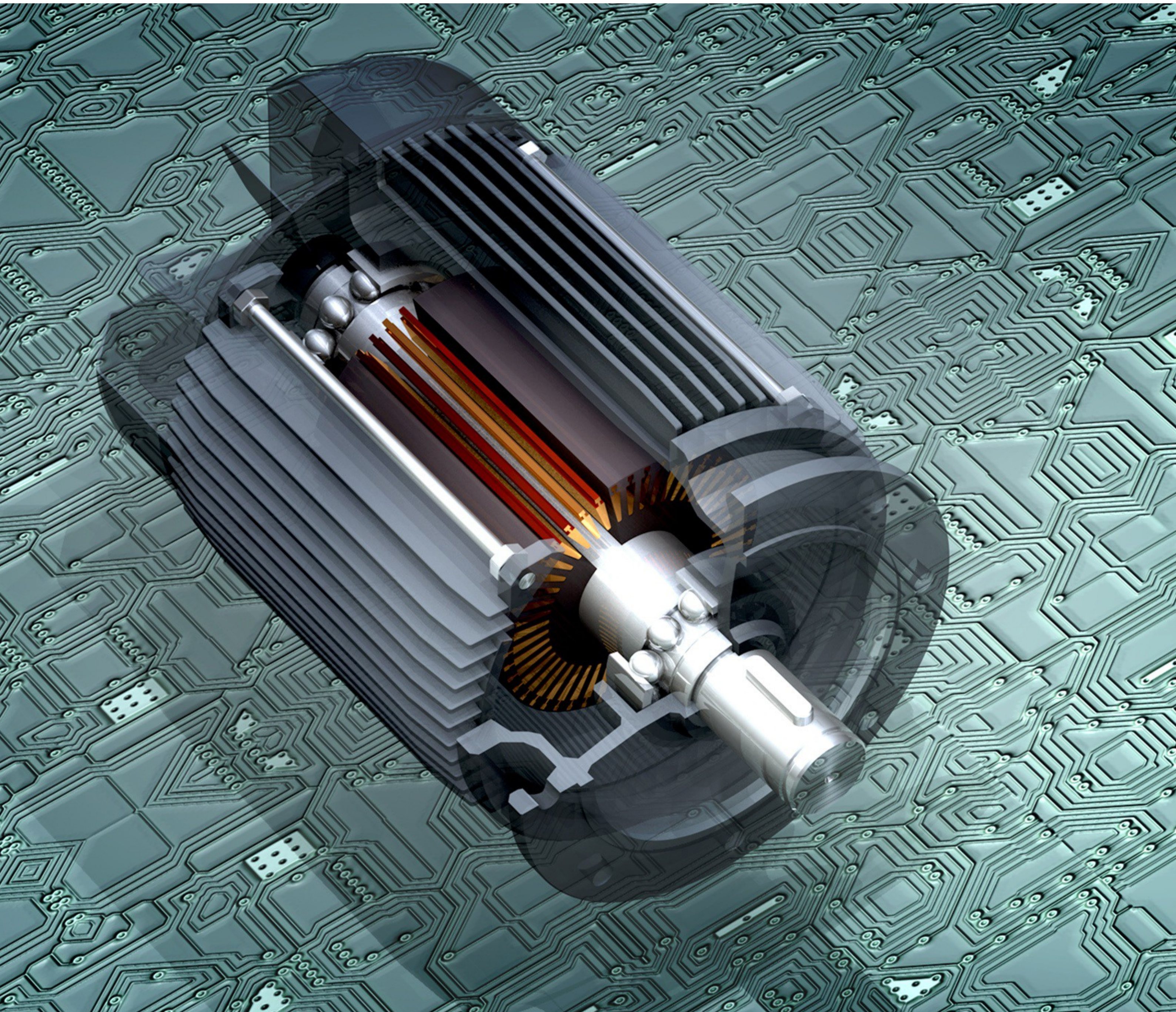
Eco design for power drive systems EN50598

Proposed amendment to achieve up to 44 TWh/a energy savings within the EU



The European Union has made clear its intent to tackle global climate change through its commitment to reduce CO_2 emissions from its member countries by 20% by 2020.

Electricity generation is a large contributor of CO_2 emissions and Industry is a large consumer of electricity. Within Industry, electric motors are the largest consumer of electrical energy which has prompted the Ecodesign directive for electric motors legislation which mandates minimum energy efficiency levels.

Focus is now turning to the efficiency of Variable Speed Drives (VSDs), Ecodesign for Power Driven Systems legislation has been drafted and feedback is currently being sought. Early indications suggest that this legislation does not pose any challenge to VSD manufacturers since existing designs are likely to meet proposed minimum energy efficiency levels.

Through collaboration with VSD manufacturers, REO has identified and documented a significant energy saving opportunity which could result an energy reduction of 44.56 TWh/a

REO would like to bring this opportunity to the attention of all parties involved in the finalisation of EN50598, with a view to implementing a stretched target for minimum energy efficiency levels for VSDs.

The proposed amendment is similar to the precedent set in the Ecodesign directive for electric motors legislation, which has previously helped manufacturers and consumers alike, to contribute to achieving the energy reduction targets to which EU members have committed.

Global Climate Change

Since we know that greenhouse gases significantly influence climate change patterns, governments have started to look at ways to limit the amount of greenhouse gases generated to “a level that would prevent dangerous anthropogenic interference with the climate system”.

An approach was agreed in Japan in 1997 where 192 parties signed their commitment to exploring ways for the world’s 37 most industrialised countries to reduce their impact on global warming. Known as the Kyoto Agreement, this became effective from 2005.

This was expanded to include developing nations in 2009 when 120 heads of government, representing over 80% of global greenhouse gas emitters, agreed targets for their respective countries under the Copenhagen Accord.

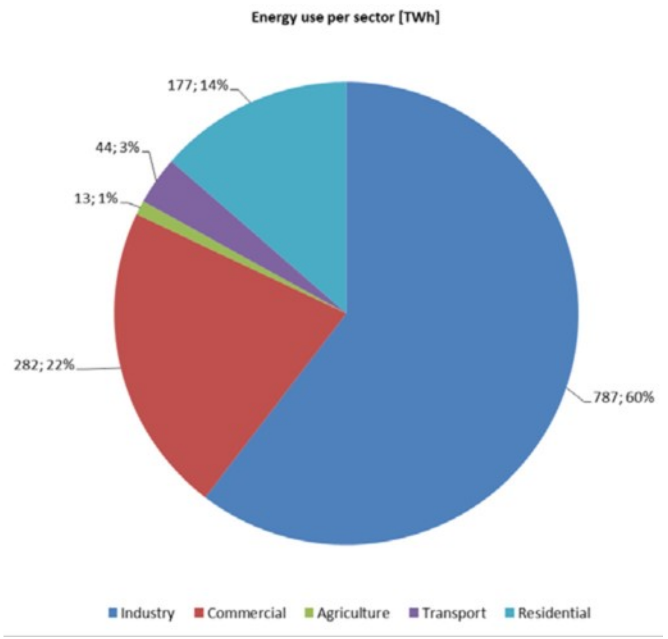
The European Union is the world’s third largest emitter behind China and the USA, and as part of the Copenhagen Accord signed a commitment to reduce Carbon Dioxide (CO_2) emissions to 20% below 1990 levels by 2020.

In 2017, nearly 200 countries signed the Paris agreement. This agreement reaffirms the commitment to keep global temperatures down and limit carbon emissions.

Ecodesign Directive

In response to the targets agreed at the Copenhagen Accord, the European Union began to look at potential areas in which to introduce legislation that would result in activity that would reduce greenhouse gas emissions.

Electrical Energy generation was identified as a prime source of CO_2 emissions and a study from that time (by the International Energy Agency) showed that Industry was the largest consumer of electrical energy;



Extract from Lot30 Motors CF Explanatory Notes - GAMBICA

Within Industry, Motor Driven Systems were identified as the largest consumer of electrical energy;

Motor type	Output size P_m (kW)				Operation		Number running stock	Life time	Sales	Motor efficiency		Power P_e	Electricity demand	
	Min	Max	Median	Total GWm	h/a	Load factor	Million	Years	Million per year	Nominal	Mean	Total GWe	TWh/a	Fraction
Small	0.001	0.75	0.16	316	1 500	40%	2 000	6.7	300	40%	30%	422	632	9.1%
Medium	0.75	375	9.5	2 182	3 000	60%	230	7.7	30	86%	84%	1 559	4 676	67.6%
Large	375	100 000	750	450	4 500	70%	0.6	15.0	0.04	90%	88%	358	1 611	23.3%
Total				2 948			2 231	6.8	330		79%	2 338	6 919	100%

Source: A+B International, 2009.

Extract from "Walking the Torque" Hugh Falkner & Shane Holt

Whilst only 9% of the global stocks of motors are within the "medium" 0.75 kW to 375 kW power range, they are responsible for 67% of the electricity consumed by motor systems. Hence these motors became the subject of legislation under Regulation 640/2009 with regard to Ecodesign requirements for electric motors.

The minimum requirements established by this Regulation are as follows:

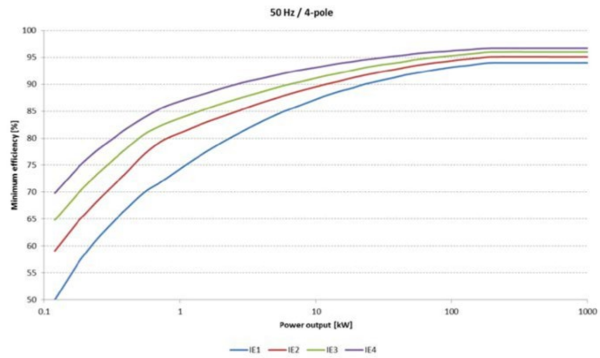
● from 16 June 2011: motors shall not be less efficient than the IE2 efficiency level

● from 1 January 2015: motors with a rated output of 7.5 – 375 kW shall not be less efficient than the IE3 efficiency level, or meet the IE2 efficiency level and be equipped with a VSD.

● from 1 January 2017: all motors with a rated output of 0.75 – 375 kW shall not be less efficient than the IE3 efficiency level, or meet the IE2 efficiency level and be equipped with a VSD.

The IE efficiency levels were taken from the international standard IEC 60034-30:2009, which at the time of drafting of the Regulation covered motors in the 0,75 – 375 KW power range and has subsequently been amended to extend to 1MW.

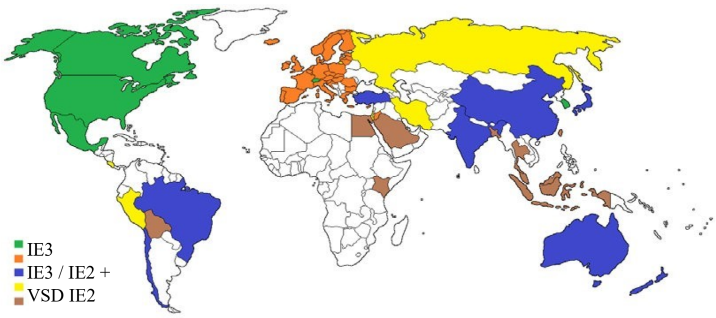
An example of these efficiency levels can be seen below;



Extract from Lot30 Motors CF Explanatory Notes - GAMBICA

Ecodesign Impact on Market

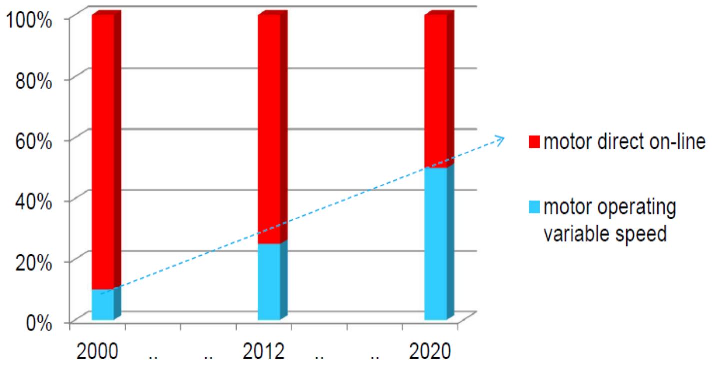
The Ecodesign for motors legislation has had a significant effect on the sale of both higher efficiency motors, and variable speed drives (since VSD's were specified in the legislation);



Extract from Lot30 Motors CF Explanatory Notes - GAMBICA

From the 1st of January 2015, the European Economic Area will be the only market where the minimum requirements can be met by using two different approaches, the use of an IE3 motor or the use of an IE2 motor but equipped with a VSD.

According to industry estimations, the penetration of VSDs in Europe will continue increasing in the coming years, from 20% in 2012 to more than 40% in 2020.



Extract from Lot30 Motors CF Explanatory Notes - GAMBICA

The total energy use of electric motors in the EU has been estimated at 1300 TWh, considering that around 30% of the motor systems incorporate a VSD, their total energy use can be estimated at 400 TWh.

Whilst the EU has mandated that from 1st January 2015 IE2 efficiency motors can continue to be sold on the proviso that they are used in conjunction with a VSD, in reality the EU is unable to enforce this.

In recognition of this inability to guarantee that legislation has the impact of reducing electricity consumption, the EU has decided to apply minimum energy efficiency standards to VSDs with effect from 1st January 2018 and to remove the permitted sale of IE2 efficiency level motors from 1st January 2020.

The proposed VSD Ecodesign legislation is shown below;

EN 50598-1

Ecodesign for power drive systems, motor starters, power electronics & their driven applications – Part 1: General requirements for setting energy efficiency standards for power driven equipment using the extended product approach (EPA), and semi analytic model (SAM).

EN 50598-2

Ecodesign for power drive systems, motor starters, power electronics & their driven applications – Part 2: Energy efficiency indicators for power drive systems and motor starters", are well placed in order to give support to any proposal regarding the minimum energy efficiency of variable speed drives.

EN 50598-3

Ecodesign for power drive systems, motor starters, power electronics & their driven applications – Part 3: Quantitative Ecodesign approach through life cycle assessment including product category rules and the content of environmental declarations.

The efficiency requirements are listed in Appendix 1. Anecdotally it is anticipated that in excess of 99% of all VSDs of existing design will meet the IE1 requirement and therefore it is not anticipated that this legislation with have any impact upon energy consumption in the short term.

Variable Speed Drive (VSD) Legislation

Whilst there were many different pieces of legislation regarding Electromagnetic Compatibility (EMC) of equipment, it wasn't until 2004 that legislation that specifically applied to VSD's when they became subject to specific EMC legislation EN61800.

EN61800 relates to "Power Drive Sytems" which is equipment which contains a VSD and a Motor;

Extract from EN61800-3

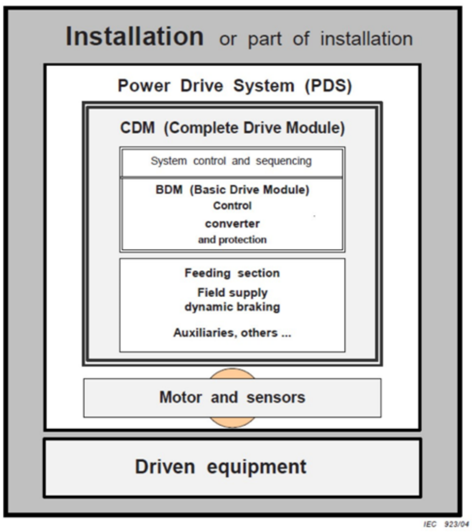


Figure 1 – Definition of the installation and its content

In March 2017, the European standard EN 50598 Part 1 and Part 2 has now been transferred to the international standard IEC 61800-9.

The 4 areas that are referenced within the original EN61800 are;

i. Immunity to electromagnetic emissions interference (EMI)
ii. Radiated Emissions
iii. Conducted Voltage Emissions
iv. Harmonic Current Emissions

Whilst all active electronic devices will generate emissions of some type, the construction of variable speed drives means that they are prime sources of electromagnetic interference (EMI).

EN61800 defines the limits for Conducted Emissions in the form of both Voltage and Current Harmonic Distortion. These are split into four separate categories;

C1 Power Drive System (PDS) of rated voltage less than 1000 V, intended for use in the first environment (Residential).

C2 PDS of rated voltage less than 1000 V, which is neither a plug in device nor a movable device and, when used in the first environment, is intended to be installed and commissioned only by a professional.

C3 PDS of rated voltage less than 1000 V, intended for use in the second environment (Industrial) and not intended for use in the first environment.

C4 PDS of rated voltage less than 1000 V, intended for use in the second environment but not intended for use in complex systems in the second environment.

Drive Manufacturers are competing with each other to demonstrate that their products are to a level of EMC compliance that makes their product suitable for installation by in any environment (C1).

Whilst the VSD itself may not be compliant to C1 levels, through the use of a VSD combined with EMC mitigating components within the Power Driven System, compliance can be achieved.

Drive manufacturers are therefore keen to specify components that are matched to their products and to make the EN61800 test results accessible to their customers.

Variable Speed Drive Testing

It was with this objective that REO (UK) entered discussions with one of their Strategic customers in the Drive Manufacturing sector, to specify a range of harmonic mitigating products which were matched to their VSD range and which would ensure compliance with EN61800.

A range of relevant products were selected by REO to meet the following requirements;

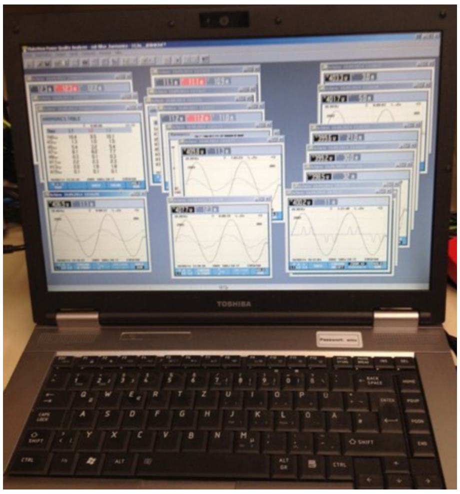
i. Good EMI mitigation / low cost
ii. Very good EMI mitigation / medium cost
iii. Excellent EMI mitigation / higher cost

A range of different VSD frame sizes (power range 22KW to 160KW) were provided by the Drive Manufacturer. EN61800 testing environments were understood and created at REO's facility in Kyritz (Germany) and testing commenced.

The REO product which was selected as likely to provide the optimum EMI mitigation was the REOWAVE Passive harmonic filter.

A number of Motor-Generator test sets were used to load each VSD to proportions of its rated power output, whilst measurements with and without the relevant sized REOWAVE Passive harmonic filter in circuit were made.

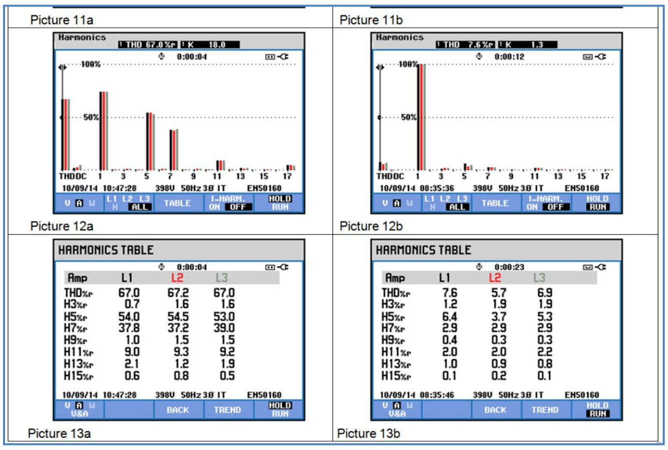
Motor-Generator Test-Sets at REO Kyritz facility



Recording of Total Harmonic Distortion and other data

As requested by the VSD Manufacturer, the tests were performed in such a way that the drive output power at each proportion of load tested, was the same without a REOWAVE Passive fitted and with the REOWAVE Passive fitted.

This allows a direct comparison to be made of the Total Harmonic Distortion, with and without the filter;



Extract from 22KW Manufacturer A Harmonics Report CNW8981-45-400-50

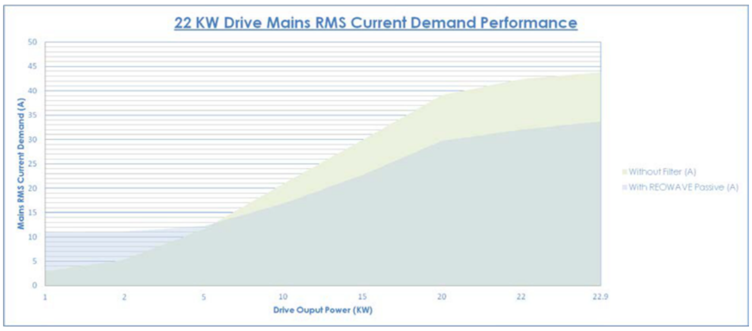
As an example, from the results of the full load test on the 22KW drive shown above, it can be seen that the Total Harmonic Distortion (THD) without the filter was 67.0% and with the filter fitted it was 7.6%, within the limits specified in EN61800-3-12 that apply to a drive of this size.

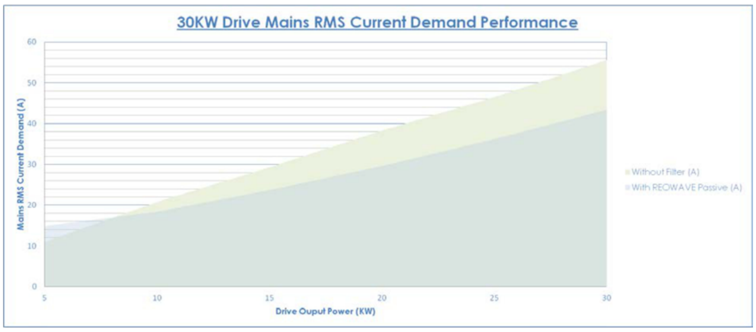
Incidental Test Observations

For the tests involving the REOWAVE Passive Harmonic filter, the Drive manufacturer was specifically interested in recording the Total Harmonic Distortion applied to the supply current, which was done at various levels of load. For ease of comparison, the motor current (and therefore the drive power) was required to be exactly the same for each test load, both with and without a filter fitted (highlighted in orange). The table of results for a 22KW VSD are shown below;

The surprising finding from these results can be seen highlighted in red; at 22KW full load, the mains current is reduced from 42.4A without the filter to 32A with the filter, a reduction of 25%.

These findings were replicated with each VSD tested, the results for a 22KW drive and a 30KW drive of a different manufacturer are shown below;





A popular misconception is that since the measured power (rms or apparent power) is the same with and without a filter fitted, then the cost of the energy consumed will be the same with or without a filter. This is not so.

Electricity meters do indeed display power consumption in kilowatt hours (KWh). However, scrutiny of the EU legislation which applies to Electricity meters installed within the EU

	Output Power (KW)	Power Factor	Power (KW)	S (KVA)	Q (KVAr)	I (A) Line	I (A) Motor
Without	1	0.53	1.17	2.19	1.85	2.9	8.8
With REOWAVE Passive		0.16	1.19	7.56	7.46	11	8.9
Without	2	0.29	2.23	7.68	7.35	11.1	9.18
With REOWAVE Passive		0.57	2.24	3.9	3.2	5.3	9.15
Without	5	0.63	5.27	8.35	6.47	11.6	11.4
With REOWAVE Passive		0.62	5.29	8.53	6.69	12.2	11.4
Without	10	0.7	10.32	14.78	10.59	20.9	17.6
With REOWAVE Passive		0.88	10.37	11.85	5.72	16.8	17.1
Without	15	0.72	15.25	21.12	14.62	29.9	31.5
With REOWAVE Passive		0.96	15.34	15.95	4.37	22.7	31.5
Without	20	0.74	20.38	27.46	18.4	39.1	37.6
With REOWAVE Passive		0.99	20.49	20.65	2.62	29.7	37.3
Without	22	0.75	22.34	29.69	19.55	42.4	40
With REOWAVE Passive		0.99	22.48	22.61	2.46	32	39.6
Without	22.9	0.76	23.32	30.86	20.21	43.8	41.1
With REOWAVE Passive		1	23.41	23.51	2.09	33.7	41.8

Extract from 22KW Manufacturer A Harmonics Report CNW8981-45-400-50

(EN50470) tells us that since the mains voltage that a meter monitors does not / should not deviate, the measurement that is made and displayed as power consumption is actually RMS current.

As defined in parts 1 and 3 of EN50470 it can be seen that the RMS current that is measured by compliant meters should be accurate from minimum to maximum rating, with power factors between 0.5 and 1.8 and with specified dc, even harmonic order distortion and odd harmonic distortion profiles.

Summary of Findings

In summary, within a very broad spectrum of the quality of supplied electrical energy, the consumer is actually charged for the RMS current drawn from the supply. Therefore in the tests that REO have made on various drive sizes and of different manufacturer, over the half to full load operating range, the use of a REOWAVE Passive harmonic filter reduces the paid-for energy consumption of the power driven system by between 19.1% and 24.5%.

It is anticipated that the energy consumption reductions that have been observed will be applicable to Variable Speed Drives which use a B6 input rectifier, however since this is the most cost effective design for obtaining DC power which is required within the drive, it is estimated that the majority of drives within the medium power range will be of this design.

Potential Impact

From the International Energy Association report "Walking the Torque" published in 2011 the following statistics in relation to the European Union were published;

Electric Motor Driven Systems (EMDS) = 89 Million

Total running hours per year = 2525

Equivalent Full-Load Hours per year = 1478

Energy Consumption per year = 824TWh

Proportion of medium (0.75-375KW)EMDS
Consumption = 67.6%

Average EMDS = 8.2KW

It was stated that the proportion of EMDS which combined a Variable Speed Drive (VSD) in 2012 was 20% and that this was predicted to increase to 40% by 2020

We can therefore suggest that the energy consumption from medium sized EMDS by 2020 is predicted to be 557 TWh/a
(67.6% x 824 TWh/a = 557 TWh/a)

We can also suggest that the average load operation of EMDS is 1478 / 2525 = 59%

Using an energy reduction figure lower than those seen practically in the tests performed by REO of 20%, it can be seen that the maximum potential energy saving that could be achieved if the predicted 40% of Motor Driven Systems that will use a Variable Speed Drive, if they were also fitted with a harmonic filter, an annual 44.56 TWh reduction in energy consumption could be achieved;

20% x 557 x 40% (2020 proportion of EMDS with VSD) TWh/a = 44.56 TWh/a

Recommendation

Since (anecdotally) over 99% of all existing VSD designs will meet the IE1 efficiency level proposed in the Ecodesign for power drive systems legislation EN 50598 that is intended for commencing from 1st January 2018, there will be negligible impact made on reducing electricity consumption and subsequently influencing the EU target of reducing CO_2 emissions by 2020.

It is proposed that an amendment to EN 50598 be requested. That it be mandated that all VSDs from 1st January 2018 should meet IE2 levels, or should be at least IE1 energy efficient and be equipped with a harmonic filter.

At least by making this amendment, some impact will be made upon on reducing electricity consumption and subsequently influencing the EU target of reducing CO_2 emissions by 2020. Whilst it is completely unrealistic to say that an energy reduction of 44.56 TWh/a could be achieved by 2020, any proportion of this that were to be achieved would be an improvement on the present situation.

Points for Consideration

Alternative Solutions

On page 5 of this document, it was noted that REO had selected three product types for which to perform tests;

i. Good EMI mitigation / low cost
ii. Very good EMI mitigation / medium cost
iii. Excellent EMI mitigation / higher cost

The tests referenced here relate to the “Excellent EMI mitigation / higher cost” product category. It should therefore be noted that products within the other two mitigation and cost categories also deliver energy savings but these are of a lower order than those described here.

Internal VSD Filtering

It should be pointed out that a Harmonic Filter contains both inductive and capacitive components which a VSD input stage may also contain in varying configurations. In practical applications this could alter the performance of the Harmonic Filter and consequently the energy saving results that are achievable.

Whilst both the 22KW VSD from Manufacturer A and the 30KW from Manufacturer B referenced in the test results here, both contained internal EMC filtering which may not be the case with all VSDs.

Power Supply Quality

The testing environment that was used to make the tests referred to here, was as per the specification outlined in EN61800-3; a three phase supply of unity power factor and less than 1% total harmonic distortion.

In practical applications the VSD three phase supply is likely to already contain a degree of harmonic distortion and also have a power factor less than 1 which may or may not have been artificially altered using some form of power factor correction.

Whilst it is believed that in the majority of situations, these factors should not prevent a harmonic filter from delivering the sort of results that have been referenced here, it is worth noting that there may be supply conditions that do impact the energy saving results that are achievable.

References

“Walking the Torque” (International Energy Efficiency Information Paper May 2011)
Hugh Falkner & Shane Holt

EN61800-3 Adjustable speed electrical power drive systems
British Standard

EN 61000-3-2 Electromagnetic Compatibility for Low Voltage Systems (<16A)
British Standard

EN 61000-3-12 Electromagnetic Compatibility for Low Voltage Systems (16-75A)
British Standard

EN50470-1-2006 Electricity Metering Equipment (ac)
British Standard

EN50470-3-2006 Electricity Metering Equipment (ac)
British Standard

Lot30 Motors CF Explanatory Notes
Gambica

22KW Manufacturer A Report Harmonics
CNW8981-45-400-50
REO

30KW Manufacturer B Report Harmonics
CNW8981-45-400-50
REO

Appendix 1

Pr50598 Ecodrive for Power Driven System – proposed efficiency levels from January 2018

Rated output power [kW]	IE1 Maximum power losses at 90% of the maximum speed and 100% of the maximum torque [W]	IE2 Maximum power losses at 90% of the maximum speed and 100% of the maximum torque [W]	IE1 Efficiency	IE2 Efficiency
0.12	100	75	83.3%	62.5%
0.18	104	78	57.8%	43.3%
0.25	109	82	43.6%	32.7%
0.37	118	89	31.9%	23.9%
0.55	129	97	23.5%	17.6%
0.75	142	107	18.9%	14.2%
1.1	163	122	14.8%	11.1%
1.5	188	141	12.5%	9.4%
2.2	238	179	10.8%	8.1%
3	299	224	10.0%	7.5%
4	375	281	9.4%	7.0%
5.5	479	359	8.7%	6.5%
7.5	583	437	7.8%	5.8%
11	784	588	7.1%	5.3%
15	1014	761	6.8%	5.1%
18.5	1212	909	6.6%	4.9%
22	1413	1060	6.4%	4.8%
30	1866	1400	6.2%	4.7%
37	2262	1697	6.1%	4.6%
45	2712	2034	6.0%	4.5%
55	3252	2439	5.9%	4.4%
75	4370	3278	5.8%	4.4%
90	5193	3895	5.8%	4.3%
110	5582	4187	5.1%	3.8%
132	6679	5009	5.1%	3.8%
160	8058	6044	5.0%	3.8%
200	10028	7521	5.0%	3.8%
250	12445	9334	5.0%	3.7%
315	15674	11756	5.0%	3.7%
355	17628	13221	5.0%	3.7%
400	19866	14900	5.0%	3.7%
500	24794	18596	5.0%	3.7%
560	27771	20828	5.0%	3.7%
630	31224	23418	5.0%	3.7%
710	35187	26390	5.0%	3.7%
800	39637	29728	5.0%	3.7%
900	44564	33423	5.0%	3.7%
1000	49521	37141	5.0%	3.7%

Appendix 2

Extract from 22KW Manufacturer A Report Harmonics CNW8981-45-400-50

used filter	inverter output power	power faktor	measured power (filter input)			mains current	motor current
			P [kW]	S [kVA]	Q [kVAr]		
with REOWAVEpassive	1,0kW	0,16	1,19	7,56	7,46	11,0A	8,9A
without filter		0,53	1,17	2,19	1,85	2,9A	
with REOWAVEpassive	5,0kW	0,62	5,29	8,53	6,69	12,2A	11,4A
without filter		0,63	5,27	8,35	6,47	11,6A	
with REOWAVEpassive	10,0kW	0,88	10,37	11,85	5,72	16,8A	17,5A
without filter		0,70	10,32	14,74	10,59	20,9A	
with REOWAVEpassive	15,0kW	0,96	15,34	15,95	4,37	22,7A	31,5A
without filter		0,72	15,25	21,12	14,62	29,9A	
with REOWAVEpassive	22,0kW	0,99	22,48	22,61	2,46	32,0A	39,8A
without filter		0,75	22,34	29,69	19,55	42,4A	
with REOWAVEpassive	26,6kW (over load)	1,00	27,30	27,39	2,23	39,7A	47,0A
without filter		0,77	27,00	35,13	22,48	50,4A	

Appendix 3

Extract from 30KW Manufacturer B Report Harmonics CNW8981-45-400-50

used filter	inverter output power	power faktor	measured power (filter input)			mains current	motor current
			P [kW]	S [kVA]	Q [kVAr]		
with REOWAVEpassive	5,0kW	0,49	5,19	10,55	9,19	14,9A	15,7A
without filter		0,66	5,14	7,84	5,92	11,0A	
with REOWAVEpassive	10,0kW	0,79	10,34	13,12	8,08	18,4A	20A
without filter		0,71	10,16	14,39	10,19	20,8A	
with REOWAVEpassive	15,0kW	0,92	15,41	16,83	6,75	23,7A	26,8A
without filter		0,74	15,09	20,40	13,73	29,3A	
with REOWAVEpassive	20,0kW	0,97	20,34	20,97	5,08	29,6A	37,6A
without filter		0,76	20,18	26,48	17,14	38,3A	
with REOWAVEpassive	25,0kW	0,99	25,43	25,61	3,03	36,2A	44,9A
without filter		0,78	25,03	32,15	20,18	46,5A	
with REOWAVEpassive	30,0kW	1,00	30,73	30,74	0,80	43,4A	52,6A
without filter		0,79	30,08	38,03	23,28	55,6A	