Power Supply Protection: *Freewheeling Diodes*

Freewheeling diodes across inductive loads provide a path
for release of stored inductor energy while voltage drops to zero

Customer Application

A DC power supply is connected to an inductive load. The load is being switched and high voltage transients in the load circuit are causing switch and power supply failures.

Technical Challenge

Protect the switch and power supply and clamp the high voltage transients in the load.

Technical Approach and Solution

Say that we have a circuit with a power supply and an inductive load on it. From the instant that electrical power is supplied to the circuit, the inductive load will accumulate stored energy. If an attempt is made to open the path with a switch, this energy will generate a high reverse voltage and arc across the contacts of the switch. This could damage the switch, load and other circuit components. A freewheeling diode placed across the inductive load will provide a path for the release of energy stored in the inductor while the load voltage drops to zero.

Fig 1 shows a power circuit with a power supply, series resistor, inductive load and diode connected as a freewheeling diode, $\mathbf{D}_{f}$. The circuit operation is divided into two modes, 1) the current charge mode, which begins when the switch is closed, and 2) the current discharge mode, which begins when the switch is opened. It is when the switch is opened that the freewheeling diode comes into play.

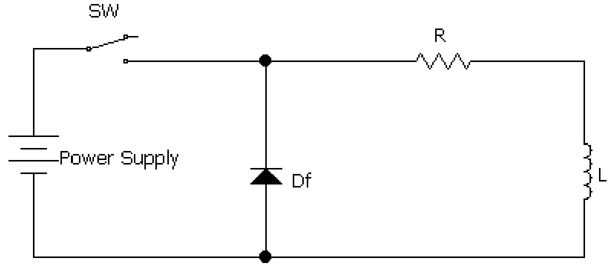


Fig 1

Mode 1- Current Charge

Mode 1 begins when the switch is closed at time t = 0. The equivalent circuit for this mode is shown in figure 2.

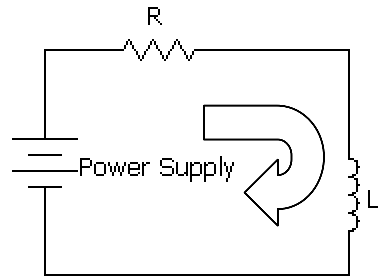


Fig 2

We know that for an inductor the voltage developed across it will be equal to the inductance times the change in current with respect to time

$$Vl = L\, di/dt$$

Since we are using a programmable supply, the charging current is the value that the supply is programmed for. To calculate the charging time, we need to know the inductance, the circuit resistance and the compliance voltage of the supply.

$$t = -(L/R)\ \ln(1-(IR/V))$$

where: L is the load inductance, R is the circuit resistance, V is the supply voltage and ln is the natural log of the values shown

Current Discharge

This mode begins when the switch is opened and the load current starts to flow through the freewheeling diode as shown in fig 3. Of note is that the inductor voltage reverses immediately upon this happening and the current continues to flow through the previously reverse biased diode, **D_f**.

Discharge current= $V/R\ e^{(-Rt/L)}$

Discharge time=$(L/R)\ (\ln (V)- \ln (I)- \ln (R))$

The current will peak at a value relative to the value of supply voltage divided by the circuit resistance and the freewheeling current will exponentially decay to zero at a rate relative to the L/R ratio multiplied by the difference of the natural log values of voltage, time and resistance.

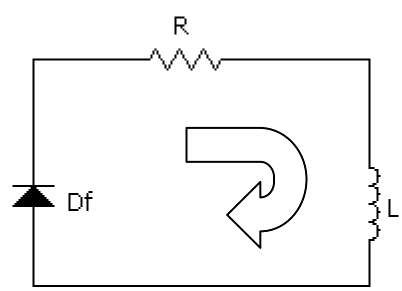


Fig 3

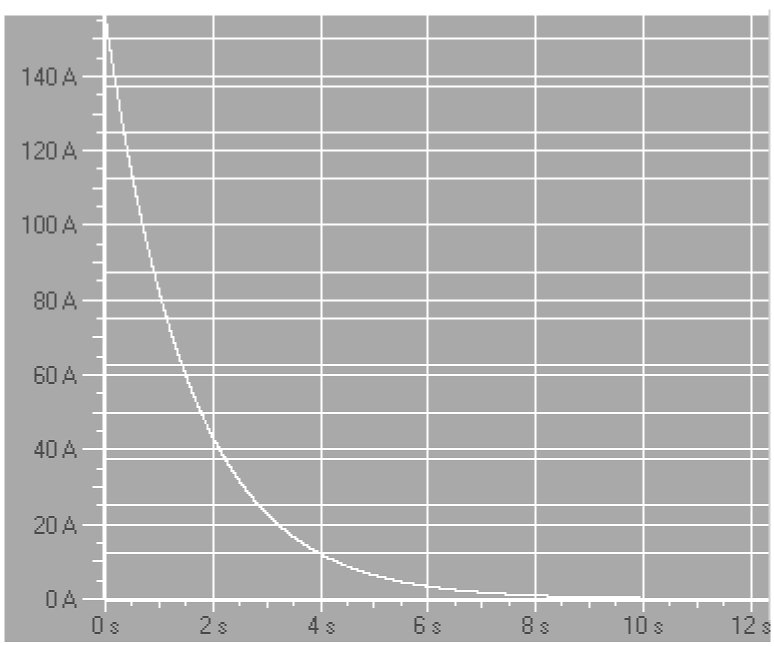
Example 1:

V batt = 250V Rated Power supply
Current = 80A
R = 1.6 Ω (include inductor winding and cable resistances)
L = 2.5H
Charging Current = 80A (current limit of power supply)
Charging time = -(L/R) ln(1-(IR/V)) = (2.5H/1.6Ω)ln(1-(80x1.6)/250V) = 1.12 sec

Induced voltage Vind = 80Ax1.6Ω = 128V (Voltage induced when the switch opens)

Discharge current = Vind/R e^(-Rt/L) = (128V/1.6Ω) e^((-1.6Ωxtime)/2.5H) = 80A
where at t=0 the peak current is simply the initial charging current

Discharge time =
(L/R) (ln (Vind)- ln (I)- ln (R)) = (2.5H/1.6Ω) (ln(128V)- ln(0.8A)-ln(1.6Ω)] = 7.2 sec
where the current is discharged to 1% of the starting value (0.8A)



Diode Selection

Example 2: V=250V, I=156A pk

International
IOR Rectifier

IRK.91 SERIES

STANDARD DIODES

ADD-A-pak™ GEN V Power Modules

Features

- High Voltage
- Industrial Standard Package
- Thick Al metal die and double stick bonding
- Thick copper baseplate
- UL E78996 approved
- 3500V_{RMS} isolating voltage

Benefits

- Up to 1600V
- Full compatible TO-240AA
- High Surge capability
- Easy Mounting on heatsink
- Al_2O_3 DBC insulator
- Heatsink grounded

100 A

Mechanical Description

The Generation V of Add-A-pak module combine the excellent thermal performance obtained by the usage of Direct Bonded Copper substrate with superior mechanical ruggedness, thanks to the insertion of a solid Copper baseplate at the bottom side of the device. The Cu baseplate allow an easier mounting on the majority of heatsink with increased tolerance of surface roughness and improve thermal spread.
The Generation V of AAP module is manufactured without hard mold, eliminating in this way any possible direct stress on the leads.

The electrical terminals are secured against axial pull-out: they are fixed to the module housing via a click-stop feature already tested and proved as reliable on other IR modules.

Electrical Description

These modules are intended for general purpose high voltage applications such as high voltage regulated power supplies, lighting circuits, temperature and motor speed control circuits, UPS and battery charger.

Major Ratings and Characteristics

Parameters		IRK.91	Units
$I_{F(AV)}$		100	A
	@ T_C	100	°C
$I_{F(RMS)}$		157	A
I_{FSM}	@ 50Hz	2020	A
	@ 60Hz	2110	A
I^2t	@ 50Hz	20.43	KA^2s
	@ 60Hz	18.65	KA^2s
$I^2\sqrt{t}$		204.3	$KA^2\sqrt{s}$
V_{RRM} range		400 to 1600	V
T_J		-40 to 150	°C
T_{STG}		-40 to 150	°C

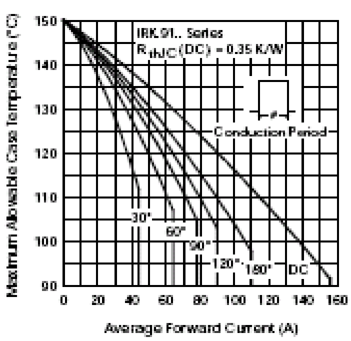


Fig. 2 - Current Ratings Characteristics

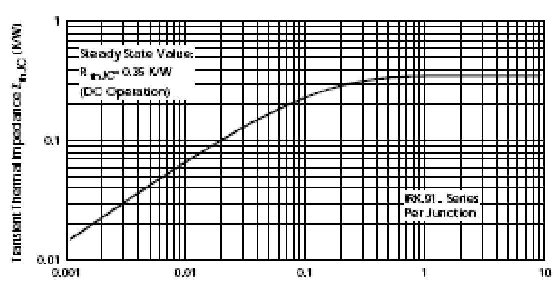


Fig. 11 - Thermal Impedance Z_{thJC} Characteristic

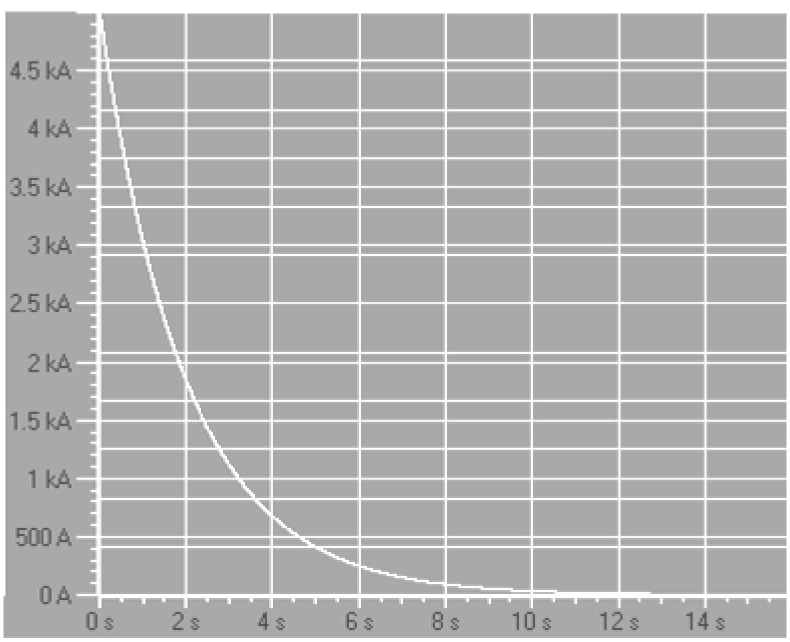
Example 2:

V = 60V
Rated Power supply current = 500A
R = 0.012 Ω (include inductor winding and cable resistances)
L = 24mH
Charging Current = 500A (current limit of power supply)
Charging time = -(L/R) ln[1-(IR/V)]
= (24mH//.012Ω)ln(1-(500x.012)/60) = 0.21 sec

Induced voltage Vind=500Ax0.012Ω = 6V (Voltage induced when the switch opens)

Discharge current= Vind/R e^(-Rt/L)=(6V/0.012Ω) e^((-0.012Ωxtime)/24mH)
where at t=0 the peak current is simply the initial charging current 500A

Discharge time=
(L/R) [ln (Vind)- ln (I)- ln (R)] = (24mH/.012Ω) (ln(6V)- ln(5A)-ln(0.012Ω)]=9.2 sec
where the current is discharged to 1% of the peak value (5A)



Diode Selection Example 2: V=60V, I=5000A pk

Bulletin I2035 rev. B 04/00

International IOR Rectifier

SD6000C..R SERIES

STANDARD RECOVERY DIODES

Hockey Puk Version

6690A

Features

- Wide current range
- High voltage ratings up to 2400V
- High surge current capabilities
- Diffused junction
- Hockey Puk version
- Case style B-44 (R-PUK)

Typical Applications

- Converters
- Power supplies
- High power drives
- Auxiliary system supplies for traction applications

case style B-44 (R-PUK)

Major Ratings and Characteristics

Parameters		SD6000C..R	Units
$I_{F(AV)}$		6690	A
	@ T_{hs}	55	°C
$I_{F(RMS)}$		11150	A
	@ T_{hs}	25	°C
I_{FSM}	@ 50Hz	76400	A
	@ 60Hz	80000	A
I^2t	@ 50Hz	29200	KA^2s
	@ 60Hz	26650	KA^2s
V_{RRM} range		1200 to 2400	V
T_J		- 40 to 175	°C

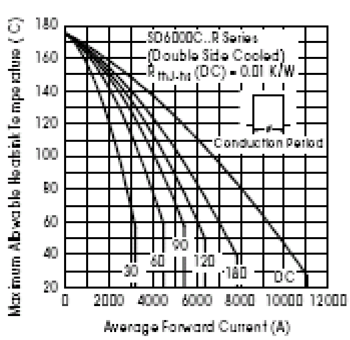


Fig. 4 - Current Ratings Characteristics

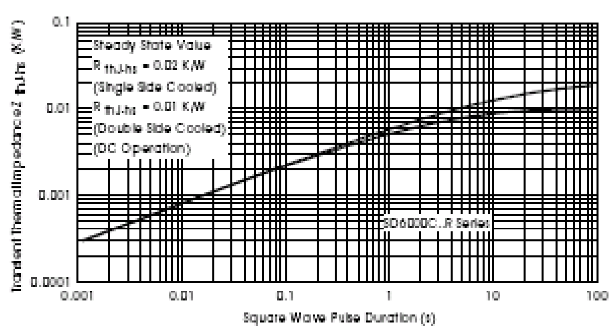


Fig. 10 - Thermal Impedance Z_{thJ-hs} Characteristics

About AMETEK Programmable Power

Located in San Diego, Ca., AMETEK Programmable Power designs, manufactures and markets precision, programmable AC and DC power supplies, electronic loads, application specific power subsystems, and compliance test solutions for customers requiring & valuing differentiated power products and services.

AMETEK Programmable Power boasts one of the industries' broadest portfolios of programmable power products under the well known and respected Sorensen, Elgar, California Instruments and AMREL brands. AMETEK programmable power supplies and sources serve a wide range of stimulus (T&M) and process power needs in applications including semiconductor fabrication, commercial and defense ATE, oil exploration, solar array and battery string simulation, avionics, general R&D and EMC compliance testing.

With strong brands, a broad product portfolio, exceptional precision power conversion and control expertise, proven power system integration capabilities and deep applications knowledge, AMETEK Programmable Power is your trusted "power partner."

Contact your AMETEK PP sales rep for application assistance to optimize a solution for your test needs.

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