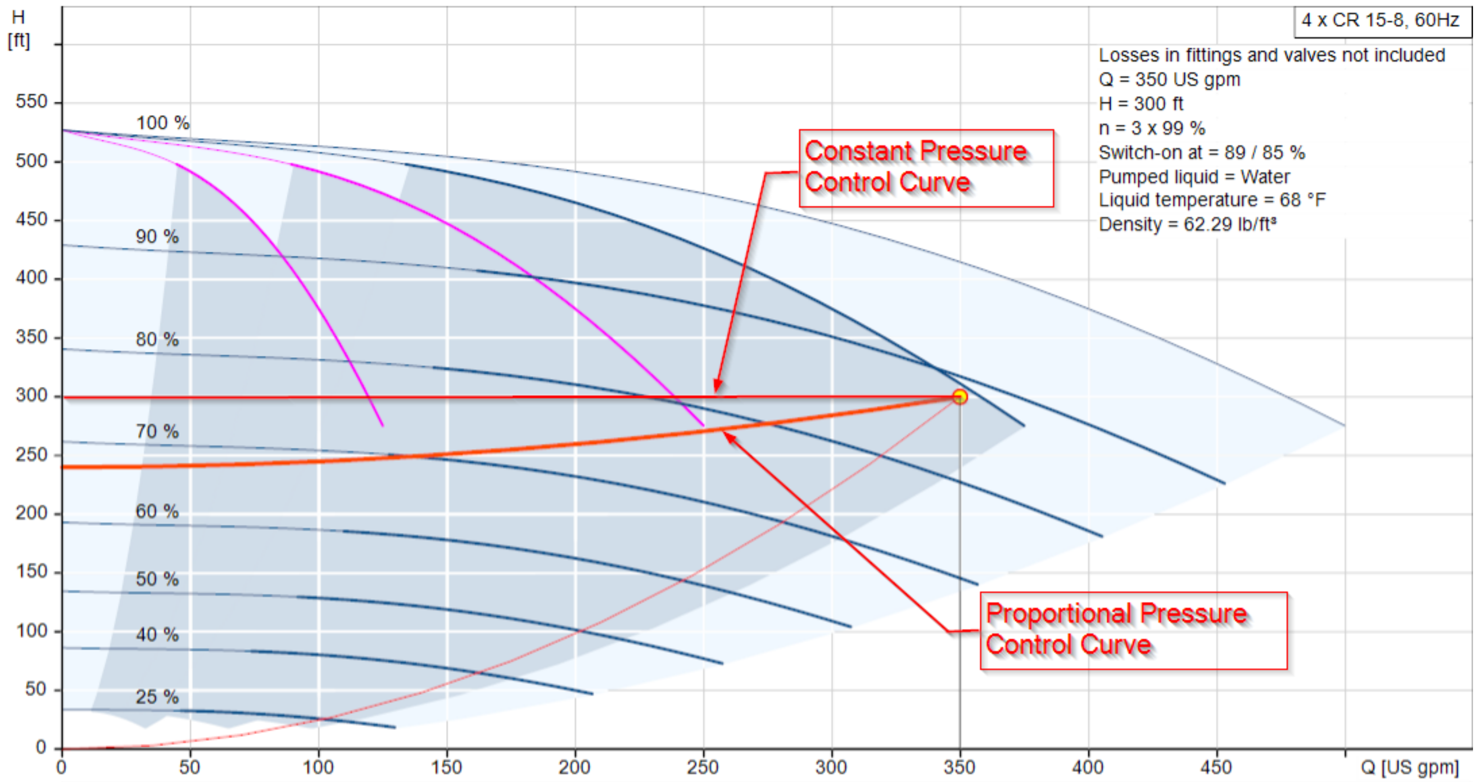
- PRV losses are Wasted Energy!

VFD Controlled Pumps and Constant Pressure

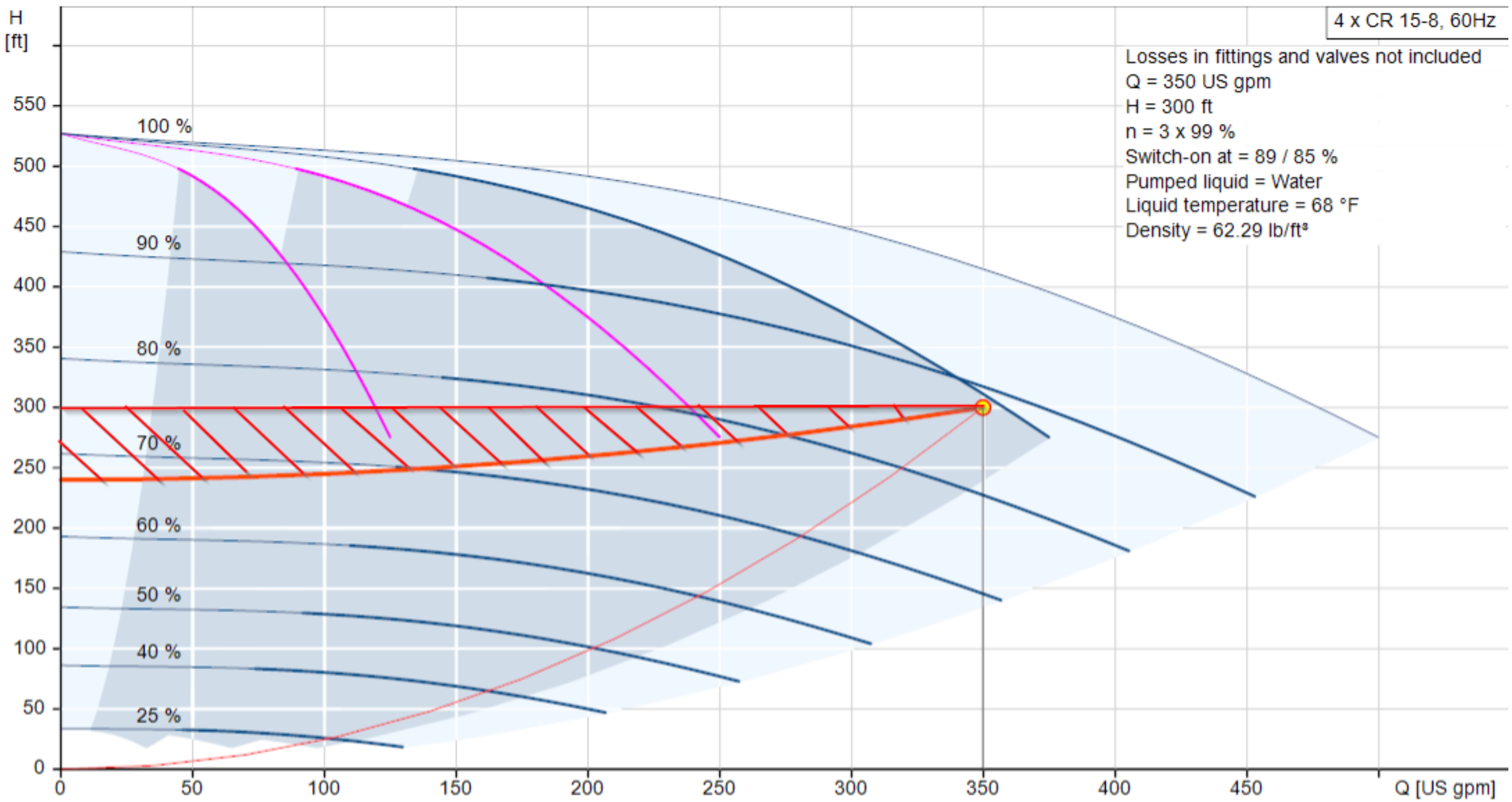


VFD controlled pumps exactly match pumps speed to meet pumping requirement

VFD Controlled Pumps and Proportional Constant Pressure



VFD Controlled Pumps and Proportional-Constant Pressure



The hatched area represents additional energy saving by lowering pressure at lower flows, **thus compensating for less friction head at lower flows**.

Energy saving example summary

Flow (GPM)	Required TDH, feet	Hours per Day	Hours per Yr	% Time
0.0	**300**	**2.4**	876	10%
50.0	**300**	**10.8**	3,942	45%
150.0	**300**	**4.8**	1,752	20%
250.0	**300**	**3.6**	1,314	15%
350.0	**300**	**2.4**	876	10%
		24	8,760	

Annual Operating Days: **365**

Electricity Cost [$/kWh]: **0.100**

1. 4-Pump PRV 15HP 3x460V ========➔ Annual Operating Cost: $15,191

   All Fixed Speed Premium Eff. Motors – 350 GPM @ 300 ft. PRV Constant

Flow				Actual TDH	BHP				Efficiency [%]	Input	Annual
Pump 1	Pump 2	Pump 3	Pump 4	Operating Pumps	Pump 1	Pump 2	Pump 3	Pump 4	Operating Pumps	kW	kWh
0.0	0.0	0.0	0.0	527.0	6.6	0.0	0.0	0.0	0.0	5.4	4,756
50.0	0.0	0.0	0.0	492.1	10.2	0.0	0.0	0.0	61.0	8.4	33,032
75.0	75.0	0.0	0.0	447.9	12.3	12.3	0.0	0.0	69.2	20.3	35,515
83.3	83.3	83.3	0.0	426.9	12.7	12.7	12.7	0.0	70.8	31.5	41,360
87.5	87.5	87.5	87.5	415.1	12.9	12.9	12.9	12.9	71.4	42.5	37,247
										Total	151,910

2. 4-Pump VFD 15HP 3x460V ========➔Annual Operating Cost: $10,383

   All VFD and Premium Eff. Motors – 350 GPM @ 300 ft. Constant Pressure

Flow			Speed, RPM			BHP			Efficiency [%]			Input	Annual
Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	kW	kWh
0.0	0.0	0.0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
50.0	0.0	0.0	2,804	0	0	5.7	0.0	0.0	65.9	0.0	0.0	5.0	19,717
75.0	75.0	0.0	2,999	2,999	0	8.0	8.0	0.0	71.5	71.5	0.0	13.8	24,166
83.3	83.3	83.3	3,079	3,079	3,079	8.8	8.8	8.8	71.9	71.9	71.9	22.8	29,929
116.7	116.7	116.7	3,484	3,484	3,484	13.1	13.1	13.1	67.3	67.3	67.3	34.3	30,018
												Total	103,830

3. 4-Pump **ECM** 15HP 3x460V =========➔Annual Operating Cost: $9,625

   All ECM/PM IE5 Motors) – 350 GPM @ 300 ft. Constant Pressure

Flow			Speed, RPM			BHP			Efficiency [%]			Input	Annual
Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	kW	kWh
0.0	0.0	0.0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
50.0	0.0	0.0	2,772	0	0	5.7	0.0	0.0	65.9	0.0	0.0	4.7	18,365
75.0	75.0	0.0	2,965	2,965	0	8.0	8.0	0.0	71.5	71.5	0.0	12.8	22,413
83.3	83.3	83.3	3,044	3,044	3,044	8.8	8.8	8.8	71.9	71.9	71.9	21.1	27,759
116.7	116.7	116.7	3,444	3,444	3,444	13.1	13.1	13.1	67.3	67.3	67.3	31.6	27,718
												Total	96,255

Energy saving example summary

1. 4-Pump PRV 15HP 3x460V ========➔ Annual Operating Cost: $15,191

   All Fixed Speed Premium Eff. Motors – 350 GPM @ 300 ft. PRV Constant

Flow				Actual TDH	BHP				Efficiency [%]	Input	Annual
Pump 1	Pump 2	Pump 3	Pump 4	Operating Pumps	Pump 1	Pump 2	Pump 3	Pump 4	Operating Pumps	kW	kWh
0.0	0.0	0.0	0.0	527.0	6.6	0.0	0.0	0.0	0.0	5.4	4,756
50.0	0.0	0.0	0.0	492.1	10.2	0.0	0.0	0.0	61.0	8.4	33,032
75.0	75.0	0.0	0.0	447.9	12.3	12.3	0.0	0.0	69.2	20.3	35,515
83.3	83.3	83.3	0.0	426.9	12.7	12.7	12.7	0.0	70.8	31.5	41,360
87.5	87.5	87.5	87.5	415.1	12.9	12.9	12.9	12.9	71.4	42.5	37,247
										Total	151,910

2. 4-Pump VFD 15HP 3x460V ========➔Annual Operating Cost: $10,383

   All VFD and Premium Eff. Motors – 350 GPM @ 300 ft. Constant Pressure

Flow			Speed, RPM			BHP			Efficiency [%]			Input	Annual
Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	kW	kWh
0.0	0.0	0.0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
50.0	0.0	0.0	2,804	0	0	5.7	0.0	0.0	65.9	0.0	0.0	5.0	19,717
75.0	75.0	0.0	2,999	2,999	0	8.0	8.0	0.0	71.5	71.5	0.0	13.8	24,166
83.3	83.3	83.3	3,079	3,079	3,079	8.8	8.8	8.8	71.9	71.9	71.9	22.8	29,929
116.7	116.7	116.7	3,484	3,484	3,484	13.1	13.1	13.1	67.3	67.3	67.3	34.3	30,018
												Total	103,830

3. 4-Pump **ECM** 15HP 3x460V =========➔Annual Operating Cost: $9,625

   All ECM/PM IE5 Motors) – 350 GPM @ 300 ft. Constant Pressure

Flow			Speed, RPM			BHP			Efficiency [%]			Input	Annual
Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	kW	kWh
0.0	0.0	0.0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
50.0	0.0	0.0	2,772	0	0	5.7	0.0	0.0	65.9	0.0	0.0	4.7	18,365
75.0	75.0	0.0	2,965	2,965	0	8.0	8.0	0.0	71.5	71.5	0.0	12.8	22,413
83.3	83.3	83.3	3,044	3,044	3,044	8.8	8.8	8.8	71.9	71.9	71.9	21.1	27,759
116.7	116.7	116.7	3,444	3,444	3,444	13.1	13.1	13.1	67.3	67.3	67.3	31.6	27,718
												Total	96,255

Flow (GPM)	Required TDH, feet	Hours per Day	Hours per Yr	% Time
0.0	300	2.4	876	10%
50.0	300	10.8	3,942	45%
150.0	300	4.8	1,752	20%
250.0	300	3.6	1,314	15%
350.0	300	2.4	876	10%
		24	8,760	

Annual Operating Days: 365

Electricity Cost [$/kWh]: 0.100

Conclusions:

- Incorporating VFD reduces energy cost by 32% **($4,803 annual savings)** over Fixed Speed/PRV
- All **ECM/PM** motors reduces energy costs by 37% **($5,566 annual savings)** over Fixed Speed/PRV
  - Additional **$763** annually with **ECM**

Energy saving with advanced controls

1. 4-Pump PRV 15HP 3x460V ========➔ Annual Operating Cost: $15,191
   Fixed Speed Premium Eff. Motors – 350 GPM @ 300 ft. PRV Constant Pressure

Flow (GPM)	Required TDH, feet	Hours per Day	Hours per Yr	% Time
0.0	240	2.4	876	10%
50.0	240	10.8	3,942	45%
150.0	251	4.8	1,752	20%
250.0	271	3.6	1,314	15%
350.0	300	2.4	876	10%
		24	8,760	

Annual Operating Days: 365

Electricity Cost [$/kWh]: 0.100

2. 4-Pump VFD 15HP 3x460V ========➔ Annual Operating Cost: $10,383
   All VFD and Premium Eff. Motors – 350 GPM @ 300 ft. Constant Pressure

4. 4-Pump **ECM** 15HP 3x460V ========➔ Annual Operating Cost: $8,600
   All **ECM** IE5 Motors – 350 GPM @ 300 ft. **Proportional Pressure Pressure**

Flow			Speed, RPM			BHP			Efficiency [%]			Input	Annual
Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	Pump 1	Pump 2	Pump 3	kW	kWh
0.0	0.0	0.0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
50.0	0.0	0.0	2,512	0	0	4.5	0.0	0.0	67.9	0.0	0.0	3.6	14,274
75.0	75.0	0.0	2,775	2,775	0	6.6	6.6	0.0	71.9	71.9	0.0	10.7	18,808
83.3	83.3	83.3	2,941	2,941	2,941	8.0	8.0	8.0	71.8	71.8	71.8	19.2	25,202
116.7	116.7	116.7	3,444	3,444	3,444	13.1	13.1	13.1	67.3	67.3	67.3	31.6	27,718
												Total	86,001

<u>Conclusions:</u>

- Incorporating advanced controls with **Proportional Pressure control** and all **ECM/PM motors** reduces energy costs by **43% ($6,591 annual savings)** over Fixed Speed/PRV Constant Pressure
  - **17% ($1,783 annual savings)** over VFD & Premium Eff. Motors Constant Pressure

The Comparison

	Fixed Speed/PRV - Constant Pressure	VFD – NEMA Premium Constant Press.	PMSM IE5 Constant Pressure	**PMSM IE5 Proportional Pressure**
Annual Energy Cost:	$15,191	$10,383	$9,625	**$8,600**
Index:	100	68	63	**57**

The Comparison

Potential Retrofit Savings: +43%

	Fixed Speed/PRV - Constant Pressure	VFD – NEMA Premium Constant Press.	PMSM IE5 Constant Pressure	**PMSM IE5 Proportional Pressure**
Annual Energy Cost:	$15,191	$10,383	$9,625	**$8,600**
Index:	100	68	63	**57**

Advantages of PMSM

Higher full & variable speed efficiency

Flatter efficiency curve

Cooler operating temperatures

Higher torque at low speeds

Increased power density

Rare-earth permanent magnets produce more flux (and resultant torque) for their physical size than induction types.

Reliability:

Lower operating temperatures reduces wear and tear, maintenance

- Extends bearing and insulation life
- Robust construction for years of trouble-free operation in harsh environments.

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Thank you!

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