Modified Symmetric Auctioneering Diode Configuration

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1. Introduction
   This white paper presents a modified symmetric auctioneering diode configuration which combines the benefits of the symmetric and asymmetric auctioneering diode configurations detailed by Doerry and Ashton (2019). Bob Ashton described this configuration to the author on September 20, 2019.
2. Conventional auctioneering diode configurations.
   Figure 1 depicts the traditional asymmetric auctioneering diode configuration. Upon loss of one of the sources, power will automatically, without control action, smoothly transition to the alternate source. Since all off the negative supplies are connected together, there are multiple return paths, all with roughly the same impedance, for the differential current. These multiple paths cause common mode currents to flow through the system. The common mode currents can cause circuit breakers to trip inappropriately, and can be a source of EMI.
   Figure 2 depicts the traditional symmetric auctioneering diode configuration. This configuration is effective at eliminating the multiple current return paths and resulting common mode currents. This configuration does however, have an undesirable characteristic in that in the case of certain double ground faults (depicted in red on figure 2), the voltage across the loads can be double the nominal system voltage. Figure 3 depicts how this voltage doubling occurs.

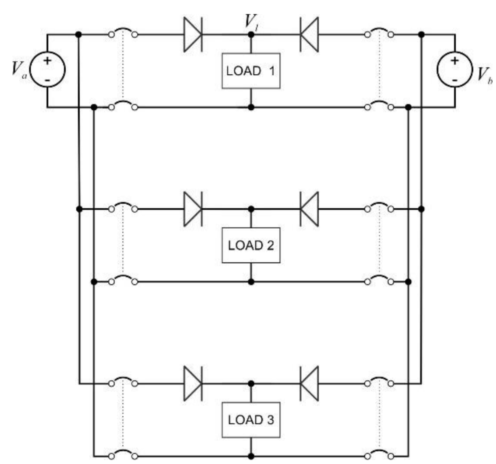

Figure 1: Asymmetric Auctioneering Diode configuration

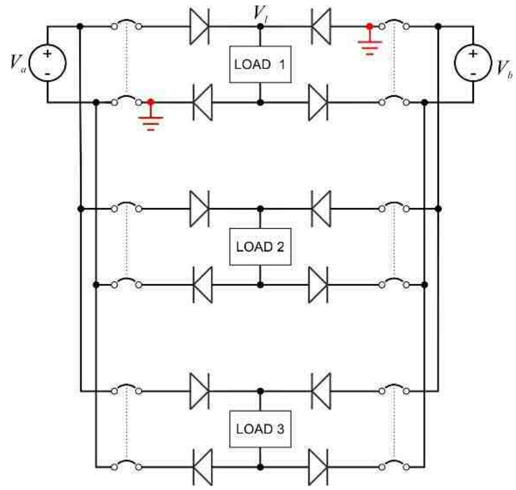

Figure 2: Symmetric Auctioneering Diodes

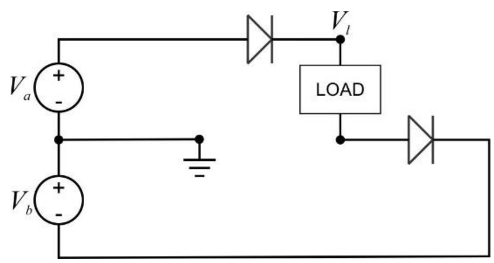

Figure 3: Voltage Doubling with Symmetric Auctioneering Diodes

3. Modified Symmetric Auctioneering Diode Configuration
Figure 4 depicts the modified symmetric auctioneering diode configuration. Using anti-parallel diodes on one of the conductors eliminates the voltage doubling depicted in Figure 3 while still preventing multiple return paths. If a diode is modeled as a constant diode voltage drop if forward biased, and an infinite impedance if reverse biased, then figure 5 demonstrates that the direct return path through diode D-1an1 has only 1 diode drop, while the other return paths have 3 (e.g. D-1bn1 to D-2bn2 to D-2an1). D-1an1 effectively shorts out the other paths.

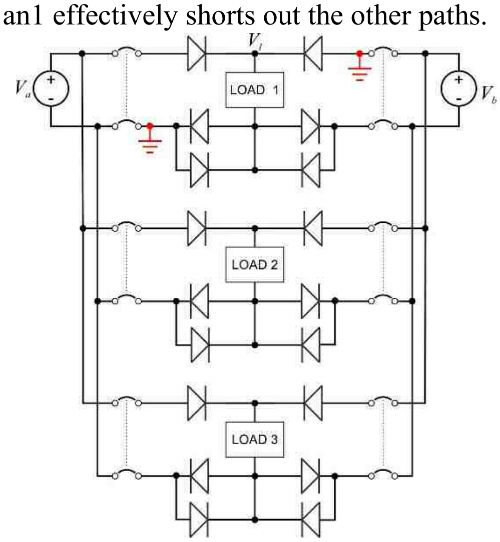

Figure 4: Modified Symmetric Auctioneering Diode Configuration

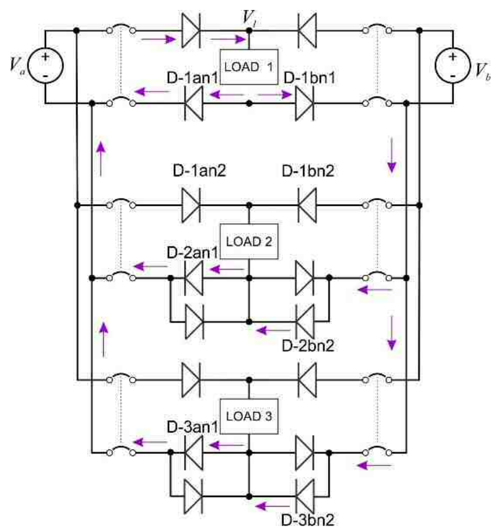

Figure 5: Modified Symmetric Auctioneering Diode Current Path

A more sophisticated exponential model of a diode can also be used to show that the multiple return paths are effectively blocked by this circuit. Equation [1] is the large signal model for a diode

$$I = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right) \qquad [1]$$

Where

I_S is typically about 10^{-12} amps

V_T is about .026 Volts

n is between 1 and 2. (1.08 works well and is used here)

Table 1 provides the calculated voltage-current characteristic for this model. In this table, the resistance is the slope of the line and is equivalent to the small signal impedance r_D at the d.c. operating point I_Q calculated using equation [2]. Figure 6 plots the voltage vs current for this diode.

$$r_D = \frac{n \cdot V_T}{I_Q} \qquad [2]$$

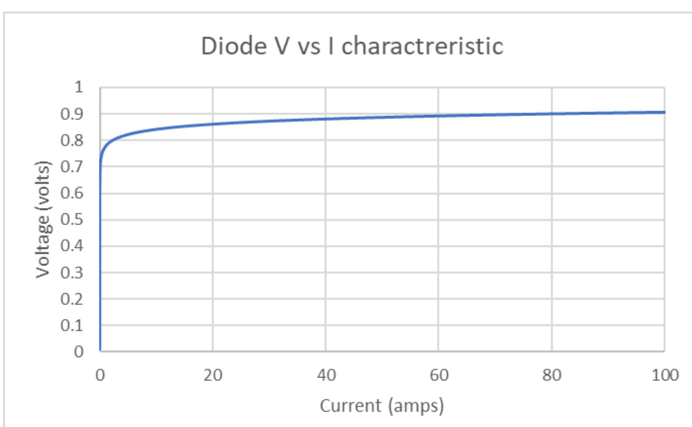

Figure 6: Voltage-Current characteristic for diode

Table 1: Diode voltage-current characteristic

I (amps)	V (volts)	R (ohms)
4.28E-13	0.01	6.56E+10
1.04E-12	0.02	2.70E+10
1.91E-12	0.03	1.47E+10
3.16E-12	0.04	8.90E+09
4.93E-12	0.05	5.69E+09
7.47E-12	0.06	3.76E+09
1.11E-11	0.07	2.53E+09
1.63E-11	0.08	1.73E+09
2.37E-11	0.09	1.19E+09
3.42E-11	0.10	8.21E+08
2.08E-10	0.15	1.35E+08
1.24E-09	0.20	2.27E+07
7.35E-09	0.25	3.82E+06
4.36E-08	0.30	6.43E+05
1.54E-06	0.40	18275.38
5.41E-05	0.50	519.08
1.90E-03	0.60	14.74
6.71E-02	0.70	0.42
9.57E-02	0.71	0.29
0.14	0.72	0.21
0.20	0.73	0.14
0.28	0.74	0.10
0.40	0.75	7.06E-02
0.57	0.76	4.94E-02
0.81	0.77	3.46E-02
1.16	0.78	2.42E-02
1.65	0.79	1.70E-02
2.36	0.80	1.19E-02
3.37	0.81	8.33E-03
4.81	0.82	5.83E-03
6.87	0.83	4.09E-03
9.81	0.84	2.86E-03
14.01	0.85	2.00E-03
20.00	0.86	1.40E-03
28.56	0.87	9.83E-04
40.77	0.88	6.89E-04
58.21	0.89	4.82E-04
83.12	0.90	3.38E-04

Figure 7 depicts the return path for an arbitrary number of load return paths, but with only one load turned on. All other circuit details are eliminated. If we assume the voltage drop across D-1an1 is 0.90 volts corresponding to 83.12 amps, then the current through the other common mode paths will be based on the voltage drop across D-1bn1 and the voltage drop across the parallel combination of the two diodes for each load. If we assume the voltage drop across D-1bn1 is 0.4 volts, corresponding to 1.54 microamps, then the voltage drop across each of the other diodes in the common mode return paths is 0.25 volts ((0.9 – 0.4) / 2) which corresponds to 7.35 nanoamps. This means that the number of common mode return paths in parallel must be 1540 / 7.35 = 210 return paths. If the number of return paths is actually less, then the voltage across D-1bn1 will also be less and the current through D-1bn1 will be less. If there is only one common mode return path, then voltage drop across the diodes will be the same (in this case 0.9 / 3 = 0.3 amps) which corresponds to a lower limit current of 43.6 nanoamps. The common mode current is actually half the current through common mode current path. Thus, the common mode current through D-1bn1 will likely range between 43.6 nanoamps and 1.54 microamps for a differential mode current of roughly 83 amps.

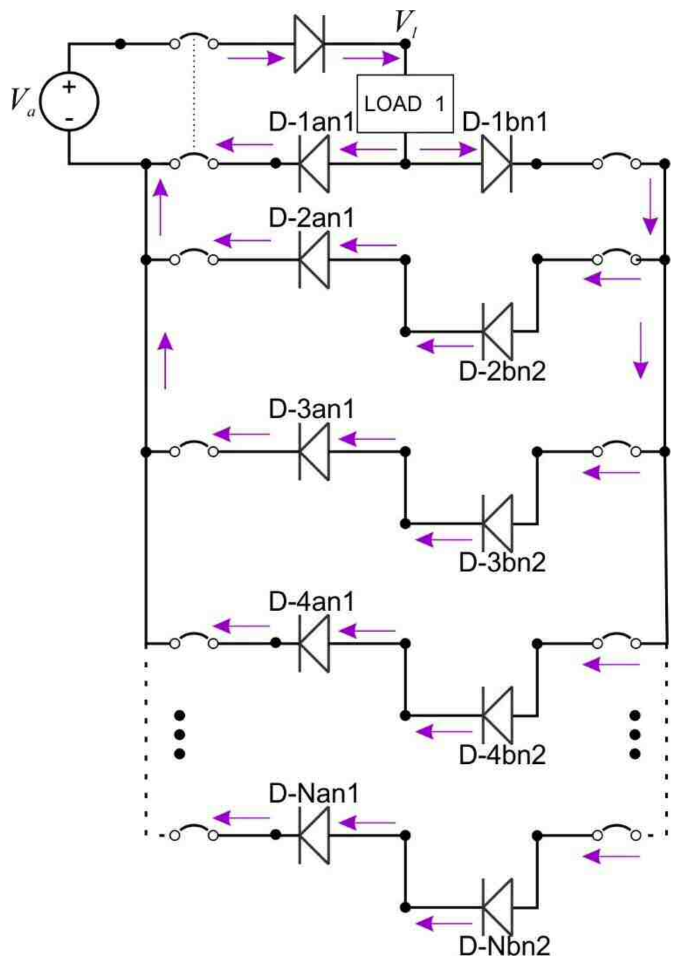

Figure 7: Return Paths for N number of loads

From Table 1, the small signal impedance of D-1an1 is 0.338 milliohms. Compare this to the small signal impedance of D-1bn1 which varies from 18.3 kilo-ohms at 0.4 volts to 643 kilo-ohms at 0.3 volts. The many orders of magnitude difference in impedance suggests that the modified symmetric auctioneering diode configuration behaves like a symmetric auctioneering diode in terms of impedance, but is not subject to voltage doubling during certain double ground faults.

References

Doerry, Norbert, and Robert Ashton, "Auctioneering Diodes: Pros and Cons ," presented at 2019 IEEE Electric Ship Technologies Symposium (ESTS 2019), Arlington VA, August 14-16, 2019