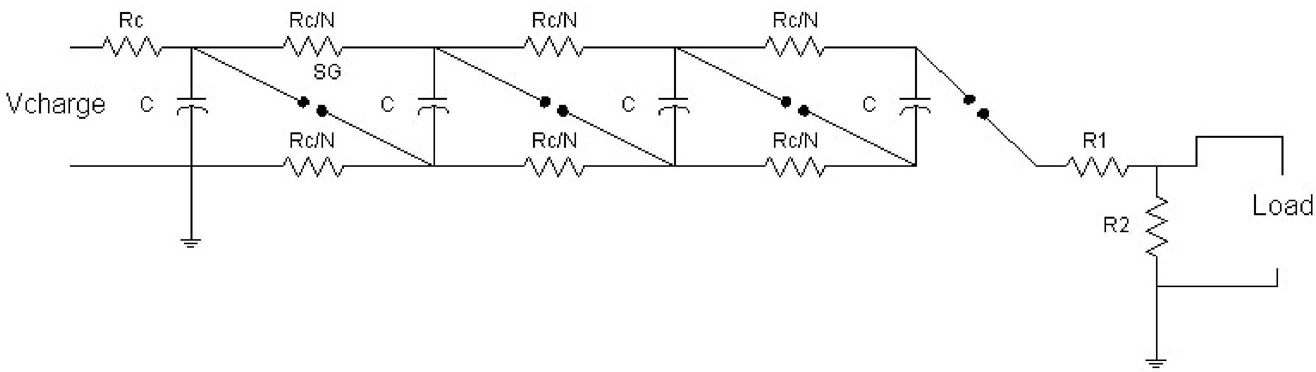
Marx Generators

A Marx Generator is a clever way of charging a number of capacitors in parallel, then discharging them in series. Originally described by E. Marx in 1924, Marx generators are probably the most common way of generating high voltage impulses for testing when the voltage level required is higher than available charging supply voltages. Furthermore, above about 200 kV, the discharge capacitor becomes very expensive and bulky. The Fitch circuit is becoming popular where very good control over impulse voltage is required.



How it works

The charging voltage is applied to the system. The stage capacitors charge through the charging resistors (Rc). When fully charged, either the lowest gap is allowed to breakdown from overvoltage or it is triggered by an external source (if the gap spacing is set greater than the charging voltage breakdown spacing). This effectively puts the bottom two capacitors in series, overvoltaging the next gap up, which then puts the bottom three capacitors in series, which overvoltages the next gap, and so forth. This process is referred to as "erecting". A common specification is the erected capacitance of the bank, equal to the stage capacitance divided by the number of stages.

The charging resistors are chosen to provide a typical charging time constant of several seconds. A typical charging current would be in the 50-100 mA range. The charging resistors also provide a current path to keep the arc in the spark gaps alive, and so, should be chosen to provide a current of 5-10 amps through the gap. The resistors are sometimes called "feed forward" resistors for this reason. The discharge through the charging resistors sets an upper bound on the impulse fall time, although usually, the impulse fall time is set by external resistors in parallel with the load (or integrated into the generator, as described below).

For example, with a stage voltage of 100 kV, a desired output voltage of 1 MV (i.e. 10 stages), the charging resistors should be about 20-40 kOhms (corresponding to an arc current of 5 to 10 Amps). If the capacitors were 1 uF, then the discharge time constant would be 20 milliseconds, much, much longer than the 50 microsecond time constant of the standard test impulse. This example generator would have a stored energy of 5 kJ/stage or 50 kJ for the total system. At a charging current of 50 mA, it would take at least 20 seconds to charge the entire stack.

If a constant voltage charging source is used, significant energy is dissipated in the charging resistors, equal to the stored energy in the capacitors.

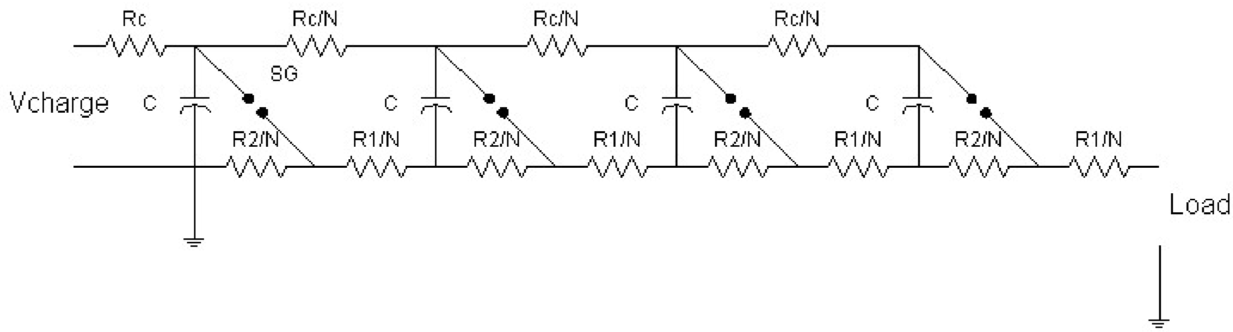
Design enhancements and considerations

Charging with a constant current source

If the Marx generator is charged from a constant voltage source, the energy dissipated in the charging resistors will be equal to that stored in the Marx capacitors. If the bank is charged with a constant current source, this energy loss can be substantially reduced.

Integrating the waveshaping resistors into the generator

In the classic capacitor discharge impulse generator, the shape of the pulse is controlled by external impedances (usually resistors) at the "output" of the pulse generator. As voltages get higher, it gets harder to build practical resistors with low parasitic inductance that will also withstand the full impulse voltage. The usual remedy for this is to include the wave-shaping resistors in the Marx bank itself, as illustrated in the following figure.



Reducing the jitter

If the gaps in the Marx generator don't all fire at exactly the same time, the leading edge of the impulse will have steps and glitches as the gaps fire. These delays also result in an overall longer rise time for the impulse. If the jitter in the gaps is reduced, the overall performance is improved.

The traditional Marx generator operating in air has all the gaps in a line with the electrodes operating horizontally opposed. This allows the UV from bottom gap to irradiate the upper gaps, reducing their jitter. Tests reported in Craggs and Meek showed that obstructing the UV led to greatly increased jitter in the bank output, which they attribute to the lack of UV irradiation on the upper gaps.

For a Marx generator which is immersed in oil, or using enclosed spark gaps, resistor or capacitor networks can be used to propagate the trigger pulse to all the gaps, rather than relying on the overvoltaging of the upper gaps to fire them.. A design from Maxwell labs uses a series of resistors to apply the trigger impulse to all the gaps.

Laser irradiation or triggering of the gaps could also be used.

Craggs and Meek also report the use of radioactive sources included within the gap electrodes to reduce the jitter.

Other switching devices

The Marx technique has been used to generate impulses of several kilovolts from a relatively low charging source using avalanche transistors as the switching device instead of a spark gap. In this case, the resistors need to be chosen to keep the transistor turned on.

Alternate charging schemes

Particularly for lower output voltages, the capacitors can be charged in parallel from a common source through a series resistor or inductor. The charging impedance has to withstand the full output voltage for the top stage. For the solid state Marx generator running at a few kV described above, this isn't as much of a problem as it would be for a megavolt range lightning impulse simulator.

Inductors as the charging impedances

The charging resistors can be replaced by inductors, eliminating the power loss in the resistors.

Increasing the repetition rate by using Hydrogen spark gaps

Hydrogen has a very fast recovery time, facilitating the production of high rep rate pulses from a Marx circuit. An example of this is a design by Grothaus, Moran and Hardesty, shown in U.S. patent #5311067. This is a very compact pulser running in a pressure tank filled with hydrogen.
