Interface between Propulsion and Brake system in Modern Metro Rolling Stock

By:
Jitendra Jha
Project Manager/Rolling Stock,
Bangalore Metro Rail Corporation Limited
Email Id- jitendra@bmrc.co.in

1. Propulsion System: Source of Electro-Dynamic (ED) brake

1.1 Concept of Electro-Dynamic (ED) brake

When a train is running say at a velocity of “V m/s”, it is having a kinetic energy of $\frac{1}{2}MV^2$. In case of conventional train, when train is stopped from a velocity of “V m/s” to “zero speed” (dead stop), thus total energy of the train say “$E=\frac{1}{2}MV^2$” which was generated during powering of the train, is destroyed in the form of heat energy on account of friction between brake pad/brake block with wheel tread/wheel disc. In the process, not only the energy is lost during braking but in the process of dissipation, it leads to wear and tear of the brake rigging components and wheel and this reduces its life.

Suppose, if part of the energy of the train during braking, say ΔE out of E is extracted and converted in to electrical energy then, the train will be left only with total energy

$E_1= E-\Delta E$. Suppose, after extracting energy ΔE, the velocity of train becomes V_1 m/s then $E_1= \frac{1}{2} MV_1^2$. Since, E_1 is less than E, obviously V_1 will be less than V. From this, it is concluded that when we are generating electrical energy from a moving train during braking, the overall effect of the train will be slowing down and this is called “regenerative braking”. Since this brake depends on the velocity of the train and during the motion of the train the mechanical energy is converted in to electrical energy, this brake is also called Electro-Dynamic (ED) brake. When train is stopped fully on Electro-Dynamic (ED) brake, then velocity of the train becomes zero and accordingly brake power of the train will become zero. Thus, a standing train with Electro-Dynamic (ED) brake only will have no brake power.

1.2 Regeneration during braking in the Modern Metro Rolling Stock

In the modern metro Rolling Stock, the propulsion system is based on 3-phase AC traction asynchronous motors fed by Variable Voltage Variable Frequency (VVVF) inverter. The VVVF traction inverter is micro-processor controlled. We know that conventional 3-phase asynchronous motor is ideally not suited for traction purpose because of its low starting torque. Thus, we have been using DC motors for traction purpose because of its high starting torque. With the advent of high power electronic switches (like IGBT) and with fast switching “ON” and “OFF” sequence of processor, it has now become possible to use 3-Phase asynchronous motor for traction purpose. Although physically we use 3-phase asynchronous motor, but we get the traction and braking characteristics similar to DC series motor because of the fast switching “ON” and “OFF” of IGBT electronic switches through micro-processor. Also, these 3-phase traction motor can be controlled like separately excited DC series motor where we can vary Voltage (v) and Frequency(f) independently. That’s why it is called Variable Voltage Variable Frequency (VVVF) inverter.

DC power is collected through the Third Rail current collector and fed into the Inverter. The inverter converts this DC power into Variable Voltage Variable Frequency (VVVF) power for the control of the Traction Motor.

In the modern metro Rolling Stock, there are four traction motors supplied by two propulsion Inverter units per Motor car. The traction motors operate in both the acceleration and in the dynamic braking modes.

In dynamic braking, the traction motor acts as a generator and feeds power back to the third rail system. Electric Braking or the dynamic braking offers braking force.

1.3 Same equipment in propulsion system both in powering and regenerated braking

The equipments of propulsion system which are required in powering, the same are required during regenerative braking also. No additional equipment is required during “regenerative braking”.

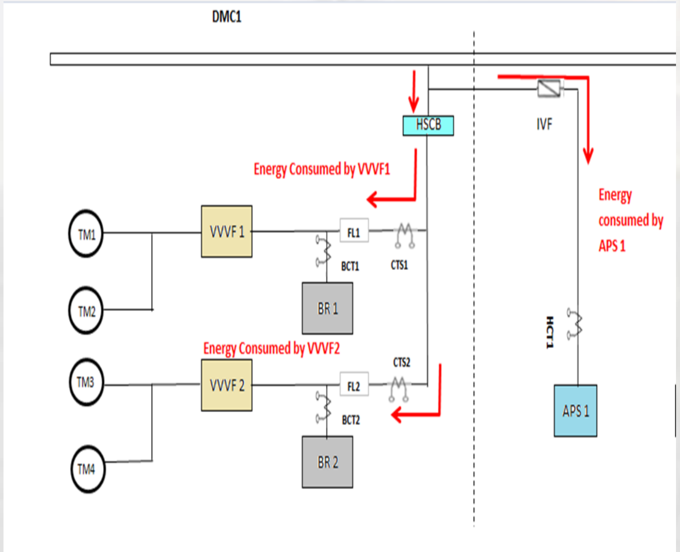


Fig.1- Flow of energy during powering

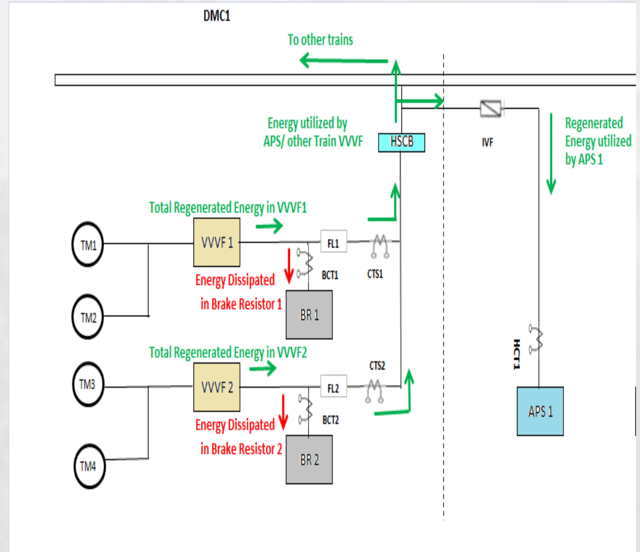


Fig.2- Flow of energy during braking

From the flow of energy during braking, it can be seen that regenerated energy is used by the following:

i. Part of the regenerated energy is used by the Auxiliary Power Supply (APS) system of the same train.

ii. Remaining regenerated energy is fed in to the 3rd rail system which is utilized by other trains on the section, if 3rd rail voltage is high say around 900V, then it will not be able to receive the regenerated energy further and in this condition the regenerated energy will be dissipated in the brake resistor of the train.

To improve the receptivity of the regenerated energy in the modern power supply system, this energy is used to meet the requirement of station utility and in this process the loss of energy in the brake resistor is minimized.

1.4 Use of the regenerated energy by the other trains

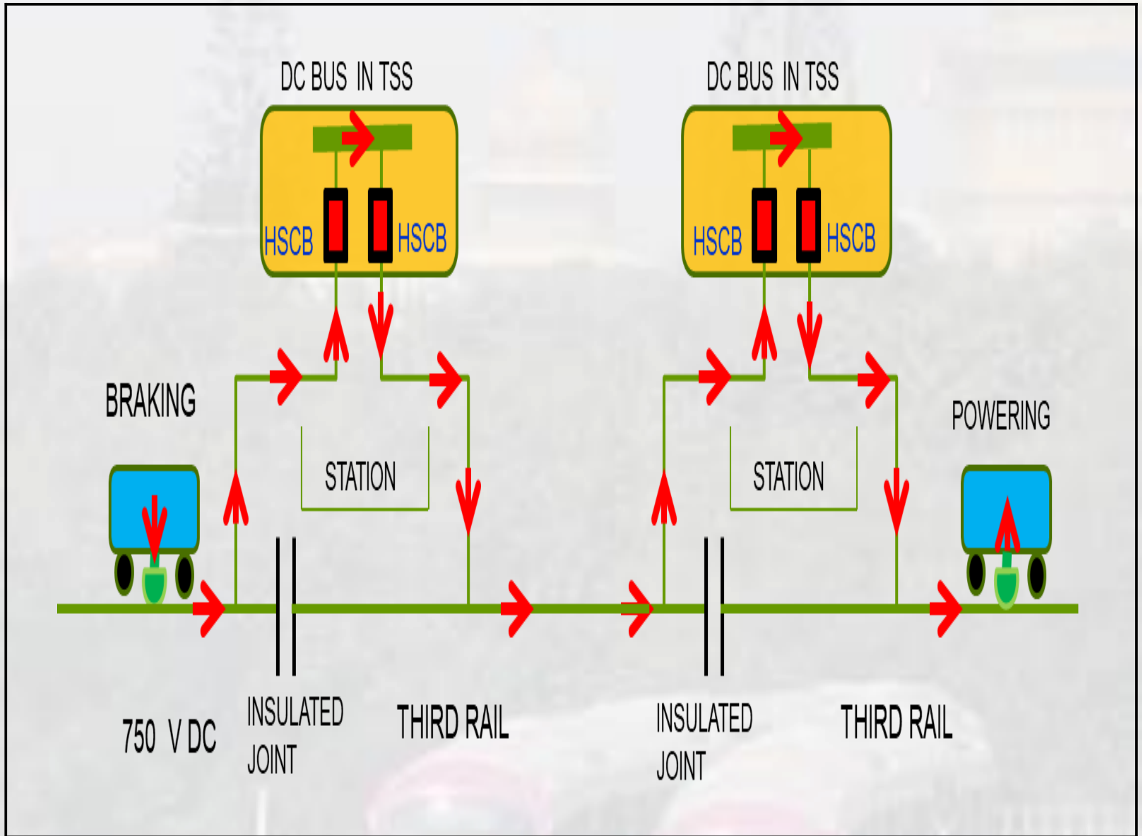


Fig.3-Flow of Regenerated Energy via TSS to other Third Rail Sections

From the fig.3, it can be seen that the train during braking in one section can feed the energy to the train in powering in other section, if DC bus circuit in TSS is closed.

1.5 Benefits of Regeneration

1.5.1 Energy Saving

The energy consumption of BMRCL trains on Purple Line (East-West corridor) for one week is given in table.1 below:

Table.1- Day wise VVVF energy data for a week of Purple Line (East-West Corridor)

Sl. No.	Date	VVVF (kWh) Motoring	VVVF (kWh) Re-generation	VVVF Net energy (kWh) consumption	% Re-generation with respect to VVVF motoring.	Loss in Brake Resistor	% Loss with respect to VVVF regeneration
1	05-03-2018	48801	16602	32199	34	877	5.2
2	06-03-2018	47611	16325	31286	34	816	4.9
3	07-03-2018	48345	16619	31726	34	738	4.4
4	08-03-2018	47564	15927	31637	33	946	5.9
5	09-03-2018	49100	16809	32291	34	844	5.0
6	10-03-2018	33921	11581	22340	34	795	6.8
7	11-03-2018	23657	7918	15739	33	666	8.4

From the Table.1, the following observations are made: -

i. In the normal days, almost 95% regenerated energy is utilized by auxiliaries of the same train or by the other train of the section as loss in the brake resistor is in the range of 4% - 5% during weekdays.

ii. During weekend, the utilization of regenerated energy is reduced by 2% further, may be on account of lesser number of the train in the section during weekend and also due to higher 3rd rail voltage from supply side.

1.5 Benefits of regeneration (contd..)

1.5.2 Life of brake pad

Reach-1 between Baiyappanahalli and MG Road of Phase-1 Purple Line was commissioned on 20.10.2011 and 5 trainsets has been running on the section since 20.10.2011 and their brake pad replacement detail is shown in Table.2 below:

Table.2- First Brake Pad Replacement Details

Sl. No.	TS#	Revenue on Date (ROD)	First Brake Pad Change		Remarks
			Date	KM Earning	
1	TS#01	20/10/2011	17/06/2017	276,599	DMC-1, Axle-2, Left Wheel (LW)
2	TS#02	20/10/2011	23/01/2017	265,699	DMC-2, Axle-1, Right Wheel (RW)
3	TS#03	20/10/2011	08/03/2017	257,792	DMC-1, Axle-1, RW
4	TS#04	20/10/2011	20/03/2017	302,692	DMC-1, Axle-2, LW & RW
5	TS#05	20/10/2011	07/02/2017	289,493	DMC-2, Axle-2, LW

From the above, it can be seen that average brake pad life is achieved in the range of 278,455 kilometers which is almost double than the life being achieved in the conventional rake.

1.5 Benefits of regeneration (contd..)

1.5.3 Wheel life

Table.3- Wheel Diameter							
	Car	**Bogie**	**Axle, Wheel**	**As on 24-09-11**	**As on 22-01-18**	**Wear (in mm)**	**Remarks**
KM Earned					318156	-	
Diameter (Std.: 860 - 780mm)	DMC-1	Bogie-1	Axle-1, LW	860.26	850.60	9.66	
			Axle-1, RW	860.27	849.70	10.57	
			Axle-2, LW	860.29	852.35	7.94	
			Axle-2, RW	860.39	851.39	9.00	
		Bogie-2	Axle-1, LW	860.26	852.55	7.71	
			Axle-1, RW	860.40	852.04	8.36	
			Axle-2, LW	860.28	852.14	8.14	
			Axle-2, RW	860.49	851.28	9.21	
	TC	Bogie-1	Axle-1, LW	860.32	853.00	7.32	
			Axle-1, RW	860.34	853.14	7.20	
			Axle-2, LW	860.34	853.82	6.52	
			Axle-2, RW	860.37	853.44	6.93	
		Bogie-2	Axle-1, LW	860.32	853.17	7.15	
			Axle-1, RW	860.37	853.42	6.95	
			Axle-2, LW	860.25	851.96	8.29	
			Axle-2, RW	860.46	851.16	9.30	
	DMC-2	Bogie-1	Axle-1, LW	860.19	846.67	13.52	
			Axle-1, RW	860.25	846.34	13.91	
			Axle-2, LW	860.32	848.95	11.37	
			Axle-2, RW	860.38	849.01	11.37	
		Bogie-2	Axle-1, LW	860.26	848.23	12.03	
			Axle-1, RW	860.25	848.39	11.86	
			Axle-2, LW	860.23	849.11	11.12	
			Axle-2, RW	860.27	848.33	11.94	

So far, no wheel turning has taken place on account of flange thickness reaching to condemning limit. Only BMRCL is turning the wheel of same axle to match the dia. difference. In DMC-2, average wheel dia. reduction is 12.14 mm which works out to be 3.81 mm per lakh kilometer. This results in to wheel life of 20 Lakh kilometers. Average kilometer earned in East-West corridor is around 1.20 lakh kilometers per year per rake and hence in terms of year, wheel life is expected to be around 16 years against the wheel life of around 4-5 years of Rolling stock without regenerative brakes

2. Optimization of Electro-Dynamic (ED)/Regenerative brake

From the above, it is seen that due to regenerative braking, not only energy is saved but it results in to savings by way of increased wheel disc pad/wheel life and this has got tremendous advantage in terms of saving the man-hours for replacing the pad and wheel apart from the cost of the brake gears and wheel. Thus, the aim of the owner of the modern metro Rolling Stock should be to increase the regenerative braking to the maximum extent possible. With the improvement in High Speed Circuit Breaker (HSCB), propulsion control system and VVVF inverter, it is now possible to increase the regenerated power by extending the constant torque zone during braking.

2.1 Constant Torque Zone in BMRCL Phase-I train

2.1.1 Constant torque zone in braking in BMRCL Phase-I train was from 36 Kmph to 5 Kmph. From the Table.4 below, it can be seen that if constant torque zone is extended from 50 Kmph to 5 kmph then regenerated current will further increase. Thus BMRCL decided that in Intermediate car contract, constant torque in braking zone will be from 50 Kmph to 5 Kmph both in original cars and in intermediate motor cars. In future new trains, this will be from 65/60 Kmph to 5 Kmph to have increase in the regenerated power during braking.

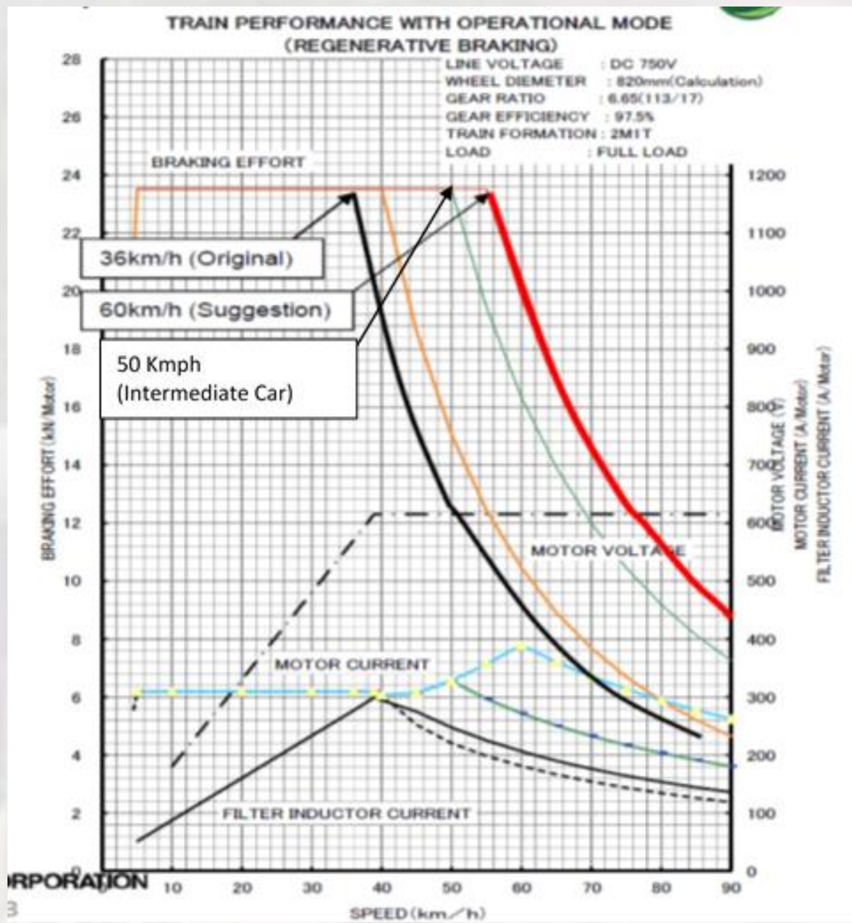


Fig.4- Extending the constant Torque zone from 36 Kmph to 50 Kmph and 36 Kmph to 60 Kmph

2.1 Constant Torque Zone in BMRCL Phase-I train (Contd…)

2.1.2 In the Fig.5 below, it is seen that when constant torque zone in braking is extended from 50 Kmph to 5 Kmph, regenerated current increases from 423 A at 80 Kmph to 820 A and maximum current increases from 940 A to 1310 A. From the area curve, it can be concluded that regenerated power during braking will increase substantially.

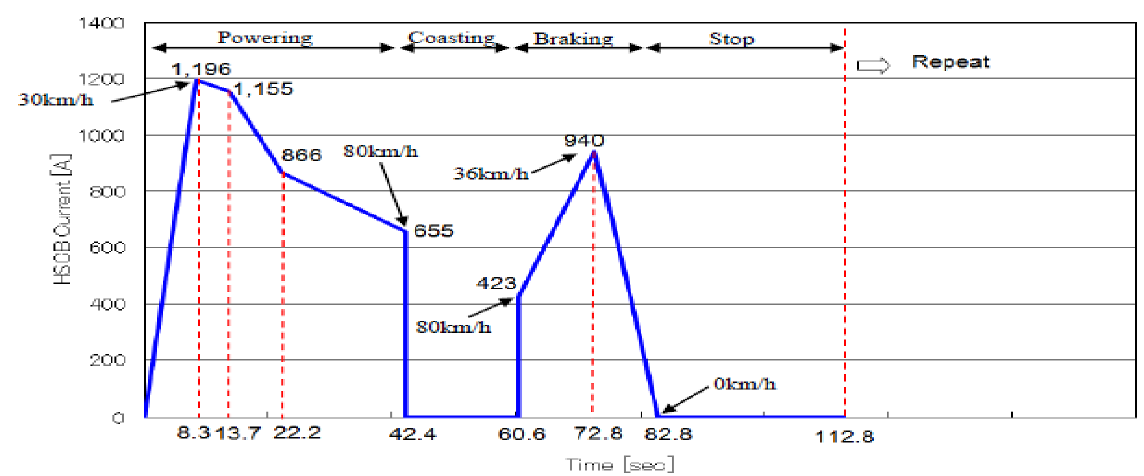


Figure 1. Typical HSCB current pattern with the conventional braking performance (Up to 36km/h)

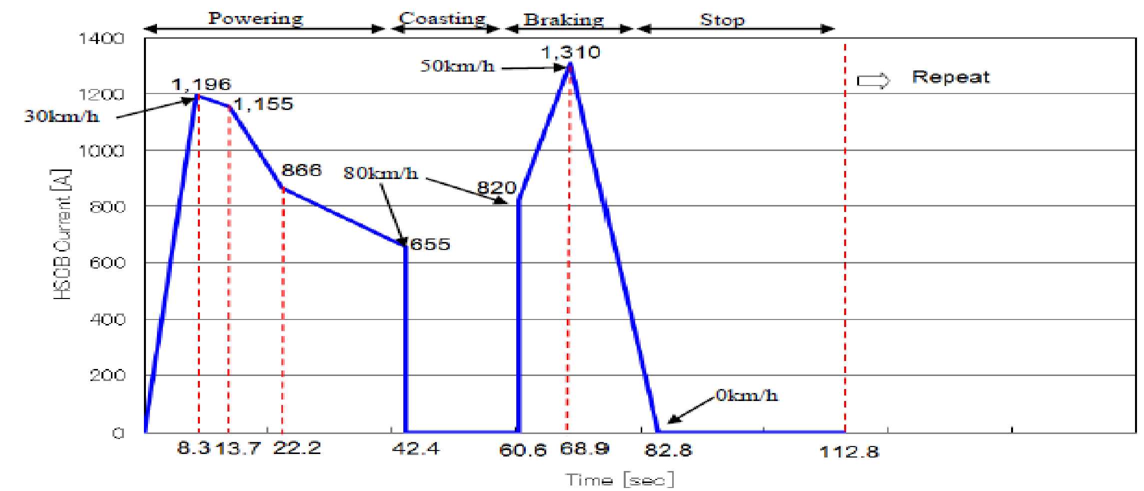


Figure 2. Typical HSCB current pattern with the new braking performance (Up to 50km/h)

Fig.5- Comparison of HSCB line current during powering and braking with constant torque zone in braking 36 Kmph to 5 Kmph and 50 Kmph to 5 Kmph

2.1 Constant Torque Zone in BMRCL Phase-I train (Contd…)

2.1.3 Comparison of Energy Consumption

With the improvement in regenerative Braking performance by extending constant torque zone from 36kmph to 50kmph, as per the simulation results 19.1% net energy consumption decreases in normal mode (E-W Corridor) and 16.3% net energy consumption decreases in normal mode (N-S Corridor).

A simulation study was done to simulate the energy saving on Purple Line (East-West corridor) and Green Line (North-South Corridor) with existing 3-Car trainset having constant torque in braking from 36 Kmph to 5 Kmph with intermediate 3-Car train unit having constant torque in braking from 50 Kmph to 5 Kmph. The results are shown in Fig.6. From the above, it can be seen that in Normal mode in Purple Line (East-West corridor), regenerated energy increases to 130.22 to 172.8 kWh i.e. an increase of 31.16% of regenerated energy and overall energy consumption decrease by 19.1% with the train with improved braking characteristics.

Similarly, from Fig.6 above, it can be seen that on Normal mode in Green Line (North-South Corridor), regenerated energy increases from 100.5 kWh to 129.2 kWh i.e. an increase of 28.55% of regenerated energy and overall energy consumption decreases by 16.3% with the train with improved braking characteristics.

	Operational mode	Route	Distance (km)	Energy Consumption (kWh/3car Phase 1)			Energy Consumption (kWh/3car Intermediate Phase 2)		
				Powering	Braking	Net	Powering	Braking	Net
E-W Line	Allout mode	MYRD-BYPH	17.91	272.6	-68.9	203.7	271.6	-97.4	174.2
		BYPH-MYRD	17.91	215.1	-88.5	126.6	214.2	-131.8	82.4
		Round trip	35.81	487.6	-157.3	330.3	485.8	-229.1	256.6
	Normal mode	MYRD-BYPH	17.91	227.9	-62.7	165.2	227.2	-83	144.2
		BYPH-MYRD	17.91	129.9	-67.5	62.4	129.8	-89.8	40
		Round trip	35.81	357.8	-130.2	227.6	357	-172.8	184.2
N-S Line	Allout mode	YPM-RVR	14.18	193.2	-58.7	134.5	192.1	-83.3	108.7
		RVR-YPM	14.18	194.4	-59.6	135.2	194	-85.3	108.7
		Round trip	28.36	388	-118.3	269.7	386.1	-168.6	217.4
	Normal mode	YPM-RVR	14.18	146.9	-52.7	94.1	146.7	-68	78.7
		RVR-YPM	14.18	132.6	-47.8	84.8	132.2	-61.1	71.1
		Round trip	28.36	279.4	-100.5	178.9	279	-129.2	149.8

- 19.1% net energy consumption decreases at normal EW line
- 16.3% net energy consumption decreases at normal NS line

Fig.6- Comparison of energy consumption with constant braking zone from 36 kmph to 5 kmph and 50 kmph to 5kmph

2.1 Constant Torque Zone in BMRCL Phase-I train (Contd…)

2.1.4. From the above, it can be seen that regenerated energy can be increased to the extent of 16% to 19% in BMRCL trains by increasing the constant torque zone from 36 Kmph- 5 Kmph to 50 kmph -5 Kmph and this has been implemented in 6-Car trainset with integration of intermediate car unit (-MC-MC-TC-) in to original car (DMC-TC-DMC) to form 6-Car train set (DMC-TC-MC-MC-TC-DMC). In future new 6-car trainset, BMRCL will extend the constant torque zone from 50 Kmph-5 Kmph to 60 Kmph-5 Kmph. If in future, technology is further developed then this zone can be further extended to 70 Kmph-5 Kmph. This implies that train will be running in powering and during braking, 95% of the braking effort will be available for Electro-Dynamic (ED) brake only. Only blending of Electro-Dynamic (ED) with Electro-Pneumatic(EP) brake will be required at the higher end of the speed and also at the lower end of the speed during stopping. With such type of innovation/improvement in the propulsion system will further result in to economic benefits to the operators. Hence, the aim of the Rolling Stock operator should be to optimize the braking characteristics.

2.2 Motorization percentage in the train

2.2.1. Increase in motorization percentage in the train, increases the regeneration. A train with 66% motorization has higher regeneration with respect to a train having 50% motorization.

2.2.2 A simulation studies was carried out on KMRCL track with 3M3T (50% motorization) formation and 4M2T (66% motorization) formation and the results are summarized in Table. 4 below

Table.4- Comparison of performance between 50% motorization and 66% motorization		
Item	**3M3T**	**4M2T**
Starting Acceleration	$0.73m/s^2$ (3M3T train)	$1.0m/s^2$ (4M2T train)
Scheduled Commercial Speed with 10% coasting	33.1 kmph	34.1 kmph
Deceleration by Regeneration (Electrical Brake)	$0.75m/s^2$	$1.0m/s^2$
Net Energy Consumption	427.8kWh	331.1kWh

From the Table.4 above, it is seen that with 66% motorization it is possible to achieve deceleration of $1m/s^2$ with ED brake (regenerative brake) only and net energy consumption decreases by 22.6% mostly on account of increase in regeneration due to increase in motorization percentage

2.2.3 Rolling stock with 100% motorization will be costly in comparison to Rolling Stock 66% and 50% motorization. Since, with 66% motorization it is possible to achieve a deceleration rate in Dynamic brake of 1 m/s2, now norms of 66% motorization is widely adopted by most of the metro system in India

3. Direct Service Brake System: Source of Electro-Pneumatic Friction Brake

3.1 The microprocessor-based Brake Electronic Control Unit (BECU) performs the local brake control functions. It is used for receiving and interpreting the brake demand signals as well as other train-lined signals to control the electro-pneumatic brake system. The BECU provides a linear brake control, according to the brake demand input arriving from the master controller. Based on the brake demand either by TO in manual mode or in ATO mode (Auto mode), first priority is given to Electro-Dynamic (ED) brake and any shortfall is met by purely Electro-Pneumatic (EP) friction brake applied by BECU. Supplementation of the ED-Brake with the Electro-Pneumatic (EP) brake is called blending of EP friction brake with ED brake. EP friction brake is applied through bogie based BECU and Brake Control Unit (BCU) which operates wheel mounted disc brake by controlling the brake cylinder pressure (brake caliper).

3.2 Direct Brake circuit

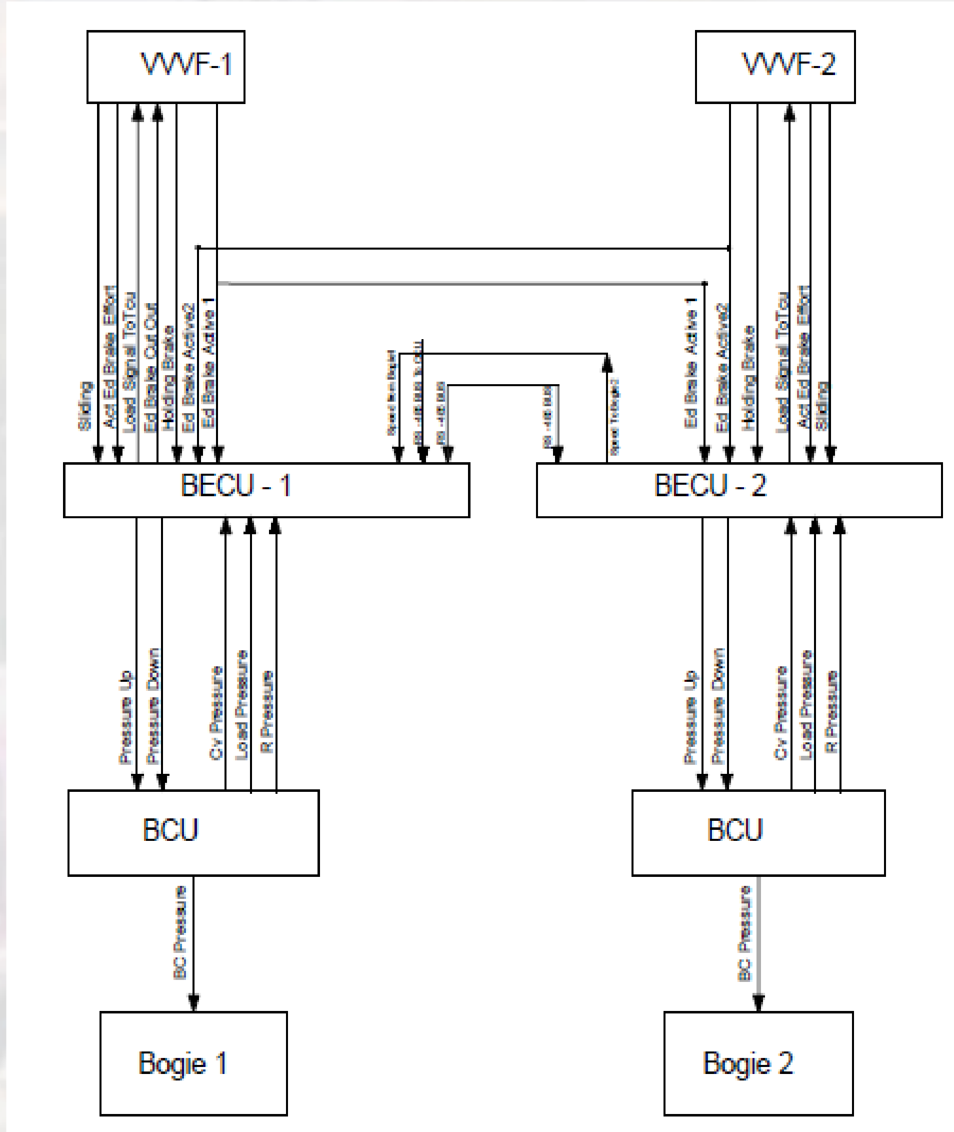


Fig.7- Direct Brake circuit

4. Interface between Propulsion System and Brake System

4.1 Requirement of interface

From the above technical description of Electro-Dynamic (ED) brake, the following issues needs to be addressed in case of use of Electro-Dynamic (ED) brake:

i. Braking effort provided by Electro-Dynamic (ED) brake may not be sufficient at higher end of the speed and hence it has to be supplemented from the Electro-Pneumatic (EP) friction braking effort. Electro-Pneumatic (EP) friction brake is controlled by Brake Electronic Control Unit (BECU). Electro-Dynamic (ED) brake is controlled by propulsion system. The braking demand either by the Train Operator (TO) during manual mode driving or through ATO under Auto mode driving is monitored by Brake Electronic Control Unit and VVVF. First priority is given to ED brake. If the demand is not met by ED brake, then its feedback goes to BECU and BECU supplements the shortfall through EP friction brake. This is called blending of ED and EP friction brake. Blending is not possible unless there is an interface between propulsion system (VVVF) and Brake system (BECU).

ii. As explained earlier, it is clear that when a moving train is stopped with Electro-Dynamic (ED) brake only, the brake power of the train becomes zero because velocity becomes zero and under this condition if train stops on gradient there is a possibility of roll back of the train. Several incidents happened in Indian Railway where an un-braked train rolled back and led to severe accidents. Thus, interface is required where the fading of ED brake is known to the BECU and as soon as ED starts fading, BECU starts applying Electro-Pneumatic (EP) friction brake and finally when the train is stopped, it stops with EP friction brake only. This concept is called “Holding Brake”.

iii. During the application of ED brake, wheel slide may take place because of excessive braking torque. If slide is not controlled, it will damage the wheels. Thus, slide has to be detected by VVVF and BECU both. First, slide is controlled by VVVF and then if it is not possible to control the slide within stipulated time then BECU will cut-off ED brake and control the slides through brake system. Detection of slide by BECU is at axle level and controlling may be either bogie level or axle level.

4.2 Blending between Electro-Dynamic (ED) brake and Electro-Pneumatic (EP) friction brake

4.2.1 Interface signals between propulsion system and brake system

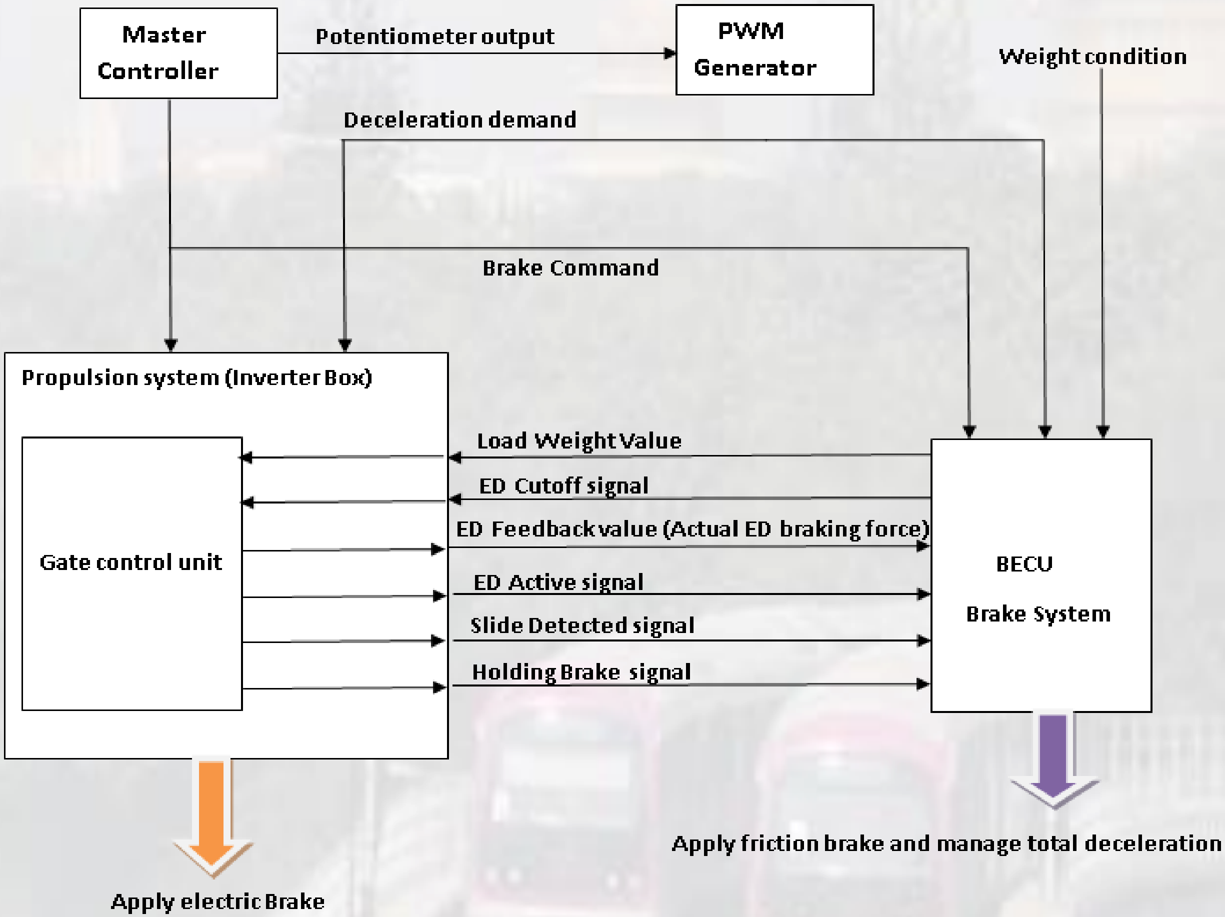


Fig.7- Interface signals between propulsion and brake system

4.2 Blending between Electro-Dynamic (ED) brake and Electro-Pneumatic (EP) friction brake (Contd…)

4.2.2 Description of interface signals

Table.5- Description of interface signals

Signal	Analog / Digital	Indicating
Load weight value	Analog	Train weight
ED Cut off signal	Digital	ED brake must be cut-off.
ED Feed-back signal (Actual ED braking force)	Analog	ED braking force
ED Active signal	Digital	ED brake is being applied.
Slide Detected signal	Digital	Slide control is being applied.
Holding Brake signal	Digital	Holding brake is applied.

4.2.3 Functional description of the signal

Table.6- Functional description of the signal

Signal	Description
Load Weight	This signal transmits the load weights from BECU to VVVF control
ED Active	This signal is send by VVVF to BECU if ED brake function is alive and effective
ED Feedback (Actual ED brake effort)	This is the feedback signal from VVVF control to BECU which sends the actual ED braking effort by VVVF system corresponding to the requested brake force either by TO or through ATO system
ED cut off	This signal is sent from BECU to VVVF control in case slide is detected and not controlled by VVVF and subsequently ED is cut-off and wheel slide protection is taken over by BECU.
Sliding	When the slide is detected by VVVF in ED braking, the same is communicated to BECU by VVVF and if BECU doesn't control within the specified time then ED brake is cut-off and wheel slide protection is taken over by BECU (EP friction brake).
Holding brake	This signal is sent by VVVF to BECU so that in case of ED getting fade out, EP friction brake will start applying by BECU and when the train going to standstill to hold the train, it will apply EP friction brake to hold the train.

4.2 Blending between Electro-Dynamic (ED) brake and Electro-Pneumatic (EP) friction brake (Contd…)

4.2.4. Explanation of interface

In Fig.8 interface between ED brake and EP friction brake is explained. The interface is briefly described as under:

i. At point A_0, train is at maximum speed and brake command is applied either by TO or by ATO system. Thus, corresponding to A_0, powering command is low and brake command is high. T_a is the response time to start regenerative operation and hence during this period brake cylinder pressure is BC pressure means EP friction brake is high.

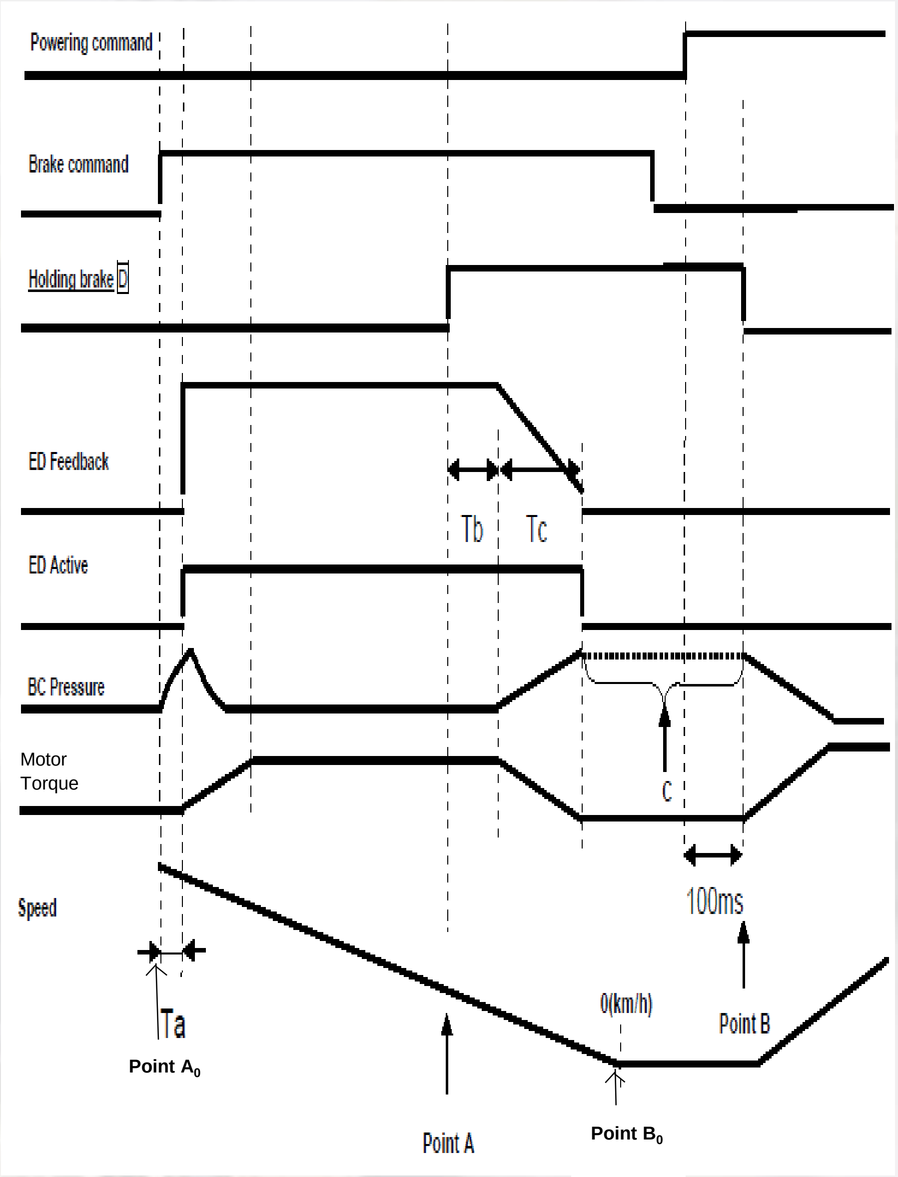
ii. After the response time T_a, regenerative brake is available and hence ED active signal as well as ED feedback signal is high. This implies that ED brake is available and accordingly BC pressure has started decreasing and hence come to the minimum level. That means priority is given to ED brake whereas EP friction brake is only supportive to the shortfall of the brake demand which is not met by ED brake signal.

iii. At point A, holding brake signal to VVVF becomes high indicating that the train is likely to achieve zero speed. Holding brake signal at point A becomes high when speed is around 7 Kmph. After time T_b, ED brake starts fading out and EP friction brake starts increasing.

iv. At point B_0, the speed of the train becomes zero and corresponding to that point, ED active signal has become low and also ED feedback has become low. But Brake cylinder pressure has increased as holding brake signal is high even if there is no brake command either from TO or from ATO.

v. When after stopping the train, again powering command is high, then after 100ms holding brake signal becomes zero and brake cylinder pressure (EP friction brake) starts fading out and again train will regain the speed in powering.

vi. Response time T_a, ED fade out time (T_b+T_c) are interface issues between propulsion system and brake system and has to be finalized during design phase. In BMRCL Phase-I project, T_a= 0.2 sec, T_b= 0.45 sec, T_c = 1.4 sec.



4.3 Holding Brake

4.3.1. As explained earlier, when ED brake starts fading, prior to time of T_b (0.45 sec), Holding brake signal from VVVF becomes high. Under the circumstances after the time of T_b+T_c when ED starts fading out, brake system simultaneously starts applying EP friction brake and when the train stops completely, ED brake becomes zero and holding brake with brake cylinder pressure of around 1.7 bar holds the train. The decay of ED brake and simultaneous application of EP friction brake is possible only because of the interface between propulsion system (VVVF) and brake system (BECU). This prevents the train from Roll back.

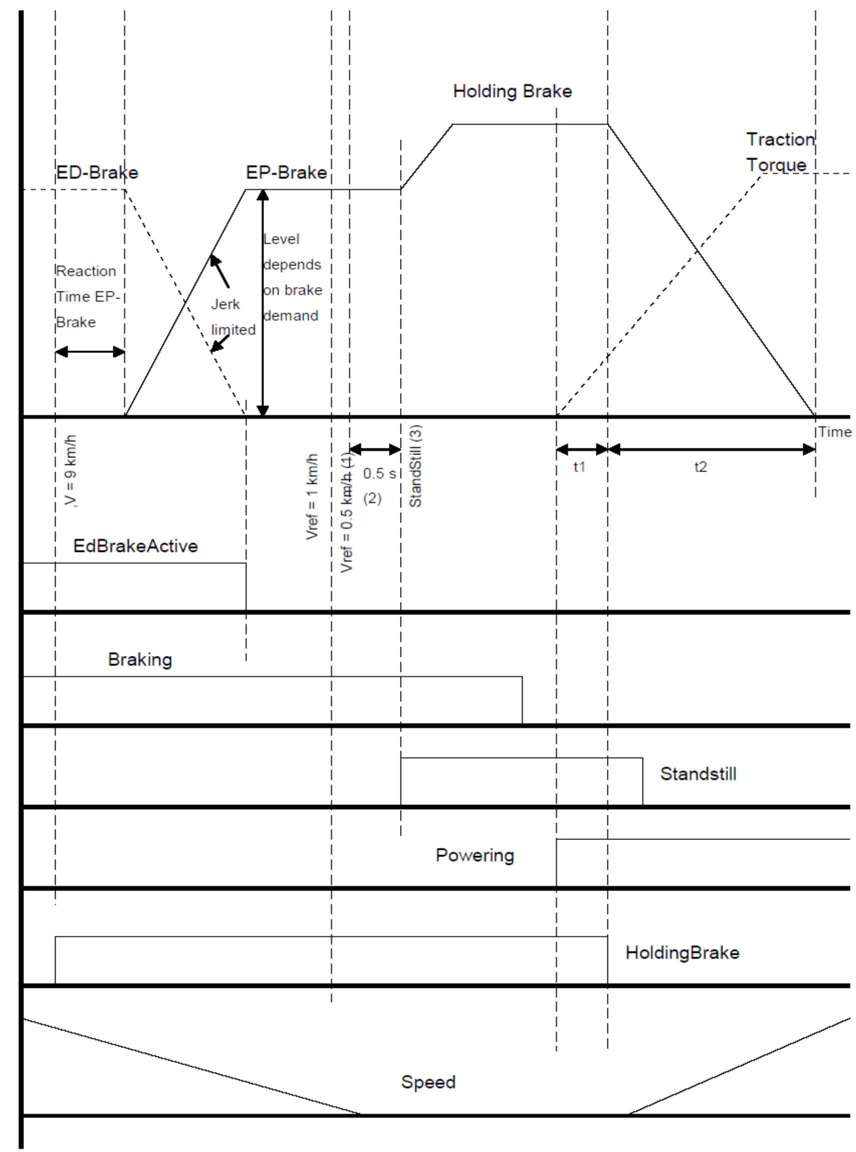
4.3.2 Schematic diagram for the holding Brake

In Fig.9, at around 9 Kmph (to be adjusted based on the project requirement) during braking (corresponding braking signal is high), Holding brake signal from VVVF becomes high and after reaction time Tb around 0.45 sec, ED starts fading out and at the same time EP friction brake starts (Brake Cylinder Pressure starts increasing). After a time of Tc sec (1.4 sec), ED brake completely fades out and brake cylinder pressure achieves a certain value say around 1 bar (which is to be adjusted depending upon the brake demand) but the train is still running. Since the train is in running condition, excess brake cylinder pressure at this point will lead to jerk in forward direction and for smooth stopping this pressure has to be adjusted.

4.3 Holding Brake (Contd…)

When the train stops, brake cylinder pressure is further increased by the BECU say around 1.7 bar. This is called “Holding Brake” as during this period the train is in stationary condition and the train is hold through EP friction brake only.

Again, when powering is resumed by either by TO or through ATO, powering command from VVVF becomes high and correspondingly braking command remains low. After t1 sec of powering command, holding brake starts decreasing (releasing) and correspondingly tractive effort starts increasing. After t2 sec of powering command, holding brake fully gets release. Time t1 and t2 is the project specific time and to be finalized normally in interface with propulsion system and brake system. In BMRCL Phase-I project, t1 (reaction time including signal processing time is 0.8 sec) and t2 (brake cylinder pressure release time which is around 4 sec).



Schematic Diagram for the holding brake

Fig.9-Schematic diagram for the holding Brake

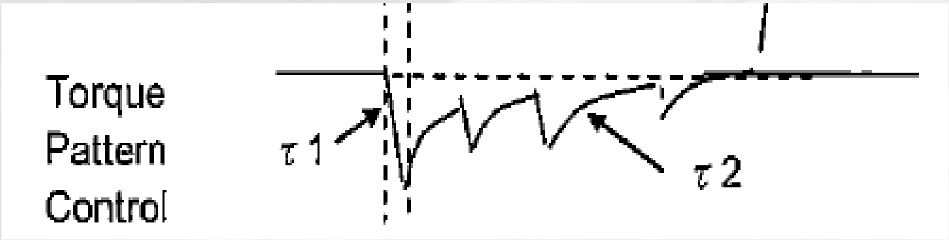
4.4 Wheel Slide Protection (WSP) control

4.4.1. During braking, if excess torque is applied on a particular wheel then that wheel will not have a rotary motion and it will only linear motion and this phenomenon is called sliding of wheel. If it is not controlled, then wheel will be skidded and hence there is need to control the slide on priority basis.

4.4.2. In modern Rolling Stock, for control of the slide both propulsion system (VVVF) and brake system (BECU) has to interface to each other. Slide control by VVVF is faster than that of the BECU and usually sliding condition is corrected first by VVVF and if VVVF is unable to control the slide then slide control is taken over by BECU as explained below:

(a) When the VVVF detects a slide condition during dynamic brake mode, the slide correction is applied (i.e. the dynamic brake torque is reduced). At this time, the VVVF sends the signal of "Slide Detected Signal" to the BECU. BECU will ensure that pneumatic brake force will not increase during sliding condition.

(b) During the slide control by VVVF, dynamic brake torque on the sliding wheel is reduced as shown in Fig.10 below



τ1= Time constant for reduction of torque. Normally, it is in the range of 50ms

τ2= Time constant for recovery of torque. Normally, it is in the range of 1 sec

Value of **τ1** & **τ2** needs to be finalized based on the field trials

4.4 Wheel Slide Protection (WSP) control (Contd…)

(c) If this “Slide Detected Signal” remains high and reduction of torque on the sliding wheel is more than 70% for 2 sec, then VVVF detects Wheel Slide Detection (WSD) failure and ED brake is cut-off by VVVF.

(d) If the “Slide Detected Signal” from VVVF received by BECU remains high for maximum 5 sec then BECU will set “EDbrakecutout” signal high and same is sent to VVVF and subsequently ED brake applied by VVVF is cut-off. Thereafter, slide detection and control function is completely taken over by BECU. After detecting the slide, BECU operates dump valve which releases the brake on the sliding wheel and again applies the brake through dump valve. The application and release time of brake through dump valve by BECU requires to be finalized during field trial. The time lag between the detection of slide by BECU and operation of dump valve is also required to be finalized during field trials.

4.4 Wheel Slide Protection (WSP) control (Contd…)

4.4.3. In Fig. 11 below, it is seen that when the train is in braking mode, brake demand is high, powering command and holding brake command is low. ED active and ED feedback signal is high. From the motor current of torque component, it is seen that in “Area A” sliding has taken place and VVVF is controlling the slide. As soon as slide is detected, sliding signal becomes high and if it continues for max. 5 sec, ED cutout signal by BECU becomes high. ED brake is cut out and now the slide controlling is taken over by BECU by operating the dump valve whose effect can be seen by brake cylinder pressure graph in “Area B”. Maximum brake cylinder pressure during slide control is project specific and should be decided based on the field trials.

When the slide is stopped and the train stopped at correct stopping point, at that time brake command is low. Further, normal powering is resumed and if speed is more than 10 Kmph and service brake is applied (brake command will become high), ED brake will resume automatically.

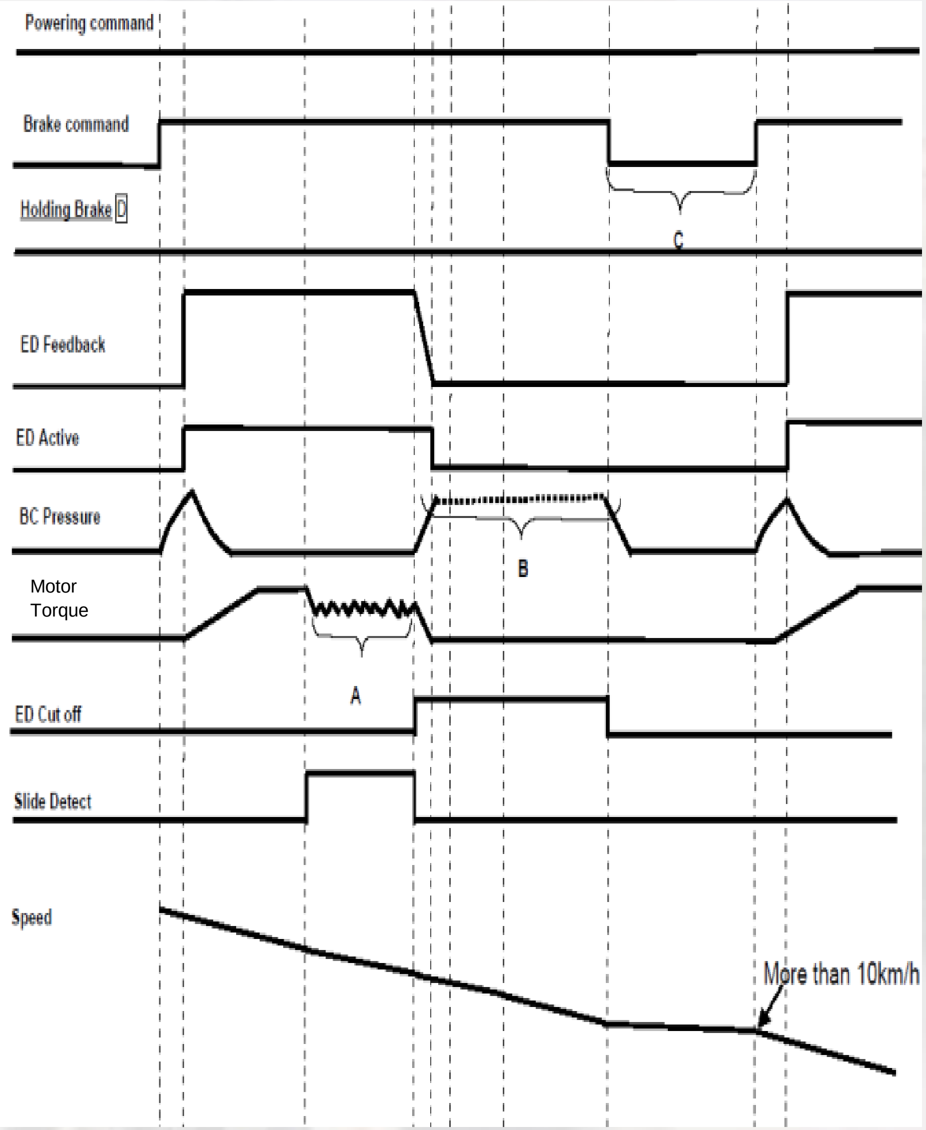


Fig. 11- Schematic Diagram for Wheel Slide Protection (WSP)

5. Conclusion

For safe operation of the train, brakes on the train should be applied and released with minimum wear and tear to the brake gear and brake wheels. For ensuring the safe operation during braking, interface between propulsion system and brake system is essentially required. This is possible only when both the systems are micro-processor controlled and both the system can receive signals from each other. With interface with each other, we can implement the concept of blending, holding brake and at the same time we can control the slide during braking. This is possible only when we can adopt 3-phase microprocessor-controlled propulsion system and microprocessor-controlled brake system.

6. References

i. Design criteria of Bangalore Metro Phase-I Rolling Stock project.

ii. Maintenance records from Rolling Stock O&M wing

Thank You