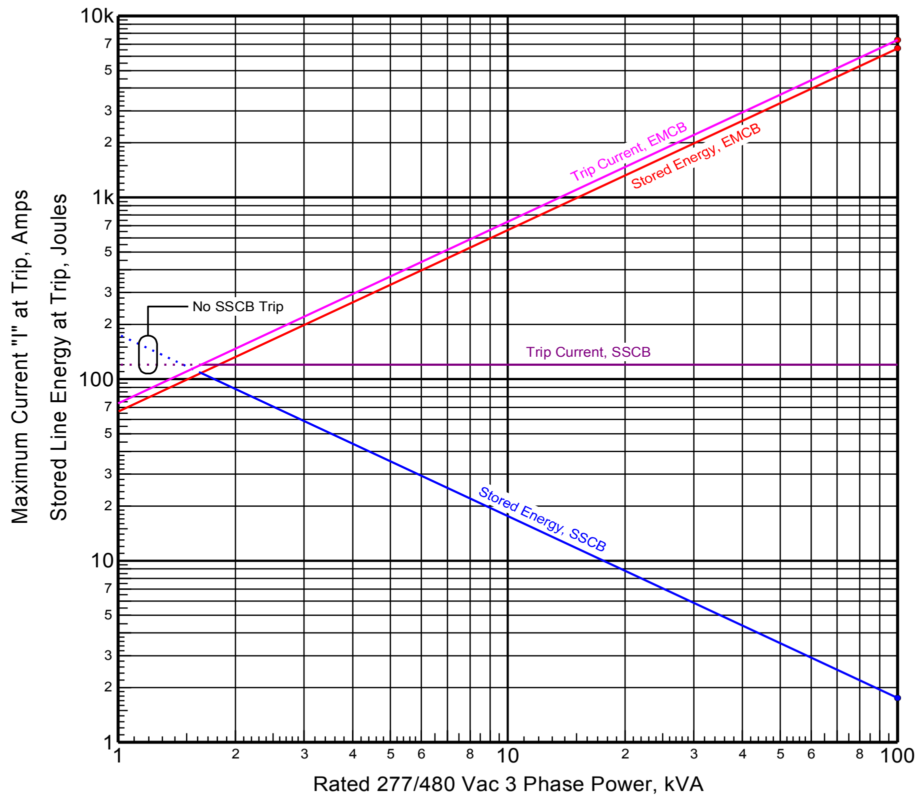
WBGlobalSemi, Inc.

Solid State Circuit Breaker (SSCB) with Low State Loss, Bruce Carsten, CTO Circuits & Systems, WBGS, Inc.

Power America RFI: Focus Area 3: Develop commercial SSCB power module with 50% state loss reduction using high power SiC BJTS by leveraging working prototype as test bed.

BACKGROUND: SiC SSCBs can deliver significant advantages versus electromechanical circuit breakers.

SSCB advantages include (1) much faster interruption of fault currents (microseconds or less, vs. milliseconds), which is: (2) fast enough to prevent full fault currents from being reached; (3) thus no significant line voltage sag; (4) no ionizing arc on circuit interruption; (5) no contact bounce; (6) capable of digital CCC (Command, Control & Communication) including remote monitoring and reset for smart grids & micro grids; and (7) potentially indefinite operating lifetime.



We propose that SiC Bipolar Junction Transistors (BJTs) can be a preferred semiconductor for this application as (1) they have substantially higher temperature tolerance than silicon devices; (2) 15 kV voltage capacity has been demonstrated in the lab, including by WBGS CTO SiC Semiconductors; (3) high current capability will be available for prototyping Q-2, 2019; (4) low conduction drop; (5) fast switching speed - comparable to MOSFETs; (5) lowest cost in volume production due to a simplest construction versus other SiC device types.

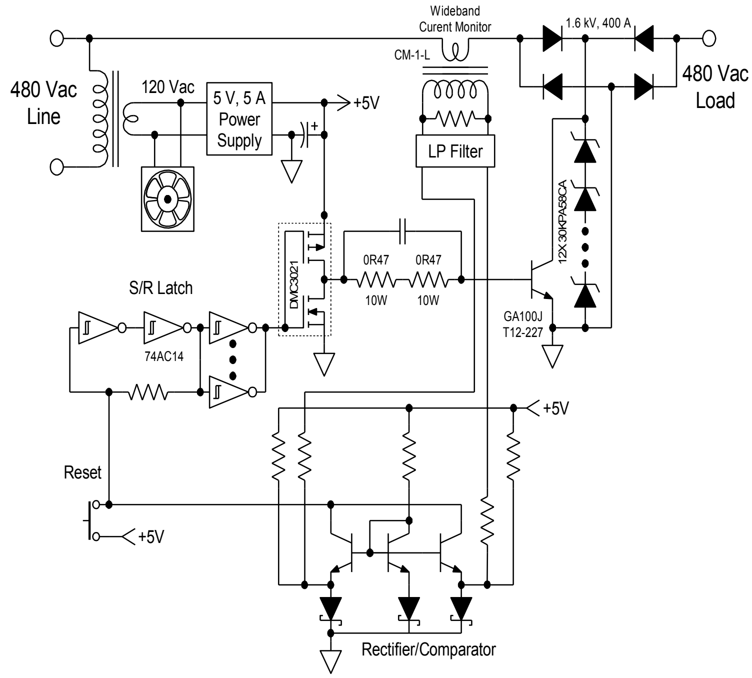
We propose the following specifications for an advanced SSCB power module using SiC BJTs to deliver 50% lower state loss than available from SSCBs using SiC MOSFETs or other SiC devices.

Module Target Specification for Smart Grid Alpha Product (TLR 5) to test new generation BJTs

Parameter	Units	Target	Conditions
Operating Voltage	V	13,000	Dc or Peak ac
Maximum Voltage	V	25,000	Transient Peak
Carrying Current	A	100	Continuous
Peak Current	A	200	1 ms
Demonstrated Operations*		100	15 kV Peak, 200 A, 150 °C
Interrupt Time	µs	< 1.0	15 kV Peak, 200 A, 150 °C

* Into a short circuit

Current Prototype Power Circuit Design



There will inevitably be ON state loss which is the disadvantage of SSCBs, equal to the load current times the ON state voltage on the devices in series in the circuit breaker. Our design shows a full wave diode bridge and a single BJT switch which means that there are three devices in series with the load current, two diodes and a BJT. For 480V operation with 1200V devices the loss is 0.9 V for each diode if Silicon devices were used (2V with SiC Schottky devices) and .6 to 1.2V (depending upon temperature) for the BJT so for 50A the on state loss is 120W. This is 0.9% of the line - neutral load power (277 V x 50 A).

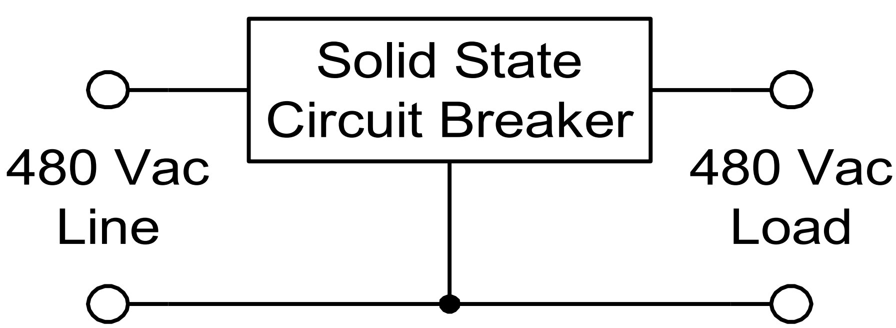
The ON state loss for the proposed 13kV at 100A SSCB, utilizing the same configuration, and assuming we need 3x 10kV devices in series and (using Cree information) at 50% load we get 4V on state voltage for a 10kV SiC Schottky and 5.3V for a 10kV MOSFET (at 100°C). In our design we have 24V for the diodes and 15.9V for the MOSFETs so 4kW loss for a 1.3MW load or 0.3% loss.

A more efficient configuration has two back-to-back (anti-series) switches with anti-parallel diodes, where we would get 12 V for the diodes and 15.9 v for the MOSFETs, for 2.8 kW loss. If our BJTs have half the on state voltage of MOSFETs we could get down to a 20 V on state voltage, or 2 kW (0.15%) loss. We may also want to parallel the SiC Schottky diodes with SiC PIN diodes to improve surge current (or use a merged diode design) - all possible with time and funding. Delivery of 6.5 kV BJTs at 50A in Q-2, 2019 will enable a final design and commercialization of an improved SSCB.

Regarding start-up mode our SSCB can operate in a trailing edge phase modulation at the start to get a soft start effect. This can be done as a time varying duty cycle or one responding to peak load current.

Regarding safety for line maintenance workers a mechanical lock off switch can be incorporated.

For 480 Vac single phase operation, the SSCB will operate in series between the line and load as usual, but will also require a third connection to supply power to the transistor drive and control circuitry.



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Breadboard Module Target Specification for Smart Grid

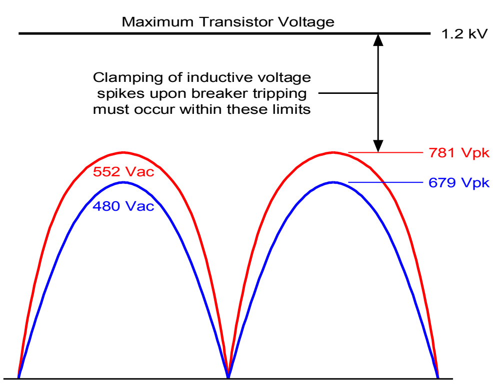
	Units	Target	Conditions
Operating Voltage	V	480	Dc or rms ac
Maximum Voltage	V	800	Transient Peak
Carrying Current	A	70	Continuous
Peak Current	A	120	1 ms
Demonstrated Operations*		100	780 V peak, 120 A, 150 °C
Interrupt Time	μs	< 1.0	780 V peak, 120 A, 150 °C

* Into a short circuit

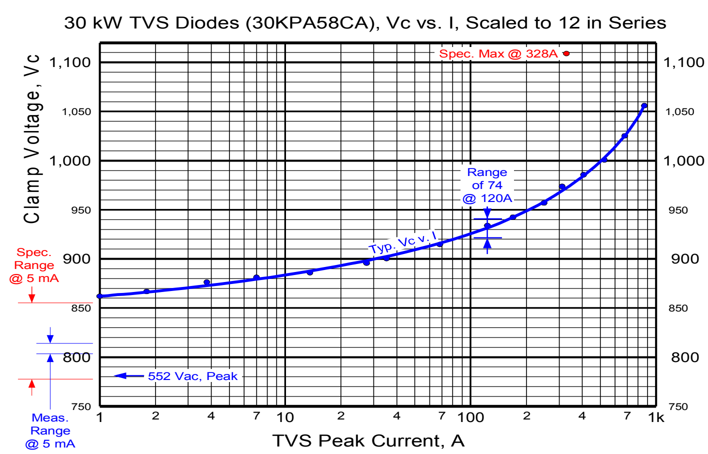
Our design current is 70 A rms, or 100 A pk, with trip at 120 A. Overcurrent is sensed by a current monitor, which 'sets' an S/R latch to turn the breaker off. A diode bridge is used to 'steer' the ac line current in the same direction through the SiC BJT. Various approaches were considered for sensing the AC current and a "current monitor" was found to perform far better, requiring only a low pass filter to remove a short (10 ns) initial spike and prevent sub us trip times.

However, current monitors are designed with an internal 'burden', and have a low impedance output. This makes it more difficult to 'rectify' the low voltage output (1.2 V @ 120 A) and the use of a rectifier/comparator circuit in the schematic needs to be investigated.

A principle difficulty with SSCBs is the energy stored in the inductance of the power line when the breaker trips with an overcurrent. For fast acting SSCBs this problem becomes <u>worse</u> for low fault current power sources, as the line inductance is greater, causing *more* energy to be stored at the trip current. Empirical measurements show an array of 12 "30 kW" TVS diodes will be adequate to adsorb the inductive energy. SiC TVS diodes *may* be the preferred solution; this needs to be investigated.



Voltages for rectified 480 Vrms ac nominal line, and for 15% high line



Our minimum goals are to develop and demonstrate a basic 'dc' SSCB "module" with the following features (1) contain least 2 or 3 SiC BJTs operating in series, to demonstrate the ability to "stack" multiple transistors for higher voltage ratings; (2) operate with at least 2 modules in parallel, to demonstrate the ability to operate with multiple transistor series strings for higher current ratings; (3) operate with 2 modules connected for ac applications. Development of this prototype and upgrading with high power SiC BJTs in Q-2, 2019 will enable a realistic path to an improved SSCB with initial commercial testing in the July 2019 - June 2020 time line.