CSR / Environment

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DC Link Capacitor Life Prediction from FFT Analysis of Ripple Current

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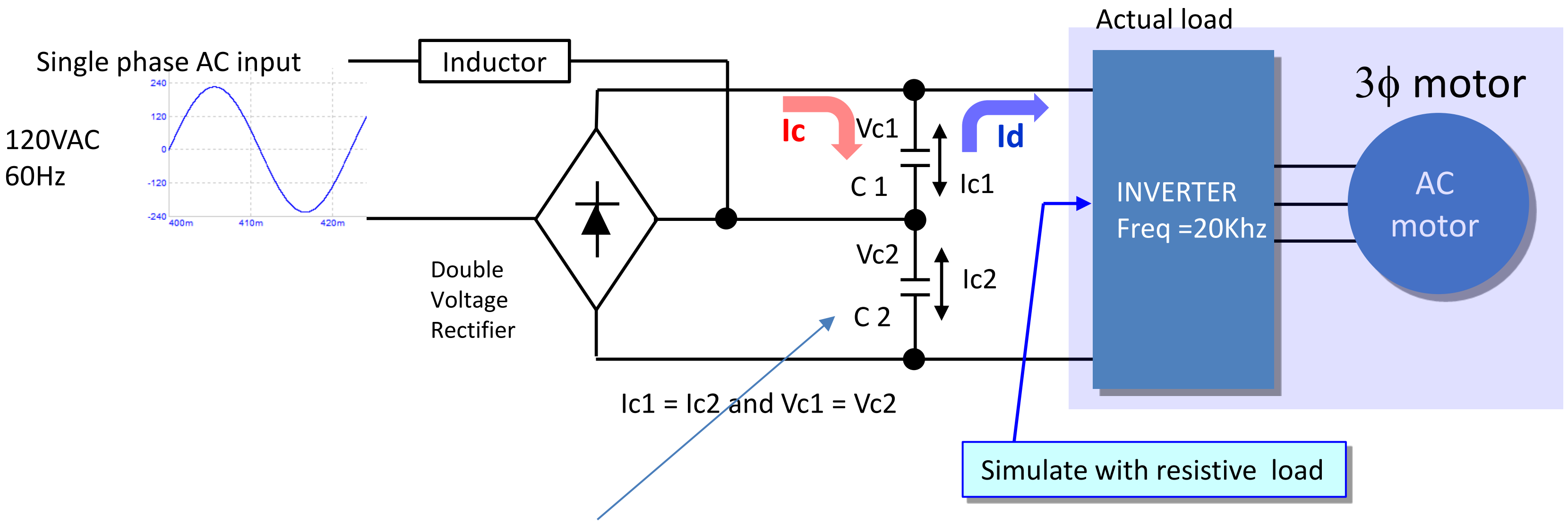
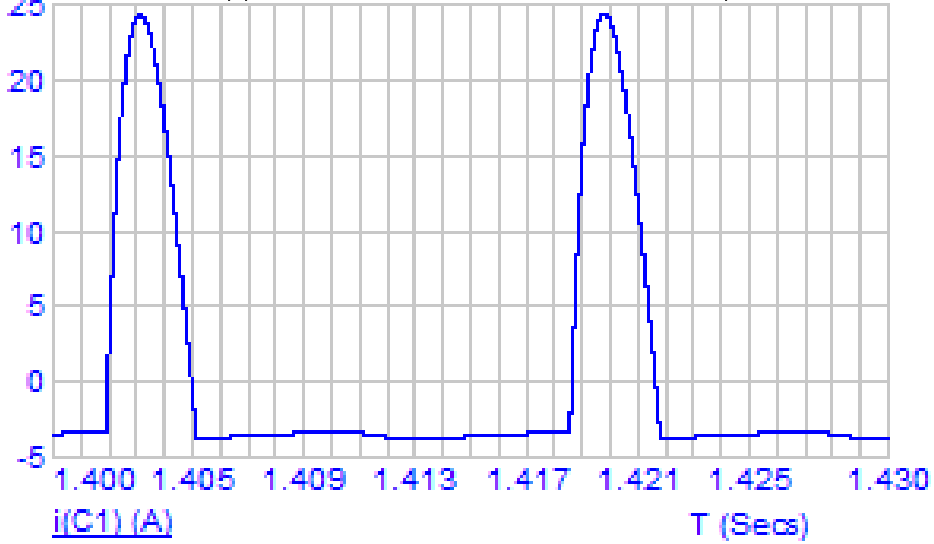
Green Technology DLCAP™

Contents

1. Typical double rectifier circuit for an appliance application.

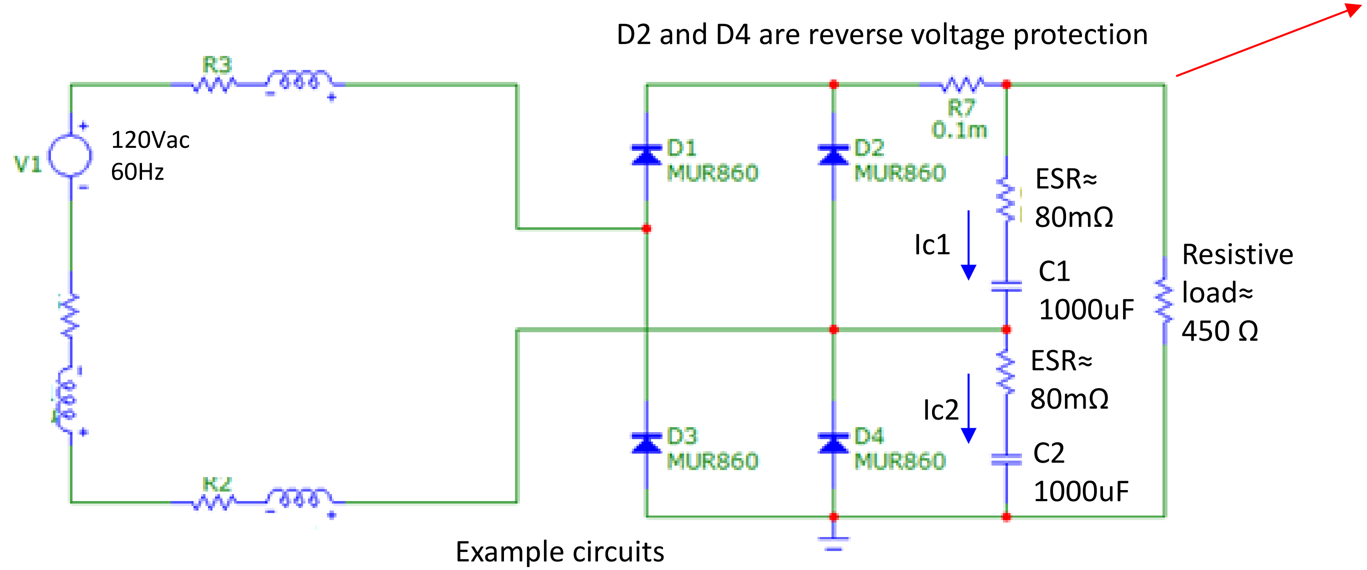


Actual ripple current at Ic1 = Ic2 with different phase

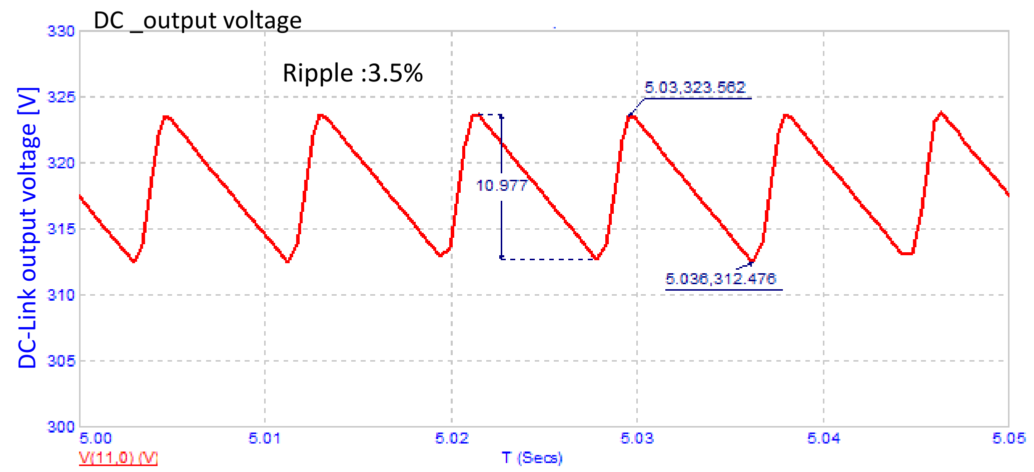


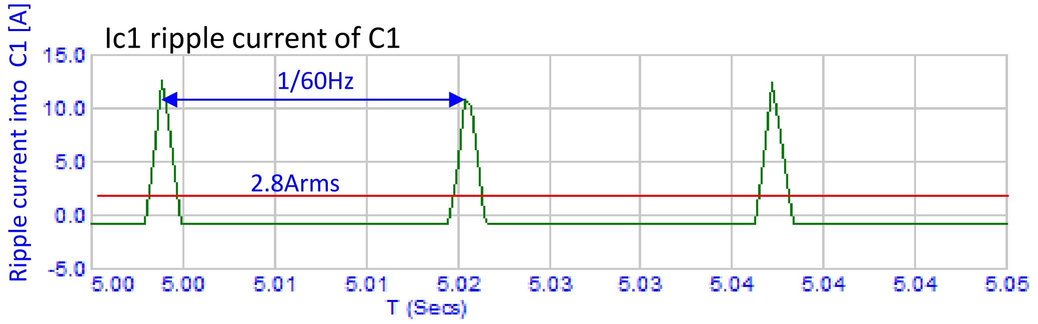
A rated ripple current in the data sheet is specified by a sin wave form (sin2πft). However, most of real world is a distorted wave form.

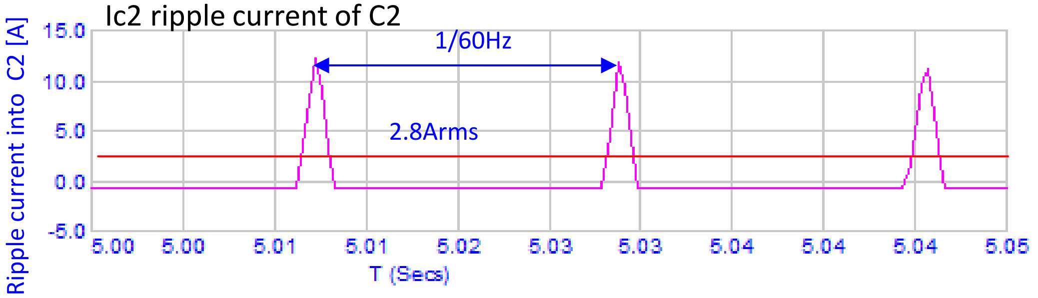
1.1 DC Link capacitor ripple current analysis with the SPICE simulation with resistive load.



Example circuits





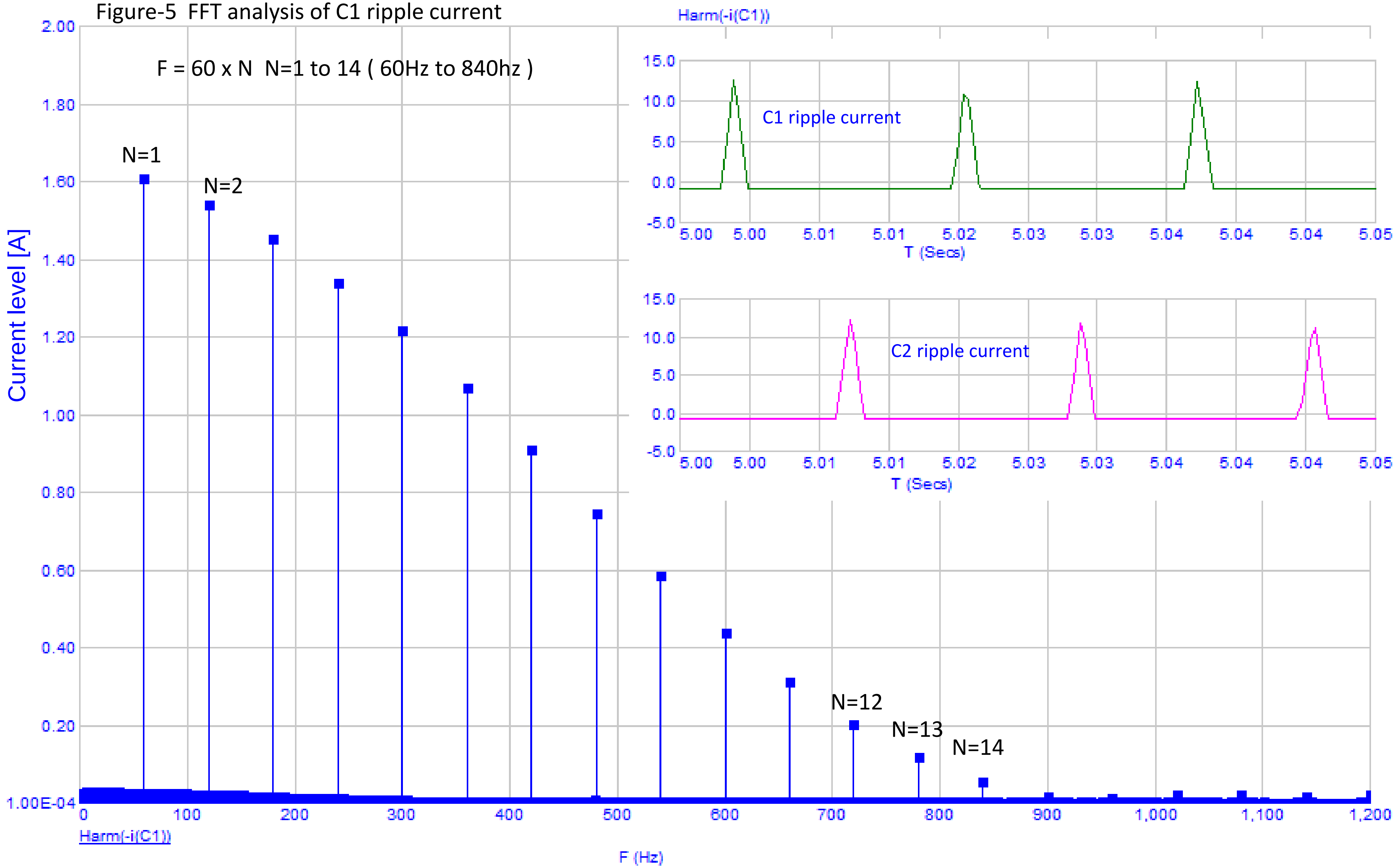


- AC 1nput 120Vac
- Output ripple voltage frequency:120Hz
- C1 and C2 ripple current frequency: 60Hz
- RMS ripple current can be simulated.
- Or can be calculated from FFT frequency components.
- The simulated RMS current of C1 is 2.8Arms

2. DC Link ripple current FFT analysis

Find out rms ripple current for each frequency to convert to a rated ripple current to predict a capacitor life.

Figure-5 FFT analysis of C1 ripple current



3. Ripple current calculation to convert the rated ripple current at 120Hz for provided FFT analysis data

The converted total RMS ripple current $\mathrm{Ix} = \sqrt{\sum_{n=1}^{14} \left(\frac{\mathrm{In}}{\mathrm{Kn}}\right)^2}$

Kn is the multiplier each frequency components for to the rated ripple current at 60H.
Figure-3 is created for Table -1 below. See data sheet of KMS series .

◆RATED RIPPLE CURRENT MULTIPLIERS

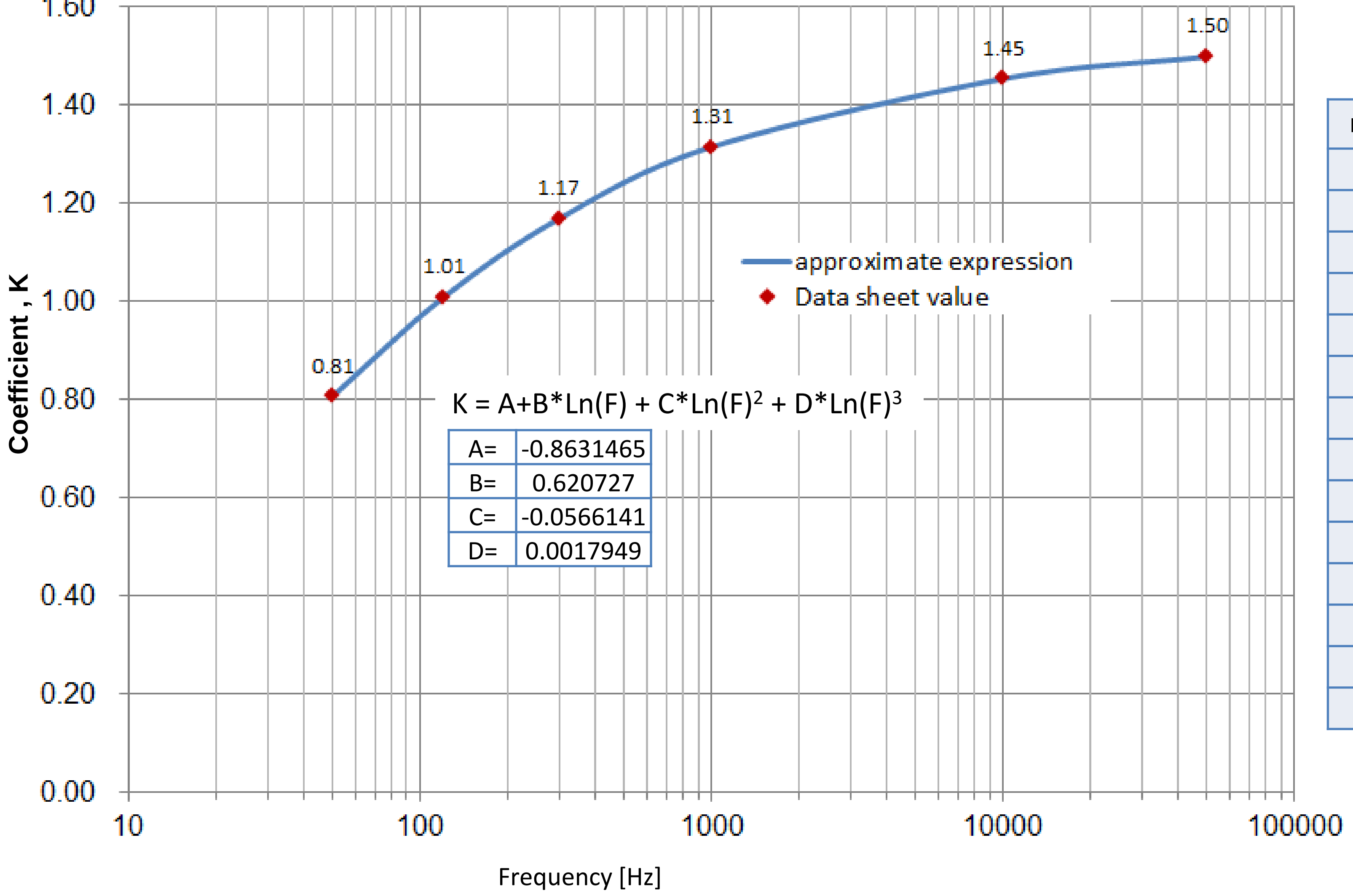
◎Frequency Multipliers Table-1 Coefficient: K

Frequency(Hz)	50	120	300	1k	10k	50k
160 to 250V_{dc}	0.81	1.00	1.17	1.32	1.45	1.50
315 to 450V_{dc}	0.77	1.00	1.16	1.30	1.41	1.43
500V_{dc}	0.70	1.00	1.16	1.30	1.41	1.43

Kn for each Frequency Fn, see Figure-4 shows the frequency multipliers graph which is cleated form approximate expression of Table-1 above.

3.1 Frequency Multiplier coefficient (K) Characteristics

Figure-6. Frequency multiplier



N14	Fn(Hz)	Kn
1	60	0.852
2	120	1.008
3	180	1.085
4	240	1.134
5	300	1.169
6	360	1.195
7	420	1.216
8	480	1.234
9	540	1.248
10	600	1.261
11	660	1.272
12	720	1.281
13	780	1.290
14	840	1.298

3.2 Converted RMS current to rated ripple current on the data sheet

Rated ripple current, Io = 2.66Arms at 120Hz

See page-7 Item.5 "What is the frequency Multiplier " in the report sent the " Whirlpool project-UCC 3-17-2014"

$$Ix = \sqrt{\left(\frac{1.13}{0.852}\right)^2 + \left(\frac{1.096}{1}\right)^2 + \left(\frac{1.0423}{1.085}\right)^2 \quad ---- \left(\frac{0.0601}{1.298}\right)^2} = \underline{2.53Arms}$$

KMS Series ◆STANDARD RATINGS

WV (Vdc)	Cap (μF)	Case size ϕD×L(mm)	tan δ	Rated ripple current (Arms/ 105℃, 120Hz)	Part No.
250	680	25.4×40	0.15	2.02	EKMS251VSN681MQ40S
	680	30×30	0.15	2.08	EKMS251VSN681MR30S
	680	35×25	0.15	2.19	EKMS251VSN681MA25S
	820	25.4×45	0.15	2.26	EKMS251VSN821MQ45S
	820	30×35	0.15	2.34	EKMS251VSN821MR35S
	1,000	25.4×50	0.15	2.53	EKMS251VSN102MQ50S
	1,000	30×40	0.15	2.66	EKMS251VSN102MR40S
	1,000	35×30	0.15	2.70	EKMS251VSN102MA30S

2.53A is less than the rated ripple current 2.66A rms.

See Figure-4

N= 1~14

Fn(Hz)	Kn	RMS [A]	[RMS/Kn]^2
60	0.852	1.13	1.757163
120	1.008	1.096	1.1823915
180	1.085	1.0423	0.9229947
240	1.134	0.9687	0.7300086
300	1.169	0.8811	0.5685148
360	1.195	0.7806	0.4266411
420	1.216	0.6739	0.3070296
480	1.234	0.5636	0.2087444
540	1.248	0.454	0.1322957
600	1.261	0.3493	0.0767612
660	1.272	0.2539	0.0398633
720	1.281	0.1704	0.0176861
780	1.290	0.1025	0.0063146
840	1.298	0.0601	0.0021452
			2.5255799

Source: Report by R.Holling / R.Ferreira 2/26/2014.
EKMS251VSN192MR40S-United Chemi-Con Lifetime-Estimation

4 Life Equation

$$Lx = Lr * 2^{\wedge}(To - Tx)/10 * 2^{\wedge}(\Delta To - \Delta T)/k * (Vo/Vx)^{4.4} \qquad Vo/Vx < 1.25$$

The foundation of life equation is based the Arrhenius' Law . However it will be slightly different by type of capacitors. Large screw type including snap-in type will be used following equation. We, Nippon Chemi-Con use the life equations based on the tremendous of life data to verify it. Total volume of production for small(SMD) to large (screw type) are approx., 1-2 billions pcs per/month.

Lx: Calculated Life
Lr: Rated life on the data sheet → 3000 hrs for KMS
To: Rated Temperature → 105℃
Tx: Ambient temperature
ΔTo: Specified by manufacture → 5℃ for KMS
ΔT: Self-heat. $\Delta To*(Ix/Io)^2$
Io: Rated ripple current
Ix: Actual ripple current.
NOTE: if ΔT has already been measured, use the number.

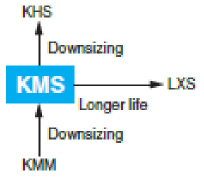
Vo: Rated voltage → 250V
Vx: Actual voltage → 140*√2 = 198V 250/198 = 1.26 → use 1.25
Vo/Vx = $(1.25)^{4.4}$ = 2.67

An example:

NIPPON CHEMI-CON **LARGE CAPACITANCE ALUMINUM ELECTROLYTIC CAPACITORS** Downsized snap-ins, 105℃

KMS Upgrade! Series

- For solar power generation
- Endurance with ripple current : 105℃ 3,000 hours
- Rated voltage range : 160 to 600V
- Capacitance range : 47 to 3,300µF
- Non solvent resistant type
- RoHS2 Compliant



600V Lineup!

Lr=3,000Hrs

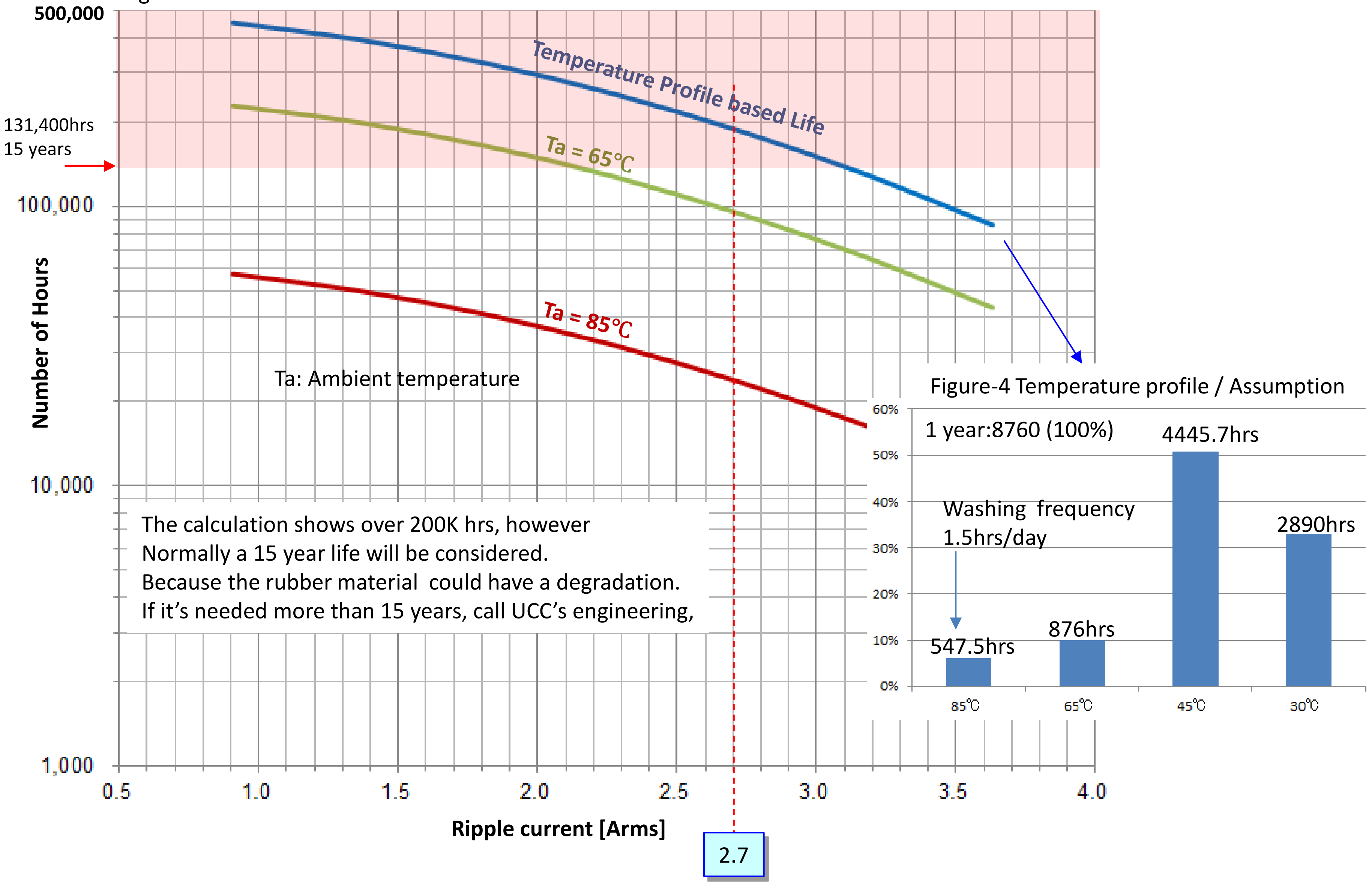
To=105°C

◆SPECIFICATIONS

Items	Characteristics			
Category Temperature Range	-25 to +105℃			
Rated Voltage Range	160 to 600V DC			
Capacitance Tolerance	±20% (M)			(at 20℃, 120Hz)
Leakage Current	I≦3√CV Where, I : Max. leakage current (µA), C : Nominal capacitance (µF), V : Rated voltage (V)			(at 20℃ after 5 minutes)
Dissipation Factor (tan δ)	Rated voltage (V DC)	160 to 400V	420 to 600V	
	tan δ (Max.)	0.15	0.20	(at 20℃, 120Hz)
Low Temperature Characteristics (Max. Impedance Ratio)	Rated voltage (V DC)	160 to 400V	420 to 600V	
	Z(-25℃)/Z(+20℃)	4	8	(at 120Hz)
Endurance	The following specifications shall be satisfied when the capacitors are restored to 20℃ after subjected to DC voltage with the rated ripple current is applied (the peak voltage shall not exceed the rated voltage) for 3,000 hours at 105℃.			
	Capacitance change	≦±20% of the initial value		
	D.F. (tan δ)	≦200% of the initial specified value (600V DC : ≦300%)		
	Leakage current	≦The initial specified value		
Shelf Life	The following specifications shall be satisfied when the capacitors are restored to 20℃ after exposing them for 1,000 hours at 105℃ without voltage applied. Before the measurement, the capacitor shall be preconditioned by applying voltage according to Item 4.1 of JIS C 5101-4.			
	Capacitance change	≦±15% of the initial value		
	D.F. (tan δ)	≦150% of the initial specified value		
	Leakage current	≦The initial specified value		

4.1 Case study of Calculated Life at Ta=85°C, 65°C and a Temperature Profile

Figure-3



5. Life prediction by a capacitor SPICE Thermal Model.

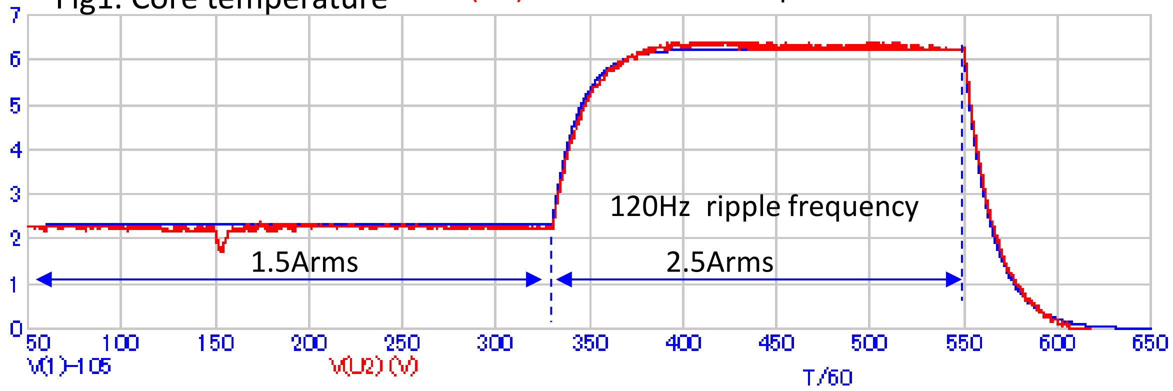
$$Lx=Lr*2^{(To-Tx)/10}*2^{(\Delta To-\Delta T)/k}*(Vo/Vx)^{4.4}$$

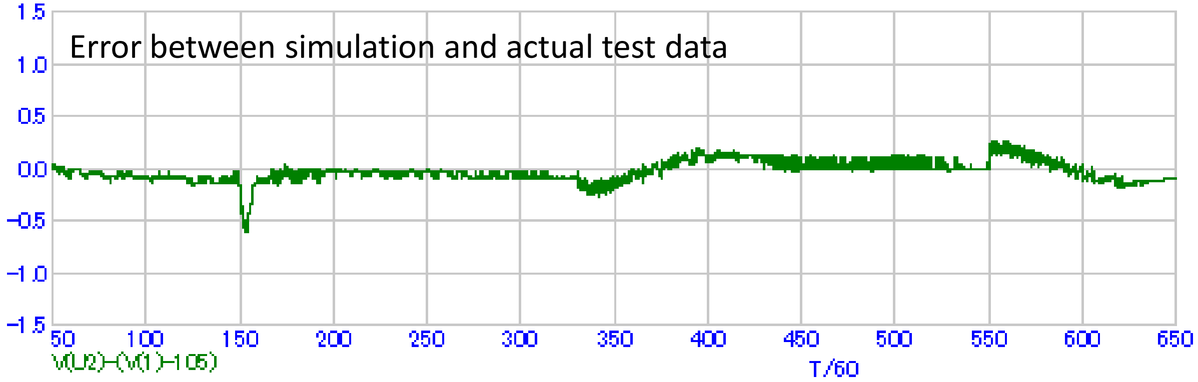
ΔT: Self-heat core temperature is a key parameter to calculate the life.

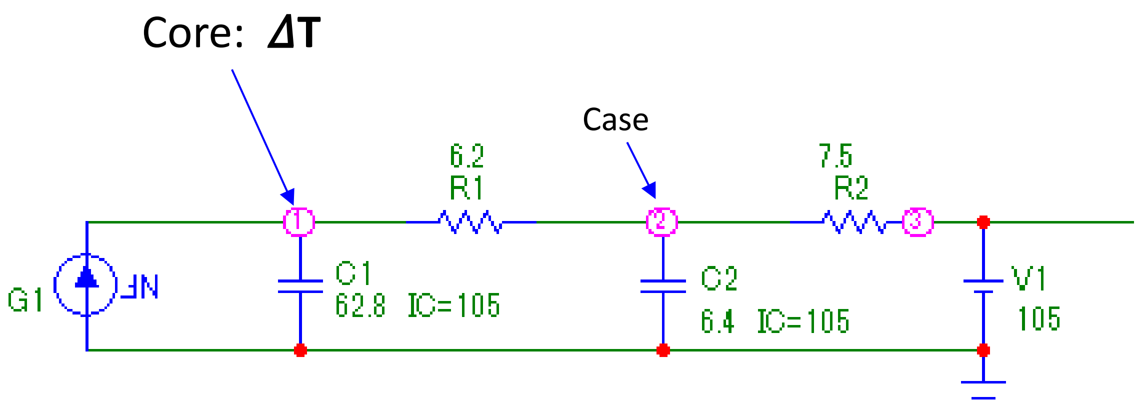
1) **Thermal model to simulate self-heat core temperature.**
2) **Actual temperature test data. (this is the bet way)**

Core Temperature:
V(1)-105 for simulated core temperature
V(U2) for actual core temperature measured

Fig1. Core temperature







SPICE Thermal Model for P/N EKMS451VSN471MA40S

Technical Point of Contact

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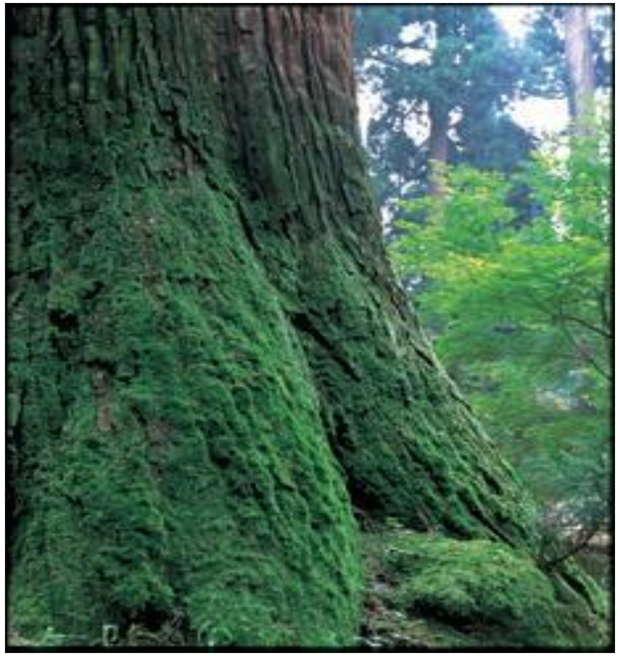

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Thank you

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