Spang Power Electronics

Analysis of Straight SCR Control Versus SCR with Tapped Transformer for Silicon Carbide Elements

The resistance of silicon carbide elements can increase as much as four (4) times the original nominal value over its useful lifetime. In order to get maximum utilization of the element, it is then desirable to design the power supply to compensate for this.

How Much Voltage Range Is Needed?

Power = $w = (v^2/R)$

Let R_N = New element resistance

Let R_A = Aged element resistance

Let v_N = New element voltage required for full power

Let v_A = Aged element voltage required for full power

Then, in order to deliver the same power to the aged element as to the new element:

$(v^2_A/R_A) = (v^2_N/R_N)$

Since the element resistance can increase four (4) times with age,

$R_A = 4R_N$

Therefore:

$(v^2_A/4R_N) = (v^2_N/R_N)$

$4R_N \times (v^2_A/4R_N) = 4R_N \times (v^2_N/R_N)$

$v^2_A = 4v^2_N$

$\sqrt{v^2_A} = \sqrt{4v^2_N}$

$v_A = 2v_N$

This indicates that a two-to-one (2:1) voltage range will maximize the useful life of the silicon carbide element.

Compensation

With SCR control, there are two major approaches in use.

(1) Use straight SCR control (no transformer) with input power at approximately twice that required when the element is new (i.e. $v_A = 2v_N$). Use power or watt regulation to maintain the SCR output to required level.

(2) Use an SCR power control unit and tapped transformer. The secondary taps would cover a 2:1 range to compensate for element aging. The taps also provide a good degree of power limiting, making watt regulation a desirable option instead of a necessity.

Both approaches generally incorporate current limiting to protect against higher current draws during the resistance change occurring with element heat up.

Power Factor

While both approaches provide good control of power to the silicon carbide heating element, they differ greatly in their effect on power factor and feeder equipment sizing.

With increasing penalties charged by power companies for poor power factor, it is desirable to avoid this situation. Poor power factor can also require higher feed equipment ratings, leading to higher cost.

When power factor is considered, a tapped transformer coupled with SCR control becomes more desirable. This becomes even more critical as the total SCR controlled power increases.

Straight SCR Control

Consider a typical SCR control application using straight SCR control (Fig. 1).

The silicon carbide heating element is rated to deliver 12kw at 120 volts. As it ages, it will require twice this, or 240 volts, to obtain full power. The input power, therefore, is at 240 volts.

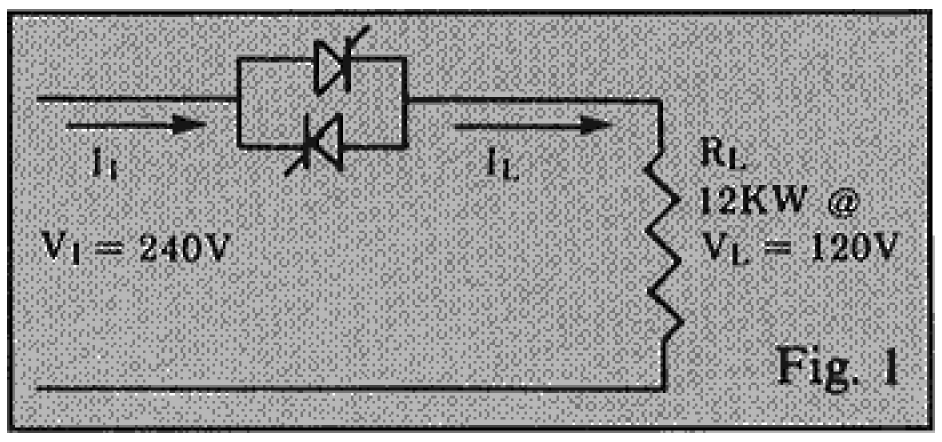

Fig. 1

Since the element can be approximated as purely resistive,

Load Power = $w_L = v_L \times I_L$

$I_L = (w_L/v_L)$ = 12000w/120v =100 amperes

Thus, to deliver 12kw at 120 volts, 100 amperes must be drawn through the SCRs from the 240 volt input line.

Although the *Real Power* (watts) read on w_I going into the unit is 12kw, the total *Apparent Power* (volt-amperes) into the unit is not 12 kva.

$vA = v_I I_I$ = 240v x 100A = 24,000 vA

kva = $(v_I I_I/1000)$

= 240v x IOOA/1000 = 24 kva

Power Factor is defined as

P.F. = kw(IN)/kva(IN)

Thus, the Power Factor for this example is: P.F. = 12kw/24 kva = 0.5

Two results of this type of control are:

(1) Depending on the power used, this control system can result in a power factor penalty on the electric bill. The larger the percentage of total plant power represented by this control, the worse the total plant power factor and the higher the operating costs.

(2) The kva requirement must be supplied by the plant system. In this example, 24 kva iA required for a 12kw load. This would mean that the feeder transformer and lines

needed to be sized for 24 kva, *not* 12kw.

A similar 150kw system would require 300 kva to power!

Excessive power can lead to wasted capacity on the plant electrical system. This wasted capacity translates into extra costs.

An interesting relationship between power factor and SCR input and output voltages can be developed for rapid estimation of power factor under most conditions.

Since P.F. = kw(IN)/kva(IN) = kw(OUT)/kva(IN)
= (v_L x I_L /v_I x I_I) and $I_L = I_I$ then
P.F. = ($v_L I_L/v_I I_L$) = (v_L/v_I)

Therefore, the power factor at any point is the ratio of output voltage to input voltage.

SCR—Tapped Transformer Control

Consider a tapped transformer coupled with SCR control to minimize power factor. The transformer is tapped over a 2:1 range with 5 taps. The taps are spaced equal *percentages* apart. Each tap is approximately 84% of the voltage of the next higher tap.

The example is similar to Figure 2. The five power taps are at 120v, 142v, 169v, 202v and 240v.

When the element is new, the 120 volt tap provides 12kw with unity power factor.

$I_L = (w_L/v_L)$ = 12000w/120v = 100A
$I_I = I_L$ x (N_S/N_P)

where (N_S/N_P) is transformer ratio
(N_S/N_P) = (v_S/v_P) = 120v/240v
therefore:
I_I = 100A x ½= 50 amperes thus
kva(IN) = $v_I I_I$/1000 = 240v x 50A/1000 kva(IN) = 12 kva and
P.F. = kw/kva =12kw/12kva = 1

Next, consider the worst case. That would be drawing full power at the voltage corresponding to the next tap down. That is, using 120 volts on the 142 volt tap.

$I_I = (w_L/v_L)$ = 12000w/120v = 100A $I_I = I_L$ x (Ns/Np) now the transformer ratio is (Ns/Np) = (vs/vp) = 142v/240v = 0.59 $I_I = I_L$ x 0.59 = 100 x 0.59 = 59 amperes thus kva (IN) = $v_I I_I$/1000 = 240v x 59A/ 1000 kva (IN) = 14.16 kva and P.F. = kw/kva = 12kw/14.16 kva = 0.84.

Therefore, the transformer allows operation at full power with a 0.84 power factor or better throughout the 2:1 voltage range. This is quite an improvement over the 0.5 power factor of the straight SCR approach described above.

In the worse case, the power factor of 0.84 has less effect in terms of power factor penalty on the electric bill than the 0.5 power factor of straight SCR control. A savings in operating cost results.

Furthermore, the kva requirement supplied by the plant system is less. In the examples; only 14 kva is required with SCR and tapped transformer instead of 24 kva required with straight SCR control or a plant capacity savings of 10 kva!

A similar 150kw system with SCR and tapped transformer control would only require 179 kva instead of 300 kva required for straight SCR control—a plant capacity savings of 121 kva or 40%!

The savings in feed transformers and wiring costs can result in reduced total installation costs.

The savings can mean the difference between using existing power distribution equipment or buying more equipment to meet the capacity requirement!

Summary

The above examples show that savings on operating and installation costs are possible using the SCR-tapped transformer approach to control silicon carbide heating elements.

The actual economy depends on several factors:

(1) How much of total plant loading does the SCR control represent? The greater the percentage the greater the savings.
(2) How high is the local power company's power factor penalty? The higher the penalty the greater the savings.
(3) Is a step-down transformer required even with straight SCR control (i.e. 480v to 240v)? If so, the cost of the tapped transformer can be greatly offset.
(4) What effect do the kva requirements have on plant loading? The SCR-tapped transformer can prevent the need for adding plant capacity and this can mean substantial savings.
(5) Other installation costs such as input wiring, feeder breakers, etc. should be considered. All are related to the input kva requirements. The lower kva required by the SCR-tapped transformer approach means installation savings.

In general, the higher the load kw the greater the savings with use of the SCR-tapped transformer.

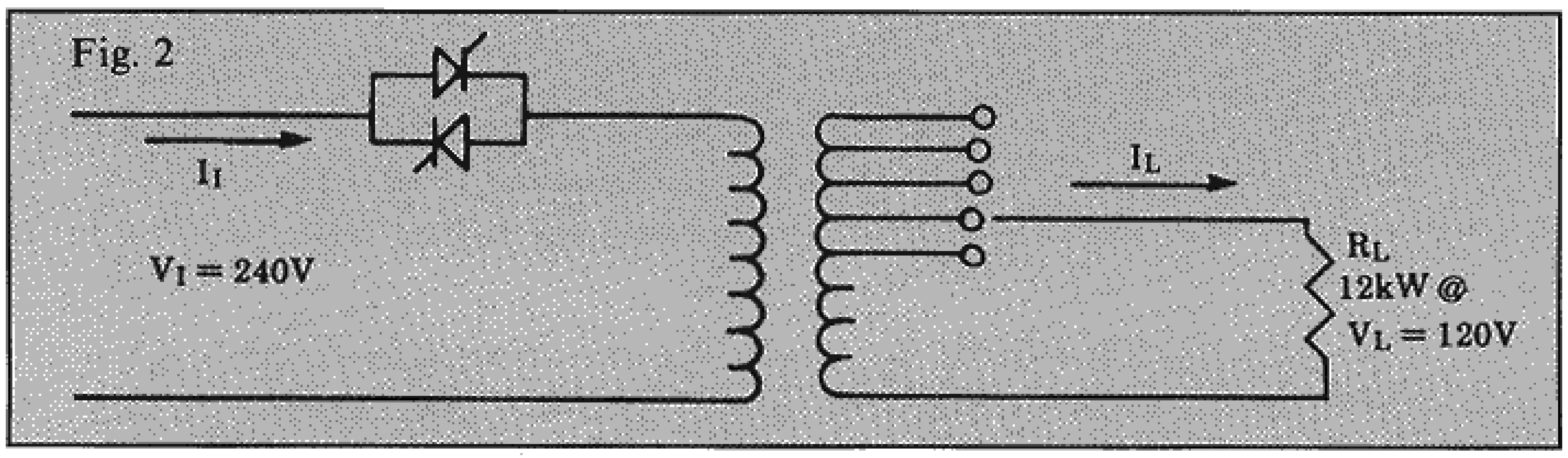
Fig. 2