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Analysis for Size of Ultra-Capacitor Bank to be Installed on 1.5kV System for Energy Storage during Regenerative Braking DC Drives

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Abstract: *Economic indicators of electro-dynamic braking have not been properly estimated. Vehicles with alternative power trains are in transitional stage between developments of pollution – free vehicles. According to these aspects the investigation on conventional hybrids drives and their control system is carried out in the paper. The equations that allow evaluating effectiveness of regenerative braking for different variants of hybrid drive are given. Suitable size of ultra-capacitor for efficient energy storage medium in all hybrid electric vehicles has been evaluated. This paper also discuss the advances in double layer electrolytic capacitor technology have opened new areas to complement batteries as a storage medium. Equations for both constant current as well as constant power discharges are discussed. An iterative method for determining the minimum number of ultra-capacitor cells is introduced. The effects of ultra-capacitor sizing on the rating of interface power electronics are examined.*

Keywords – *Ultra-capacitors, hybrid electric vehicles, energy storage, diesel locomotives, braking.*

I. Introduction

Evaluation on diesel loco Vehicle’s, indicates 20–40 % of mechanical tractive power is lost during braking. Estimation of recovered energy is very important [5]. When a vehicle brakes, energy is released to grate, most of this energy is lost in the system. The challenging alternative is to store the braking energy and to use it during acceleration operation of the vehicle. Conventional diesel locomotives powered electrical vehicles cannot use regenerative brake energy. High interest and the onrush of hybrid vehicle are conditioned by a number of hybrid drive advantages:

- Decreasing of fuel consumption and of exhaust emissions. (In India per day petroleum consumption in year 2010 was 3,116.22 barrels /day).
- Possibility of breaking energy regeneration.
- Possibility of using in hybrid vehicles with decreased volume preserving dynamic characteristics.
- Increase of efficiency coefficient due to serial and multiple energy conversion.
- High percentage of recovered energy. Estimation of recovered energy is very important. It is needed to reduce electric demands.
- It can be a new energy savings opportunities and power will help in supply optimization, in case of hybrid traction vehicles systems, which are using regenerative braking energy.

Ultra-capacitor technology has been commercially available for over the past decade. They can store much more energy than conventional capacitors and are available in sizes up to 4000F with voltage ratings of up to 3V per cell. They can be discharged or charged faster than batteries and can deliver 10-20 times more power e.g. ultra-capacitors typically have 10 times the specific power (W/kg) as well as a much lower charge time when compared to lead acid batteries. They also offer 10 to 100 times the energy density (Wh/Kg) of conventional capacitors. In terms of energy and power density, ultra capacitors can therefore be placed between batteries and conventional capacitors.

II. LOCOMOTIVE ENERGY SAVINGS SYSTEMS

For the time being locomotives new energy [10] savings technologies include: 1–optimized design vehicle; 2–energy management control system; 3 – energy storage system; 4 – low energy climate system; 5–clean diesel motor power pack; 6–new technologies traction motor. Energy savings upto8–15 % are efficient optimized train, up to 10–15 % using efficient energy management control system, up to 25–30% using efficient energy management control system, up to 25–30% using effective energy storage system, upto25–30% using low energy intensity fuel. Clean diesel motor power pack reduces particle emission upto70–80%.New technologies traction motors increases energy efficiency2–4 % at reduced volume and weight. New technologies can create energy savings up to 50 %. Figure 1 show new energy savings technologies possibilities.

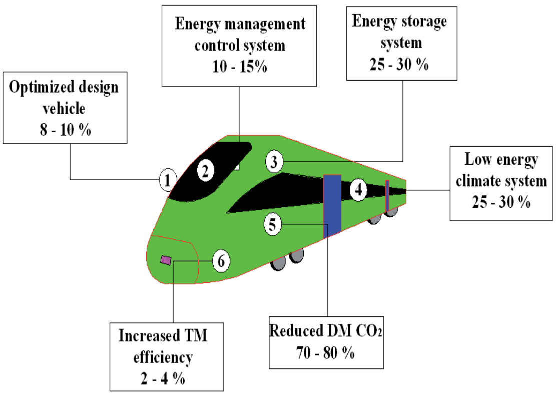

Fig.1.Circuit diagram of locomotive energy savings structure [7]

III. MODELING OF ULTRA-CAPACITORS

Ultra-capacitors can be used as a temporary power source for back up purposes. Batteries were first used for this application; however the large energy storage capability of ultra-capacitors makes them an alternative to batteries. Ultra-capacitors cannot replace batteries completely; however they can be used to complement each other. In the hybrid electric vehicle, the ultra-capacitor can be used during vehicle operation. Although batteries cannot deliver large current sat extremely low temperatures, they can deliver enough current too slowly charge an ultra-capacitor, which can be used to start the vehicle. This could prompt the use of longer lasting batteries rather than large batteries designed to deliver hundred few amps during a cold start.

TABLE – 1
A Comparison of Conventional Storage Technologies [1].

Available Performance	**Lead Acid Batter**	**Ultra-Capacitor**	**Conventional Capacitor**
Charge Time	1to5hrs	0.3to30s	10^{-3}to10^{-6}s
Discharge Time	0.3to3 hrs	0.3to30 s	10^{-3}to10^{-6}s
Energy(Wh/kg)	10 to100	1to10	<0.1
Life Cycle	1000	> 500000	> 500000
Specific Power (W/kg)	< 1000	< 10000	< 100000
Charge/Discharge efficiency	0.7to0.85	0.85 to0.98	>0.95

When sizing the ultra-capacitor, it is necessary to understand V_{max} the implications of the various factors that not only affect the capacitor, but will also affect the design of the interface power electronics. These factors affecting the choice of capacitor include:

- The peak capacitor voltage,
- Allowable maximum percentage discharge,
- Peak current flowing through the capacitor,
- Capacitor time constant (τ),
- Capacitance per cell,
- Cell voltage,
- Number of cells needed,
- Mass of the cell array,
- Cost of the cell array.

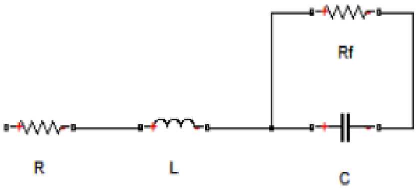

Fig. 2. First order model of an ultra-capacitor

The equation relating the capacitance to the voltage, current and discharge time can be expressed as follows:

$$\boldsymbol{C} = \frac{\boldsymbol{I}}{\boldsymbol{V}_{\mathbf{max}} - \boldsymbol{V}_{\mathbf{min}}}\boldsymbol{t} + \boldsymbol{\tau}$$

Where,
C is the capacitance,
I is the average current,
V_{max} is peak capacitor voltage,
V_{min} is the lowest voltage after discharge
& τ is the product of the equivalent series resistance and the capacitance

IV. Diesel Electric Locomotive

In a Diesel-electric locomotive, the Diesel engine drives an electrical generator whose output provides power to the traction motors. There is no mechanical connection between the engine and the wheels. The important components of Diesel-electric propulsion are the Diesel engine (also known as the prime mover), the main generator, traction motors and a control system consisting of the engine governor as well as electrical and/or electronic components used to control or modify the electrical supply to the traction motors, including switchgear, rectifiers and other components. In the most elementary case, the generator may be directly connected to the motors with only very simple switchgear.

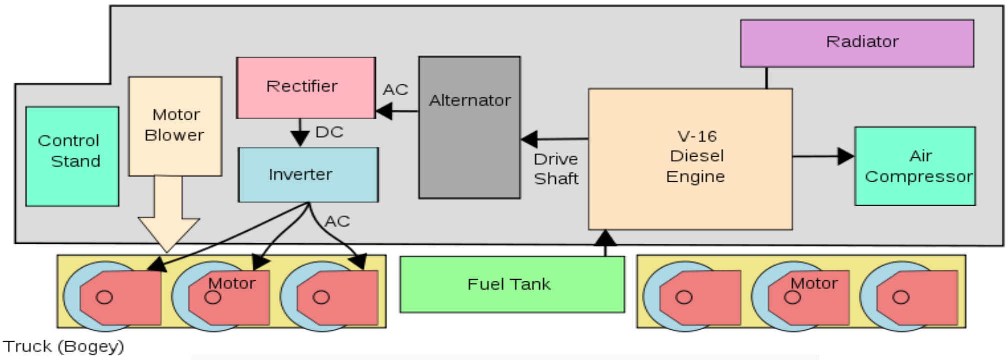

Fig. 3 Schematic diagram of Diesel electric locomotive [8]

V. Dynamic Braking

A common option on Diesel-electric locomotives is dynamic (Rheostatic) braking.

Dynamic braking takes advantage of the fact that the traction motor armatures are always rotating when the locomotive is in motion and that a motor can be made to act as a generator by separately exciting the field winding. When dynamic braking is utilized, the traction control circuits are configured as follows:

- The field winding of each traction motor is connected across the main generator.
- The armature of each traction motor is connected across a forced-air-cooled resistance grid (the dynamic braking grid) in the roof of the locomotive's hood.
- The prime mover RPM is increased and the main generator field is excited, causing a corresponding excitation of the traction motor fields.

The aggregate effect of the above is to cause each traction motor to generate electric power and dissipate it as heat in the dynamic braking grid. A fan connected across the grid provides forced-air cooling. Consequently, the fan is powered by the output of the traction motors and will tend to run faster and produce more airflow as more energy is applied to the grid.

Ultimately, the source of the energy dissipated in the dynamic braking grid is the motion of the locomotive as imparted to the traction motor armatures. Therefore, the traction motors impose drag and the locomotive acts as a brake. As speed decreases, the braking effect decays and usually becomes ineffective below approximately 16 km/h (10 mph), depending on the gear ratio between the traction motors and axles.

Dynamic braking is particularly beneficial when operating in mountainous regions, where there is always the danger of a runaway due to overheated friction brakes during descent (see also comments in the air brake article regarding loss of braking due to improper train handling). In such cases, dynamic brakes are usually applied in conjunction with the air brakes, the combined effect being referred to as blended braking. The use of blended braking can also assist in keeping the slack in a long train stretched as it crests a grade, helping to prevent a "run-in", an abrupt bunching of train slack that can cause a derailment. Blended braking is also commonly used with commuter trains to reduce wear and tear on the mechanical brakes that is a natural result of the numerous stops such trains typically make during a run.

VI. Scope With Regenerative Braking

During braking, the traction motor connections are altered to turn them into electrical generators. The motor fields are connected across the main traction generator (MG) and the motor armatures are connected across the load. The MG now excites the motor fields. The rolling locomotive or multiple unit wheels turn the motor armatures, and the motors act as generators, either sending the generated current through onboard resistors (dynamic braking) or back into the supply (regenerative braking).

For a given direction of travel, current flow through the motor armatures during braking will be opposite to that during motoring. Therefore, the motor exerts torque in a direction that is opposite from the rolling direction.

Braking effort is proportional to the product of the magnetic strength of the field windings, times that of the armature windings.

VII. Specification & Analysis Of Regenerative Braking

A. Specifications Of The 1.5kv Drive System

GHp = 2600Hp

THp = 2400Hp

$V_{rated} = 1.5$ KV, $I_{start} = 200$A

B. Parametric Condition of Loco During Braking

In diesel locomotives in braking will be done at two parameters:

i. Constant Parameters
  - Braking Torque & Armature Current

ii. Variable Parameters
  - Speed of Locomotive & Braking Voltage

C. Parameter of Loco During Braking

i. Constant Parameters
  - Braking Torque - 1326.67 N- m
  - Armature Current – 800 A

ii. Variable Parameters
  - Speed of Locomotive – 80 – 20 KMPH
  - Braking Voltage – 1.5 – 29 V
  - Time of electric braking 30 – 40 seconds

$$P_{regen} = I_{a(braking)} * V$$

$$P_{regen} = 800 * 26.5_{(max)} = 21.2 \text{ KW}$$

$$P_{regen} = 800 * 2.5_{(min)} = 2 \text{ KW}$$

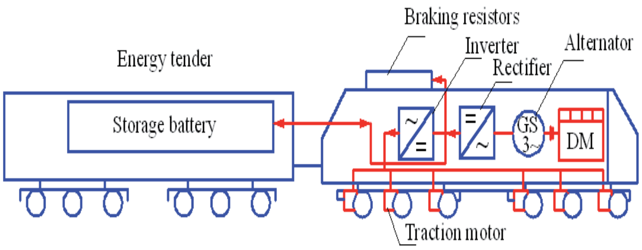

Fig.4.Circuit diagram of hybrid energy traction system using energy tender vehicle [6]

VIII. Analysis Of Size Of Single Cell Capacitance

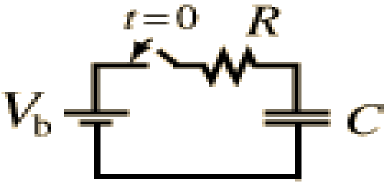

Fig. 5 Energy Storage System

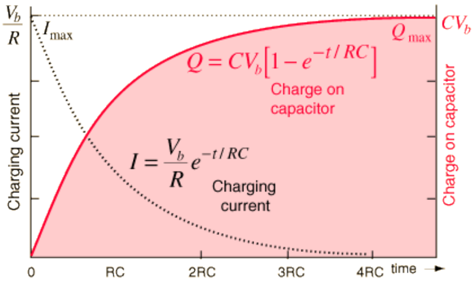

Fig. 6 Charging Characteristics of Capacitor

Where, V_b = braking voltage
Let, Vb = 2.5V, I_{max} = 800A
R = 0.003125Ω, C = 12200F
Just after the switch is closed
The charge will approach a max. Q_{max} = 30500 C
At t = 1 sec. τ = 0.02623
The charging current is 0.974112 A
I_{max} = 779.2891979027497 A
& the charge on capacitor is = 0.0258885C, Q_{max} = 790C
As we already discussed that braking will be performed at constant current, so the ultra-capacitor bank to be installed in series (to make I_{max} constant) & voltage is varied.
For voltage variation bank of capacitor must be installed in series
So the voltage 1 capacitor bank is 2.5 V
Therefore, 2.5 * 12 = 30 V (required)
Series capacitor capacitance

$$\frac{1}{C} = \frac{12}{c_n}$$

$$\frac{1}{C} = \frac{12}{12200} = .009836$$

C = 1016.67F

Fig.7 High-performance double layer technology capacitor (ultra –capacitor) [3]

So, from the above analysis, it can be interred that if bank of ultra-capacitor is installed on the locomotive, this will help in reducing the number of batteries, which are required to provide cranking (initiation or starting) to the locomotive. The ultra-capacitors have very high discharging capability as compared to the storage batteries. The stored energy in capacitor & battery, both as combined will be provide much better cranking torque to start the locomotive drives.

IX. Conclusion

1. Electro-dynamic braking is the main braking technique used for modern electrically-driven locomotives.
2. Hybrid traction technology locomotives can use regenerative braking of high-speed and a low-speed range.
3. Hybrid traction technology locomotives can reduce 25– 30% energy consumption.
4. The regulation algorithms offered allow us to obtain various types of flat characteristics enabling

asynchronous traction motor to be extensively used in traction, recuperation and dynamic braking modes of operation.

5. The regenerative braking power it possible use in diesel electric locomotives for starting engine, acceleration, and operation mode.
6. The power stored in the locomotive in traction is completely utilized. When ordinary mechanical braking is applied, no useful work is done by the power and it is not used in braking.

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