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Regenerative Braking System for Energy Harvesting from Railways and Vehicles: A Review and an Approach

Kapil Chalkhure[1], Shivani Jijankar[2], Anand Dhore[3], Arti Sanganwar[4], Prof. Vikramsingh R. Parihar[5*]

U.G Students, Department of Electrical Engineering, PRMCEAM, Badnera-Amravati, India[1,2,3,4]

Assistant Professor, Department of Electrical Engineering, PRMCEAM, Badnera-Amravati, India[5]

Abstract: This paper presents an overview and an approach of regenerative braking system for energy harvesting from railways and vehicles. In this paper. after a brief introduction, the focus is on literature review wherein we have studied 15 papers related to the topic and have successfully analyzed them. On the basis of the literature review, we have proposed a system which can offer higher economic benefits by lowering the operation costs of supplying energy to train stations. The topology and the control strategy for battery chargers on high-speed electric trains are also discussed.

Keywords: Regenerative braking system, energy harvesting, regenerative mechanisms

I. INTRODUCTION

A significant amount of kinetic energy is available during braking of trains because its movement is wasted in the form of both the power used for applying the brake and also the power lost as heat in the break. This power can be saved using regenerative braking. In regenerative braking instead of the conventional frictional braking system, a different mechanical system is used, wherein when the brake is applied instead of a conventional frictional braking system, a generator is mechanically connected to the wheel. The generator acts as a huge load and stops the vehicle/train. But in the time duration between the brake being applied and the vehicle/train coming to a total halt, the generator is running using the rotation of the wheel.

In this paper a prototype of a regenerative braking system will be demonstrated. For the demonstration of the project a wheel will be used to which a small regenerative braking system will be connected to demonstrate the power being produce through regenerative braking. We are mainly focusing on Regenerative braking system for energy harvesting from railways of China. In India this technology is not available up till now, but it should be available at Mumbai local center as the frequency of locals are very high.

II. LITERATURE REVIEW

Sr. no.	Ref. no. Authors & year	Concept used	Performance Evaluation Parameter	Claim by concerned authors
01	Seong-geun Han,Hak-man Kim & je-se Park (ISSN:2005-4297 IJCA)	They modeled DC electric railway system based on the solid state transformer that is composed of voltage source converter & DC-DC converter	Simulation by using hils, Power vs Time, Voltage vs Time	When the regenerative energy is generated or consumed by the load, the catenary voltage of dc line has been maintained at 1500v using the solid state transformer controller
02	Seyed Saeed Fazel, Saman Firouzian, Babak Khalkhali Shandiz	Energy flow of the single train evaluated at TPS instead of trains pantograph through the proposed electrical model of network	Effective mass, maximum traction effort, Maximum Braking effort, maximum velocity, maximum	Utilizing the rolling stocks regenerative braking capability has shown significant amount of energy saving, also demonstrate desirable operation under several scenario , both saving energy & economical point of view

			braking acceleration, hight vs position	
03	GouYanan Vol.09 (2016)	When the electric vehicle spending up, the motor controls the current output by the battery through the sensor signal, and then its speed is adjust for providing power. The motor becomes generator when electric vehicle braking,	Simulation and Analysis based on advisor, Time velocity relationship,Time motor speed, Time Motor torque, time charging	the design of the electric vehicle energy recovery system converts the braking energy into electric energy which charges for the battery.
04	Shaofeng Xiea, Jinbo Fenga, Gangyi Zhangb (ICAEE 2011)	A scheme of Simulation Traction Load (STL) with regenerative braking based on back-to-back dual PWM converters is proposed in this paper. Under the control of the current inner loop and voltage outer loop, the DC/AC section can feed the energy from DC/AC section back to power system. The feed-back energy can be supplied to other customers.	None	the STL may simulate actual traction load exactly. DC/AC unit may send energy from AC/DC unit back to supply system timely with unity power factor and low harmonic components. Wit hysteresis current control method, STL shows all characteristic of actual traction load exactly. The dynamic response speed can reach the requirement. The loss of STL is very low.
05	Pulkit Gupta, anchal Kumar, sandeepan Deb, 4shayan Volume- 2, Issue- 5, May-2014	Flywheel is used for converting the kinetic energy to mechanical energy. Also, Electric Motor is used to convert Kinetic Energy into electrical energy.		The results from some of the test conducted show that around 30% of the energy delivered can be recovered by the system.
06	Madan Singh Vol. (4) – No. (1) ISSN Print (2314 – 7318) and Online (2314 – 730X) January 2013	When a motor turns faster than the commanded speed as set by its drive, the motor in effect acts as a generator. During regenerative braking vehicles’ electric motor is reconnected as a generator and its output is connected to an electrical load, which provides the braking effort,		Regenerative energy provides distributed generation (DG) to loads in close proximity if not stored in battery. One unit (megawatt-hour, MWh) generated near load with a distributed generation can, depending on grid location, displace up to 1.45 MWh of grid power
07	S.S Joshi, OH Pande, Arun Kumar	The modern design of Metro Rolling Stock incorporating three phase induction motors and Converter Inverter enables recovery of a major portion of consumed electricity by way of using regenerative braking.	CI–Converter Inverter, TIMS – Train Integrated Management System DT Car– Driving Trailer Car, M Car– Motor Car	Regenerative braking has indirect benefits in terms of reduction in maintenance, increase in train availability and reduced heat load generation in underground corridors.

08	S.J. Clegg (1996)	It has three main system components, ICE, generator and electric motor, which are arranged in series. The mechanical energy generated by the ICE is converted to electrical energy by the generator and this is again converted into mechanical energy in the electric motor		Battery have Good efficiency poor power and good omplexity ,hydrulik efficiency is poor, electrostatic poer is good
09	Soniya.K. Malode1, R.H.Adware2 Volume: 03 Issue: 03 Mar-2016	The kinetic energy is stored in the vehicles, which is translated and kinitc enrgy stored in the battery and the ultracapacitor during deacceleration	Simulation of regenerative in matlab, power by motor, battery, generator	It have ability to save the waste energy up to 8- 25% These system improved by the advanced technologies of power electronic components, are ultra capacitor, DC-DC converter. The research says that regenerative braking is already in used in many Electric Vehicles. It also improves the fuel consumption by 33%.
10	Dengke Yuan, Shuai Gu, Junjun Liu, Yicheng Zhang, Chuanxian Lv Energy Procedia 16 (2012)	This analyzes an emergency self-traction system (ESTS), in which an onboard energy storage system (ESS) is designed and installed in the metro vehicle, ESTS can recycle the vehicle regenerative energy, which buffers the peak power between the external power supply and the traction motors, to reduce power losses distributed in power supply network, transmission line as well as the input filter module of vehicles.	velocity (km/h), distance (km), electric power (kW), electric energy (kWh), ESS, MATLAB simulation diagram of ESTS	improves the flexibility of the metro vehicle in rescue. also enables the ESS to recycle the regenerative energy of the vehicle by using bidirectional DC/DC converter. Batteries on board are utilized to supply the main power and energy demand of the traction motors. The DC/DC converter is elaborately designed to control the bidirectional power flow between the SC tank and the vehicle traction system.
11	Hanmin Lee, Gildong Kim, Changmu Lee	effect of the energy storage system for energy saving, applying EDLC as the storage unit of the energy storage system, the energy storage system design, installation and field tests. The ESS reduces primary energy consumption without affecting transport capacity and punctuality.	Time vs Distance, Powerflow algorithm, Energy storage system(ESS), Super capacitor energy storage(SCES), Capacity determination	The ESS is charged by energy regenerated by braking vehicle. The ESS discharges energy for traction power of accelerating vehicle. Therefore, the feeder voltage is stable at
12	Motomi Shimada Ryoichi Oishi Daijiro Araki Yasushi Nakamura	and the regenerative brake with effective speed extended function that extends the operating range of the regenerative brake to higher speeds by using the storage battery to boost the DC (direct current) voltage of the inverter and	FC voltage vs Speed,	This article has described the features and benefits of using on-board and wayside absorption of regenerative electric power.

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		increase the output of the electric motor, inverter, and other components.		
13	Nima Ghaviha, Javier Campillo, Markus Bohlin, Erik Dahlquist 2015	This paper reviews the application of energy storage devices used in railway systems for increasing the effectiveness of regenerative brakes. Three main storage devices are reviewed in this paper: batteries, super capacitors and flywheels. Furthermore, two main challenges in application of energy storage systems are briefly discussed.	Energy Storage System, Super capacitor, Flywheel; Max 6 keywords	Electric trains can generate energy while braking using regenerative brakes and ESSs can facilitate harvesting the generated energy. Three main type of storage systems (i.e. batteries, supercapacitors and flywheels) were presented in this paper which are used as SESSs and OESSs. Furthermore, some of the recent application of such storage systems were reviewed
14	Tristan Rigaut, Alexandre Nassiopoulos, Frédéric Bourquin, Patrick Giroux, André Pény	present hereby a methodology for the optimal management of a microgrid connecting regenerative braking energy sources, eventual distributed energy resources, heating, ventilation, air conditioning (HVAC) systems, specific electricity consumptions and electricity storage systems (ESS) for energy management in subway stations.	Current situation vs ESS,	a subway station with a simplified electricity consumption profile over a weekday and a subway station with the same profile but equipped with a 480 kWh battery allowing braking energy recovery and optimal energy management throughout the day. The state of charge is constrained to remain between 40% and 80% to ensure good ageing of the battery.
15	Priya Sharma 2015	the traction energy supplied using 750 V DC is being dealt with. In majority of the metro rail systems, the rolling stock is equipped with regenerative brakings. In the regenerative braking the electric motor can act as a generator recovering the vehicles kinetic energy and converting it into electric energy	Super capacitor, ESS	The three methods described in this paper describe the technology that can be adapted for that purpose. This not only reduces the operations cost but also improve the “Green points” of the system. The receptivity of the network is also improved.

III. Possible Approach

Following diagram shows regenerative energy storage by capacitor in detail, in which supply comes to locomotive from overhead lines through pantograph. Pulse rectifier reduces noise in ac supply and give it to dc link for transformation purpose. Dc link convert ac into dc and this dc again covered into 3-phase ac as induction motors works on 3-phase ac supply. As when train start decreasing its speed regenerative action came into picture, due to that batteries get charge. Traction control unit is nothing but the feedback control loop to monitor the disturbance (noise) error signal.

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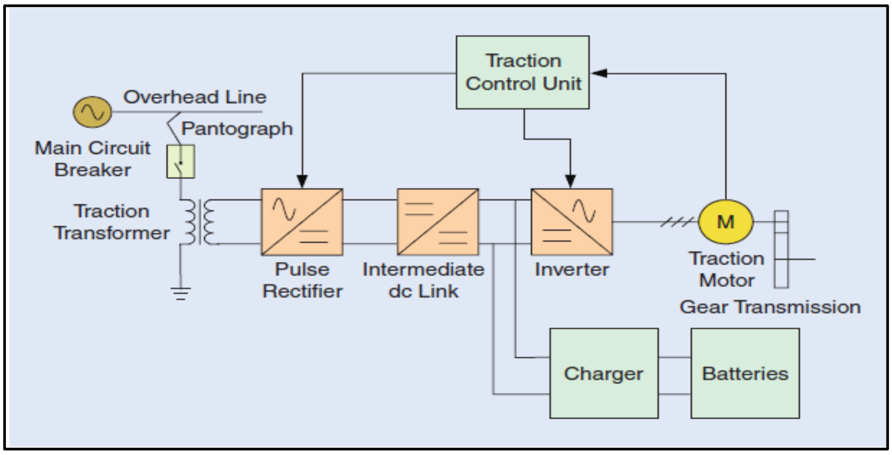

Fig.1: A diagram for regenerative energy storage

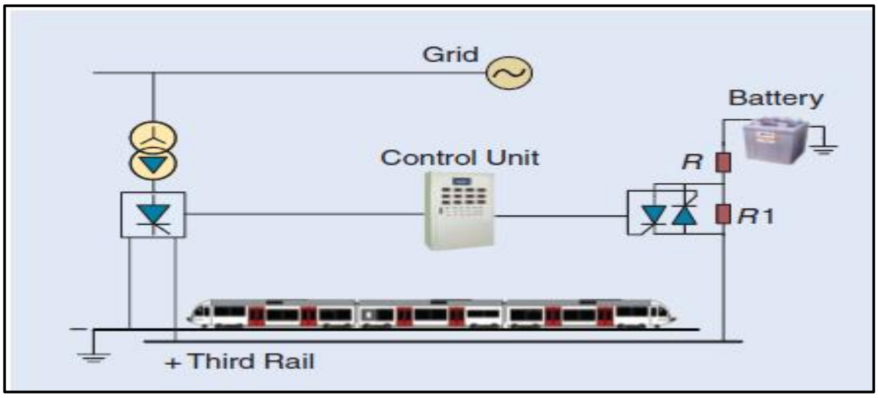

Fig. 2 The battery storage system of a commuter train

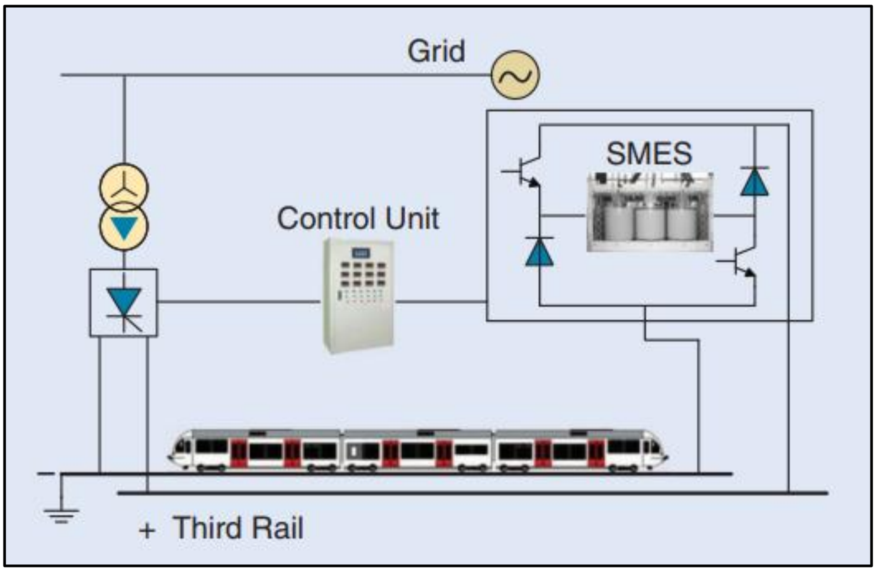

Fig. 3: The SMES system of a commuter train

SMES offers several advantages:

1) An SMES can store energy for a lengthy period with an efficiency higher than 95%.
2) An SMES can offer a large storage capacity and fast response time.
3) An SMES is easy to maintain and produces pollution free energy.
4) An SMES is easy to manipulate and has a long lifetime as it has no rotating parts.

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However, SMES has not been used widely for large-scale station applications because:
1) There is a limited production of superconducting materials.
2) There is a high cost for the refrigeration and operation of superconductive materials.
3) The quenching protection of superconducting and the ecological influence of high intensity magnetic field is at the stage of research.

Figure 4 shows the ultra-capacitor energy storage system for regenerative energy applications, which includes the ultra-capacitor bank, insulated-gate bipolar transistor (IGBT) chopper, dc high-speed circuit breaker, disconnecting switch, sensors, and microcomputer control unit. An ultra-capacitor offers a low-voltage capacity, and a large number of ultra-capacitors are often connected in series-parallel modules.

However, any major wavering in ultra-capacitor parameters, which could be due to ambient conditions, would result in ultra-capacitor voltage fluctuations. Such changes would shorten the service life of ultra-capacitors and significantly reduce their operation reliability.

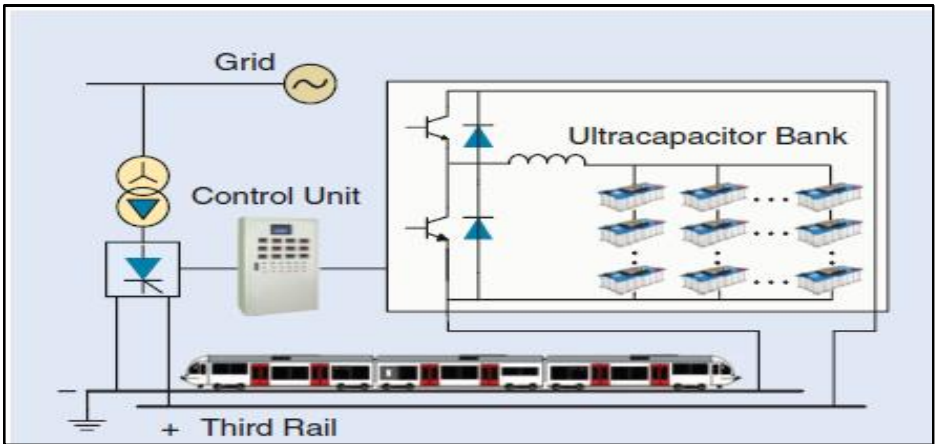

Fig. 4: The ultracapacitor storage system of a commuter train

Figure 5 shows the flywheel energy storage for regenerative energy. A flywheel energy storage system includes a rotating component, electric machine, bidirectional converter, and vacuum suspension chamber, which would make use of high-speed rotating elements.

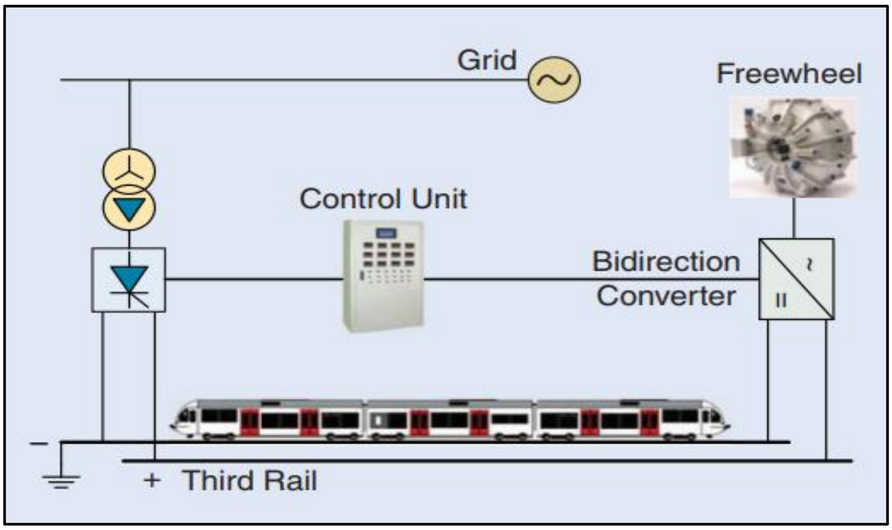

Fig. 5: The flywheel energy storage system of a commuter train

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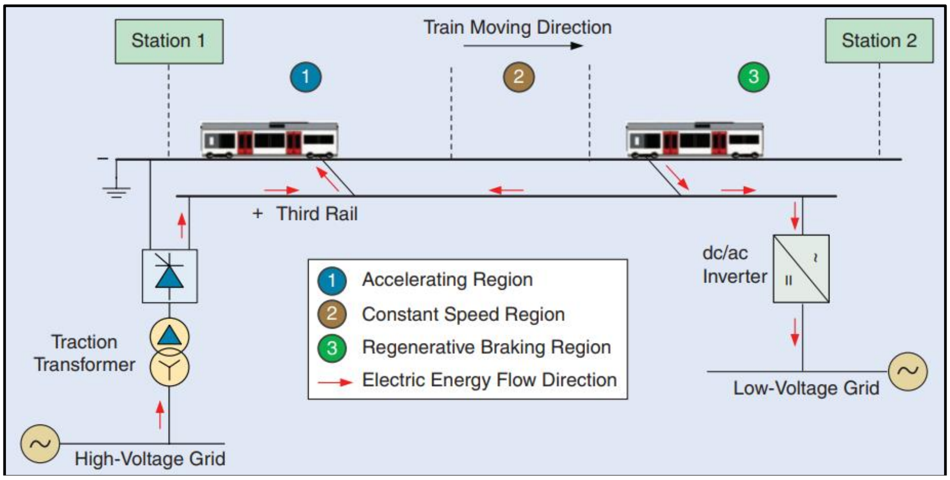

Fig. 6: The electric energy flow diagram of a train system.

IV. ECONOMIC MERITS OF REGENERATIVE BRAKING

Table 1 shows the timetable for the Metro line 13 at the Wudaokou station in Beijing, China. In this table, trains will be arriving at the station every 6–7 min between 5:19 and 6:20 h.

The interval time depends on the time of the day and the day of the week, and the average interval time on week days is5.2 min. accordingly, 420 trains pass through the Wudaokou station with a daily regenerative braking energy of 420 #16.53 = 6,942.6 kWh. For weekends, the average train interval time is 8.3 min, the number of trains is 262, and the total regenerative braking energy is 262 # 16.53 = 4,330.86 kWh. The monthly (including four weeks + two weekdays) regenerative braking energy is 187,384 kWh. The annual regenerative braking energy is 2,248,608.96 kWh. If the electricity is priced at US$0.1/kWh, the annual saving at Wudaokou station is around US$0.225 million. The annual savings for the 16 stations along the Metro line 13 is US$ 0.225 # 16 = 3.6 million annually.

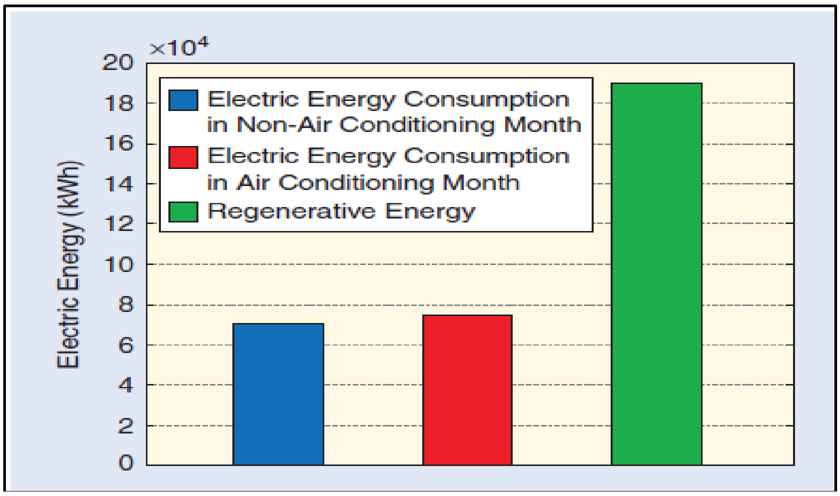

Fig. 7: The electric energy consumption and regenerative energy production per month

V. CONCLUSION AND FUTURE SCOPE

In this paper we analysed 15 research papers based on regenerative mechanisms. Through regenerative energy analyses, we can say that the can offer higher economic benefits by lowering the operation costs of supplying energy to train stations. The proposed regenerative braking scheme applies train-mounted storage batteries. The topology and the control strategy for battery chargers on high-speed electric trains, which can supply train-mounted electric equipment or be delivered to remote locations where the electric energy is not readily accessible, are also discussed.

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BIOGRAPHY

Prof. Vikramsingh R. Parihar is an Assistant Professor in Electrical Department, PRMCEAM, Badnera-Amravati having 6 years of experience. He has received the B.E degree in Instrumentation from Sant Gadge Baba Amravati University, India, in 2011 and the M.E degree in Electrical and Electronics Engineering, Sant Gadge Baba Amravati University, India, in 2014. He is editorial board member of 6 recognised journals and life member of ISTE, HKSME, ICSES, IJCSE and theIRED. His domain of research includes Electrical Engineering, Instrumentation, Electrical Power Systems, Electrical and Electronics Engineering, Digital Image Processing, Neuro Fuzzy Systems and has contributed to research in a commendable way.