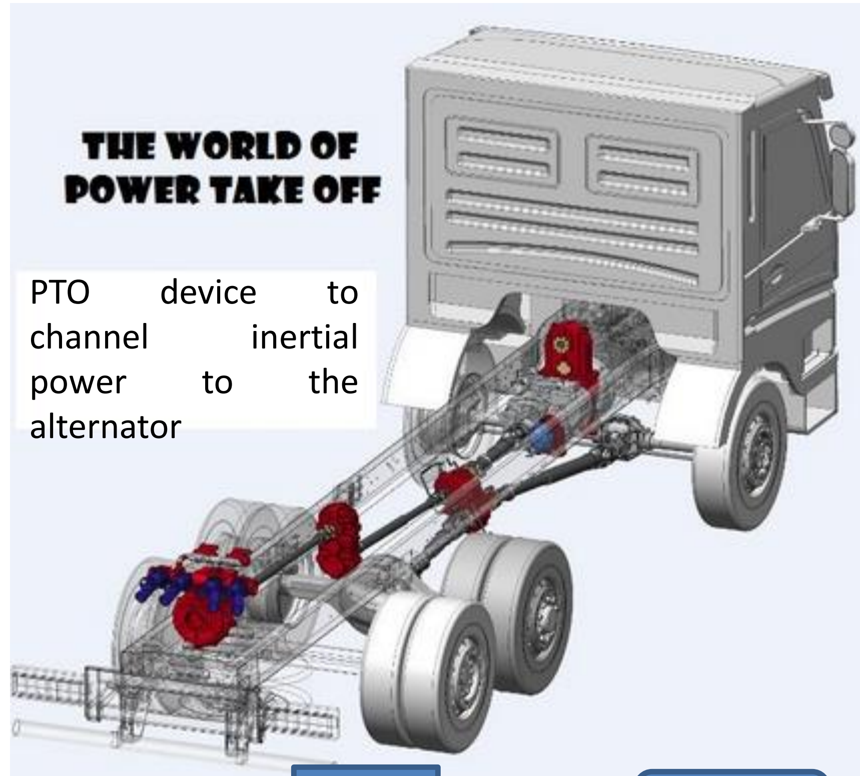
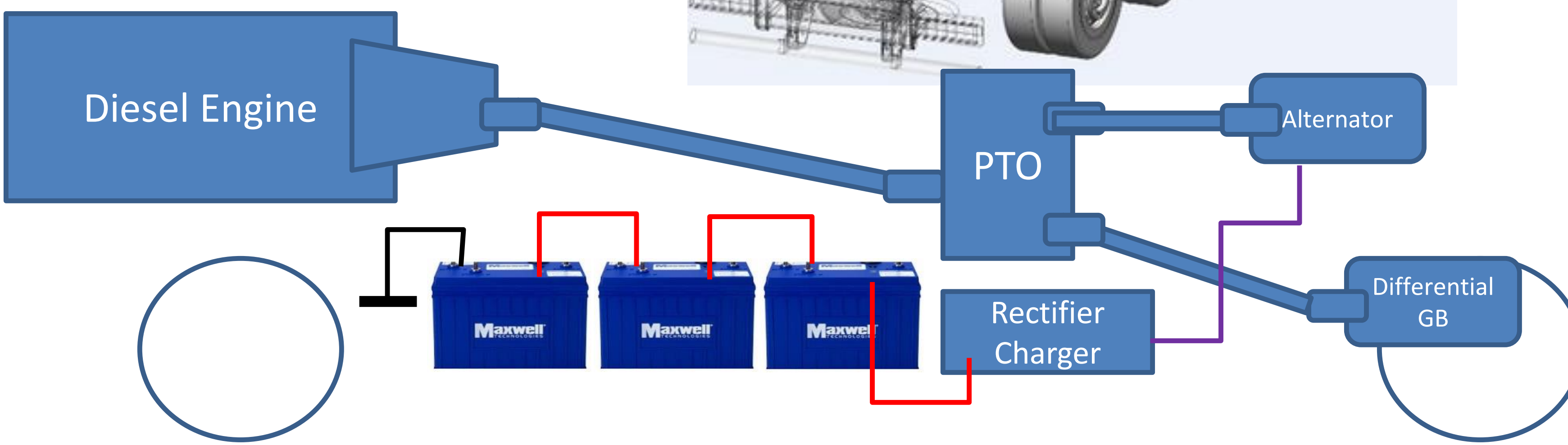
Regenerative Braking Energy Recovery

- The transport segment considered is Mid-range to Heavy Duty Diesel Trucks. These trucks donot have an electrical transmission and are in the highest numbers today.
- The concept also holds good for hybrid trucks with Electrical Transmission provided they have excess energy to return to the micro-grid
- Assumption: 10 tonner, with a safe braking distance of 100 mtr. From 80Kph to 20Kph
- The braking is a combination of electrical regeneration (the re-channelization of the energy of the braking vehicle into electrical power developed at the alternator connected to the driving wheelset via an efficient power take off device (PTO).
- For hybrids this is already a proven concept, by Wrightspeed, US for FedEx. (https://www.wired.com/2014/09/fedex-wrightspeed-diesel-ev-trucks/)
- The recovery of energy in this manner is channelized to onboard quick electrical storage and offload device, called Super Capacitor, which is suited to such duty.

Regenerative Braking Energy Synopsis – Schematic Diagram

A) The power from the driven wheel
Is channeled by a clutched PTO device
B) The braking modulation computer calculates the amount of energy to be regenerated and to be dissipated in Air brakes of the truck, based on parameters such as the voltage level of the super capacitors.





Regenerative Braking Energy Balance Calculations

1. **It is assumed that a 10MT loaded diesel truck inclusive of approximately 300Kilo's of add on electrical equipment , retarding from 80Kph to 20Kph over a safe braking distance of 100Mtrs.**
2. Energy released = 0.5 * 10000 * (u2 – v2) = **2067KJ**
3. Actual to be converted energy assuming a high efficiency = 40% * 2067 = 800 KJ (approx.) – improving this to 70% is considered as a target benchmark as per ref: http://www.eaton.in/EatonIN/ProductsServices/Vehicle/ProductsServices/HybridPower/SystemsOverview/HydraulicHybrid/index.htm
4. Time taken (Tx) to reach 20Kph from 80Kph = 7sec
5. As per Maxwell supercapacitor datasheet, stored energy storage per 125V bank = 140 Wh = 504KJ
6. Hence we need 3 Banks (approx. 180Kg added load which is much less in comparison to the total weight of the truck) to store the average energy. However this is just an approximation.
7. These banks would be fed from the retarding alternator connected to the PTO, powered not from the engine but the driven wheel set.

Regenerative Braking Energy Balance Calculations

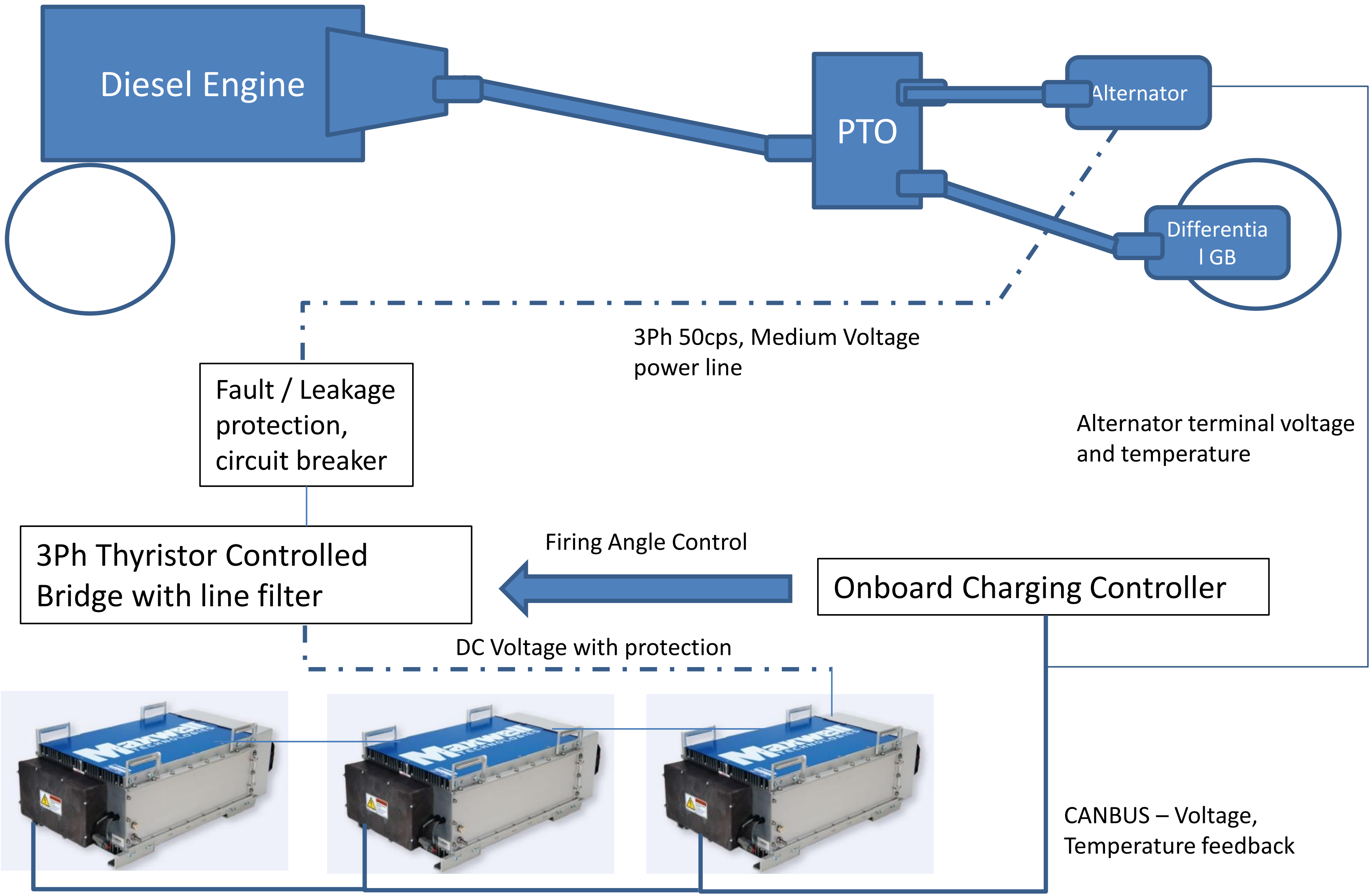
1. Assuming we connect the banks in series at the charging phase. The equivalent capacitance = 63/3F and average voltage durability of the series bank = 3 * 125VDC = 375VDC. The highest voltage durability = 3 * 136VDC = 408VDC
2. The energy that can be safely stored in the above config = 0.5*Ceq*(Vavg)^2 = 1475KJ, under a constant Vavg. However in practice the voltage is reducing.
3. Current must however be limited due to the capacity of the bank, which is 1900A (absolute max), system being a series bank. A means to limit starting current to 1000A should be adopted by controlling the rectifier output.
4. The assumption is that the alternator rectifier output voltage 375V is rated output at the moving velocity 80Kph, and linearly falls to around 94V at 20Kph.
5. Power output of the electrical machine is proportional to speed as well.
6. There is a voltage buildup with gradual charging and the charging circuit must limit this buildup to 375VDC. Under the given conditions this approximates to around 200VDC
7. The total energy saved per braking cycle is approximated under given conditions to 400KJ. In practice this value will be increased by cutting off the current limiting resistance.
8. The alternator / Generator should be a smaller machine , overloaded for a short time (7 – 10s), peak of 400KW.

Regenerative Braking – SC Charging System

1. The charging circuit applies the 3Ph 50cps falling alternator voltage to a solid state bridge rectifier with a peak short time current rating of 1000A at 375VDC max. The output of the rectifier is assumed to provide smooth voltage rise / fall characteristics. A reduced voltage at start limits the current to 1000A.
2. The capacitor bank of SC banks, has internal features to equalize the cell voltages as per specs from Maxwell below. The charger is not a constant voltage source.
3. The charging circuit will monitor the DC voltage buildup available via the CAN interface (RS485 compatible), to avoid over charging and the current. The buildup will be over multiple braking cycles, which will be monitored and limited by the charging system.
4. The charging circuit will have means to store the total energy supplied to the capacitor bank during the braking cycle and can be retrieved via an API.
5. The charging circuit will manage electrical faults, provide protection against line to ground faults, track the power line characteristics from the alternator.
6. The onboard diagnostics will monitor the temperatures of the SC , Alternator and Rectifier.

MONITORING / CELL VOLTAGE MANAGEMENT	
Temperature Interface	Serial Data (CAN)
Cell Voltage Monitoring	Group Voltage (CAN)
Connector	Deutsch DTM
Cell Voltage Management	VMS 2.0

Regenerative Braking – SC Charging Circuit



Regenerative Braking – SC Offloading System

1. The Supercapacitor bank has accumulated static charge equivalent to few braking cycles , with a voltage waveform equivalent to a saw-tooth.
2. After a number of braking cycles, the supercapacitors would be nearly fully charged , ready to offload the electrical energy to a ground terminal.
3. The offloading will also arrange the SC's in series, to discharge each SC with a modest / practicable discharge ratio of 50% to the ground terminal. The ground terminal will be capable of transforming the accumulated electrical energy to the voltage level in the microgrid.
    1. Voltage Available = 3 * Max. Rated Voltage per SC bank * Discharge Ratio
    2. Reference: http://ijsetr.org/wp-content/uploads/2015/03/IJSETR-VOL-4-ISSUE-3-589-594.pdf
4. The SC's are capable of discharging fast to a residual voltage, based on the Discharge Ratio.
5. The ground termination will need to monitor the SC terminal voltage and adjust the voltage level according to the microgrid storage apparatus requirements.
6. Fault handling and management at the receiving station will be taken care by the fault monitoring.
7. The voltage from SC bank will be fed via an SCR / controlled rectifier to the DC link to which will be connected the microgrid storage. A variable voltage DC link inverter will regulate and feed from the microgrid storage to the microgid community via the transformer and protection apparatus.

Regenerative Braking – SC Offloading System Schematic Diagram