Effizienz von elektrischen Antriebssystemen in industrieller Anwendung

Kurze Vorstellung

Adalberto Jose Rossa

- Dipl. Ing. Elektrotechnik, 25 Jahre Erfahrung im Bereich Antriebstechnik
- Leiter WEG Automation R&D Center, Freiburg (DE)
- Bis Dezember 2013 Manager IGBT & BIP Stacks bei Infineon Technologie AG, Warstein (DE)
- 1990-2011: Manager F&E Motor Drives bei WEG Automation, Jaragua do Sul Brasilien
- **Seit 2007: Mitglied “Canadian Standards Association” (CSA), “Technical Subcommittee on Variable Frequency Drives C838”, Toronto (CA)**

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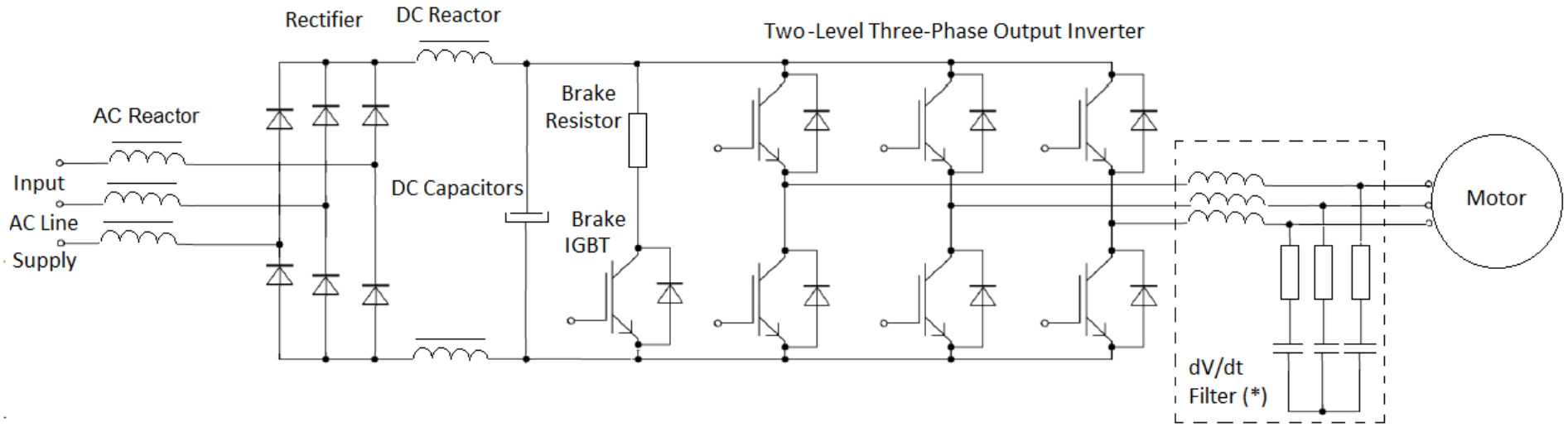
  - CSA C838-13
  - Ökodesign-Richtlinie (EU)
- Typische Energieverlust eines FUs
- Verbesserung der Effizienz eines FUs u. Trade-offs
- Fazit

General Purpose Drives (GPD) - FU

Standard-Topologie (2-Level)



VFD = Variable Frequency Drives ≡ FU

(*) Der Filter dV/dt ist ein “Zusatzteil” – Anwendung nur bei längeren Motorkabeln

Allgemeine Anforderungen

- **Oberwellen (Line Harmonics)**
  - IEC 61000-3-12: Limits for harmonic currents …input current >16 A and ≤ 75 A per phase
- **Sicherheit**
  - IEC 61800-5-1, -5-2: Safety requirements
  - UL508C: Power Conversion Equipment
- **EMV**:
  - IEC 61800-3: EMC and tests
- **Gehäuse / Umweltbedingungen**
  - IEC 60529: IP Codes
  - 60721-3-1, -2, -3: environmental conditions
- …

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C838-13

Canadian Standard Association (CSA)

C838-13: Energy efficiency test methods for three-phase variable frequency drive systems (*)

- Technical Committee on Industrial Equipment
- Subcommittee on Variable Frequency Drives
- Test lab from Hydro-Quebec, Montreal
- Erschienen März, 2013

(*) http://shop.csa.ca/en/canada/energy-efficiency/c838-13/invt/27035302013

C838-13

Scope

- Testablauf, damit man den elektrischen Wirkungsgrad eines VFD-Systems bei variierendem Drehmoment und variierender Drehzahl messen kann
- Nenn-Spannung bis 750V
- Keine Klassifizierung

6 Efficiency requirements

At present, requirements for minimum efficiency levels, regulatory or otherwise, are not being contemplated for the first version of this Standard due to a lack of sufficient information and data to make such a judgment.

C838-13

Prüfverfahren

- Ausgang-Eingang Messverfahren
- Parameter/Einstellungen VFD :

(a) control type (volts per hertz, vector, direct torque, etc.);
(b) carrier frequency (default setting: y/n; test setting: hz; and/or bandwidth: hz);
(c) voltage boost setting;
(d) minimum speed (for motor);
(e) maximum speed (for motor);
(f) current limit;
(g) autotune (yes/no);
(h) flux optimization (yes/no); and
(i) external filters, reactors.

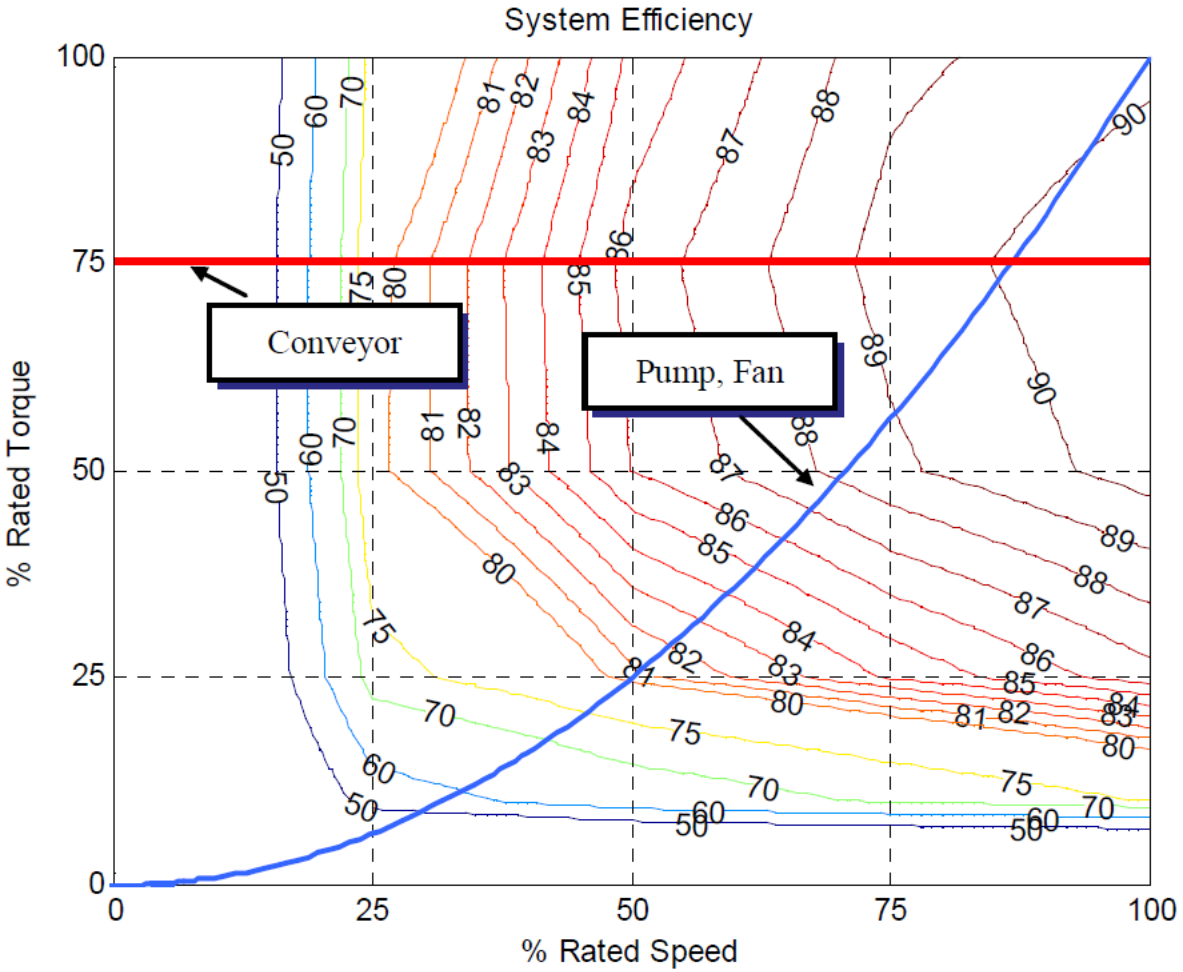
C838-13

Messpunkte: Frequenz und Drehmoment (20 Punkte)

Points	1	2	3	4	5
Frequency (%)	100	100	100	100	100
Torque (%)	100	75	50	25	10
Points	**6**	**7**	**8**	**9**	**10**
Frequency (%)	75	75	75	75	75
Torque (%)	100	75	50	25	10
Points	**11**	**12**	**13**	**14**	**15**
Frequency (%)	50	50	50	50	50
Torque (%)	100	75	50	25	10
Points	**16**	**17**	**18**	**19**	**20**
Frequency (%)	25	25	25	25	25
Torque (%)	100	75	50	25	10

C838-13

Kurven: elektrischen Wirkungsgrad



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Ökodesign-Richtlinie

- Anforderungen an die umweltgerechte Gestaltung von energieverbrauchsrelevanten Produkten (ErP)
- IEC 60034-30 (2008): AC induction motors eff. 0.75...375 kW
  - Standard Efficiency IE1
  - High Efficiency IE2
  - Premium Efficiency IE3
  - Super Premium Efficiency IE4
- **IEC 60034-2-1 (2007):** Standard methods for determining losses and efficiency from tests – motors wo/VFD

Name	Region	Requirement	Power	Due Date
ErP - Stage 1	Eurozone	IE2 motors	0,75 - 375 KW	**June 2011**
ErP - Stage 2	Eurozone	IE3 motors **or** IE2 motors + VFD	7,5 - 375 KW	**2015**
ErP - Stage 3	Eurozone	IE3 motors **or** IE2 motors + VFD	0,75 - 375 KW	**2017**

Ökodesign-Richtlinie

In Bezug auf FUs oder FUs-gesteuerte Motoren:

- Effizienz von AC-Induktionsmotor mit FU:
  - **IEC/TS 60034-2-3 Ed. 1.0:** Rotating electrical machines - Part 2-3: Specific test methods for determining losses and efficiency of converter-fed AC induction motors – 1st publication 2014 (TC 2):
    - Motor losses with VFD: **summation of losses** (preferred)
    - IE Classes of a converter fed motor (IE10 up to IE19)
- Lot 30: Produkte in Motor-Systemen: FU u. Motoren

CENELEC CLC/TC 22X

CLC/TC 22X Scope

To prepare standards dealing with power electronics.
The standards will deal with equipment, their component parts (especially electronic devices) and their extension to the system aspect. Standards for power converters interfacing general power systems to dedicated systems, for example railways, shall be dealt with jointly by TC 22X and relevant product committees.
The following are excluded:
- converters for rolling stock;
- converters and charging equipment for electrical vehicles;
- emitters for telecommunication;
- dimmers for lighting.

Title & Task

CLC/TC 22X/WG 06

Energy efficiency in power drive systems

To prepare the standardization work in the field of energy efficiency in power drive systems. CLC-TC22X will coordinate the work with the task to be done at the IEC level in Joint working groups with IEC-TC2 and in the working group from IEC-SC22G dealing with the same topic.

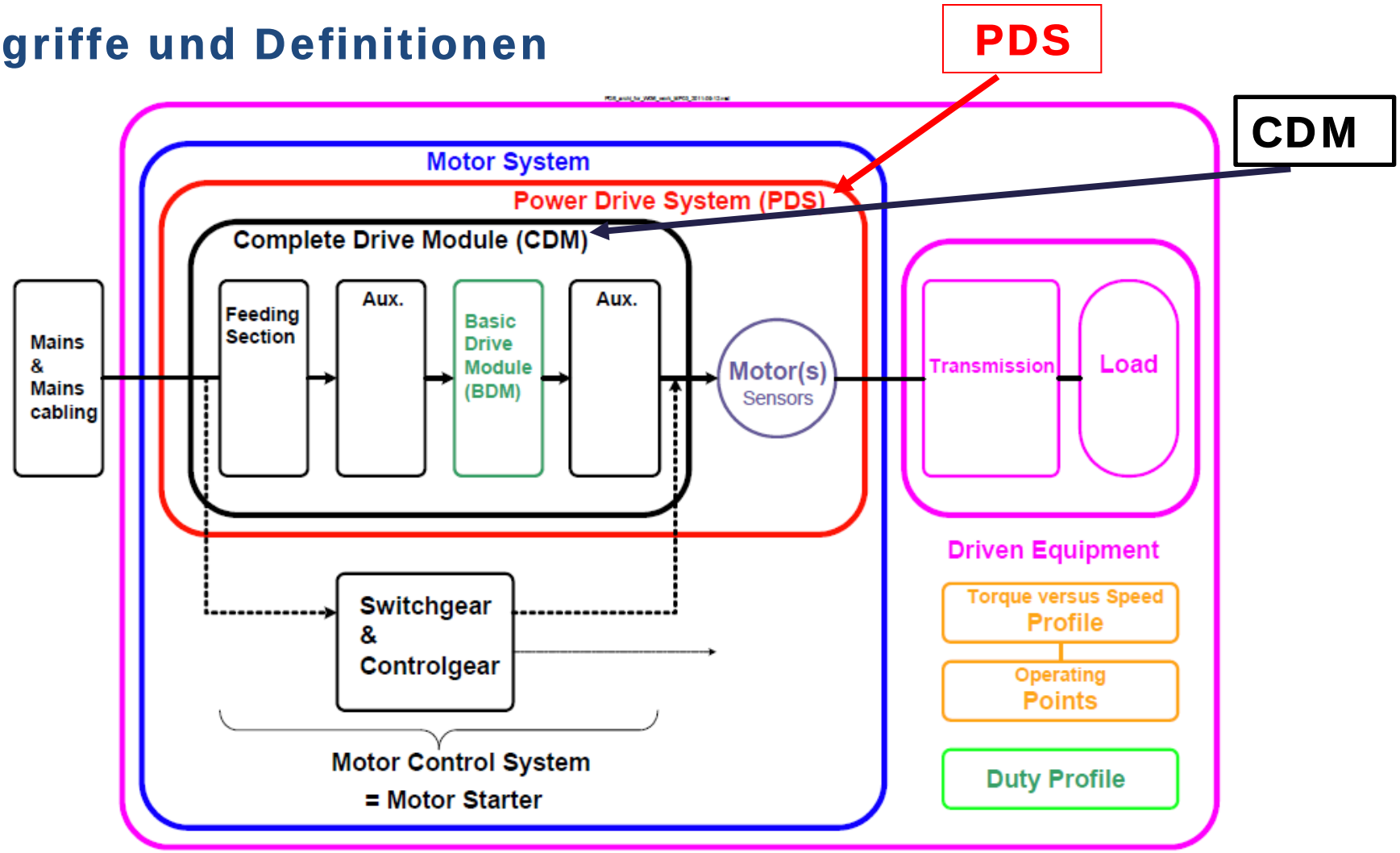
Quelle:
http://www.cenelec.eu/dyn/www/f?p=104:7:4335931309859214::::FSP_ORG_ID:863

prEN 50598-2:2013

Ecodesign for power drive systems, motor starters, power electronics and their driven applications - Part 2: Energy efficiency indicators for power drive systems and motor starters

prEN 50598-2:2013

Begriffe und Definitionen

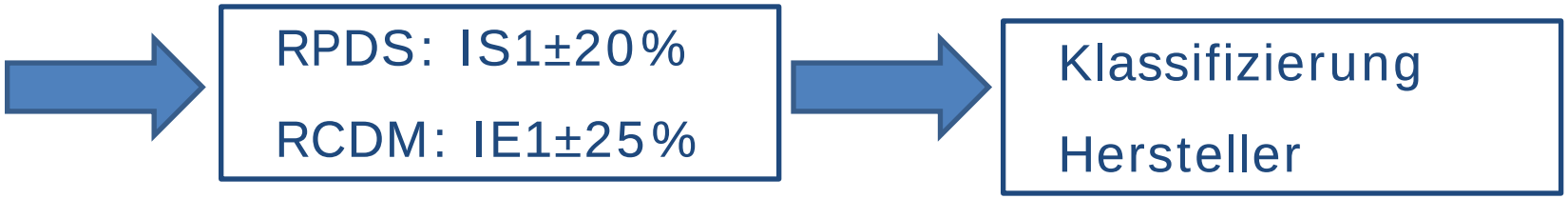


prEN 50598-2:2013

Referenz CDM (RCDM): Referenz-Kalkulation des Energieverlustes auf die Funktionsblöcke:

- Ausgang-Konverter - Wechselrichter
- Eingang-Gleichrichter
- DC-Link
- Netz-Drossel
- Steuerung (festgestellt 50W)

Nenn-Drehmoment und 90% der Nenn-Drehzahl



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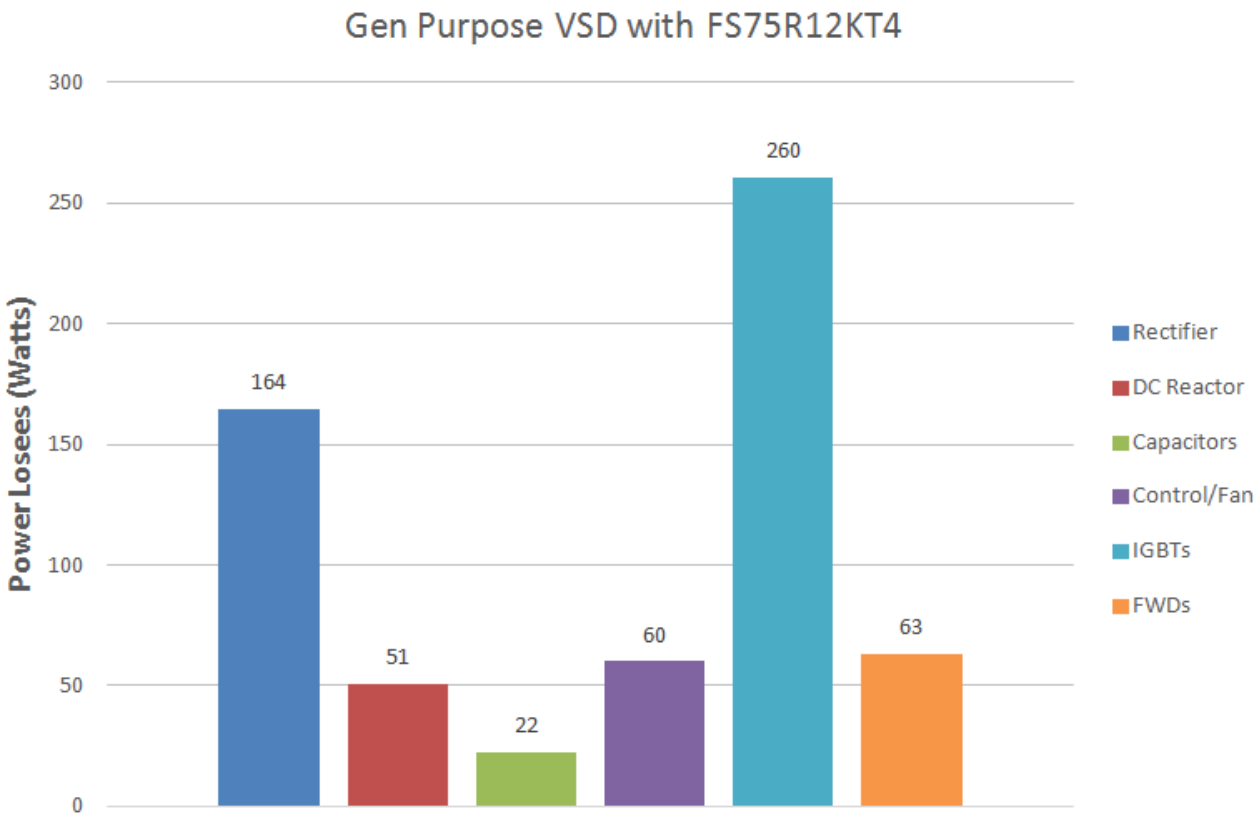
Typische Energieverlust

State-of-the-art FU 22 kW



Parameter	GPD
Line supply	400 V/50 Hz/Z=1 %
Rectifier	DDB6U144N16
DC reactor	6 %
DC capacitor	1410µF/400V
IGBT	FS75R12KT4
f_{sw} [kHz]	5
Udc [V]	621
Uout [V]	400
Modulation index (m)	0.91
Heatsink temperature [°C]	90
Motor type	AC-Induction
Fundamental Frequency [Hz]	50
Cos(φ)	0.85
η_{motor} [%]	92.3
Iout [Arms]	40.5
Motor output power [kW]	22

η_{CDM}= 97.44%

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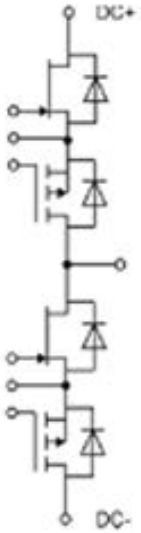
Maximierung der Effizienz

Möglichkeiten für den Frequenzumrichter

- Effizientere Komponenten
- Motoren
- Halbleiter (SiC, Si+SiC-FWD)
- Topologie Multilevel (NPC1, NPC2)
- Neue FU-Topologie
- Rückspeisung (AFE)

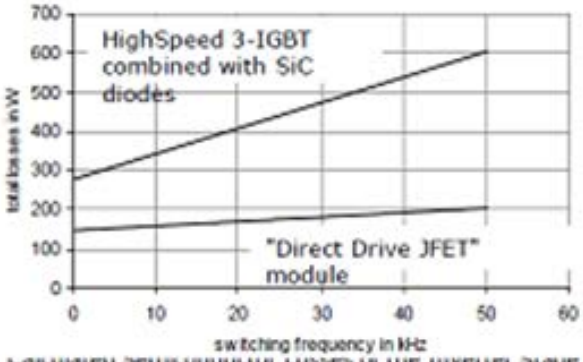
JFET SiC

SiC JFET 1200V Module



Voltage	RDSON	Sales Name
1200	35	FF45R12W1J1_B11

- Half Bridge Modules with NTC
  - Direct Drive Topology
  - Engineering Samples Q4 2011
- The SiC JFET Module can decrease overall Inverter Losses down to 1/3rd

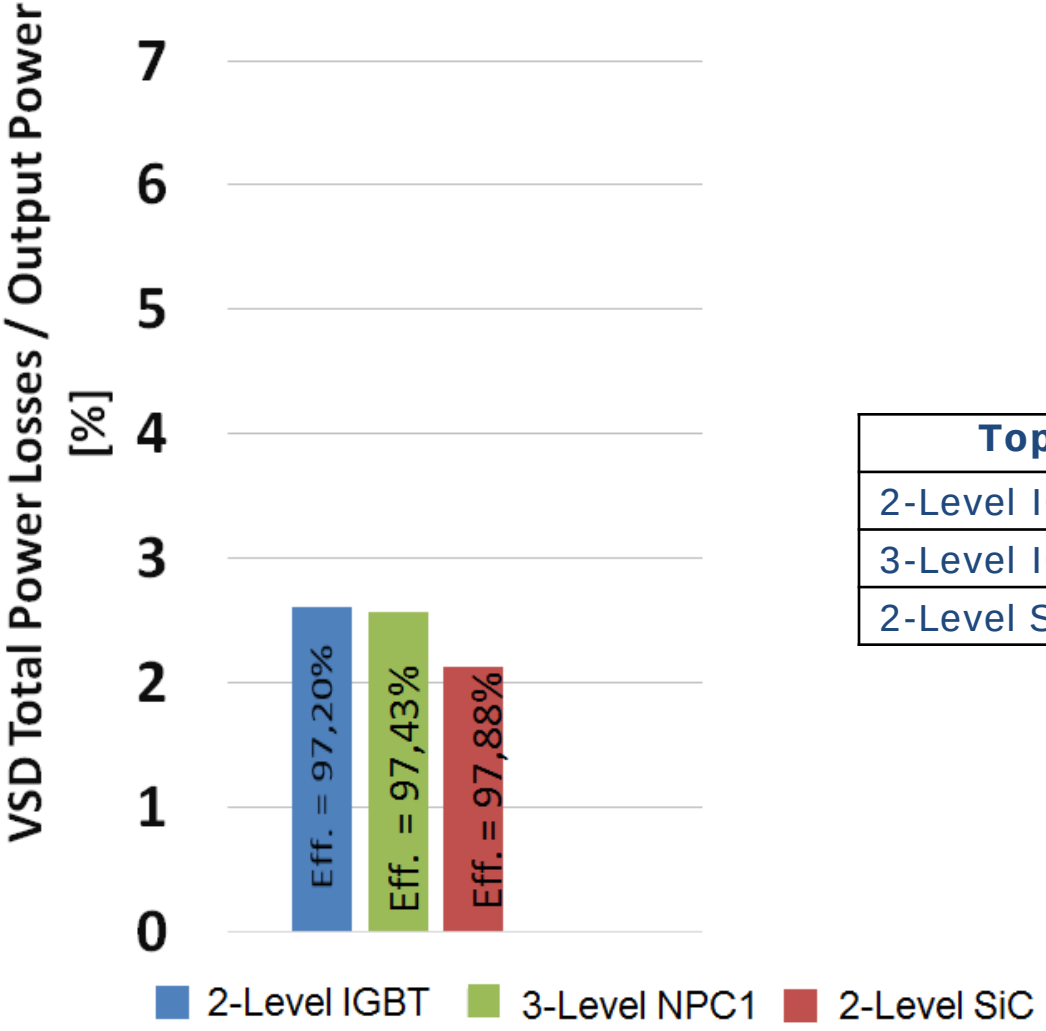


Calculated semiconductor losses of the inverter stage of a 22kVA 2-Level Converter (V_{DC}=600V, cosφ=0.9, m=1, T_j=125°C)

- In addition to the general purpose modules customized solutions in various platforms are in development

Gegenüberstellung - Verlust

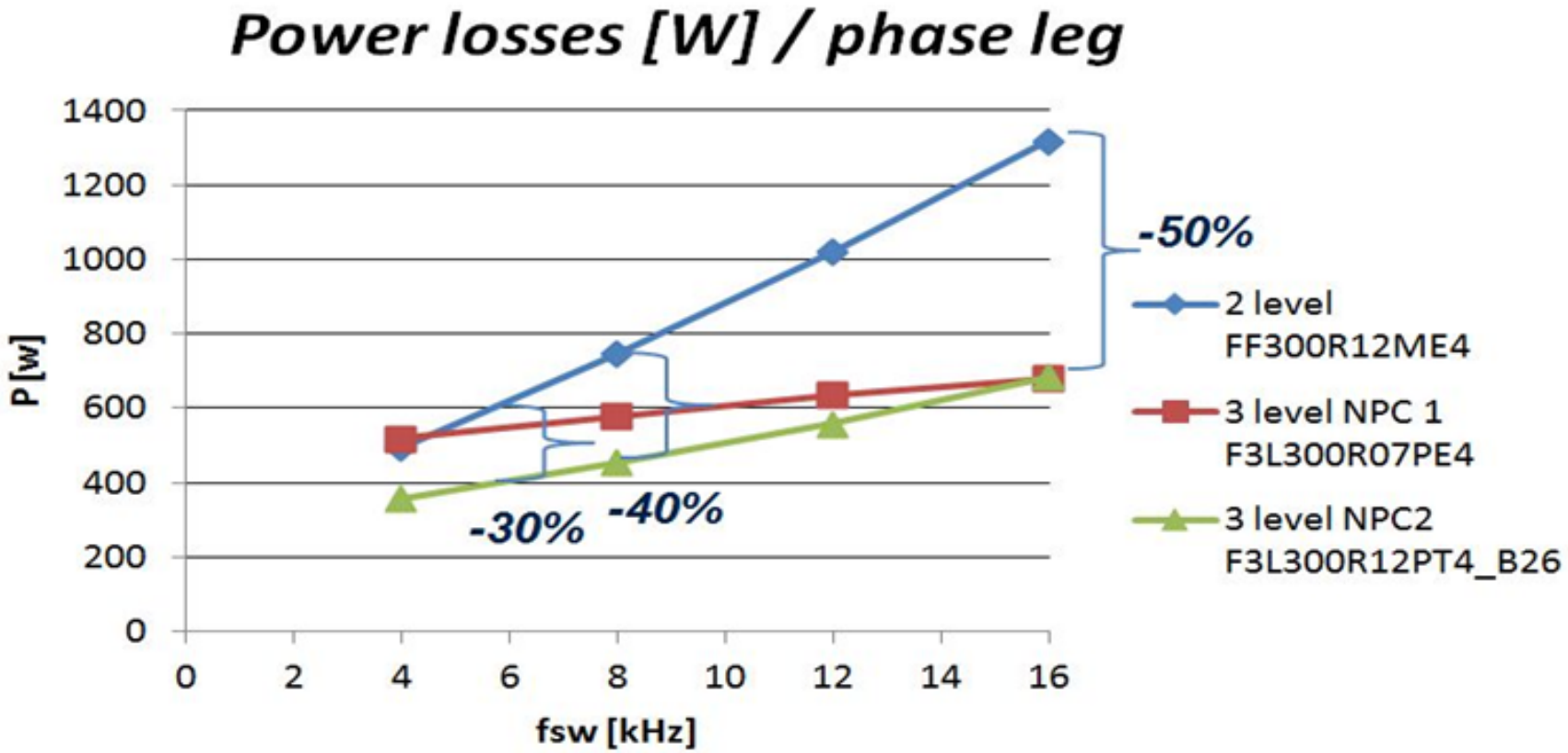
Gesamter Verlust FU 22 kW



Topologie	Module
2-Level IGBT	FS75R12KT4
3-Level IGBT (NPC1)	F3L75R07W2E3_B11
2-Level SiC JFET	45A SiC Switch

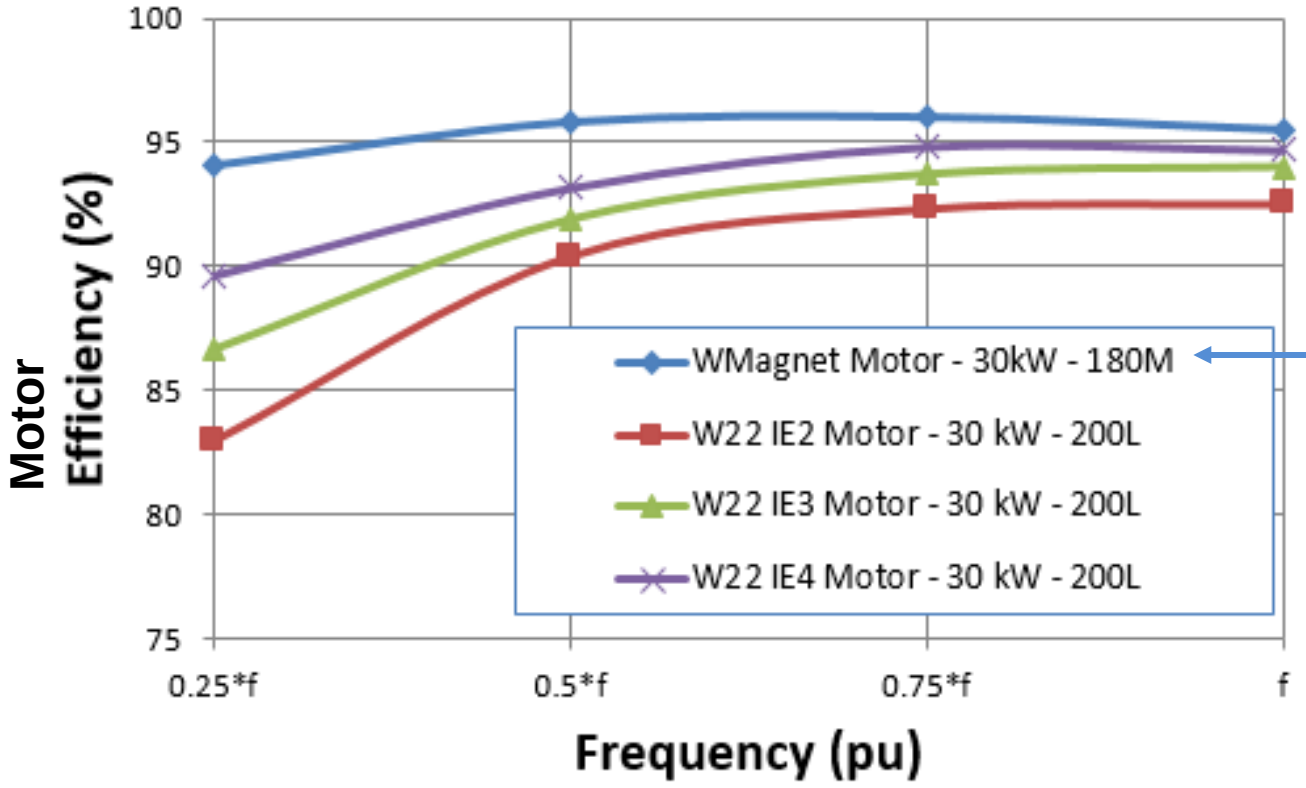
Topologie „3-Level x 2-level“

Gesamter Verlust IGBT+FWD



Effizienz bei niedrigeren Drehzahlen

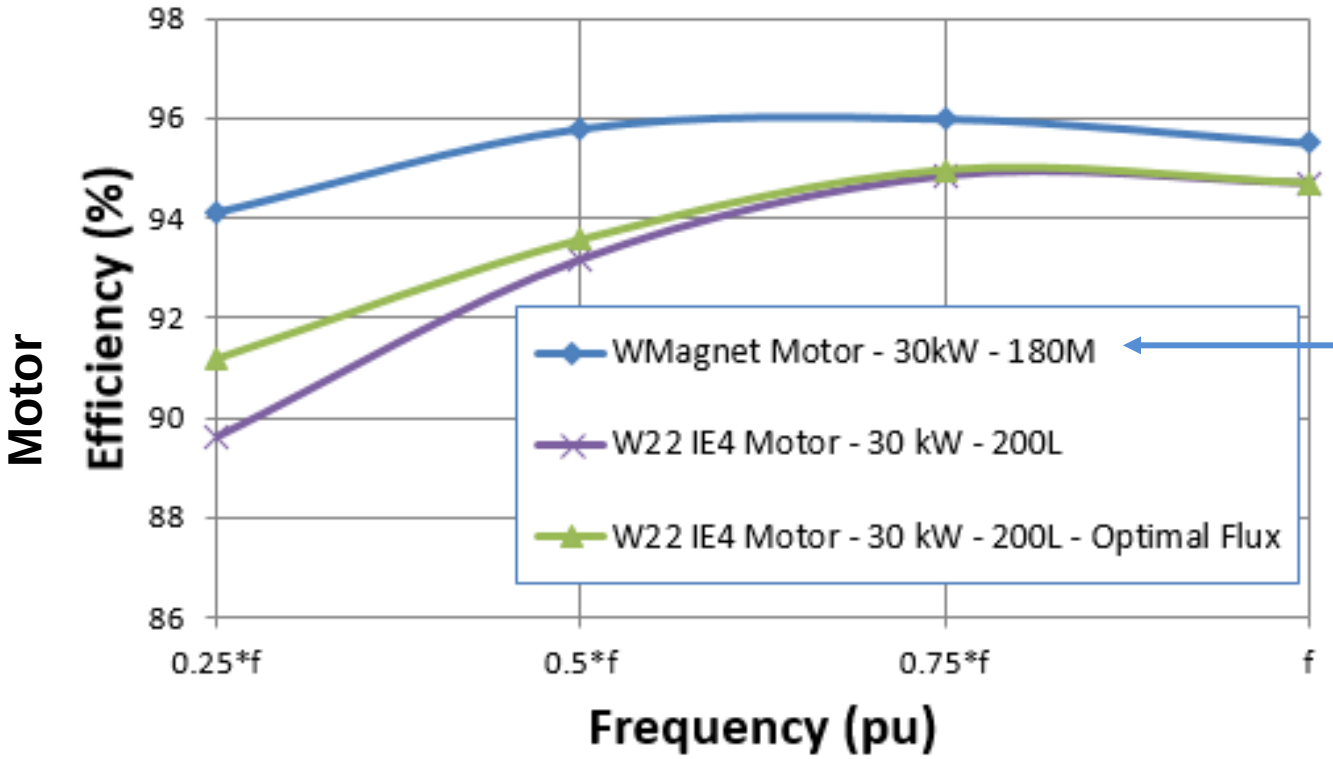
Motorklasse- und Typ – Beispiel 30 kW



Permanentmagnet - Motor

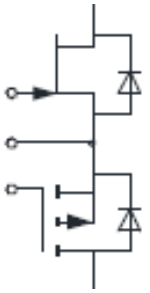
Effizienz bei niedrigeren Drehzahlen

Optimierung durch Motor IE4 u. Optimal-Flux™



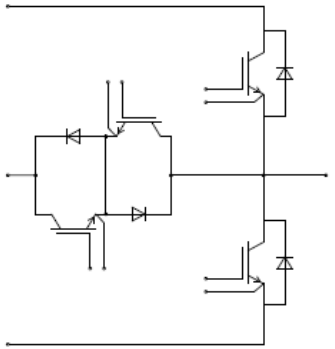
Permanentmagnet - Motor

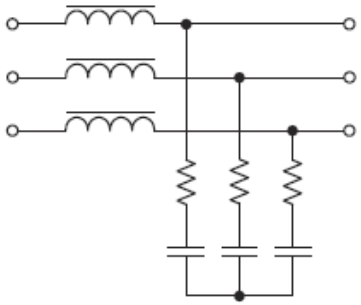
Trade-Offs

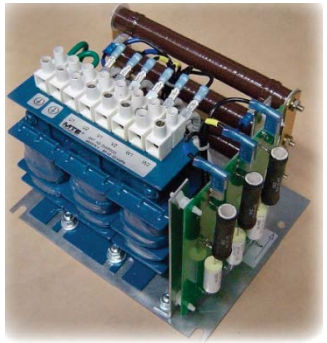


Steigende Effizienz

- Kosten (SiC, 3-Level))
- dU/dt > 5kV/µs mit SiC JFET/MOSFET
  - Stress des Motor-Isolationssystems → Filter, $V_{drop,}$ Verlust (Kernverluste, Dämpfung-Widerstände, Energierückgewinnung, ...)
  - Lebensdauer der Rollenlager↓
  - Leitungsgebundene Störausstrahlung ↑
- Komplexität, MTBF (3-Level)







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Fazit

- Anforderungen von Normen:
  - Effizienz-Prüfprotokoll/Kalkulationsprotokoll
  - Klassifizierung der FUs u. Motoren bzgl. der Effizienz (CDM: IEx; PDS: IESx)
- Systemvergleich bei Lastprofil (CDM/PDS)
- Abgleich: Kosten x Effizienz
- Bei höherer dU/dt (SiC JFET): Verstärkung des Motor-Isolationssystems u. Motor-Filters

Refereces

[1] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009,www.eurex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:285:0010:0035:en:PDF

[2] IEC 60034-30 ed1.0: Rotating electrical machines - Part 30: Efficiency classes of single-speed, three-phase, cage-induction motors (IE-code), www.iec.ch

[3] C838-13: Energy efficiency test methods for three-phase variable frequency drive systems, CSA standard, March 2013, http://www.csagroup.org/ca/en/services/codes-and-standards

[4] S. Araujo et al: Reducing expenditure with cooling in renewable power conversion systems with innovative SiC switches, CIPS 2012, Nuremberg, Germany

[5] D. Domes et al: 1st industrialized 1200V Sic JFET module for high efficiency applications, PCIM 2011, Nuremberg, Germany.

[6] A. J. Rossa et al: Inverter-Rated Motors: What they are and how to identify them, Switchgear & Drives Technical Forum, 2009, Hyatt Regency, Perth, Australia

[7] www.infineon.com/IPOSIM

[8] IEC/TS 60034-25 ed2.0 (2007-03): Rotating electrical machines - Part 25: Guidance for the design and performance of a.c. motors specifically designed for converter supply, www.iec.ch

[9] http://ecatalog.weg.net/files/wegnet/WEG-induction-motors-fed-by-pwm-frequency-converters-technical-guide-028-technical-article-english.pdf

[10] Y. Sozer et al: New Inverter Output Filter Topology for PWM Motor Drives, IEEE Transactions on power electronics, Vol. 15, No. 6, November 2000

[15] N. Hanigovszki et al: A Novel Output Filter Topology to Reduce Motor Overvoltage,

2004, IEEE

[16] A. J. Rossa: Mitigating Stray Currents in AC Drives Installations (Parts 1, 2 & 3), Drivesmag.com, 2011-2012

[17] R. Bayerer et al: Power Circuit design for clean switching, CIPS 2010, Nuremberg, Germany

[18] K. Vogel et al: “The effect, measurement and reduction of parasitic inductance in power electronic converter design”, PESA 2012, Sao Paulo