सत्यमेव जयते

भारत सरकार
रेल मंत्रालय

Government of India
Ministry of Railways

Technical Specification For Electric Hybrid (Electric + Battery) Locomotive

Specification No. RDSO/2021/EL/SPEC/0143(Rev. 1)
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Approved by	**Signature**
PEDSE	

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1.	-	All	0	First issue
2.	xx.xx.2021	All	1	In compliance to MOM issued vide RB letter no. 2021/Elect./(TRS)/138/1(PUs) ,dated 06.09.2021.

CONTENTS

1. Hybrid Electric Loco Concept & Scope

The Hybrid Electric Locomotive (HEL) is basically an electric locomotive with the ability to operate from Battery. Since the advent of electrified rail road, the concept of a vehicle which could be self or electrically propelled has been pursued to meet particular operating needs. End of an electrified section is always a bottleneck to the customer. Therefore, HEL can bridge this gap between electrified & non-electrified routes. Development of battery operated locomotive is an effort to reduce emission of Green House Gases (GHG) under Clean Development Mechanism (CDM) of Kyoto protocol.

This Specification defines the system and performance requirements for the design, development, construction and testing of a Hybrid Electric Locomotive. HEL can work under 25kV Over Head Equipments (OHE) as the primary power source in electrified routes and work with battery power in non-electrified sections.

2. Advantages of Hybrid Electric Locomotives

The advantages of the HEL may be summarized as follows:

- Improved operational flexibility in last mile operation on main line as well as in goods yards, sidings and in shunting operation which are non-electrified.
- In the event of major accident and natural calamities where OHE gets affected, HEL provides excellent operational flexibility to work on battery mode until normalcy is established.
- Emission free, noise free operation of HEL & dependency on diesel locos will not be there.

3. Design of a Hybrid Electric Locomotive

- Housing the on-board equipments of both electric and battery loco with a common Traction & Auxiliary control system.
- Keeping the Axle load within permissible limits of Indian Railways.
- Weight balancing of locomotives with addition of battery & its control panel.

3.1 This proposed specification is for converting the existing electric locomotive (WAG9H) in HEL instead of evolving a new design of a hybrid electric locomotive with transfer of technology which will be a time consuming process & may not be cost effective. The purpose of the specification is to provide the technical specification for integration of Traction battery with the propulsion equipment.

3.2 In general the operating characteristics of the HEL shall be similar to the base locomotive to which the retrofit has been applied. However, significant areas of improvements as the results of the retrofit is likely to be achieved in proposed design.

3.3 WAG9H is being manufactured at CLW/BLW/DMW with indigenized control software.

3.4 The power rating of the Battery Set will be approximately 857 kWh to keep the size of on board Battery set & accessories minimum to be accommodated in the space available & the fact that switching over to Battery mode will be required during last mile connectivity or in case of exigencies. The existing Traction Motors(TM) will be utilized.

3.5 A design objective during the development of the HEL will be to keep the interface identical in both Electric & Battery Mode for crew.

3.6 Changeover from electric mode to Battery mode & vice-versa may be accomplished following due safety precautions. Provision of only manual change over switch from OHE to Battery & vice versa should be there during prototype development. Automatic change over switch for the purpose may be decided during regular cut in as per outcome & experience gained during prototype testing.

3.7 A annunciation panel shall be provided in the cab to inform crew the status of Battery mode equipment on the locomotive.

3.8 HEL shall be equipped with regenerative braking in both electric mode and in battery mode.

3.9 The machine room layout of various equipments shall be designed by the supplier. Further the CG should be balanced. Firm shall ensure the CG of the locomotive along with the CG of each equipment. Further firm shall ensure the weight balancing with weight distribution of all equipments inside the locomotive.

3.10 Battery for Traction purpose

3.10.1 **Type of battery:** ACC battery meeting the performance requirement should be used. Design approval should be taken from purchaser during the design approval stage. The battery should be able to deliver the required energy requirement so that load of 5900T shall be started on level gradient and should continue to haul the load with speed of 30kmph for duration upto 60minutes.

3.10.2 The responsibility for safe operation of battery with reliability shall lie with the supplier. Suitable battery management system (BMS) with fail safe protection system for the on-board battery bank and its charger should be adopted for reliable operation of the battery.

3.10.3 It should be properly mounted in the locomotive with proper care of its size, weight and cooling arrangement to withstand the shock and vibration.

3.11 **Battery charger for traction battery**: On-Board Battery charger should be able to operate both from Catenary and external 415V 3-phase supply. Battery charger shall also be able to operate from power generated during regenerative braking while working under battery mode. The battery charger shall be rated such that it can charge the battery from fully discharged state to fully charged state within 5 hours.

3.12 **Battery for Control Electronics**: There should be separate Ni-Cd type 199Ah/C5A or other type of ACC battery shall be used for control electronics of the locomotive.

3.13 Determination of battery power, Ampere hour, weight & space requirement to haul a train of 5900t load on level gradient by WAG9H locomotive at 30kmph speed is given below. This stipulated requirement is only for guidance purpose. Supplier shall do the necessary calculation to determine the battery capacity to meet the performance requirement stipulated in this specification.

Rail horse power requirement (kW)	707
Auxiliary load (kW)	150
Total Power requirement for Traction & Auxiliary (kW)	857
Time for operation on battery Hour	1
kWh	857
Considering DC link voltage as Volts	2800
Ah	306
Battery voltage	12.8

Ah of battery	300
No. of battery required to match with DC link voltage	219
No. of parallel path to achieve required Ah	1
Total no of battery	223
l*b*h of battery (mm)	522,267,220
volume of battery (m3)	0.031
Total space required (m3)	6.91
Wt of battery (kg)	34.36
Total Wt of battery (tonne)	7.67

Note: Following auxiliaries will not run during battery mode.

1. TFP Oil Pump= 2x4.7=9.4kW
2. One Compressor = 15kW
3. Scavenger Blower for OCB+TMB=2x6=6kW
4. No requirement of Machine Room Blower & its Scavenger running in battery Mode.

3.14 Detail of particulars of lithium iron phosphate (LiFePO4) battery used for aforesaid calculation is as under:-

- Lithium iron phosphate (LiFePO4) battery provides 100% of its rated capacity.
- LiFePO4 batteries are lighter, take less space and last longer.
- Require no maintenance and they have up to 10x longer life.
- LiFePO4 Batteries use the safest and mostly has a built-in Battery Management System (BMS).
- Specification: Voltage: 12.8V, Amp Hours: 300Ah considered for 30kmph
- Dimension & Weight: Lx B x H : 522mm x 267mm x 220mm, Weight: 34.36 kg

4.0 Design Parameters

Sharpest curve to be negotiated Single unit without buffer Double unit with buffer	174m radius and 1 in 8½ turnout in either Direction
Locomotive weight	132T (Max.)
Nominal Axle Load	22.0T (Max.)
Wheel diameter (mm)	1092mm(New) 1016mm(Condemning)
Gear ratio	1:5.133
Maximum operating Speed at level gradient with train load of 5900t - Battery Traction Mode - Electric Traction Mode	 30 kmph 100kmph
Tractive effort Vs Speed characteristics	RDSO graph See Annexure-IV
Starting Tractive Effort	OHE Mode: Starting Tractive Effort under dry rail conditions shall not be less than 500kN Battery Mode: Starting Tractive Effort under dry rail conditions shall not be less than 288kN

Installed power under standard conditions in Battery Traction Mode	857 kWh @ 2800VDC (to achieve a speed of 30kmph for 1 hr)
Installed power under standard conditions in Electric Traction Mode Power to the wheels(Including Auxiliary Power)	6000HP
Installed power under standard conditions in Battery Mode Power to the wheels (Including Auxiliary Power)	1140 HP

5.0 EXTENT OF MODIFICATION

5.1 Schematic Circuit Diagram of Hybrid Electric Locomotive

Existing design of WAG9H locomotive shall be suitably modified for Hybrid mode working with a new General Arrangement, duly incorporating the proposed changes. Effort shall be made for fitment of battery mode equipments in existing loco without major layout changes of existing locomotives & the general arrangement with existing Traction/Auxiliary converter is shown in Annexure-I for guidance purpose.
In case, Integrated Converter is proposed in place of existing converters, the general arrangement of the HEL is shown in Annexure-II for guidance purpose. The standard locomotive is designed for regenerative braking during electric mode operation. Before determining the extent of the modification required to the basic WAG9H locomotive, it is necessary to establish the power circuit to be used and the method of its control, thus enabling interfaces with existing equipment to be identified and defined.

5.2 Power & Auxiliary Circuit of Hybrid Electric Locomotive with existing traction/auxiliary converter

A number of options exist in the choice of the power circuit to be adopted for the HEL. The operation, control and performance of the locomotive in the electric mode are unchanged. In Battery mode, the power circuitry remains the same in principle; the Battery is taking the place of the transformer & battery supply is being fed at DC link.

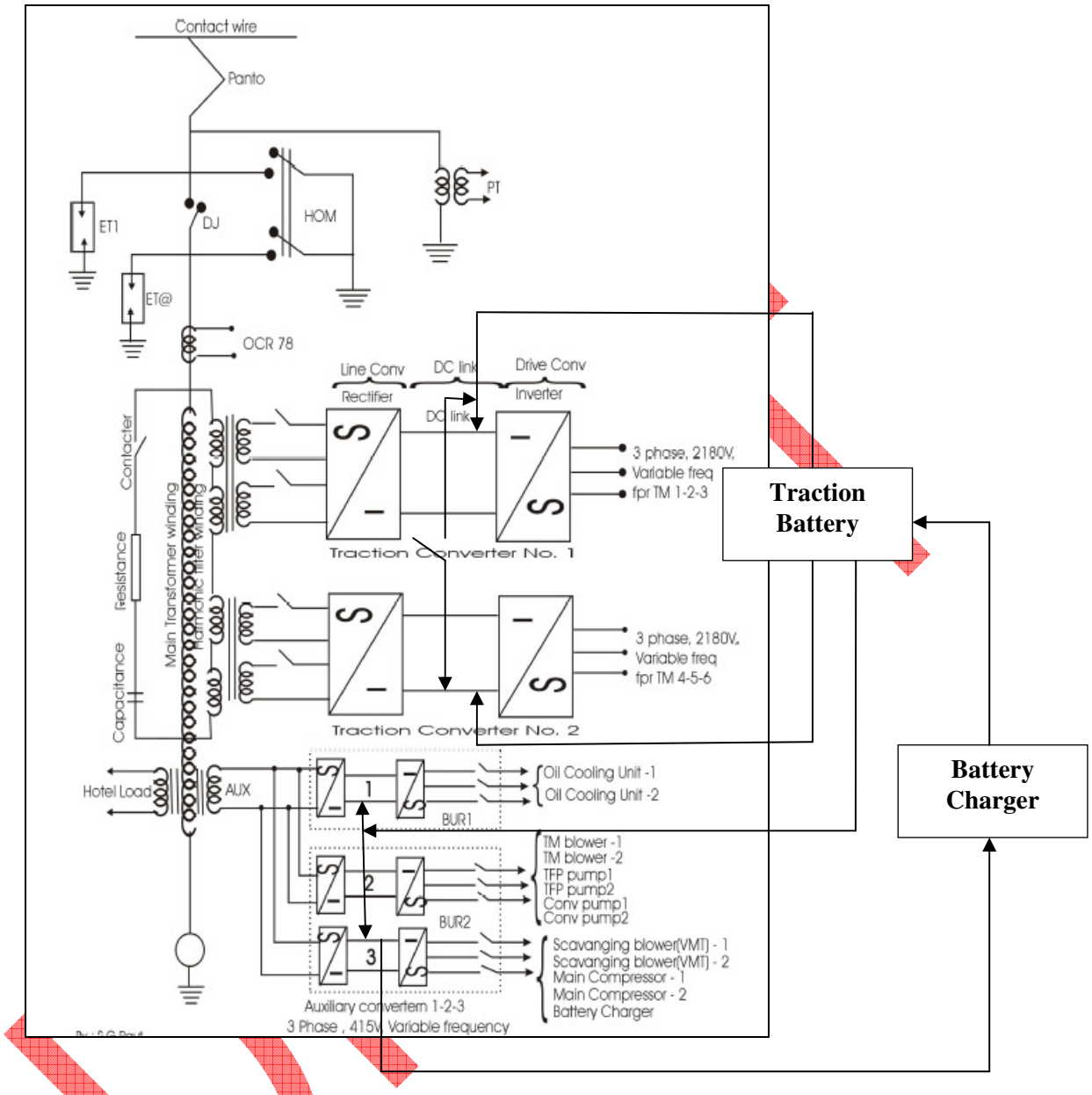


Fig.1 Traction & Auxiliary Circuit of HEL with existing traction/auxiliary converter

5.3 Power & Auxiliary Circuit of Hybrid Electric Locomotive with Integrated Converter

Existing Power Circuit to be modified for additional traction Battery set & Integrated Converter to be installed & interfaced as under.

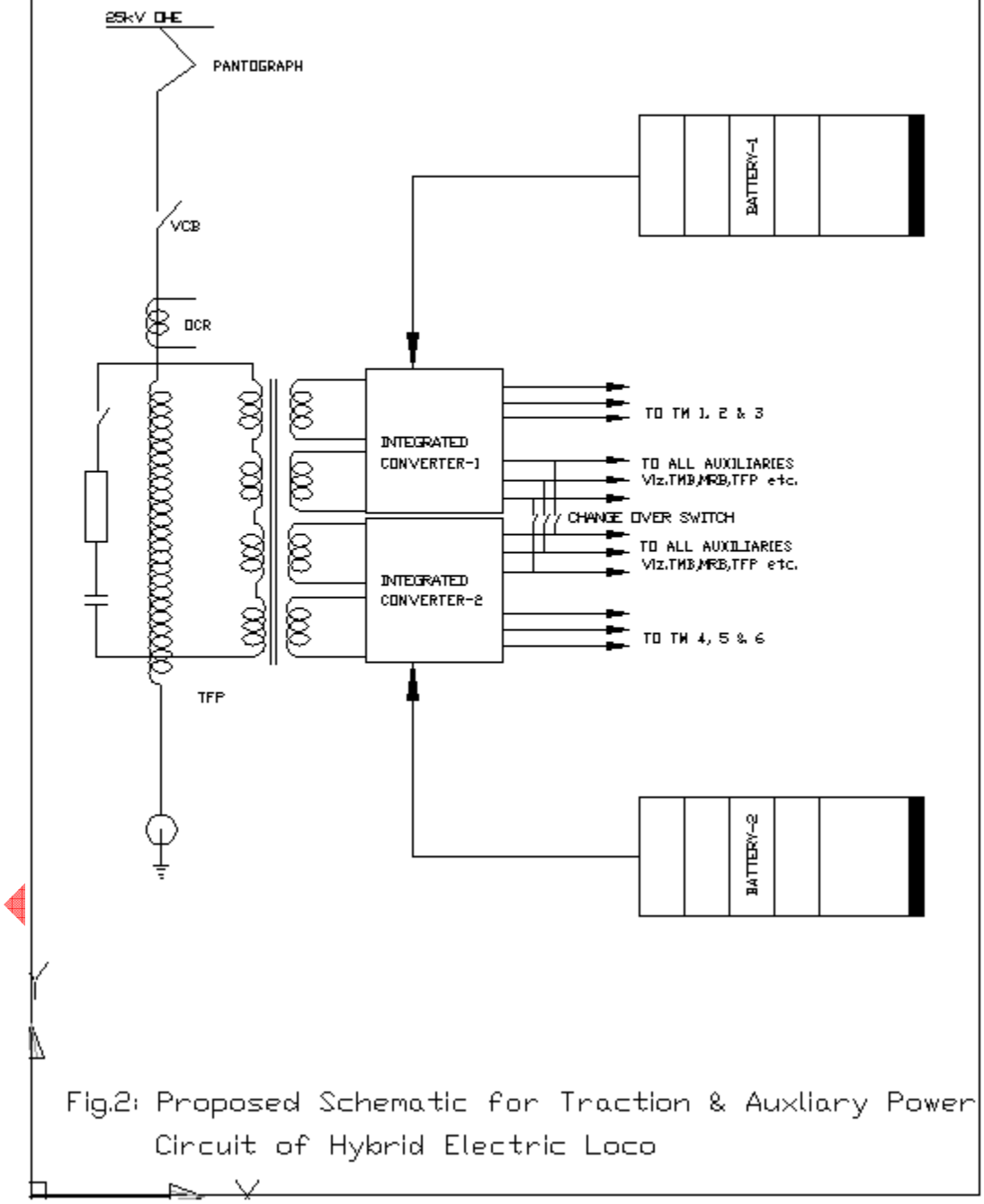


Fig.2: Proposed Schematic for Traction & Auxliary Power Circuit of Hybrid Electric Loco

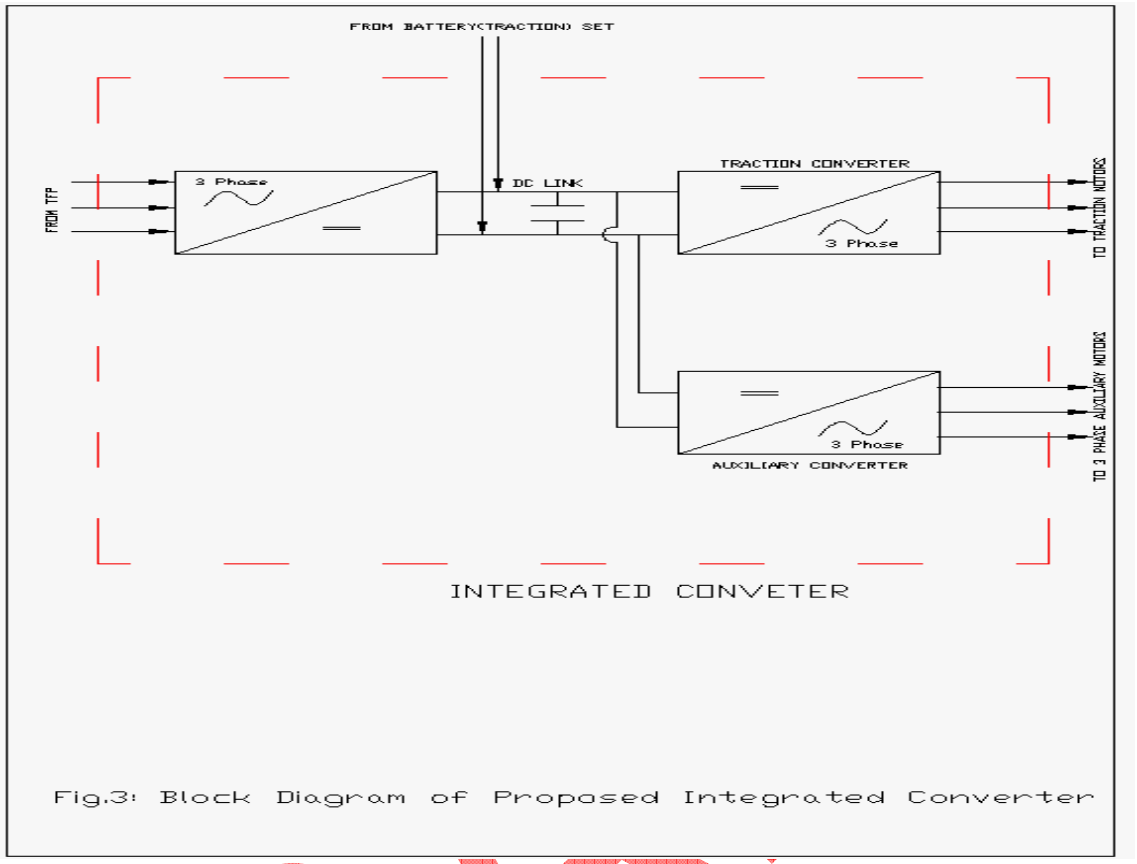


Fig.3: Block Diagram of Proposed Integrated Converter

6. Mechanical Designs

The mechanical design of HEL will generally remain same as that of base line loco i.e. WAG9H.The general arrangement and equipment layout of the locomotive shall be jointly worked out by RDSO, Production Units and the firm (supplying the Battery mode equipments).The underframe/superstructure will be modified as per final layout of locomotive.

7. Description of additional equipments to be installed & interfaced:

7.1 Advance Chemistry Cell Battery (Traction) set: 857 kWh, 2800V DC.

7.2 The existing separate Traction & Auxiliary convertor shall be used. However, Integrated Converter (Traction & Aux Converter) can also be used in case fitment of additional equipments for battery mode is not possible. The rating particulars shall be as under:

DC link Voltage	2800V
Output Voltage line to line	2180V
Power Rating to be handled	2x2250kW which includes the power requirement of Auxiliary supplies.

7.3 **Integrated converter**: Suitably designed integrated converter may be used and the traction battery should be integrated in the DC link of the power converter. Firm may propose an integrated converter consisting of traction converter and auxiliary converter with common DC link should be housed in same cubicle.

Both integrated converter shall be identical in all aspects. In such a case, auxiliary converter shall be capable of supplying the complete load of the auxiliaries at rated frequency including battery charger for locomotive battery. In case of isolation of one of the auxiliary converter, the other converter shall take the complete auxiliary load including battery charging and the change over arrangement shall be automatic. Firm shall propose the design during design stage prior to manufacturing of prototype unit. In order to reduce energy consumption as well as to increase equipment life, multiple level ventilation control shall be adopted, which shall vary the output of all the blowers according to the cooling needs. Auxiliary converter output and control system shall be designed considering the total harmonic distortion at output voltage shall be less than 10% and supply regulated to ±5% of the nominal voltage under all operating condition.

The following aspects should be considered while designing the integrated converter:

- ✓ Fault of any converter module (traction converter/auxiliary converter) inside the integrated converter shouldn't affect the performance of remaining converters of the integrated converter.
- ✓ The integrated converter and footprint shall be designed in such a way that there would be no mounting issue in the locomotive. The design shall be submitted to purchaser during detailed design stage.
- ✓ Firm shall design the cable index related to integrated converter and same should be provided to purchaser at the time of approval of design document.
- ✓ There shall be Bogie controlled operation for Electric Hybrid Locomotives.
- ✓ Suitable redundancy in the vital PCBs connected with safety and power supplies, so that the locomotive failure and degradation in performance is minimized in the event of the failure.
- ✓ As the single auxiliary converter of one Integrated Converter shall be sufficient for total auxiliary load and in case of failure, the total load shall be shifted to another auxiliary converter of other Integrated Converter. Hence it leads to redundancy of the battery chargers.

Firm shall submit the detailed design along with the interfacing of the Integrated Converter for approval and all the validated results shall be submitted to purchaser.

8. Dimensions & environmental conditions

8.1 HEL dimensions and profile shall within or fully conform to IRSOD 1D-clearance diagram latest revision.

8.2 The Climatic and environmental conditions to be considered are as under

Atmospheric temperature	Maximum temperature of metallic surface under the Sun: 75 degree Celsius and in shade: 55 degree Celsius Minimum temperature: - 10 degree Celsius (Also snow fall in certain areas during winter season)
Humidity	100% saturation during rainy season
Reference site conditions	i) Ambient temperature: -10 ^{0}C to 55 ^{o}C ii) Humidity: 100% iii) Altitude: 1776 m above mean sea level
Rain fall	Very heavy in certain areas.
Atmospheric conditions	Extremely dusty and desert terrain in certain areas. The dust concentration in air may reach a high value of 1.6 mg/m^3. In many iron ore and coal mine areas, the dust concentration is very high affecting the filter and air ventilation system.

Coastal area	Humid and salt laden atmosphere with maximum pH value of 8.5, Sulphate of 7 mg per liter, maximum concentration of chlorine 6 mg per liters and maximum conductivity of 130 micro Siemens /cm.
Wind speed	High wind speed in certain areas, with wind pressure reaching 150 kg/m^2.
Electromagnetic pollution	High degree of electromagnetic pollution is anticipated in locomotive machine room/HT & LT compartment, where the equipment shall be mounted. Necessary precaution shall be taken in this regard. The system shall be interference free from the communication system between the Guard-Driver-Control and Public address system. The system should be tested as per IEC 61000 for Electro Magnetic Compatibility.
Vibration	The system shall be designed to withstand the vibrations and shock encountered in service satisfactorily as specified in IEC 1287 and 60571 publications for the electronic equipments used on Rail Vehicle and relevant IECs as applicable to other equipment.

9. Weight Calculation for Proposed Hybrid Electric Locomotive (HEL)

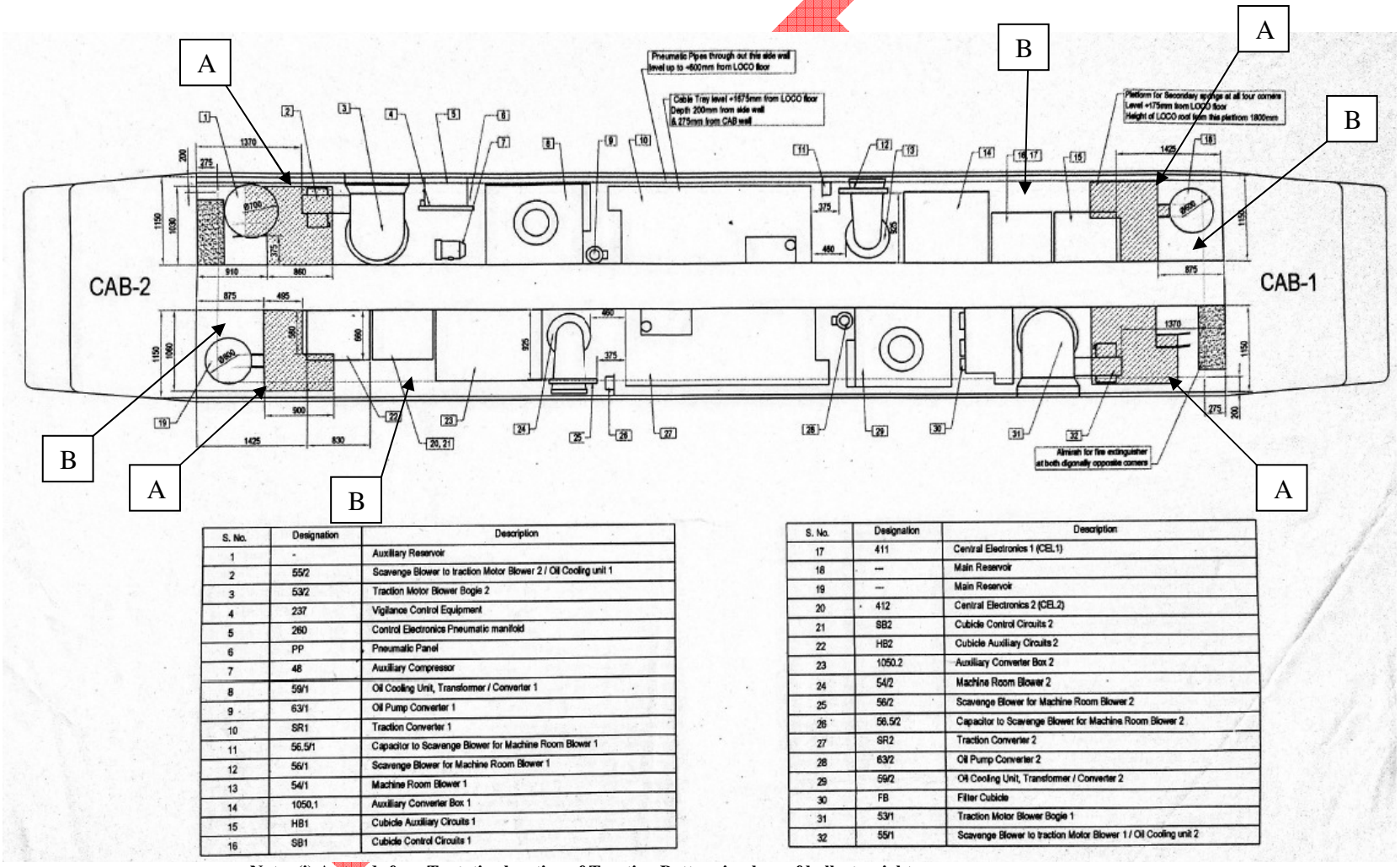
As per the layout given in Annexure-I, the total weight of the locomotive shall be less or equal to 132 t which will give maximum axle load of 22.0 t. Brief calculation of additional weight on account of HEL and reduction in weight is given in Annexure-III.

10. Simulated Performance Curve of Hybrid Electric Locomotive (HEL)

The hauling capability of proposed HEL on level gradient is indicated in Annexure-IV in both mode of operation.

Annexure-I

Tentative General Arrangement of Proposed Hybrid Electric Locomotive on WAG9H with existing Traction/Auxiliary Converter



S. No.	Designation	Description
1	-	Auxiliary Reservoir
2	55/2	Scavenge Blower to traction Motor Blower 2 / Oil Cooling unit 1
3	53/2	Traction Motor Blower Bogie 2
4	237	Vigilance Control Equipment
5	260	Control Electronics Pneumatic manifold
6	PP	Pneumatic Panel
7	48	Auxiliary Compressor
8	59/1	Oil Cooling Unit, Transformer / Converter 1
9	63/1	Oil Pump Converter 1
10	SR1	Traction Converter 1
11	56.5/1	Capacitor to Scavenge Blower for Machine Room Blower 1
12	56/1	Scavenge Blower for Machine Room Blower 1
13	54/1	Machine Room Blower 1
14	1050.1	Auxiliary Converter Box 1
15	HB1	Cubicle Auxiliary Circuits 1
16	SB1	Cubicle Control Circuits 1

S. No.	Designation	Description
17	411	Central Electronics 1 (CEL1)
18	---	Main Reservoir
19	---	Main Reservoir
20	412	Central Electronics 2 (CEL2)
21	SB2	Cubicle Control Circuits 2
22	HB2	Cubicle Auxiliary Circuits 2
23	1050.2	Auxiliary Converter Box 2
24	54/2	Machine Room Blower 2
25	56/2	Scavenge Blower for Machine Room Blower 2
26	56.5/2	Capacitor to Scavenge Blower for Machine Room Blower 2
27	SR2	Traction Converter 2
28	63/2	Oil Pump Converter 2
29	59/2	Oil Cooling Unit, Transformer / Converter 2
30	FB	Filter Cubicle
31	53/1	Traction Motor Blower Bogie 1
32	55/1	Scavenge Blower to traction Motor Blower 1 / Oil Cooling unit 2

Note: (i) A stands for; Tentative location of Traction Battery in place of ballast weight.
(ii) B stands for; Tentative location of Battery Charger.

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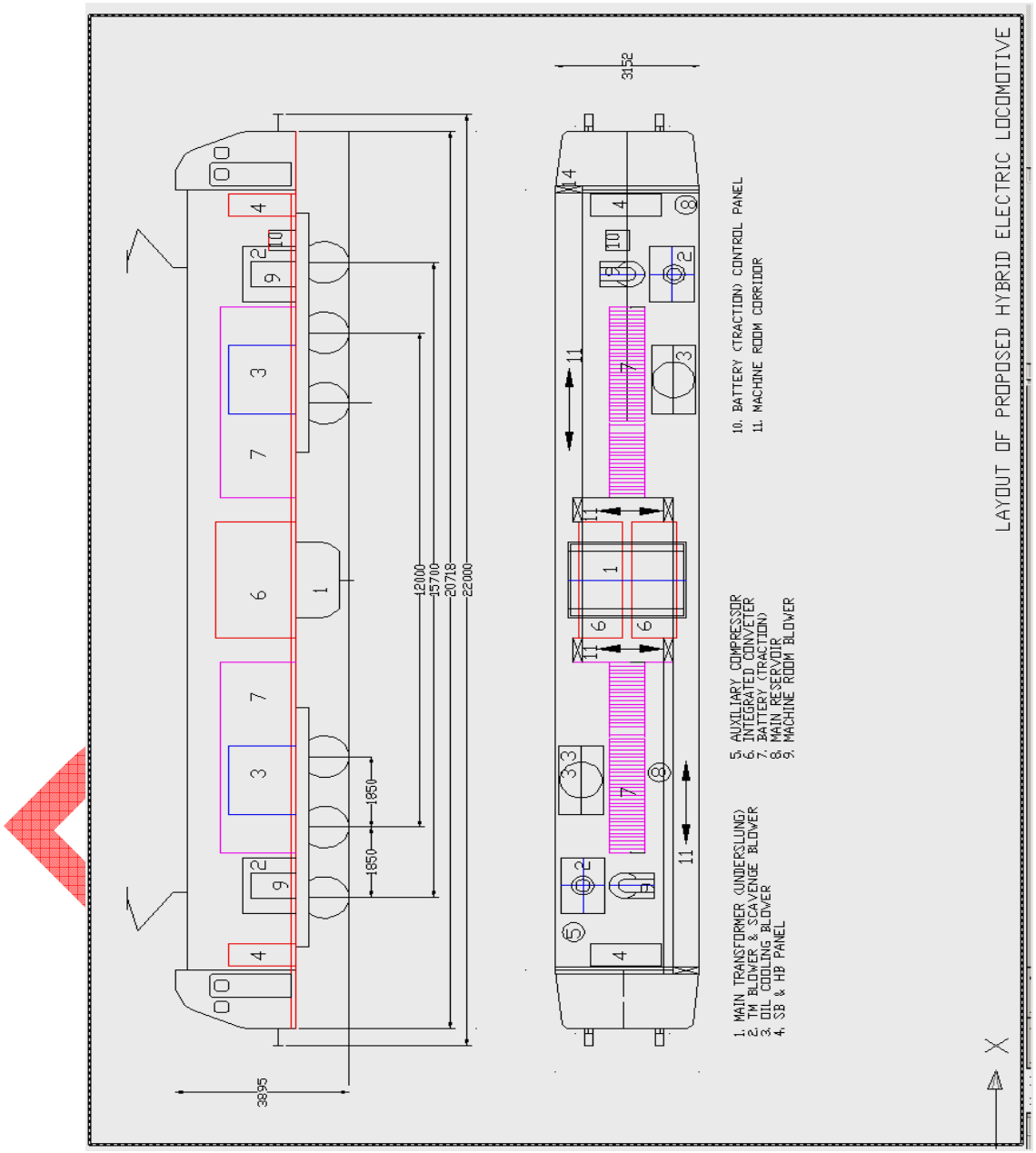
SSE/D/12	JDSE/System	EDSE

Annexure-II

Tentative General Arrangement of Proposed Hybrid Electric Locomotive on WAG9H platform with Integrated Converter



Annexure-III

Tentative Weight reduction/addition in the proposed Hybrid Electric Loco on WAG9H platform with axle load with in permissible limit of 22T

- The equipments will be placed generally in line with Tentative Layout (Annexure-I).The Additional weight for Battery mode will be compensated by removing the dead weight used in WAG9H i.e. 9t to keep the axle load within permissible limit of 22T.

SN	Item Description	Likely Weight Addition(kg)	Likely Weight Reduction(kg)	Net Change (kg)
1.	Battery set (complete), 857 kWh	7670	-	7670
2.	Dead weight		9000	-9000
3.	Modular for battery set, Battery charger & its sub-assembly	1330		1330
			Total increase in weight(kg)	**0**
			Net Increase in Axle load(kg)	**0**
			Existing Axle load of WAG9H(t) with ballast weight	**22.0**
			Axle load of Proposed Hybrid Electric Loco(t)	**22.0**

Annexure-IV

Tractive effort Vs Speed characteristics of Hybrid Electric Locomotive (HEL)