SPRING 1960

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SYMBOL OF QUALITY IN SEMICONDUCTORS

RECTIFIER NEWS

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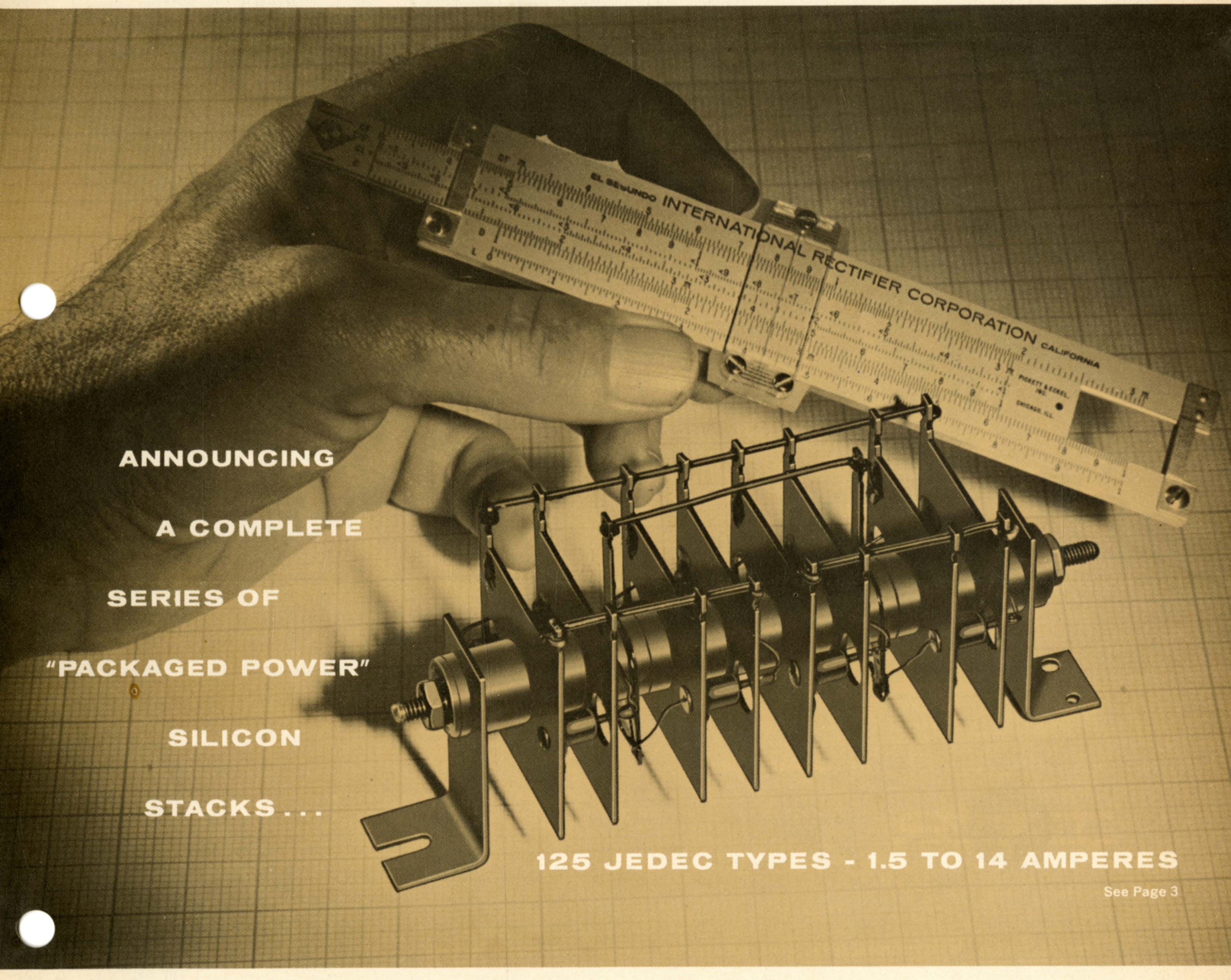

See Page 3

RN-360

A PARTIAL LISTING OF INDUSTRY'S **WIDEST LINE!**

HIGH VOLTAGE SILICON RECTIFIERS

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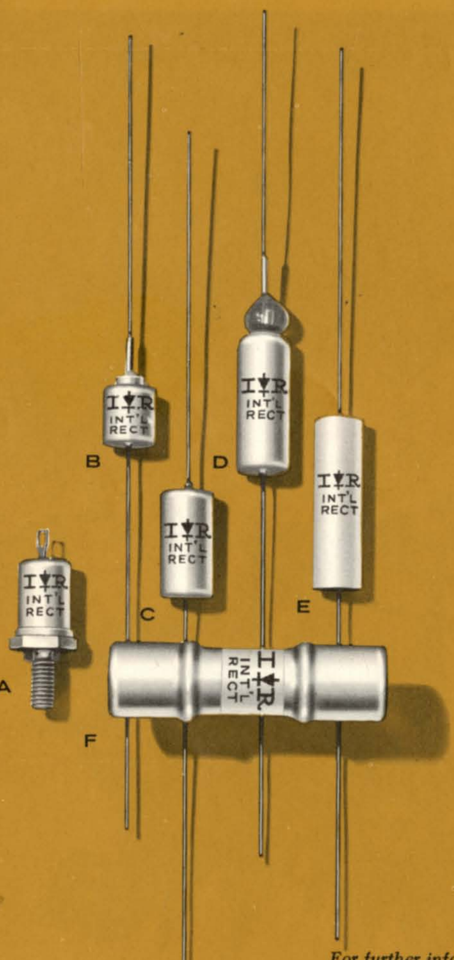

Type Number	Peak Inverse Voltage, Volts	Rectified DC Output Current, MA	Max. Voltage Drop @ Rated Current, Volts
A – 1500 PIV @ 300 MA			
1N1130	1500	300	4.5
1N1131	1500	300	4.5
B – 600 to 1000 Volts PIV @ 125 MA			
1N596	600	125	3.0
1N597	800	125	3.0
1N598	1000	125	3.0
C – 600 to 1000 PIV @ 100 MA			
1N1406	600	100	5.0
1N1407	800	100	5.0
1N1408	1000	100	5.0
D – 1200 to 2400 PIV @ 100 MA			
1N1409	1200	100	5.0
1N1410	1500	100	6.25
1N1411	1800	100	7.5
1N1412	2000	100	6.25
1N1413	2400	100	7.5
E – 600 to 10000 PIV @ 40 to 150 MA			
1N2373	600	150	3.0
1N2374	1000	150	3.0
1N2375	1500	130	4.5
1N2376	2000	130	7.5
1N2377	2400	100	9.0
1N2378	3000	100	9.0
1N2379	4000	65	15.0
1N2380	6000	65	22.5
1N2381	10000	40	37.5

Type Number	Peak Inverse Voltage, Volts	DC Output Current @ 75°C, MA	Max. Voltage Drop @ Rated Current, Volts
F – 1500 to 16000 PIV to 100 MA (Standard Types – Convection Cooled)			
1N1133	1500	75	15.0
1N1134	1500	100	7.5
1N1135	1800	65	18.0
1N1136	1800	85	9.0
1N1137	2400	50	24.0
1N1138	2400	60	12.0
1N1139	3600	65	27.0
1N1140	3600	65	18.0
1N1141	4800	60	36.0
1N1142	4800	50	24.0
1N1143	6000	50	45.0
1N1143A	6000	65	30.0
1N1144	7200	50	54.0
1N1145	7200	60	36.0
1N1146	8000	45	60.0
1N1147	12000	45	60.0
1N1148	14000	50	52.0
1N1149	16000	45	60.0
F – 1500 to 16000 PIV to 360 MA (High Current Types – Forced Cooled at 2000 LFM)			
1N1745	1500	300	15.0
1N1746	1500	360	7.5
1N1747	1800	270	18.0
1N1748	1800	330	9.0
1N1749	2400	220	24.0
1N1750	2400	270	12.0
1N1751	3600	290	27.0
1N1752	3600	280	18.0
1N1753	4800	230	36.0
1N1754	4800	220	24.0
1N1755	6000	210	45.0
1N1756	6000	280	30.0
1N1757	7200	240	54.0
1N1758	7200	230	36.0
1N1759	8000	220	60.0
1N1760	12000	220	60.0
1N1761	14000	240	52.0
1N1762	16000	220	60.0

When writing for individual data sheets, specify the series you are interested in, by voltage and current rang

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PART TWO

OF A TWO PART ARTICLE CONCERNING A FUNDAMENTAL CIRCUIT PROBLEM

VOLTAGE DIVISION OF SERIES - CONNECTED SEMICONDUCTOR DEVICES

Complete Reprints Incorporating Parts One and Two Will Be Sent to Those Writing on Their Company Letterhead.

PROPERTIES OF RECTIFIER SYSTEMS AND MEANS TO IMPROVE VOLTAGE DIVISION

BY EDWARD J. DIEBOLD, *Engineering Consultant, International Rectifier Corporation*

Introduction

Properties of the rectifier devices which affect the voltage division were discussed in the first of this two part article. Rectifier systems have other properties which must be considered for a successful design.

High voltage systems have specific properties which must be considered apart. Gas discharge effects, field discharge puncture, thermal failure of insulators, series connected insulators and partial breakdowns should not be overlooked.

Individual voltage dividing resistors and/or capacitors together with the rectifier device form an elementary part of a string. Connecting many of them in series introduces mutual influence and interaction with the system.

Voltage Definitions

High voltage systems are subjected to voltages which may be subdivided by their behavior in time. In rectifier systems, there are always direct voltage components, alternating voltage components at the power frequency, their multiples (harmonics) and transient voltages of much higher frequencies. Traveling waves (or voltage surges) may have rise times which are less than one microsecond, switching transients may be slower and harmonic oscillation of the load may be commensurate with the frequency of the system. Voltages applied to a high voltage rectifier element (consisting of several devices in series) contain all these components.

Voltages between the rectifier string and ground (or ambient devices) may be extremely high, rich in transients and containing extremely fast rising surges. It is important that these voltages are known and kept within bearable limits.

It is understood that the voltage between adjacent devices is equally divided between all the devices in series. This is not necessarily the case for all frequencies and may be disturbed by uncontrolled voltages to ground.

A problem which can be overlooked is the remaining counter-electromotive force on a d-c load, for example, in electrolytic cells, capacitor banks, filters, and other rectifiers operating in parallel. In these cases the voltage dividing circuit must divide a pure d-c voltage.

Test Voltages

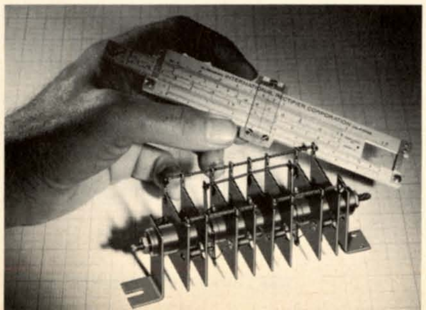
Before designing high voltage systems, the test voltages must be known. Semiconductor devices are rated by peak inverse voltage. It is logical to rate and test a series connected multitude of rectifier devices also for peak inverse voltage (a lower direct voltage is also often specified). Transient voltage peaks are usually assumed to be equal to or less than the peak inverse voltage, which eliminates the need for impulse voltage testing.

Considering the series connected rectifier devices as one entity: The insulation against ground or against a support (which may be at another than ground potential) is a different problem. The rectifier system, or parts of it, may be subjected to violent voltage swings against ground and may be subjected to switching transients of high magnitude. Failure of the insulation between system and ground is very serious; it is prevented by high insulating voltage levels. Example: NEMA voltage rating of 2,400 volts rms (3,400 volts peak inverse). However, for this same indoor voltage rating, an impulse crest voltage of 45,000 volts is required, a 60-cycle rms voltage of 15,000 volts dry, and 10,000 volts when covered with condensation. If the peak inverse voltage of the high voltage rectifier is selected as double the operating crest voltage (which is quite common) the standard insulator impulse test voltages will be 6.6 times higher and the 60-cycle test voltage 3.1 times higher than the voltage applied to the rectifier.

These high insulating voltage levels should be specified, unless overvoltages are positively eliminated.

High Voltage Breakdown

The first appearance of high voltage failure is usually the so-called corona, which is quite harmless, but the warning before breakdown. It appears in air at voltages above 300 volts, whenever the local gradient exceeds approximately 80 volts per mil crest (less at high altitude). High gradients can occur when sharp corners, surface roughness, protruding edges, or thin wires are present. Sharp corners may be considered as spheres, and edges as cylinders. On a small sphere with the opposite polarity



ON THE COVER

A broad series of over 125 JEDEC type silicon medium power rectifier stack assemblies offer ready-to-install packaged power rectifiers engineered by specialists to provide maximum power output through ideal heat transfer design. Units span a current range from 1.5 to 14.4 amps d-c output, with d-c output voltages from 31 to 1500 volts.

Designated JEDEC types 1N2638 through 1N2764, stacks consist of glass-to-metal hermetically sealed silicon diodes mounted on 1.56 inch copper cooling fins. Mounting dimensions are from 3.48 inches to 7.53 inches. Circuit configurations are: single phase half-wave, center tap, bridge and mag. amp bridge; 3-phase ½ wave and bridge, and 6-phase star.

For detailed data on this new series, write for Bulletin SR-330.

infinitely far away, the surface gradient is double the voltage divided by the radius. With a radius of $1/64$ inch (sharp corner), corona can be expected at a voltage above 600 volts. Figure 1 shows the voltage distribution around a sphere. If the sphere is smaller, the lines are more crowded together. For wires the surface gradient is the voltage divided by the radius, which means that a wire of $1/32''$ diameter shows corona in air at a voltage above 1200 volts.

Submersing the entire assembly in oil eliminates the corona (unless the gradients are five to ten times higher). If non-flammable liquids such as askarel are used, and the gradients are excessive, the offending points and ridges will grow black deposits, growing into whiskers and crusts. These are very poor insulators, at best, and will lead to breakdown if given enough time.

Corona effects in rectifier systems can lead to undesirable dust precipitation. Usually there are high direct voltage components present and, even if a-c components are responsible for creating the ionization, the d-c components are always able to re-arrange the hereby created charges. Furthermore, d-c flash-over may follow an otherwise harmless a-c spark (caused by a short transient) because the spark ionization acts as a conductor.

High gradients along the surface of insulators cause creepage corona and creepage arcs. It is difficult to give exact values for the creepage breakdown, but generally the voltage gradients along insulating surfaces are held at $1/10$ to $1/5$ of the gradients in free, undisturbed insulating spaces.

Permissible creepage gradients are not well defined, they depend on the conditions under which a system should operate. If a large amount of contamination is encountered and humidity is a problem, the creepage distances should be ample, high localized gradients along surfaces should be avoided. Generally, it is assumed that 2,000 volts per inch (crest) are safe. In clean ambient conditions, without humidity, the surface gradient may be driven as high as 5,000 volts per inch (crest). Under oil, these values can be increased, with the operating gradient to be approximately 10,000 to 20,000 volts per inch (crest).

Because the internal reverse currents of semiconductor junctions are extremely small, spatial or surface corona currents, although apparently small, may be commensurate with the reverse currents which determine the voltage division of an assembly. Thus a perfect voltage division at operating voltage may be upset by corona effects under high transient voltages. Excessive surface leakage currents may appear after prolonged operation in contaminated atmospheres, causing voltage unbalance and rectifier device failure which is hard to trace. Repeated failure after long operation may be due to contamination, not to unexplainable "aging" of semiconductors. Localized breakdown phenomena may be the cause of unexplained voltage transients generated by the rectifier system, they introduce uncertain voltage distributions.

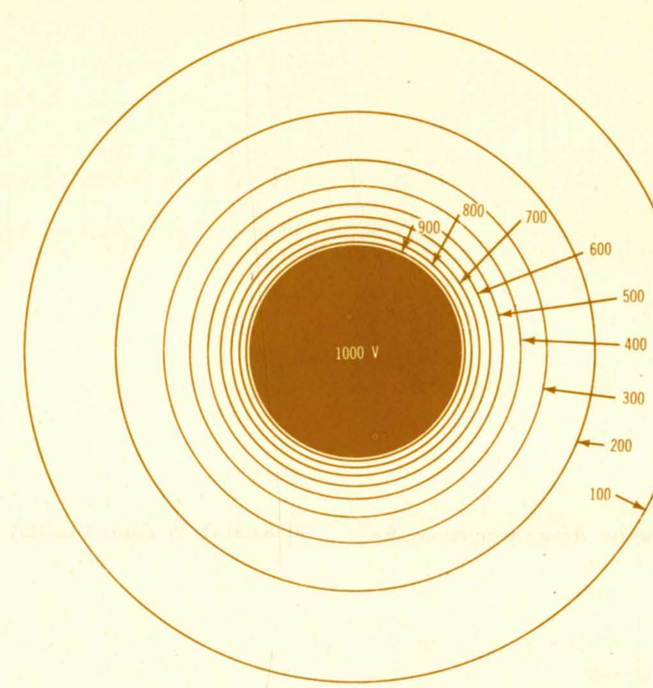


Figure 1. Voltage distribution around a sphere having a voltage of 1000 volts, the circles are equal voltage lines, voltages are given in volts.

System Properties Affecting Rectifiers

Excessive voltages on an entire assembly of rectifier devices may be caused by the properties of the system to which they are connected. A very good summary of the problems encountered and the methods of transient voltage suppression is given in the paper: "Rectifier Voltage Transients" by F. W. Gutzwiller, Electrical Manufacturing, Dec., 1959, pages 167 through 173.

Besides consideration of overall voltages, it is also essential that equal voltage distribution along strings of rectifier devices in series is maintained during the full reverse part of the cycle. This must be achieved for direct voltage components, the normal a-c reverse voltage, reverse recovery transients of an entire string, switching transients, load oscillations and traveling waves entering the system through the power line.

Transient voltage suppressor systems can alter the system properties to increase or reduce the danger of voltage unbalance. Surge absorbers using capacitors reduce the rate of rise of voltage transients, hence they are beneficial to the problems of voltage division. Silicon carbide resistors (thyrites), applied with care to eliminate excessive inductances, eliminate the dangerous voltage peaks, without reducing or increasing the ill effects of high rates of rise of voltage transients. Spark gaps eliminate excessive peaks but, because of the negative resistance characteristic of the arc, may be the source of dangerous high frequency oscillations.

Capacitances to Ground

High voltage systems with many devices connected in series are upset in their voltage distribution by connections to ground created by capacitive displacement currents. These can only be reduced to a minimum, beyond which they must be carefully considered in the system design.

Displacement currents to ground are proportional to the rate of rise of the voltage to ground and the capacitance to ground. These currents must be furnished by the reverse current of the string of semiconductor devices, which is given by the voltage appearing on each device, its reverse resistance and reverse capacitance. Reverse resistances of semiconductor devices are high, non-linear and vary greatly between individuals, reverse capacitances are low and non-linear. Reverse voltages appearing on the devices are relatively low, whereas voltages to ground may be very high and subject to violent fluctuations. Thus reverse currents in the string are due to moderate voltages appearing on low impedances, whereas displacement currents are due to much higher voltages on higher impedances. Displacement currents, however, should be much lower than reverse currents, otherwise they upset the voltage division. The numerical analysis is not easy because it must consider some elusive factors, such as:

Capacitance and maximum voltage rate of rise on stray capacitances between individual devices, mounting hardware, cooling fins and other accessories on one side and any close or remote object or group of objects which may draw displacement currents (electrostatic lines of force) on the other side.

Variations of the above along a string of series-connected devices and between individual strings.

Minimum reverse resistances and maximum reverse capacitances of individual devices.

Figure 2 shows schematically a string of rectifier devices connected in series. There are N identical devices D, each of them having an identical leakage resistance R and an identical parallel capacitance P. Indices refer to the position in the strip. Between devices and ground there are the capacitances G, all of them assumed to be identical. Terminals A (anode) and C (anode) are subjected to the voltages E_a and E_c, wherein the cathode voltage is higher than the anode voltage because the devices are assumed to be in the blocking part of the cycle. All the resistive and capacitive properties of the devices are assumed to be in the components R, P and G.

Capacitances G to ground, other devices, the walls of a building, shields or enclosures are not always easy to determine. It is not permissible to assume that the capacitance is zero, merely because the ground is far away. For example, a 1½ inch square plate, held infinitely far away from the ambient enclosure, has an approximate capacitance of 1.5 micromicrofarad. If the space is filled with askarel, the capacitance is approximately 7 micromicrofarad. If a tank wall is in close proximity (to contain the askarel), the capacitance increases. To obtain valid results from the systems shown in Figure 2, the following assumptions must be made:

1. The number of devices in series is substantially larger than unity (e.g. 10 or more).
2. Voltages E_c and E_a are applied at the same time and rise proportionally as time advances.
3. Voltages E_c and E_a increase exponentially with time as in:

$$E_c = E_f \frac{\exp t/T}{\exp t_f/T}$$

wherein E_f is the final voltage occurring after the time t_f, having the final rate of rise of E_f/T volts per second.

4. The series inductance L of the entire string of rectifiers (against return in the other strings or ground) must be substantially smaller than the expression:

$$L \ll \frac{N}{P}\left(\frac{T}{2\pi}\right)^2$$

Note: Small wires have a high inductance. Traveling waves with fast rise time cannot propagate into an inductive system. Instead, they create extremely high voltages at the incoming terminals.

Although real voltages do not follow the assumed rise curve, the theory is still valid if the final voltage and the steepest rate of rise are used to determine the time constant T. Figure 3 shows on the left hand side the assumed curve with the rise time constant T and the final voltage E_f. On the right hand side appears a more realistic voltage in which the steepest rate of rise and the highest voltage are used to determine an analog rise time constant.

With these assumptions, voltages against ground, at any time during the rise time interval t_f, are determined by:

$$E_n = \left(E_n - E_a \cosh \frac{N}{m}\right) \frac{\sinh \frac{n}{m}}{\sinh \frac{N}{m}} + E_a \cosh \frac{m}{n}$$

wherein $m = \sqrt{\dfrac{T/R + P}{G}}$

and n is the position number of the device under investigation. The abbreviation sinh and cosh are hyperbolic functions.

Example: A string consists of 40 Silicon diodes in series, each of them having a reverse resistance of 10,000 ohms, a reverse capacitance of 300 micromicrofarad and a capacitance to ground of only one micromicrofarad. The cathode

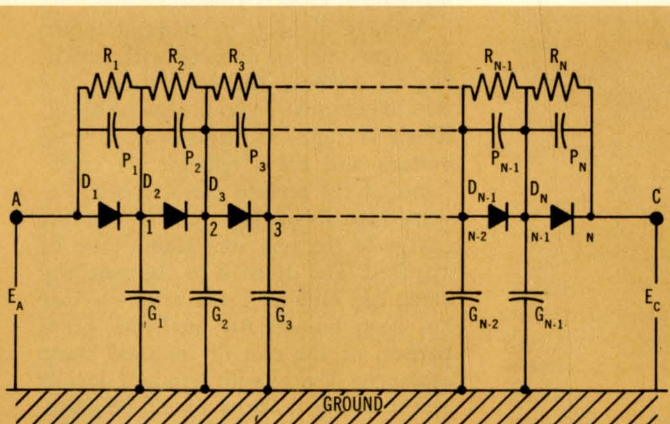


Figure 2. Equivalent circuit of a rectifier string subjected to high voltages against ground.

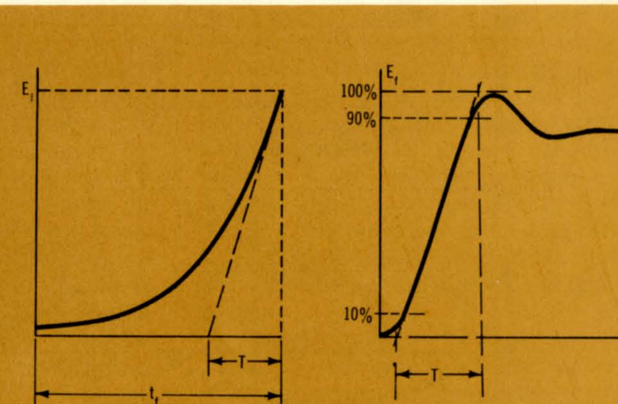


Figure 3. Determination of the Rise Time Constant T.

potential is double the anode potential. The rise time constant is more than one microsecond. Thus we have

$T = 10^{-6}$ $P = 3 \times 10^{-10}$

$G = 10^{-12}$ $R = 1 \times 10^{4}$

$N = 40$ $E_c = 2\, E_a$

hence $m = 20$ and the voltage distribution can be calculated. Figure 4 lower curve shows the voltage distribution for a rise time constant of one microsecond, each space between two dots representing one diode. Very obviously this voltage distribution is wrong, 21 diodes are completely useless, diode No. 40 is subjected to 4.8% of the voltage, although in the average the voltage per diode should be 1.25% of the total voltage. If the minimum rise time constant is increased to 20 microsecond (upper curve of Figure 4), the voltage distribution is almost linear and diode No. 40 is subjected to only 2% of the total voltage.

It can be shown that the highest voltage across any one device occurs always at the end of the string which has the higher voltage. If we designate as x the ratio of the highest voltage across any one device over the average voltage per device, we obtain:

$$x = \frac{N/m}{\sinh N/m}\left[1 + \frac{E_c}{E_c - E_a}\left(\cosh N/m - 1\right)\right]$$

This value x should always be close to unity.

If conductive shields are employed around the string of rectifier devices, the capacitance G increases, but the terminal voltages E_c and E_a are now the voltages between the shield and the terminal. For example, if the shield is held at the average voltage between cathode and anode, we have

$$E_c = E_s = -E_a$$

and

$$x = \frac{N}{2m}\left(\frac{\cosh N/m + 1}{\sinh N/m}\right)$$

Limiting ourselves, for example, to $x = 2$, the allowable ratio N/m is 3.75.

For a shield held at cathode or anode potential, the ratio x (in either case) is: $x = N/m \text{ ctgh } N/m$. If N/m is greater than one,

$$x \cong N/m\,(1 + 2 \exp - 2\, N/m)$$

For $x = 2$, we have $N/m = 1.91$.

Without shield, and a ground potential such that $E_c = 2E_a$ (as in Fig. 4), the ratio is:

$$x = 2N/m\left(\frac{\cosh N/m - \frac{1}{2}}{\sinh N/m}\right)$$

For $x = 2$, we have $N/m = 1.15$.

Conclusions

Voltage surges between the string of devices and ambience are important. It is essential that the maximum magnitude and minimum rise time of voltage surges be exactly known.

Shunt capacitances and resistances of the devices must be known and firmly established by the use of resistors and capacitors. Lowering the resistance is equivalent to lowering the permissible surge rise time by the same factor.

There is a definite limitation as to the number of devices which may be connected in series, if the values of capacity, resistance and rise time are given.

Shields at definite potentials (with respect to the terminals of the string) are very valuable means to improve the voltage distribution.

The inductance of the string limits the shortest permissible rise time (as shown in assumption 4). Traveling waves with faster rise time cannot be spread by the capacitances.

High capacitor and low resistor values are not a cure-all, particularly if the string contains a large number of devices in series, the ambient potentials are not firmly determined and the voltage rise times are short.

One system of grading the shunt capacitances cannot compensate for all the transient voltage conditions, it is only applicable when the voltage rate of rise and the distribution of string vs. ground voltages are always the same.

Methods of Voltage Division

Semiconductor devices fail usually as a breakdown of the blocking characteristic, without losing the ability to carry forward current. Thus it is desirable that the voltages of series connected devices should be approximately equal, but a device which fails in the reverse direction should not be subjected to the reverse voltage. The remaining voltage should be equally distributed among the other devices. Rectifier systems subjected to high transient voltages may be endangered by the failure of any one diode because the voltage distribution is upset by the double ground capacitance appearing on the non-operative device. This is particularly important near the end of a string. For this reason it may be advisable to use higher values of shunt capacitors and higher peak reverse voltage devices near the ends of strings.

Matching of Reverse Characteristics

Voltage division by artificial means can sometimes be avoided with matching of reverse characteristics. This should comprise equal avalanche breakdown voltages at rated peak inverse voltage and equal temperature coefficients of the reverse characteristic. Reverse capacitance and reverse recovery charge of the junctions should also be matched. The decision to use matching alone can only be made after the case has been numerically analyzed. Comparison of the cost of matched sharp avalanche devices with standard devices and shunting resistors should be made.

Resistive Voltage Dividers

Normal operating voltages contain mostly direct and low frequency alternating components. Voltage division can

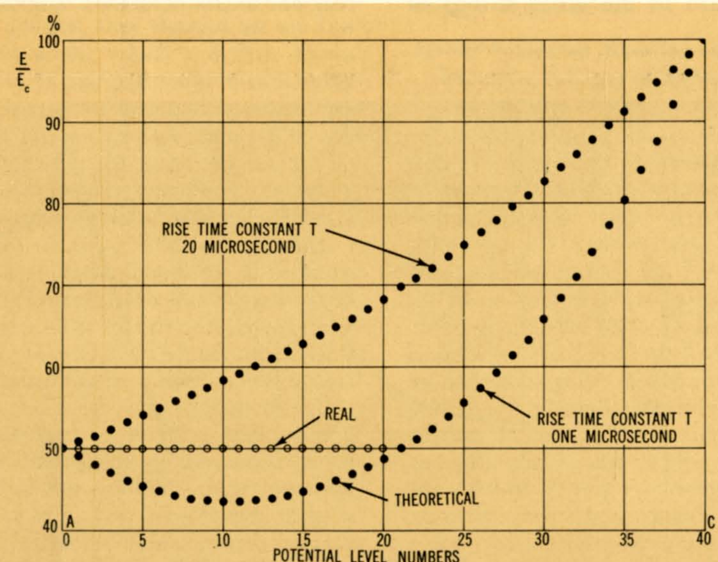


Figure 4. Voltage distribution in a string of silicon diodes.

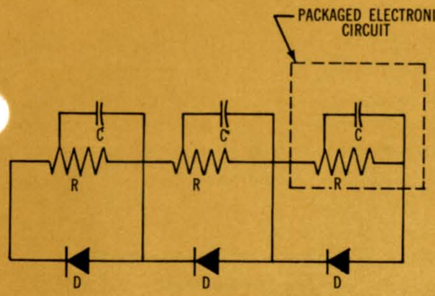


Figure 5. Packaged circuit type voltage dividers comprising shunt capacitor, shunt resistor and damping resistor.

only be assured by matching of sharp avalanche breakdown reverse voltages or with shunting resistors. Silicon devices have such low reverse currents that resistive voltage dividers are economical, both in first cost and power dissipation. Generously dimensioned resistive voltage dividers can also overcome unequal reverse currents caused by surface leakage currents of contaminated assemblies.

For a rectifier device which is rated at a given peak inverse voltage and a maximum reverse current, given as a full cycle average for single-phase, half wave rectification, the equivalent resistance of the junction is approximately 1/3 of the ratio: Peak voltage over average current. The shunting resistor should have a resistance which is less than the minimum junction resistance. The power rating of the shunting resistor is given by the operating voltage of the individual device and the resistance of the resistor. For single-phase and three-phase operation this power dissipation is approximately 25% and 24% respectively of crest voltage squared divided by resistance.

Capacitive Voltage Dividers

Capacitive voltage dividers must be dimensioned for three different factors: Equalization of unequal junction capacitances, absorption of unequal reverse recovery charges and equalization of unequal charging currents for ground or shield capacitances. The latter has been discussed above.

Junction capacitance and reverse recovery values were given in Part 1 of this paper. The shunting capacitance must be large enough to balance-out the deviation of junction capacitances from one junction to another and to absorb the voltage rise of the first device with the lowest reverse recovery charge, until the next voltage blocking device recovers. The combined action of ground capacitance and reverse recovery charge may force an extremely high voltage on the first device in a string (if this happens to have the smallest reverse recovery charge). Example: Assume a junction with an equivalent capacity of 30 micromicrofarads and an average reverse recovery charge of 80 millimicrocoulombs. If the first junction in a string has a reverse recovery charge of only 40 millimicrocoulomb, the difference of 40 millimicrocoulomb must be stored in the shunting capacitor of this first device without an excessive voltage, (e.g. 200 volts). Dividing the deviation of charge by the permissible voltage rise, we obtain a necessary capacitance of 200 micromicrofarad. This, in turn, is substantially larger than the 30 micromicrofarad of the junction and is sufficient to balance out all the junction capacitances. On the other hand we may have determined a shunting capacitance of 10,000 micromicrofarad to cope with the effects of capacitance to ground, in which case this higher value applies.

Shunting resistor and shunting capacitor may be combined into one small unit as a so-called packaged electronic circuit, as shown in Figure 5. If the shunting capacitor causes oscillations of the reverse recovery voltage it may be necessary to use a damping resistor in series with the capacitor. This can be achieved by tapping-off a small value of the shunting resistor and connecting the capacitor between this tap and the other end of the resistor.

In many cases, special conditions of the system require a different selection of shunting resistors and capacitors. If heat dissipated by shunting resistors is an obstacle, the shunting resistors can be selected with a resistance value which is higher than normally advisable, but compensated by a large capacitor which is needed for the compensation of capacitance to ground.

Multiple Transformer Connections

For very high voltage applications, transformers may be designed with several secondary windings, each winding to operate a complete rectifier bridge, rectifier doubler or rectifier quadrupler. These rectifiers will be connected in series, each of them operating at the same current, but having voltage dividing problems only of a fraction of the overall voltage. This expedient is unavoidable, if the problems of unequal voltage distribution due to ground or shield capacitances, traveling waves, or dielectric breakdown cannot be solved otherwise. If necessary, the individual transformer-rectifier units may be enclosed in an insulated enclosure which is operated at a potential corresponding to the average d-c voltage of the partial rectifier. A number of single-phase rectifiers, each of them connected in the primary of the transformer to another phase of an a-c power system, may be used to produce a three-phase, six-phase, or 12-phase d-c output.

This idea can be expanded into forced voltage division by transformers, for each level of rectifier devices used in the system. This forced voltage division may be achieved with auxiliary voltage dividing transformers. This is shown in the paper, "A New Voltage Divider Circuit For Semiconductor Rectifiers," by I. K. Dortort, AIEE Communications and Electronics, July, 1957, pages 356-358. This system does not allow for breakdown of individual devices in series. On the other hand, each level may be fused independently, which permits the use of low voltage fuses in high voltage systems. Under transient conditions, the auxiliary transformer may not be able to follow the rapidly changing overall voltage. If the a-c voltage fails altogether, the d-c voltage applied from a capacitive load to the rectifier is not equally distributed.

The described method can also be used for forcing partial voltage division in long strings of rectifiers which would not operate properly because of ground or shield capacitance-inductance distribution problems.

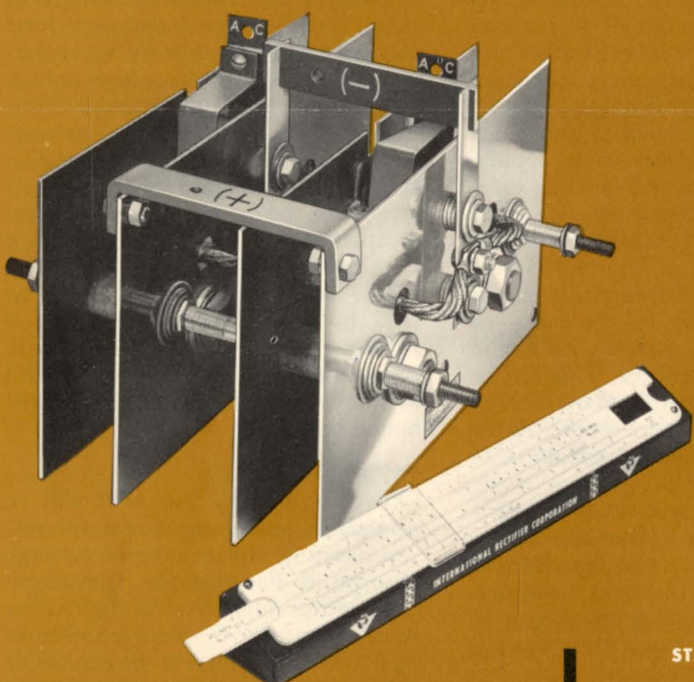
Multiple Systems

For difficult applications it will be necessary to provide the system with several means of voltage division or surge absorption. For example: Considerations of traveling waves in the rectifier stacks and ground or shield capacitances may force a limitation of the number of devices in series. Fast rising voltage surges with high voltage peaks may require the use of capacitor non-linear resistor surge-absorbers across the input or output of the rectifier terminals. Within each string the use of resistive and capacitive voltage dividers may be required, including a tap on the resistor to provide damping for the capacitor. The rating of the damping resistor may also be selected to avoid damage to the rectifier strings due to capacitor discharges or undesirable explosion of capacitors (in case of capacitor failure). Voltage dividing shields around the rectifier string reduce the effects of systematic capacitances and the probability of corona.

Complex problems of high voltage rectification can only be solved if all the available means are considered, each with its own merits and defects. Comparing several possible systems for cost, space, probability of failure and power losses determines the most advantageous design.

new developments

Built-in Paralleling Reactors Permit Higher Current Output – Increase Efficiency of High Power Silicon Stacks



The incorporation of paralleling reactors into a stack assembly forces equal current distribution through parallel circuit branches, thus correcting current unbalance which can limit output current of a silicon rectifier assembly by overloading one side of the circuit.

Stacks with built-in paralleling reactors are now available with current ratings up to 750 amps and peak reverse voltage ratings of 50 to 600 volts.

TESTS SHOW HOW PARALLELING REACTORS INCREASE CURRENT OUTPUT

To illustrate the effect paralleling reactors have on current unbalance, International Rectifier engineers tested 70U Series silicon rectifiers especially selected to have the maximum "mismatch" expected from a random yield selection.

Four of these units were assembled into a single phase bridge and operated at a 500 ampere load. Without a paralleling reactor the bridge exhibited ±27% current unbalance from an average of two parallel circuits. Tested *with* the paralleling reactor, the same unit showed a current unbalance of only ±2.9%.

With an unbalance of ±27%, the maximum output that could be expected would be 435 amps. By reducing unbalance to ±2.9% an output of 550 amperes could be achieved under identical conditions of temperature and cooling.

STANDARD "BUILDING BLOCK" TECHNIQUES USED TO ASSEMBLE VARIOUS CIRCUIT CONFIGURATIONS

The standard "building block" is a 2-1-2-D "doubler" assembly with integral paralleling reactor, and four 70 amp rated silicon junction rectifiers mounted on copper cooling fins. Two of these "building blocks" may be mounted to form a single phase bridge (as illustrated above) rated up to 550 amperes rectified d-c output, when operated within recommended temperature and cooling limits.

Three of these modules will form a three-phase bridge rated up to 750 amperes. Other configurations include "Scott four phase bridges" and six phase bridges in both series and parallel connections and proportional ratings. For detailed technical data on this new high power silicon stack line, request Bulletin SR-335.

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