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PROTECTION OF POWER ELECTRONIC CIRCUITS

The Protection made by conventional devices and measures do not provide efficient and enough protection to power switching circuits. The reason for that is the slow protection speed.

There are some important parameters to protect power switches in electrical and physical sides. Those are;

Voltage — Voltage speed (dV/dt)

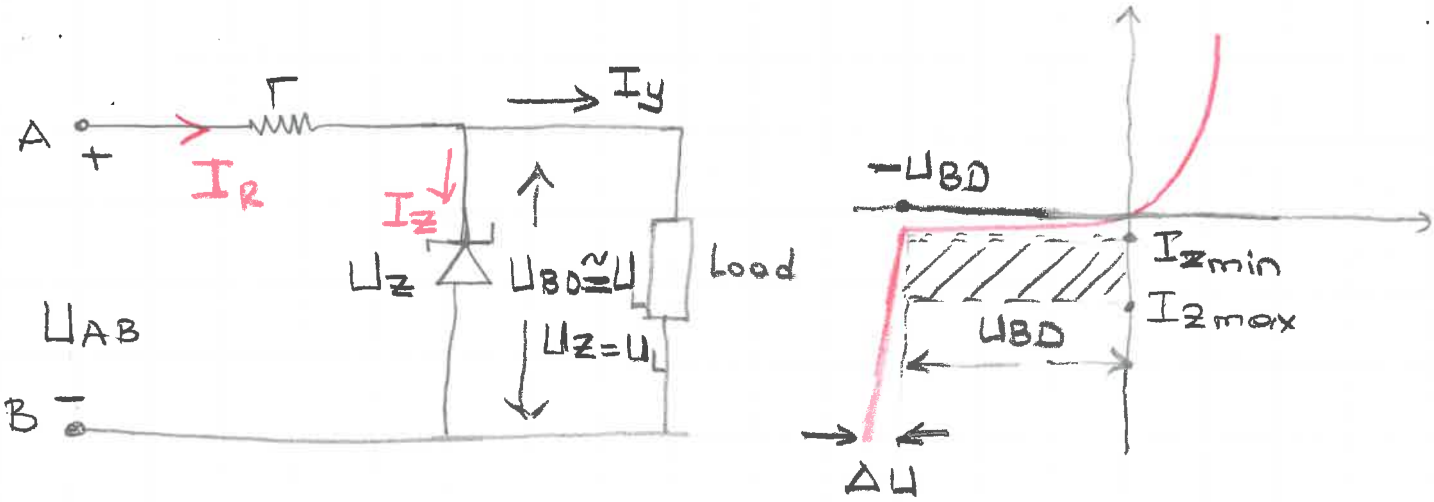
Current — Current speed (di/dt)

Temperature.

The mission of protection measures is to increase durability of power switch and prevent the risk of the damage of them.

In other words, any failure in power switches causes to corruption in the process and setback in the manufacturing phase. The electronic protection comprises additional circuits and devices such as zener diodes, resistors, capacitors... and snubber cells.

ZENER DIODE



$$U_Z = U_{BD} + r_Z \cdot i_Z = U_{BD} + \Delta U$$

$$P_{DM} = U_Z \cdot I_Z \cong U_{BD} \cdot I_{Zmax}$$

U_{BD} = Zener Breakdown voltage

r_Z = Zener resistance

P_{DM} = Max Zener power

Zener diodes are not damaged when operating in the breakdown in this region. Anyway they are designed to operate in this region.

They hold the voltage close to a constant value called the zener voltage. They are used as voltage regulators for limiter applications.

$$I_Z = \frac{U_{AB} - U_Z}{r} + I_y$$

$$I_{Zmin} = \frac{U_{ABmin} - U_{BD}}{r} - I_{ymax}.$$

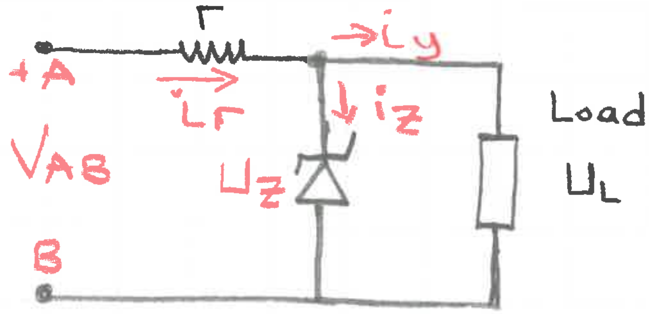
$$I_{Zmax} = \frac{U_{ABmax} - U_{BD}}{r} - I_{ymin}$$

For the optimum operating point and design,

$I_Z = I_{Z\,min}$.

In this case, the power loss will be minumum for the zener diode.

EXAMPLE



In this circuit V_{AB} is changed between 15 V and 20 V. due to the voltage fluctuation. Load voltage is 12 V. and the drawn current is changed between 0–10 mA. For optimum design, find "r" resistance and the power of zener diode?

For Zener diode, the optimum design is possible for $I_{Z\,min} \cong 0$ condition.

$$I_{Z\,min} = \frac{U_{AB\,min} - U_Z}{r} - I_{y\,max}$$

$$0 = \frac{15-12}{r} - 10 \cdot 10^{-3} \Rightarrow r = 300\ \Omega$$

$$I_{Z\,max} = \frac{U_{AB\,max} - U_Z}{r} - I_{y\,min} = \frac{20-12}{300} - 0$$

$$I_{Z\,max} = 26.67\ mA$$

$$P_{DM} = U_Z \cdot I_{ZDM} = 12 \cdot 26.67 \cdot 10^{-3} = 320\ mW$$

OPTO ELEMENTS FOR ISOLATION

Isolation is provided between drive and power circuits. The drive (triggering) circuits operate at lower voltage levels. But power switch section operates at high power levels. To avoid from any damage, isolation is implemented in power electronic

An optocoupler is basically an interface between two circuits which operate at different voltage levels The main advantage and function of it is to isolate the input and output circuits.

With an optocoupler, only contact between the output and input is a beam of light. Complete electrical isolation between two circuits is often necessary to prevent noise generated in one circuit from being passed to the other circuit.

The other industrial use of optocoupler is as signal converter between high voltage devices and low voltage solid state logic circuits. It might be called as a kind of transformer

The optocouplers works well on dc or ac signals

The optocoupler is a device that contains an infra-red LED and photodetector (such as a photodiode, phototransistor or triac...) combined in one package.

IR-LED-phototransistor based optocouplers are most commonly used. IR-LED and photo transistors are placed in an IC (integrated circuit).

Each optocoupler consists of gallium arsenide infrared LED and a silicon phototransistor.

The Operational principle is like that. When the light amount at base surface of the photo transistor is increased, transistor will be on-state and the current between the emitor and collector starts to pass. Anymore it is possible to control the target element.

For proper selection of optocoupler, those parameters are important.

- The current transfer ratio.
- Operational temprature
- Type of optocoupler

CTR: The ratio of the output collector current (IC) to the forward LED input current (IF).

$$CTR = \frac{\text{Output collector current}}{\text{Forword LED input current}} \cdot \%100 = \frac{I_C}{I_F} \cdot \%100$$

In application CTR is between 10% and 400%
An optocoupler with 50% is found to be extremely good in practice.

As the light intensity increases, the collector current increases and becomes constant.

ADVANTAGES COMPARED TO MECHANICAL RELAYS

- Not included mechanical components.
- High isolation resistance as mega ohms
- High operational speed.
- Small size
- Resistance to vibration
- Conformity to logic circuits.
- Wide band range for frequency, as MHz

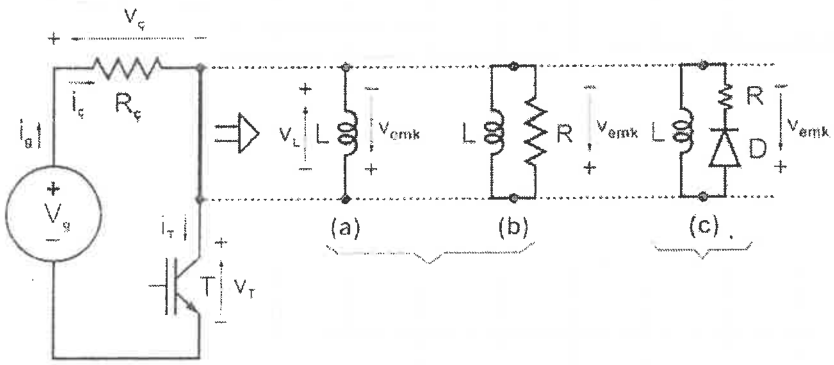
MAGNETIC CONNECTORS

They comprise primer and seconder windings with 10 μH and a few 100μH. The most important parameters of magnetic connectors:

- Max operational frequency
- Voltage transformation rate
- Isolation level.

The isolation voltage should be a few kV at least. The magnetic connectors are used to drive power switch operated above 10 kHz. For general purpose usage, opto elements are prefered.

SERIES SNUBBER CELLS

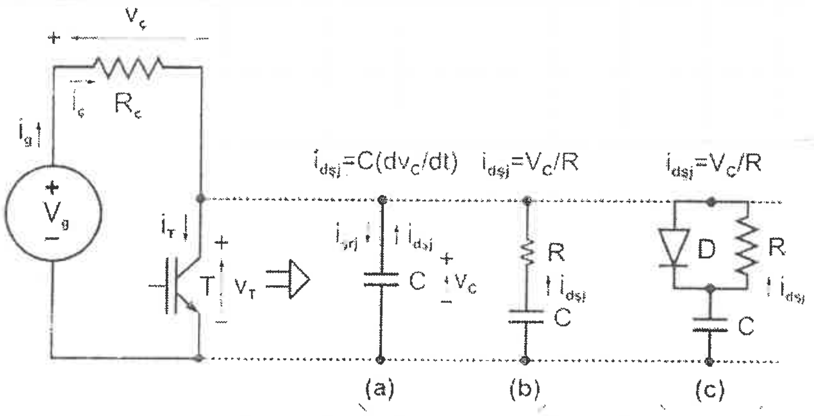


- Switching losses and temperature of junction are decreased by connection of small inductance for on-state
- But for off-state the stress of voltage increases due to high back e.m.f value.
- For avoiding this high back e.m.f value, a small R resistor value is added to inductance in parallel.
- In this case, small R value causes to a new current path

during on-state switching. So it is added a diode to prevent additional current path.

$$V_{TOFF} = V_g + V_L$$

PARALLEL SNUBBER CIRCUITS



- The main principle is to connect a small capacitor in parallel
- The charged C is a potential risk during on-state switching due to big discharge current.
- $$I_{TON\,max} = I_q + \frac{V_c}{R}$$
- to avoid that condition, a resistor with big value is connected to capacitor in series.
- During off-state switching, the high voltage drop due to high resistance value constitutes the voltage stress over power switch
- to eleminate this stress a diode is connected by defining a current path to protect the power switch

DRIVE/PROTECTION CIRCUITS

Rp: It is used for noise, leakage and stray currents. When the voltage on Rp exceeds 0.6 V., BJT is on-state anymore.

Cp: When the operation frequency and noise increase, Cp is added to circuit and it constitues a filter with Rp.

Rs: It limits the current and converts voltage signal into current signal for BJT. In mosfet this resistor is called as charge resistor since it charges and discharges the Cgs input capacitor.

Dp: It's used against to reverse current and voltage values. It is connected to gate in series for thyristors but reverse parallel for BJTs.

Zener Diode: The gate of Mosfet is highly sensitive to the voltage supplied. Two zener diodes are connected to gate as parallel to protect the mosfet strongly

The signals are amplified before supplying the power switches through transistors.

When the potential difference exists between the places of signal produced and applied, isolation is needed before power switches.

FOURIER ANALYSIS AND HARMONICS

Main representation of power quality is the harmonic distortion which represents the deviation between the ideal sinusoidal current and load current.

Some of the effects cause to:

- Added efficiency losses to the system composed by electrical installation and equipment. (Eddy currents, core losses, cupper losses
- Unexpected resonances
- Disturbances in electronic equipment, causing logical fault in digital circuits
- Unwanted overload for wiring and transformers.
- Malfunctions of motors
- Unwanted security problems.
- force effect against torque rotation, causing motor vibration added heat
- Flicker effect, causing fluctuations of light intensity
- Effect to IT equipment such as memory losses, turn offs
- Reduced service life of components and equipment under continuous distorted supply voltage.
- Increased sensitivity of electronic equipment due to peaks

There are typical two reasons of harmonic content typically

- Non-linear loads
- Power converter circuits.

The Fourier analysis states that any complex periodic signal can be obtained as the addition of different pure sin waves at different frequencies and amplitudes, multiple of the fundemental frequency

These multiples of the fundemental frequency are called harmonics

The mathematical expression of this definition, for a periodic signal

$$I(t) = I_0 + \sum_{n=1}^{N} \left[A_n \cdot \sin(n \cdot \omega t - \phi_n) \right]$$

- A_n → magnitude of current or voltage.
- I_0 → Zero Hertz component (dc or mean value greater than 0)
- $n \cdot \omega$ → angular Velocity for n^{th} harmonic
- ϕ_n → phase displacement

Assuming a signal with no dc componet

$$I(t) = I_1(t) + \sum_{n=2}^{N} I_n(t)$$

$I_1(t)$ is the fundamental waveform (component) of f_1 frequency ($\omega = 2\pi f_1$)

$I_n(t)$ is the different harmonic currents at multiple frequencies $2 \cdot f_1$, $3 \cdot f_1$, ... $N \cdot f_1$.

For symmetrical waveforms only odd harmonics may appear (3rd, 5th... of the fundamental frequency)

$$I_n(\%) = 100 \cdot \frac{I_n}{I_1} = 100 \cdot \frac{I_n}{I_{rms}}$$

$$f_x = \frac{1}{2} a_0 + \sum_{n=1}^{\infty} a_n \cdot \cos nx + \sum_{n=1}^{\infty} b_n \cdot \sin nx$$

$$f(t) = \frac{1}{2} a_0 + a_1 \cdot \cos \omega t + a_2 \cdot \cos 2\omega t \ldots + b_1 \cdot \sin \omega t + b_2 \cdot \sin 2\omega t \ldots$$

$$C_n = \sqrt{a_n^2 + b_n^2} \quad , \quad \theta_n = \tan^{-1}(b_n / a_n)$$

$$\varnothing_n = \tan^{-1}(a_n / b_n)$$

$$f(t) = \frac{1}{2} \cdot a_0 + \sum C_n \cdot \cos(n\omega t - \theta_n)$$

or

$$f(t) = \frac{1}{2} a_0 + \sum C_n \cdot \sin(n\omega t + \varnothing_n)$$

$f(t) = f(-t) \Rightarrow$ double function. The terms with Sin will be equal to zero.

$f(t) = -f(-t) \Rightarrow$ single function. The terms with Cos will be equal to zere

In three phase systems, the 3rd harmonic and its tripples will be equal to zero.

In periodic functions, the 2nd harmonic and its tripples will be zero.

$$I(t) = I_0 \cdot \sum_{n=1}^{N} \left[A_n \cdot \sin(n \cdot \omega t + \theta_n) \right]$$

$$THD = \sqrt{\sum_{n=2}^{N} \left(\frac{I_n}{I_1} \right)^2}$$

$$a_0 = \frac{1}{\pi} \int_{-\pi}^{\pi} f(x)\, dx \qquad a_n = \frac{1}{\pi} \int_{-\pi}^{\pi} f(x) \cdot \cos nx\, dx$$

$$b_n = \frac{1}{\pi} \int_{-\pi}^{\pi} f(x) \cdot \sin nx \cdot dx$$

Total Harmonic Distortion (THD)

It is defined as a ratio between the r.m.s value of all the harmonics and rms of the fundamental frequency.

$$THD_i = \sqrt{\sum_{n=2}^{N} \left(\frac{I_n}{I_1}\right)^2}$$

$$THD_i = \sqrt{0{,}15^2 + 0.12^2 + 0{,}09^2}$$

$$= 0{,}2118 = 21.19\%$$

For voltage similarly

$$THD_v = \sqrt{\sum_{n=2}^{N} \left(\frac{V_n}{V_1}\right)^2}$$

Elemination of Harmonics

Passive harmonic filters consist usually of resonant filters tuned to eleminate a certain harmonic frequency. Such effect is obtained by tunning the resonance frequency of Ls-Cs at that (for example) 5th harmonic. If other harmonic frequencies are needed to be eleminated, additional L-C filters are added for related harmonic components.

Active Harmonic filters

They are power electronic circuits to eleminate current harmonic pollution.

The working principle consists in measuring the current harmonics of the load and generating in real-time the same harmonics but in phase opposition