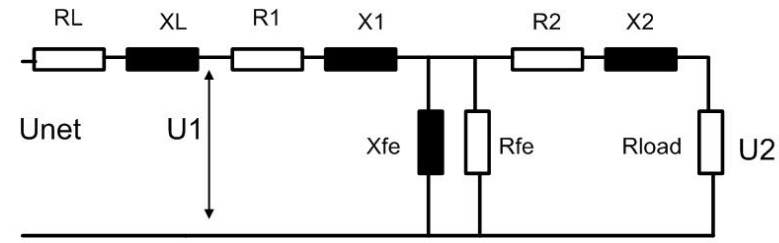
Topic1 / Design3

Designing inherently current limited single phase transformer 24V, 100A with integrated inductor

Genaral information

There are 2 constructions for creating a transformer with an integrated inductor:



Integrated inductor on the primary side

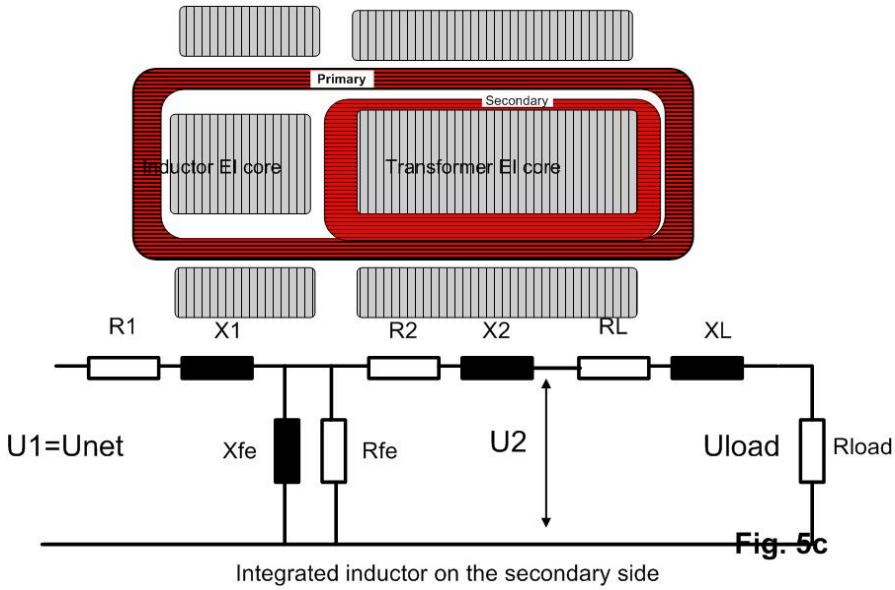
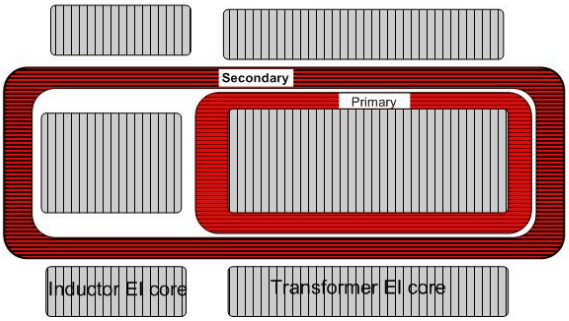


Fig. 5c

Integrated inductor on the secondary side

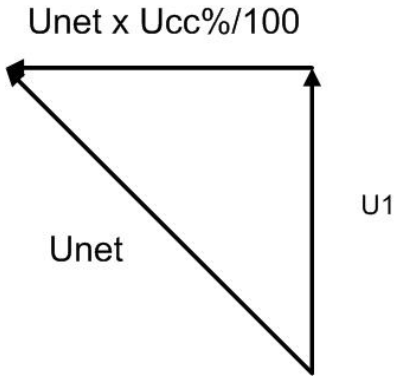


Normally the construction with the primary outside is used more often due to the fact that it protects the transformer part from voltage spikes, harmonics and it limits the inrush current. Note that the Rale Design Software doesn't support the design of the transformer with the integrated inductor full automatically. You have to design it in 2 steps; first the "transformer" and then the "inductor".
Assume the following operation mode:

- Unet = 400V, 60Hz
- Short-circuit current has to be Icc = 2 x Inominal; Ucc% = 50%
- 9 minutes @ Inominal, 1 minute @ Icc

For this operation mode the "transformer" input voltage is:

$$U1 = Unet \times (1 - (Ucc\%/100)^2)^{0.5} = 400 \times (1 - 0.5^2)^{0.5} = 346.4V$$



"Transformer" Input parameters

Primary	Voltage	346.4V -10% +24% (no-load at Unet +10%), 60Hz, sine wave
	Wire	Cu, round, single insulated
	Layer insulation	5 mil
	Final insulation	5 mil
Secondary	Nominal output rms voltage	24V on load
	Nominal current	100A
	Wire	Cu, square, single insulated
	Layer insulation	No
	Final insulation	12 mil
Core	Size	EI 250/3
	Steel	M19, alternate stacking, not annealed
Tube	Size	2.5 x 3 x 3.7
Design	Insulation class	F, max. operating temperature 155C @ 1 minute 200A and 9 minutes 100A
	Ambient temperature	40C
	Induction	<1.2T, max no-load induction 1.5T

“Transformer” output parameters

#*0	DIAGNOSE	Page 0
Name	:1 X EI 250/(3)	
Steel	-:M19 Gauge 26 / 0.0185''	
Number of Sections	-:3	
max.Cu-Fill Factor	%:90.	
max. parallel Wires	:2	
Induction on Load	T:1.215	
Max. Induction	T:1.235	
Max.Cu-Temp.rise on load	°K:111.	
Max.Cu-Temp.rise no-load	°K:21.1	
Regulation	%:3.1	
I^Inrush/I^nom-Factor	*:10.1	
Input Current No-Load	%:2.6	

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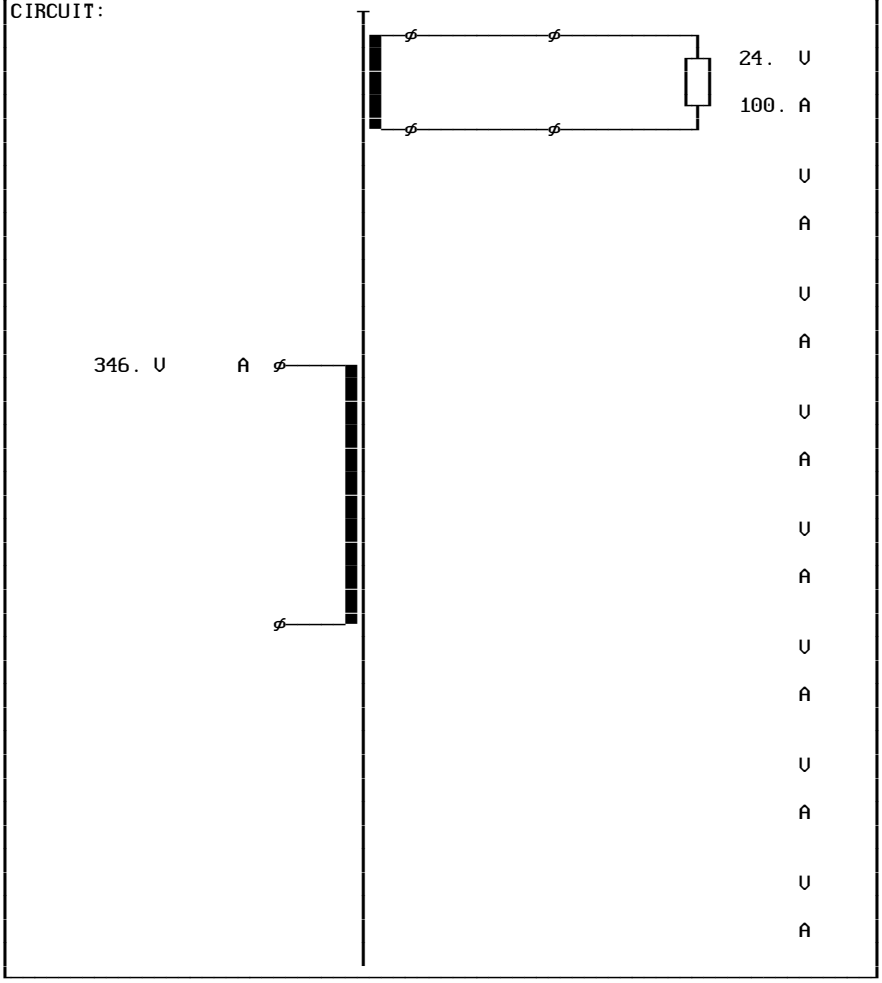
PRIMARY	U(V)	I(A)
Circuit-:1	346.	
Overult*:1.00	.	
Wire :0.0	.	
I/L. mil:5.	.	
I/E. mil:0.	.	
Formfac.:1.11	.	
Fre.Hz:60	.	
dI/Io :100	.	

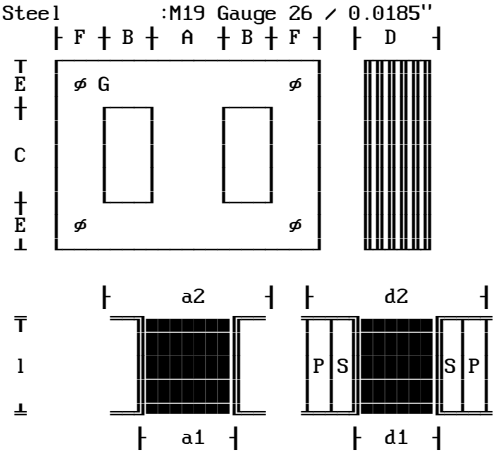
SECOND. 1--- 2--- 3--- 4--- 5--- 6--- 7--- 8---
Circuit-:11
Volta. V:24.
Curre. A:100.
Wire :3
I/L mil:0.0
I/E mil:12.0

Regulat. %:50.0	Steel -:28	Cooling *:1.00	Bobbin -:3
Udiode V:0.8	Induction T:1.21	Force ft/s:0.00	P/S-Order -:2
dUdiode V:.1	Remanence *:0.35	Bracket -:1	Rac/Rdc *:1.10
Ripple %:5.	W/kg *:1.00	Radiator -:0	Space *:2.00
Tmp. Amb.°C:40	VAr/kg *:1.00	Chassis -:1.00	Vertical -:1
Tmp.rise °K:115	Gap *:1.00	Channel in:0.00	Horizontal -:1
Time 1 Min:1.0	Annealed -:0	Cu-Surface*:1.00	Impregnat. -:2
Load 1 *:2.0	Stacking *:1.00	Rth-varni.*:1.00	Spread %:0
Time 2 Min:9.0	Hole -:1	Rth-comp. *:2.00	Selection -:1
Load 2 *:1.0	Assembly -:1	Case -:0	Criterion -:2

CIRCUIT:



Name :1XEI 250/(3)
Steel :M19 Gauge 26 / 0.0185"



/18.5

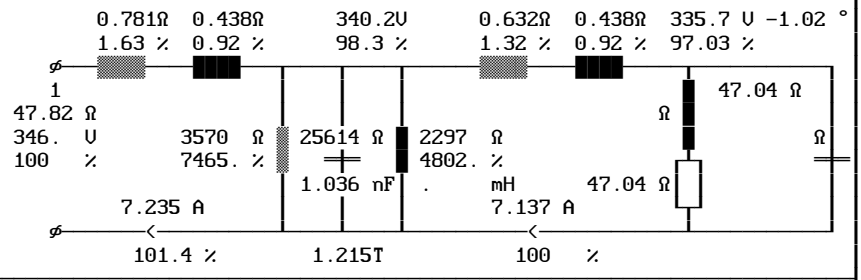
Weight	lb:30.55
Gap total	in:0.000
A-Limb	in:2.50
B-Width	in:1.25
C-Height	in:3.75
D-Stack	in:3.00
E-Yoke 1	in:1.25
F-Yoke 2	in:1.25
G-Hole	in:0.333
Radiator Fin	:0
Radiator Chan.	:0
a1	cm:2.75
a2	cm:4.93
d1	cm 3.25
d2	cm 5.93
l	cm:3.48
lp	cm:
ls	cm:
Margin	cm:0.14

X- Length 1	in:
Y- Width 1	in:
Z- Height 1	in:
x- Length 2	in:
y- Width 2	in:
z- Height 2	in:
w- Thickness	in:
Material	:
Potted	:

	Typ	Windun	MTI	DN	DN	Par	D/ø mil	B/ø mil	W/L	L	I/L mil	I/E mil	Weight lb	RWH %
1 2 3 4 5 6 7 8	1	224.	C00	12.5	12.5	1	76.3	76.3	42	5.2	5.	.	5.362	49.
1 2 3 4 5 6 7 8	11	16.0	C11	5.0	5.0	2	182.	182.	17	1.8	.	12.	4.513	40.
TOTAL													9.876	90.

NOMINAL OPERATION at Temperature °C 118.8 and Overvoltage 1.00

Output Power on Load	W:2396.	Output Power of Transfor.	W:2396.
Cu Losses	W:73.07	Fe-Losses active	W:32.42
Short-Circuit-Volt. cold	%:2.77	Regulation	%:3.06
Instantaneous pow. .5/95&	W:5789.	Efficiency of Transformer	%:95.78
dT Fe average Surface	°K:58.3	dT primary	°K:78.9
dT Case aver. Surface	°K:.	dT secondary	°K:78.7



DUTY CYCLE OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00

dT Fe average Surface	°K:77.7	dT primary	°K:111.
dT Gehäuse av. Surface	°K:.	dT secondary	°K:110.7

NO LOAD OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00

Losses active	W:33.56	Losses reactive	VAr:56.52
Current factor	%:2.63	Induction	T:1.235
dT Fe average Surface	°K:26.	dT primary	°K:21.1
dT Gehäuse av. Surface	°K:.	Rezonance frequency	kHz:2.

SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00

Losses active	W:67795	Losses reactive	VAr:59834
Current factor cold	%:3612.	Induction	T:.584
dT Fe average Surface	°K:1477.	dT primary	°K:2128.
dT Gehäuse av. Surface	°K:.	dT secondary	°K:2690.

PRIMARY (Tap:1)	1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Voltage Input/Output	V:346.
Out. Voltage no load	V:
Current Input/Output	A:7.235
Load on output	Ω:
Power factor of load	:
Current in segment	A:7.235
Current density A/in^2	:1582.
Icc-Current cold	A:261.3
Io -Current	A:0.19
Inrush Current peak	^A:102.9
Inrush Current rms	A:47.54
Cu-Losses	W:40.9
Resistance cold	Ω:.5559
Reactance	Ω:.4381
Eddy-Current Factor	:1.01

SECONDARY	1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Output Voltage	V:23.98
Output Current	A:99.91
Out. Voltage no load	V:24.7
Sec. Voltage	V:23.98
Sec. Current	A:99.91
Current density A/in^2	:1508.
Sec. Voltage cold	V:24.2
Load on output	Ω:.24
Power factor of load	:1.000
Icc cold	A:3657.
Cu-Losses warm	W:32.18
Resistance cold	Ω:.0022
Reactance	Ω:.0022
Eddy-Current Factor	:1.04
Capacitor	mF:.

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"Inductor" Input parameters

After the "transformer" design we know the following "inductor" parameters:

- The nominal current I1n = 7.235A
- The number of turns and the wire size
- Max. peak value of the current through the "inductor"
  1.41 x Icc = 1.41 x 2 x7.235 = 20.4A
- The core shape and steel
- Frequency f = 60 Hz

The nominal inductance of the "inductor has to be:

L = Unet x Ucc%/100 / I1n / 2 / Pi / f = 346.4 x 0.5/7.235/376 =0.06366H

L = 63.66mH linear up to = 20.4A

In the short-circuit mode of the "transformer" the "inductor" is set under the voltage of 346.4V. Using the formula:

U = 4.44 x f x W x B x Kfe x Afe

And:

- f = 60
- W = 224 (turns of the primary winding)
- B = 1.5T@20.4A^
- Afe the cross section of the "inductor" core

We calculate the stack of the "inductor" core 2.5"

Winding	RMS Inductance	63.66mH @ 20.4A^&1,5T realized with 224 turns , calculated with "transformer" design
	Wire	Cu, round, single insulated AWG 12.5, calculated with "transformer" design
	Layer insulation	5 mil
	Final insulation	5 mil
	Nominal rms current	100Arms, 60Hz
Core	Size	EI 250/2.5
	Steel	M19, alternate stacking, not annealed
Tube	Size	2.5 x 3 x 3.7
Design	Insulation class	F, max. operating temperature 155C @ 1 minute 200A and 9 minutes 100A
	Ambient temperature	40C
	Induction	<1.2T, max no-load induction 1.5/

"Inductor"output parameters

```
Name and Type of the Bobbin  :3   /1 X EI 250/(2_5)
Steel                        -:M19 Gauge 26 / 0.0185"
Used Space of the Bobbin     %: 51.4
Number of wires in parallel  :1          at RacRdc : 1.028/0.

Max. Current          Imax   A:2.04 20.4 .    .    .    30.6 .    40.8
Inductance         at Imax  mH:62.7 63.3 0.   0.   0.   62.1 0.   61.7
Nominal Induction at Imax   T:0.11 1.14 0.   0.   0.   1.69 0.   2.24
Minimal Induction at Imax   T:0.1  1.02 0.   0.   0.   1.49 0.   1.98
Maximal Induction at Imax   T:0.13 1.33 0.   0.   0.   1.95 0.   2.02

Nominal Current Inom    rms A: 7.23
Inductance   at Inom       mH: 63.45 Bei Ith^A: 10.19
Induction    at Inom peak   T: .571  Bei Ith^A: 10.19

Max. dT                    °K:54.3
Max. dT  at Inom           °K:41.    at Pcu W: 28.58 and Pfe W: 34.28
Q_Factor at Inom             :44.9   at Pcu W: 28.58
```

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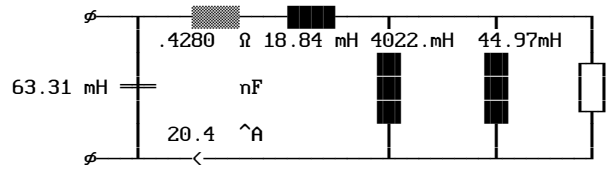
	L(mH)	I(A)
Schema :1.	61.6	20.4
L-Type *:2.		
Wire -:0.		
In/L mil:5.		
In/E mil:5.		
Al/Cu -:1.		
Fre.Hz:60		
Ripple %:10.		

1--- 2--- 3--- 4--- 5--- 6--- 7--- 8---
Harmo. -:1
Curre. A:7.23
Angle °:0.

Q-Factor :50	Steel -:28	Cooling *:1	Bobbin -:3
Cal.Freq.Hz:60	Induction T:1.41	Ventil. m/s:0	Stomach *:1
L@Freq. .Hz:60	Plate -:1	Brackets -:1	Rac/Rdc *:1.05
:0	W/kg *:1	Radiator -:0	Space Fac. *:.9
Amb.Temp.°C:40	VAr/kg *:1	Chassis -:1	Force -:1
Tmp.rise °K:115	Gap posit.*:1	Channel in:0.	Windintech.-:1
Time 1 Min:1	Annealed -:1	Cu-Surfac.*:1	Impregnat. -:2
Load 1 *:2	Stack.Fac.*:1	Rth-Varn. *:1	Full Layer -:0
Time 2 Min:9	Hole -:0	Rth-Comp. *:1	Selection -:1
Load 2 *:1	Core Asse.-:2	Case -:0	Criteriom -:2

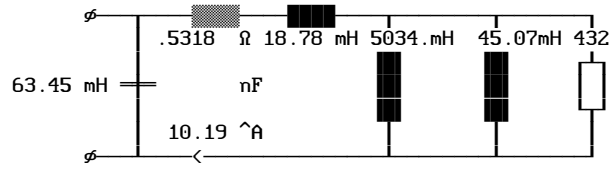
Type of the Inductance L=U/Ieff/Ω1



Bave T: 1.139
Bgap T: 1.015
Bmax T: 1.330

Nominal operation mode at the temperature °C 81.03

Nominal current Inom rms A:7.23		Peak current of Inom	^A:10.19
Al/Cu Losses/phase	W:28.58	Steel Losses/phase(activ)	W:34.28
Addy current losses factor :1.028		Q-Factor	:44.87
dT Fe (average)	°K:35.88	dT Winding (hot spot)	^°K:41.03
dT Case (average)	°K:0.0	dT Windig (average)	°K:40.70



Bave T: 0.571
Bgap T: 0.508
Bmax T: 0.666
Bx T: 0.033
By T: 0.014

Harmonics :1.	0.	0.	0.	0.	0.	0.	0.	
Current rms A:7.23	.	.	.	.	.	.	.	
Al/Cu Losses W:28.58	.	.	.	0.	.	.	.	
Fe-Losses W:34.28	.	.	.	.	.	.	.	

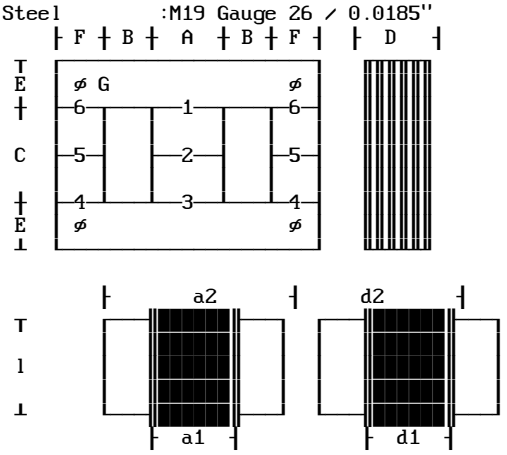
Duty cycle operation mode at the amboent temperature °C 94.30

dT Steel (average)	°K:43.90	dT Winding (hot spot)	°K:54.30
dT Case (average)	°K:0.0	dT Winding (average)	°K:53.86

Inductance and induction at the impressed peak current

Current	^A	2.04	20.4	.	.	.	30.6	.	40.8	.
Induction	^T	.113	1.14	.	.	.	1.691	.	2.243	.
L=U1/Ω1/I1	mH									
L=U1/Ω1/Ieff	mH	62.75	63.31	0.	0.	0.	62.13	0.	61.78	0.
L=ΣU*t/^I	mH									
L=dU/Ω1/dI	mH									
Leaking Ind.	mH	19.17	18.84	0.	0.	0.	19.46	0.	19.66	0.
Gap-Induct.	mH	44.51	44.97	0.	0.	0.	44.05	0.	43.76	0.

Name :1XEI 250/(2_5)
Steel :M19 Gauge 26 / 0.0185"



/18.5

Weight	lb:25.46
A-Limb(Dia.)	in:2.50
B-Width	in:1.25
C-Height	in:3.75
D-Stack/Dia.	in:2.50
E-Yoke	in:1.25
F-Rearyoke	in:1.25
G-Hole	in:0
Radiator Ribs	:0
Radiator Chann.	:0
a1	cm:2.75
a2	cm:4.93
d1	cm 2.75
d2	cm 5.43
l	cm:3.48
lp	cm:
ls	cm:
Margin	cm:0.14

X- Lenght 1	in:
Y- Width 1	in:
Z- Height 1	in:
x- Lenght 2	in:
y- Width 2	in:
z- Height 2	in:
w- Thicknes	in:
SPK Material	:
Compound	in^3:
Chann./Wind.	in:0.00
Chann.=>core	in:0.00

	Windng	T	AWG	AWG	Para	D/ø mil	B/ø mil	Pitch mil	T/L	L	I/L mil	I/E mil	Weight lb	RWH %
1	224.	0	12.5	12.5	1	76.3	76.3		42.4	5.28	5.	5.	4.129	51.
2														
3														
4														

Order / Layers Turns								
Position	1	2	3	4	5	6	7	8
Gap in	0.11	0.	0.	0.	0.	0.11	0.	0.
Voltag.V	34.22	345.3	0.	0.	0.	508.3	0.	673.9
Curren.A	1.446	14.46	0.	0.	0.	21.70	0.	28.93

Order :
Customer :
Remarks :

Date :07-28-2008
Time :23:28:57

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