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Swappable Battery Scheme as an Electrical Energy Storage, By Utilizing Regenerative Braking on Public Buses.

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ABSTRACT Recently the world is witnessing a profound efforts to optimize Electrical energy systems, which requires an inclusive quality management of power systems, thus to achieve such merit all applied methodologies should be complied with best Engineering practices as well as by adopting emerging technologies and genuine research and development outcomes which leads to diminishing energy losses, increase power efficiency and must of all energy conserving. Hence, it becomes a must to get benefited from all aspects of waste energy to generate electricity and respectively store it in order to fulfill power demand as deemed necessary.

Keywords: Electric Energy Storage, Public Buses, Regenerative Braking System

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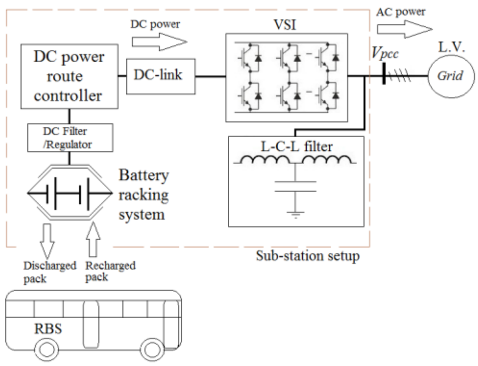
INTRODUCTION

In Kuwait the only public transportation mean is by buses, and presently there are a 3 major companies that operates the ground transportation, those operators are: KPTC, City bus and KGL, we have selected the KPTC as a case study for applying the suggested system in this paper, the KPTC fleet data can be summarized as per the data provided in table.1:

Table.1. KPTC fleet data

Route No.	Trip duration (minutes)	Nos. of buses
11	60	5
12	80	5
13	60	12
15	45	6
16	90	12
18	70	8
21	60	12
23	60	7
34	100	6
39	100	5
40	100	7
41	70	6
51	50	11
59	45	12
66	90	10
103	80	6
105	120	7
106	100	12
507	70	5
999	120	8
1022	100	8
Total buses		170

This paper is to propose a swappable-battery scheme which can be recharged from regenerative braking system of public transport buses, then the batteries when fully charged should be swapped to discharging rack station where the harvested electrical energy in batteries can be released to the L.V. grid through 3-phase grid-tied VSI, and in return the discharged empty batteries racked out from station to the bus to be recharged by



its RBS.

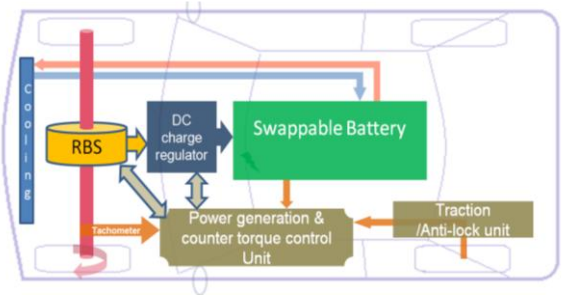


Fig. 1. Swappable scheme setup between bus and battery rack.

The average harvested power from each bus RBS depends on the duration and the force magnitude when using brakes in each journey,

Regenerative braking system (RBS) & Energy reserve system design:

The regenerative braking system RBS will be connected on the bus wheel's shaft through transmission flywheel similarly to the hybrid vehicle power train arrangement , therefore the RBS will have three operational modes: 1) Torque inhibit during acceleration, 2) Torque activation during deceleration (when using brake), 3) power generation during bus idling (stationary mode while engine is running) it consist of DC generator with external excitation loop on rotor , DC charge regulator the will optimize and monitor battery energy and voltage level , Swappable battery housing, Power generation & counter torque control unit that will be fed by signals from both: Traction /Anti-lock unit as well as the Tachometer of the front wheels.

2.1. Mechanical basic calculations:

System size calculations will be based on the basic conventional mechanical and electrical machine equations, since the basic aim of the RBS is to provide Electrical Energy during decelerating the bus by utilizing the counter electromagnetic force (back-emf).

Hence, the main factors in this system is the inertia force which depends on the bus mass and speed (equation-1), as well as the RBS's generators capacity, or in other word the maximum output power, Therefore the kinetic force developed by the bus is calculated as follow:

$$F = m * a \qquad (1)$$

Where,
m= mass of bus (kg)
a= acceleration of bus (m/s^2)

, And the momentum torque (T) of the generators driving shaft is computed as follow:

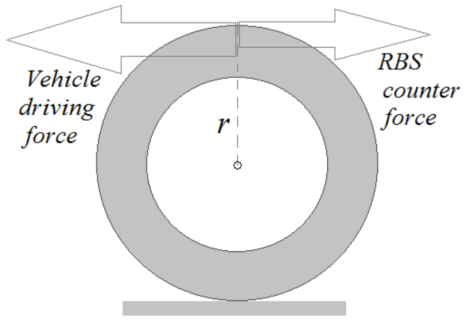
$$T = m*a*r \qquad (2)$$

Where,
r= radius of wheels (m)

,In this case there will be two forces effecting the wheel's motion , the prime force is the bus driving force dictated by it's speed and it's weight, whereas the other force is developed by the RBS electromechanical action and it shall act as a counter force.

Both forces are treated as momentum torques when considering the wheel's radius.

Fig. 3. Typical representation effective forces



distribution on bus wheel.

Assuming that bus average mass with passengers is 12000 kg , we can calculate the force exerted on bus wheels when it is decelerating from 70 km/h to 0 in 4 m/s^2 as follow:

$$F = m*a$$
$$= 12000\ kg * 5\ m/s^2$$
$$= 60000\ N$$

, Hence the driving torque on wheels can be computed as follow:

$$T = F * r \qquad (3)$$
$$= 60000 * 0.25$$
$$= 15000\ N.m$$

2.2. RBS generator sizing :

The used generator will be a DC type with a self-excited field controlled by embedded CPU (Central processing unit), which controls the excitation power (mainly the current I_f) as well as controlling the main output power that is used to recharge the battery pack (Fig. 3), the RBS-CPU assess the required counter torque to be applied by RBS according to the acquired measured speed from the wheel's tacho-sensors and traction unit, also the bus weight is involved in the CPU computation as well.

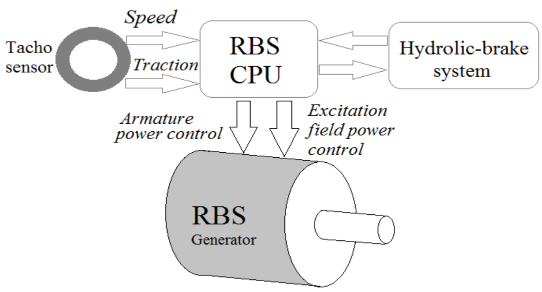


Fig. 4. **************************

Table.2

RBS generator datasheet:	
Power (kW)	**55**
RPM	**1640**
Armature:	
Volts	**400**
Amps.	**150**
Excitation field:	
Volts	**170 / 340**
Amps.	**5.78 / 2.89**

2.3 RBS average torque:

To compute the RBS torque we should first determine the rpm of the wheels in bus average speed in order to use the outcome with the RBS horsepower value and assuming that average bus speed is 70 km/h , then the rpm of wheel can be calculated from equation (5) as follow:

$$\text{Wheel perimeter} = 2\pi * r = 2*3.141*0.25 \quad (4)$$

$$rpm = (\text{speed} / \text{wheel's perimeter}) * 60 \quad (5)$$

$$rpm\ @70\ km/h = (19.4\ m.s^{-1} / 1.57m)*60 = 12.35 = 741.4\ rpm$$

$$T = [\text{horsepower} * 5252.1] / rpm = [73\ hp * 5252.1] / 741.4 = 517.3\ lb\text{-}ft = 701.3\ N.m$$

, To find out the force:

$$F = T / r = 701.3 / 0.25 = 2805.2\ N \quad (7)$$

The mechanical burden on RBS is created by the electrical torque as per the basic equation (8)
, which is dictated primarily by the variable factor, armature current (I_a):

$$T=[(\Phi*Z*P)/(2\Pi*A)]*I_a \quad (8)$$

Where,
Z = numbers of armature winding
Φ = Electromagnetic flux (Weber)
P = Number of poles
A = Number of winding's parallel paths (slots)
I_a *= Armature current (Amps)*

, Since our intended counter force is determined by back-emf , therefore the back voltage E_b which will be used accordingly with bus speed to provide the needed deceleration force is computed by the equation (9) , Where the Speed of revolution *N* (rpm) is the variable factor.

$$E_b= (\Phi*Z*P*N)/(60*A) \quad (9)$$

, Meanwhile the E_b can be calculated electrically by equation (10) by the difference between stator voltage V_s and the armature voltage V_a with respect to armature resistance Ra.

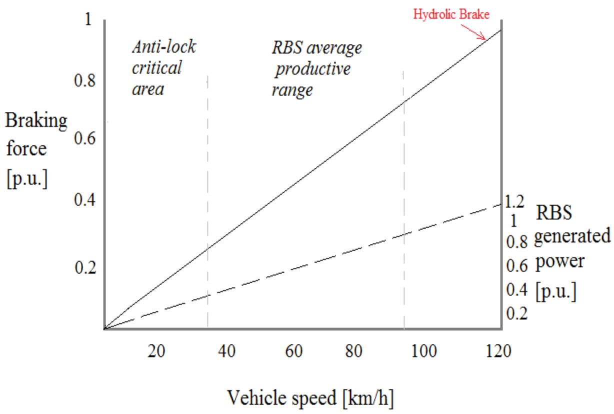
$$E_b= V_s - (I_a*R_a) \quad (10)$$

2.4 Battery pack sizing

The required power of the battery pack is around 55 kW, which is as per the average market's energy index will have the following measurements (Table.3) tentatively.

Table.3 Battery bank datasheet

kWh	**m^3**	**kgs**
45	1,15	290



Typical curve of reletaive RBS counter-force to hydrolic brake

III. RBS Energy productivity

In order to calculate the approximate required travel range to recharge the battery pack we can assume a simple equation (11) that consider the number of stops in each bus route, times the brake average duration.

Table.4 Nos. of stops per bus route

Route No.	Nos. of stops
11	82
12	123
13	66
15	55
16	102
18	89
21	74
23	71
34	135
39	158
40	177
41	82
51	52
59	52
66	105
103	99
105	173
106	160
507	86
999	159
1,022	126
Average Nos. of stops	106

*Charging time = Nos. of stops * Brake duration* *(11)*

*= 106 * 3 s*
= 318 s

, Then by using equation (12) we can determine t he number of trips required to fully recharge the battery pack, which depends on Recharging time (*R.t*) and Brake using time (*B.t*).

Nos. of trips = R.t / B.t *(12)*

= 3600 / 318
= 11.3 trips

The maximum daily bus running time is 16 hours/day, Therefore the number of trips per day for each bus is depends on its route length and of course traffic flow.

Based on tables 1&2 the average route/trip duration per bus is 80 minutes, and the average number of stops are 106 per route, also we consider that the bus has an average speed of 70 km/h which allow us to assume the average route duration as 3 hours, hence the tentative number of trips per day as follow:-

16 / 2 = 8 trips

Reference to the result obtained from equation (12) , The average time to fully recharging battery pack is 2 days (some buses with routes less than 60 km will requires more recharging days), and by simple equation we can determine the total power capacity of all KPTC 170 buses as follow:-

*170 buses * 45 kW = 7650 kW*

By considering the average trips of each bus per day (8 trips) and the obtained value of the required trips to fully recharged the battery pack (11.3 trips) that we did in the step above (Eq. 1.3) which means the battery pack needs 2 days to be fully recharges (as an average).

Hence, we can calculate the approximate Electrical energy that can be harvested annually by the 170 buses as follow:-

*7650 kW *(365 days/ 2 days) = 1,39 GW*

The total harvested energy by buses is according to the physical and mechanical specification of each type (Table.5), therefore the actual generated charging power by RBS will be varied respectively.

Table.5 KPTC fleet lineup

Passenger capacity	Curb weight
46	11500
30	9700
40	11800
40	7300
44	12500

IV. Conclusion:

Based on all above data and analysis, utilizing the public transportation buses in Kuwait will be substantially support the grid's demand especially during summer peak demand.

Moreover, by using swappable batteries the net-load of the grid will be controlled efficiently, and the power management will be optimized significantly.

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