भारत सरकार / GOVT. OF INDIA
रेल मंत्रालय / MINISTRY OF RAILWAYS

TRACTION ROLLING STOCK

THREE PHASE TECHNOLOGY

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COURSE
ON
THREE PHASE TECHNOLOGY
IN TRS APPLICATION

INDIAN RAILWAYS
INSTITUTE OF ELECTRICAL ENGINEERING
NASIK ROAD

PREFACE

There has been lot of technological developments using Three phase Technology in the field of Electrical Traction Rolling Stock. Hence, it has become necessary to compile all relevant technical matter on the subject of Three Phase Technology in to a concise book, which is named as “Traction Rolling Stock : Three Phase Technology.”

For bringing out this book Shri K.V. Gaikwad, Sr. Section Engineer and Shri Suryawanshi M.A., Raj Bhasha Supdtt. have made substantial efforts, under the guidance of Shri Rupesh Kumar, Professor (Electronics).

I am very glad to note that lot of efforts have been made in bringing out this book of “Traction Rolling Stock : Three Phase Technology “ in the present form. I am sure that this book will serve the needs of Electrical Engineers working in the field of Electrical Traction Rolling Stock.

Nasik Road
18th August, 2010

A.K. RAWAL
DIRECTOR

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1. THREE PHASE TECHNOLOGY FOR TRACTION APPLICATION

1.0 INTRODUCTION

Three phase AC drive technology has become very common and significant for modern rail vehicles. These vehicles are equipped with GTO thyristors and microprocessor control systems. Microprocessor is used for vehicle control, supervision of health and operations of all major components and diagnostics. It permits electric breaking down to standstill and selection of best PWM technique for improved performance of motor as well as unity pf. The advantages associated with this technology are evident in technical as well as economic aspects.

2.0 WHAT'S NEED FOR A CHANGE ?

Earlier, all the locomotives were using DC traction motors. The speed/torque regulation is achieved by using either tap changer on transformer or through resistance control on majority of these locomotives. Conventional relay based protection schemes are used. In most of the cases, the driver uses his discretion to diagnose and get past the problem.

2.01 FRPCPY for Tap changer and its associated equipments is about 10%.

2.02 DC motor has inherent problems of brush gear, commutator and low power to weight ratio. DC motor is essentially a high current low voltage design which calls for expensive large diameter cables and large electro-pneumatic reverser, contactors, switches etc.

2.03 Thyristorised DC traction motor drives, though made the DC motor drive more efficient, suffer because of high harmonic injection into

Power supply. Loss associated large filters had to be carried on Locomotives to overcome this.

2.04 Emphasis on regeneration is increasing day by day to reduce energy bill as well as to save energy for greater national cause.

2.05 With ever increasing need for hauling higher loads, there is need to make maximum use of available adhesion.

2.06 There is need for track friendly locomotives to reduce track maintenance efforts.

3.0. WHY THREE PHASE TECHNOLOGY?
Advantage of 3-phase induction motor over DC series motor

3.01 Three phase traction motors are robust and require little maintenance. Apart from bearing, it has no parts subjected to wear. It is insensitive to dust, vibration and heat.

3.02 No restriction on speed of motor in absence of commutators, AC traction motors can easily operate at 4000 rpm in contrast to 2500 rpm in case of DC machines.

3.03 The limit imposed due to bar-to-bar voltage for DC commutator motor is no more relevant with squirrel cage induction motors. Whole power flow from transformer to converter to DC link and down to inverter / motor may be chosen at higher operating voltage. Against nominal 750 V, 1000A system with DC machines equivalent three phase propulsion is configured around 2800 V, 300A. Due to heavy reduction in operating current, power cables are much lighter and losses are reduced.

3.04 Power to weight ratio of induction motor is much higher than the DC motor. As a typical example 1500 KW per axle can be packed per Axle with induction motors compared to 800 KW maximum with DC motors.

3.05 Since the torque speed characteristic of the induction motor is markedly steeper than that attainable by conventional Dc machines, the induction machine can take better advantage of maximum possible tractive effort. A high mean adhesion coefficient can be expected.

3.06 As the adhesion coefficient is high, it is possible to transfer a part of the braking forces for the trailing load to electric brakes of locomotive. That is, in the case where regenerative braking is used, the regenerated electric energy can be increased.

3.07 High power/weight ratio of induction motor, reduction in cable thickness, reduction in number of contactors, switches etc. result in reduction in physical dimension and weight of the entire system.

Advantages of microprocessor based control.

3.08 Almost all moving contactors, switches, relays, reversers etc. are eliminated and operation is sequenced by means of solid state logic.

3.09 The microprocessor is used for drive control. The microprocessor allows the redundancy to be built in controls rather than the power equipments.

3.10 Microprocessor based fault diagnostic system guides driving crew about the fault location and suggests remedial action. It also keeps records of faults, which can be analysed by shed staff later.

3.11 Microprocessor control software has flexibility to provide software-based solution to local operational needs.

Other advantage of three phase drive

3.12 The induction motor drives are about 20% energy efficient compared to DC drives.

3.13 Three phase drives allow regeneration and unity power factor operation. The energy saving due to regeneration and improved power factor are sizable.

3.14 Electric braking down to standstill is possible. It improves operational efficiency besides reduction in maintenance efforts.

4.0 THEN, WHY SO LATE ?

To achieve these advantages of induction motor, it is necessary to supply it with a three phase variable voltage variable frequency (VVVF) source. This could not be achieved under technically and economically feasible conditions, until the advent of GTOs and microprocessor based control system in the last few years.

5.0 SO NICE, NOW DETAILS PLEASE ?

5.01 Three phase induction motor.

To appreciate the complexity of the drive for using 3 phase squirrel cage induction motor for traction application, let us start with speed torque characteristic of a conventional fixed frequency, fixed voltage squirrel cage induction motor shown in fig. 1.1. It is described by following equation.

$$T = K\,(V / F)^2 * f_S$$

Where *V & f* are terminal voltage and frequency of supply to induction motor, f_S is slip frequency and T is torque developed.

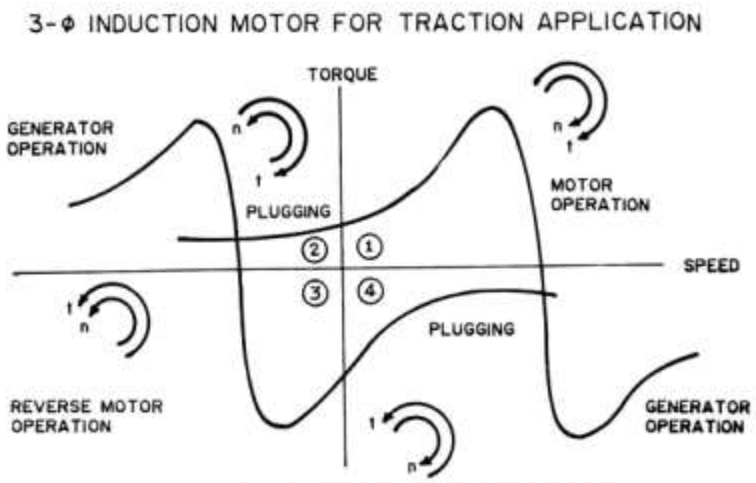


FIG. 1.1 FOUR QUARDRANT OPERATION OF THE THREE PHASE INDUCTION MOTOR.

- Though, the starting current of typical cage rotor induction motor is 5 to 6 times rated current, the starting torque is small because of the low power factor.

- Regeneration takes place, only when rotor is driven mechanically at super synchronous speeds.

Variable voltage variable frequency drive

In adjustable frequency drive, the supply frequency is reduced for starting, this frequency reduction improves the rotor power factor and this increases the torque/ampere at starting. In this manner, rated torque is available at start and the induction motor is accelerated rapidly to its operating speed by increasing the supply frequency. This method also avoids danger of low frequency crawling, which sometimes occurs when induction motors are started on fixed frequency supply.

Fig.1.2 shows T.S. characteristic for constant v/f (constant air gap flux) at different supply frequencies. The breakdown torque is maintained constant by maintaining v/f constant. The stator voltage cannot be increased beyond rated voltage. With voltage remaining fixed further, as frequency is increased above base or rated motor speed, the air gap flux and breakdown torque decreases, as shown in fig.1.3. These characteristics are suitable for traction applications, where a large torque is required below base speed and a reduced torque is sufficient for high speed running. The torque-speed characteristic for a practical traction drive system evolved from the above two strategies is shown in fig.1.4. The variation in motor voltage & current, slip freq. and torque as the function of speed for operating regions shown in fig.1.4 is shown in fig.1.5.

3 ϕ INDUCTION MOTOR FOR TRACTION APPLICATION

TORQUE - SPEED CHARACTERISTICS

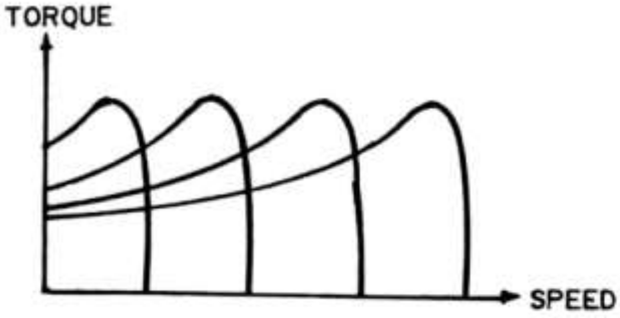


FIG. 1.2 CONSTANT V / f & DIFFERENT SUPPLY FREQUENCIES (f)

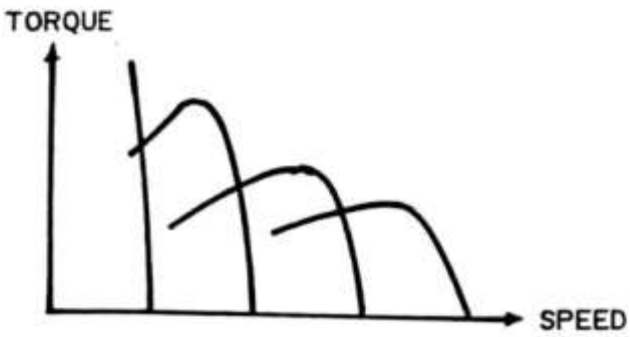


FIG. 1.3 AT CONSTANT V & VARIABLE f

3φ INDUCTION MOTOR FOR TRACTION APPLICATION

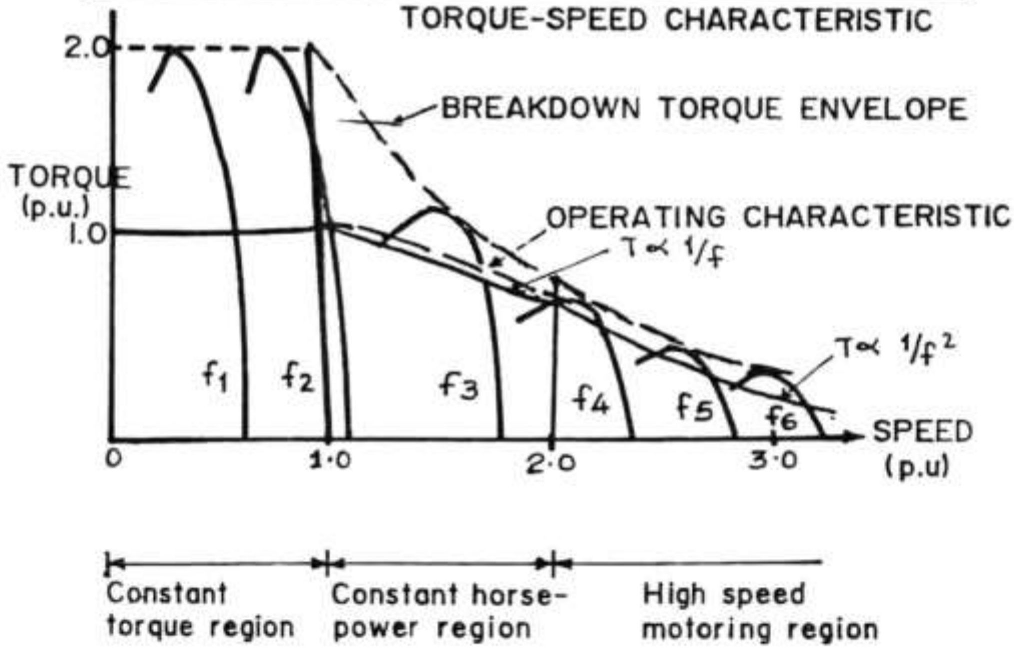


FIG. 1.4 T-S CURVE FOR A PRACTICAL TRACTION DRIVE

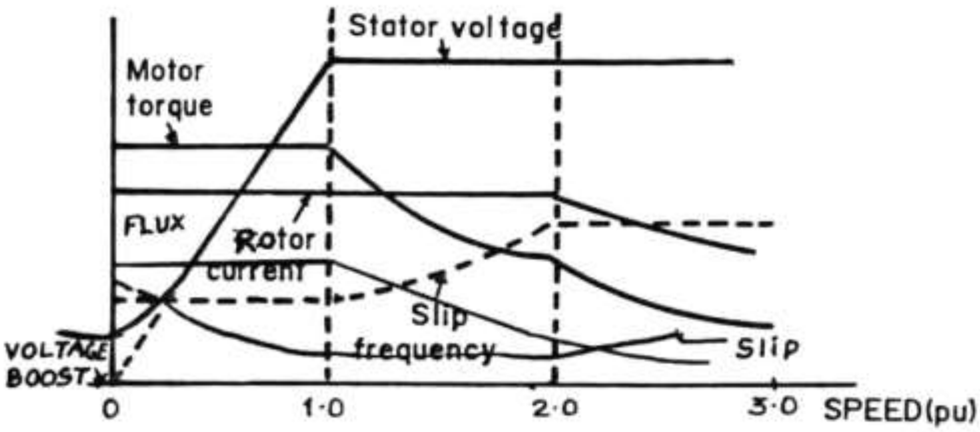


FIG. 1.5 INDUCTION MOTOR VOLTAGE, CURRENT, SLIP FREQUENCY AND TORQUE AS A FUNCTION OF SPEED FOR THE TORQUE SPEED OPERATING CHARACTERISTIC.

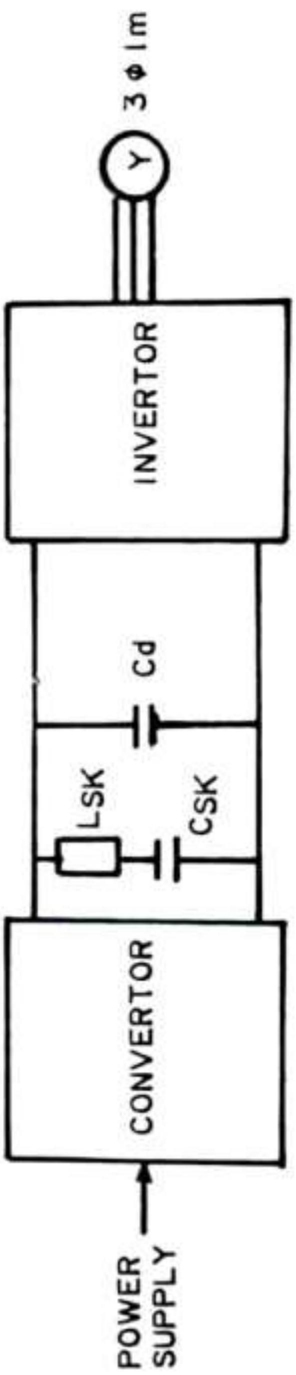


FIG. 2.1 BLOCK DIAGRAM OF 3 Φ DRIVE

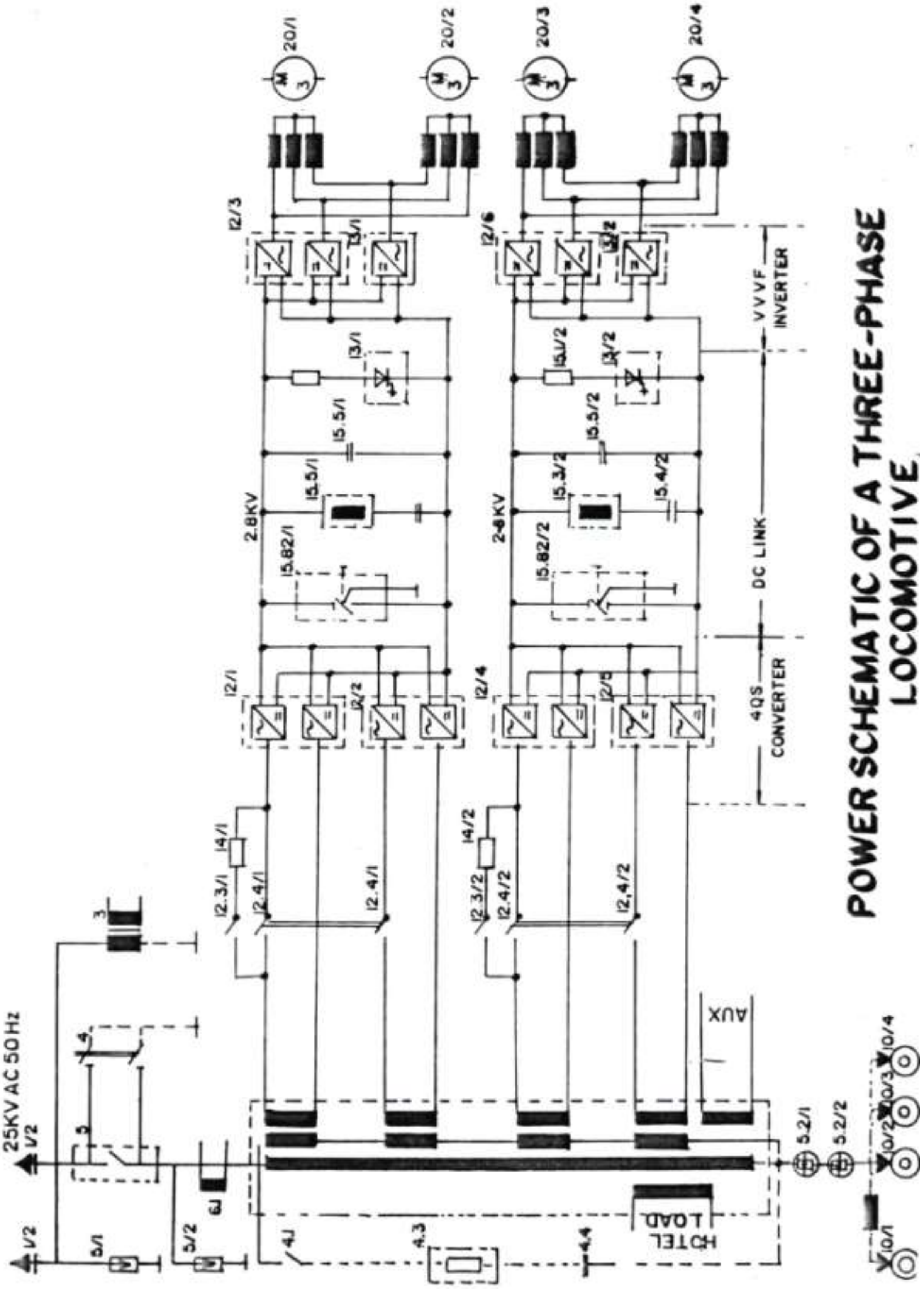

POWER SCHEMATIC OF A THREE-PHASE LOCOMOTIVE
25KV AC 50Hz
2.8KV
2-8KV
DC LINK
4QS CONVERTER
VVVF INVERTER
HOTEL LOAD
AUX

Fig. 2.2

5.02 Three phase induction motor drive

The block diagram for such an induction motor drive is shown in fig.2.1 Motor-end inverter can be a current source inverter or a voltage source inverter. In the past, when conventional thyristors were the only choice, designers opted for current source inverter. About 70% of all underground railways and light rail transport in the world today are partly or fully equipped with this technology.

The voltage source inverter, which required very complicated control electronics, when equipped with thyristors did not become a paying proposition until the development of GTOs and microprocessor based control techniques.

The circuitry of the input converter which provides a DC supply for the load side converter depends on the following:

1) Type of input power supply i.e. AC or DC.
2) Electricity utility's limits on reactive power harmonics.
3) Type of electric brakes; that's regenerative, rheostatic or both.

Fig.2.2 shows power schematic of ABB three phases AC locomotive.

The following stages are involved in power conversion.

- AC voltage is stepped down by main transformer.
- AC to DC conversion and boost up by 2.0 to 2.5-boost factor by means of front-end converter.
- Filter stage to reduce ripple in rectified DC.
- Link over voltage protection.

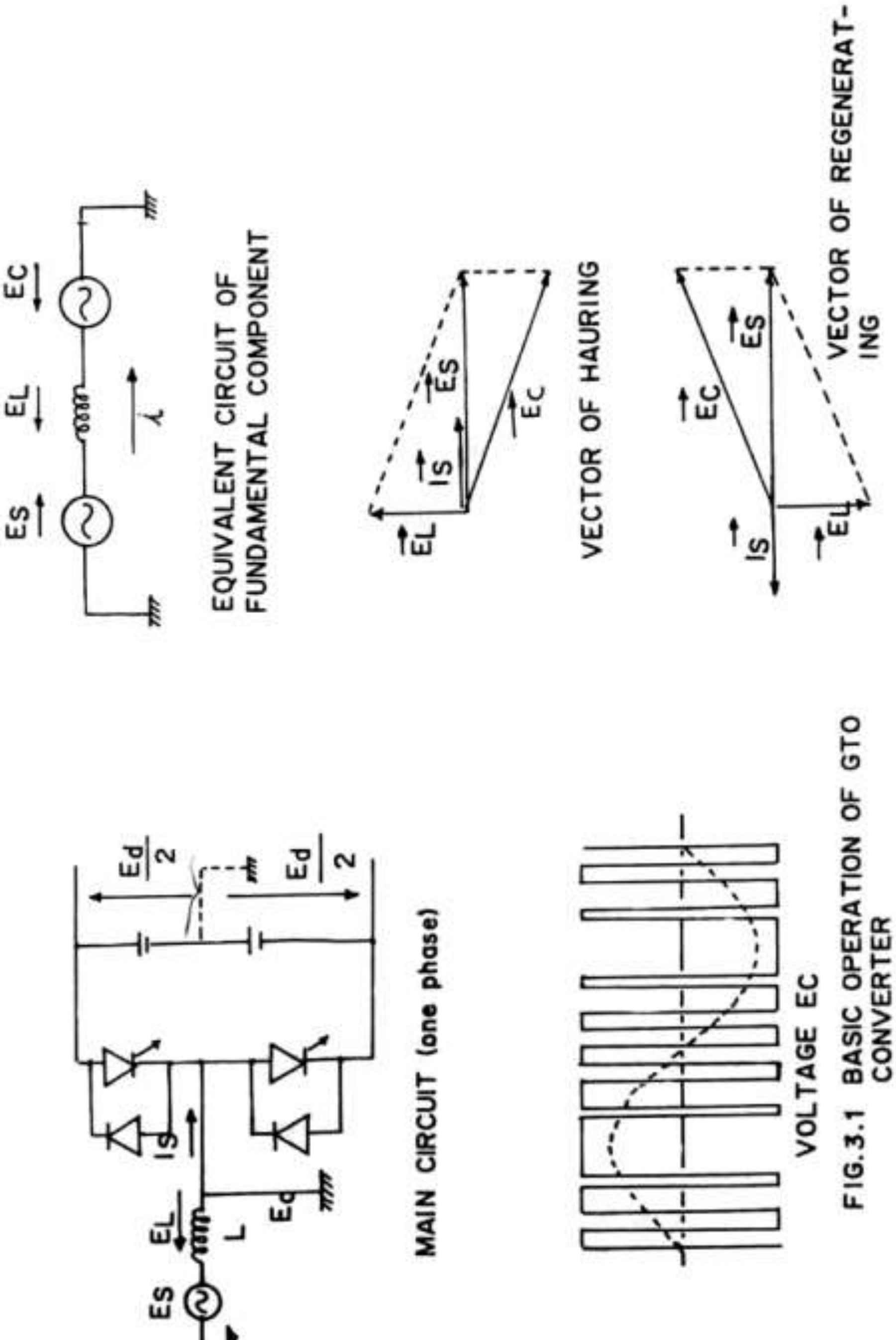


FIG.3.1 BASIC OPERATION OF GTO CONVERTER

5.03 Microprocessor control

VVVF inverter and four quadrant converter controls are quite complicated. Hardware for this control, if configured with convention equipment, will be complicated with large physical dimensions. Microprocessors are adopted as hardware optimization tool in order to make an improvement in this area. The principal features of the microprocessors control are as follows:

a) The space, weight and power consumption of the control unit can be reduced.

b) It is possible to execute high degree processing operations for control easily, accurately and at high speed, using software.

c) Failure occurring in the circuit, if any can be easily identified by self-diagnostic function.

Microprocessor technology is used for control of whole vehicle including

- Driving and braking control with automatic speed regulation.
- Supervision of all functions and for the operation of all major components of locomotive with automatic changeover or shutdown in the event of failure.
- Diagnostic system for all electrical and electronic devices on the vehicle.
- Inversion of DC to variable frequency AC by means of drive end inverter.

We shall now discuss briefly the modules used in 3 phase ABB locomotive.

a) Voltage source inverter.

A voltage source single pulse inverter is used for supplying variable voltage from 0 to 2180 V and variable frequency from 0 to 160 Hz.

b) DC link

DC link is made of the DC link capacitor, series tuned filter and over voltage protection circuit. DC link is reservoir of energy, which supplies periodic and non-periodic energy requirement of load and decouples it from supply source. The task of the DC link capacitor is to supply the reactive power needed by induction motor. The current supplied to DC link by 4-Q converter consist of second order harmonics, which is absorbed by series tuned filter.

c) Input side converter.

A 4-quadrant pulse width modulated converter is used for converting the AC to DC. It is capable of obtaining unity power on line current using proper control strategy and thereby eliminating the need for separate power factor correction equipment in the locomotive. Further more, the line current has insignificant harmonic content so that signaling and telecom circuits are disturbed.

The principle of working of the converter is explained in the diagram given in fig.3.1. The input voltage to the converter E_c is controlled by pulse width modulation of DC

link voltage E_d. The fundamental component of the modulated voltage E_c acts against source voltage E_s as shown in equivalent circuit of fundamental component. The converter input current I_s in quadrature with E_L i.e. voltage across reactor. Since E_s is equal to Vector
sum of E_L & E_C, it is possible to ensure that I_S is in phase with E_S by changing amplitude and phase of E_C through PWM and thus achieve unity PF. It could be seen that fundamental component of E_C is nothing but modulating wave itself. Thus by controlling the modulating wave, it is possible to achieve the unity pf.

5.04 Diagnostics.

The structure of the diagnostic system on these locomotives can be distinctly dived into three portions:

1) Hardware of the diagnostic system is based on 80186/16-bit microprocessor and is programmed similar to main processor. All data in main processor is also available to diagnostic Hardware for analysis.
2) Firmware is project-independent software. This takes care of special task to be performed by hardware. The firmware processes and stores the diagnostic messages. It can be viewed as the expert system for diagnostic computer.
3) The application software on the other hand is project dependent. It is written to take care of varying working conditions. It defines the rules for the expert system which evaluates and stores the diagnostic messages.

Diagnostic system processes the data available and classifies the diagnosis into three levels. These levels are programmed based on running experience of locomotives.

Level I: Audio visual indication and record only.

For faults in level-I category, the diagnostics will automatically take necessary corrective action to maintain normal locomotive operation. Wheel slip, oil temperature reaching maximum limit, DC link over voltage etc. fall under this category.

Level II: Audio – Visual indication and one bogie isolation.

This kind of action is taken when the fault is in major equipment of any one bogie. The faculty bogie is isolated and thereafter power to the locomotive is supplied by only one bogie. Examples are earth fault of DC link, opening of tuned filter, failure of traction motor, converter etc.

Level III: Audio visual indication and locomotive shut down.

This indicates eventual failure of equipment associated with both the bogies. Such faults are associated with malfunctioning of main circuit breaker, transformer, mechanical breakdown etc.

5.05 Instrumentation

A highly sophisticated data acquisition system using state of art instrumentation is used all over the locomotive.

5.06 Braking

Regenerative braking down to standstill is possible reducing the break shoe wear.

5.07 Pneumatic system

A new modular pneumatic panel supplied by Devis and Matcalfe & SAB-WABLO is used on these locomotives. Triplate structure of pneumatic panel has significantly improved reliability of pneumatic system. It uses brake electronics compatible with MICAS operating system.

5.08 Bogie and suspension system

Flexi float bogie with two stage suspension is used for track friendly design. Fully sprung traction motor in passenger locomotive with significantly reduce stress on track.

5.09 To Sum up….

The three-phase technology brings together state of art technologies in the area of devices, control, instrumentation and communication. It puts up great responsibility on all of us to equip ourselves to assimilate this technology, as it will soon pervade other areas like AC/DC traction, EMUs etc.

2. THREE PHASE ABB LOCOMOTIVE SYSTEM INFORMATION

EQUIPMENT LAYOUT

The locomotive is modular in construction. Locomotive assembly consists of five main parts (Ref. Fig 2.1): -

1. Roof
2. Driver's cab
3. Machine Room
4. Bogie
5. Frame

Layout of roof equipment

The equipments which are on the primary side of the transformer are mounted on the roof (Ref. Fig.2.2). These equipments are:-

1) Pantograph for current collection.
2) Internal air filter panel for oil cooling unit.
3) 25 KV Bushing.
4) Surge arrester.
5) Earthing switch.
6) Vacuum circuit breaker.
7) Primary voltage transformer.
8) Resistance box for harmonic filter.

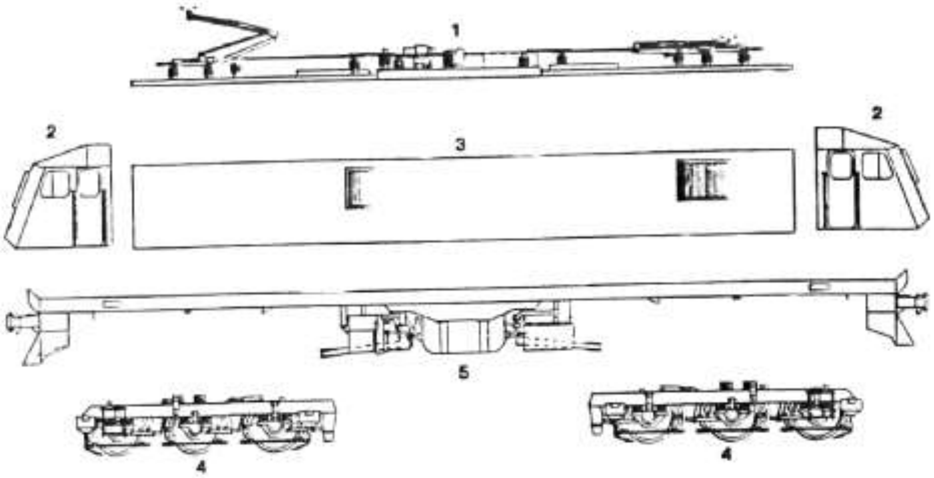


Fig. 2.1 Layout of the locomotive

1 Roof
2 Driver's cab
3 Machine room
4 Bogie
5 Frames

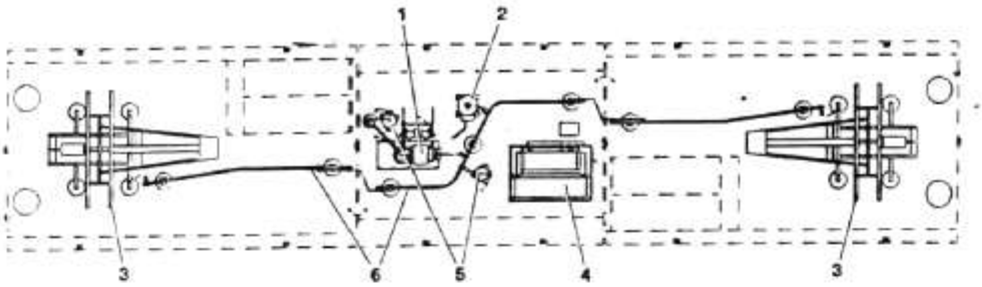


Fig. 2.2 Roof layout

1 Main circuit breaker
2 Transducers
3 Pantograph
4 Filter
5 Surge arrestor
6 Roof line

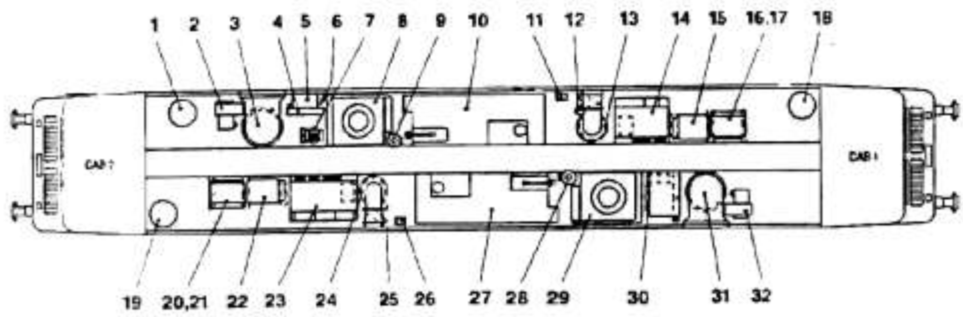
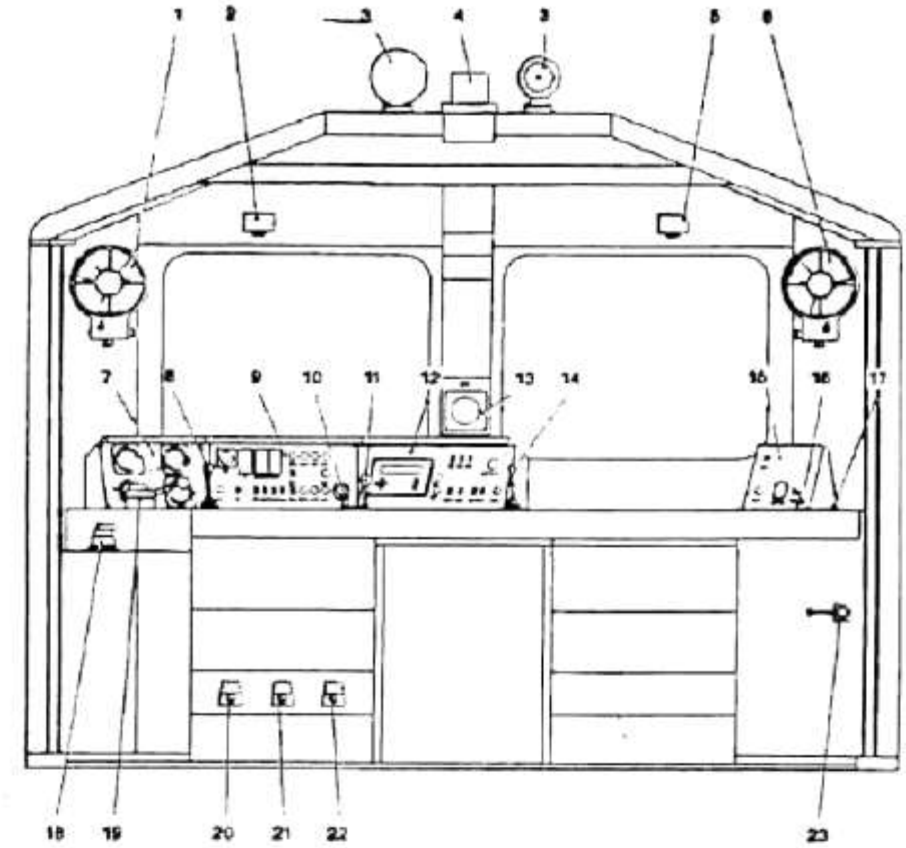


Fig. 2.3 Detailed layout of machine room

	1	Main reservoir
55/2	2	Scavenge blower to traction motor blower / oil cooling unit
53/2	3	Traction motor blower bogie 2
237	4	Vigilance control equipment
260	5	Control electronics pneumatic manifold
PT	6	Pneumatic panel
48	7	Auxiliary compressor
59/1	8	Oil cooling unit, transformer / converter 1
63/1	9	Oil pump converter 1
SR1	10	Traction converter 1
56.5/1	11	Scavenge blower capacitor to machine room blower 1
56/1	12	Scavenge blower to machine room blower 1
54/1	13	Machine room blower 1
1050.1	14	Auxiliary converter box 1
HB1	15	Cubicle auxiliary circuits 1
SB1	15	Cubicle control circuits 1
411	17	Central electronics 1 (CEL 1)
	18	Main reservoir
	19	Main reservoir
412	20	Central electronics 1 (CEL 2)
SB2	21	Cubicle control circuits 2
HB2	22	Cubicle auxiliary circuits 2
1050.2	23	Auxiliary converter box 2
54/2	24	Machine room blower 2
56/2	25	Scavenge blower to machine room blower 2
56.5/2	26	Scavenge blower capacitor to machine room blower 2
SR2	27	Traction converter 2
63/2	28	Oil pump converter 2
59/2	29	Oil cooling unit, transformer / converter 2
FB	30	Filter cubicle
53/1	31	Traction motor blower bogie 1
55/1	32	Scavenge blower to traction motor blower / oil cooling unit 1



69.7	1	Crew fan
325.21	2	Lamp driver's desk illumination
	3	Pneumatic horn
318.3	4	Emergency flash light
325.22	5	Lamp assistant driver's desk illumination
69.7	6	Crew fan
	7	Panel B
	8	Control lever for horn
	9	Panel A
140	10	Reverser
150	11	TE/BE Throttle
	12	Panel C
94.2	13	MEMOTEL (speedometer recorder and indicator
	14	Control lever for horn
	15	Panel D
	16	Operation of window wipers/washers
65.6	17	Rotary switch cab heater / fan device
293	18	Brake handle direct loco brake
	19	Brake handle automatic train brake
192.1	20	Foot switch "SANDING"
262	21	Foot switch "PVEF" for release of loco brake
235	22	Foot switch "VIGILANCE"
	23	Emergency brake cock

Fig. 2.4 Overview driver's cab

Layout of machine room equipment

Machine room, is between both the drivers cab with a central corridor. All the cooling blowers, main converters, auxiliary converters & control cubicles are fitted in the machine room. These equipments are fitted symmetrically on both sides of the central corridor. The detailed layout of the machine room equipment is given in fig. 2.3

Layout of cab-equipment

Overview of the driver's cab is shown in fig. 2.4

Layout of underframe equipment

Main traction transformer, compressors, air dryer, air reservoirs and batteries are mounted in underframe of the locomotive. Detailed layout of the underframe equipment is shown in fig. 2.5

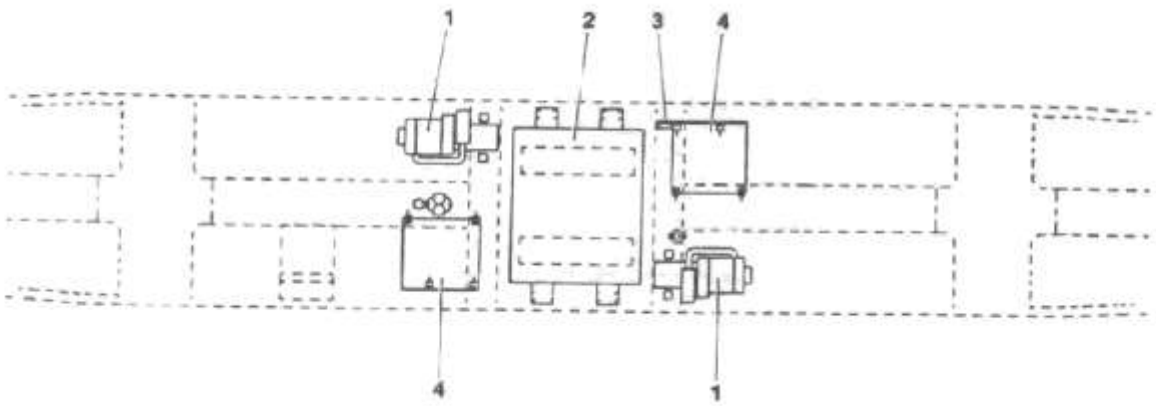


Fig. 2.5

Under frame layout

1. Main compressor
2. Transformer
3. Circuit breaker battery
4. Battery box

TECHNICAL PARTICULARS FOR WAP5 LOCOMOTIVE

1.1. Guaranteed performance at 22.5kV and half worn wheel:

(i)	Starting tractive effort	258 kN
(ii)	Continuous rated tractive effort in the speed range of 0-50 km/h	220 kN
(iii)	Continuous rated speed	50 km/h
(iv)	Continuous rated power at wheel rim in the speed range of 80-160 km/h	4000 kW
(v)	Maximum regenerative braking effort	160 kN (10-90 km/h)
(vi)	Maximum service speed	160 km/h

1.2 Arrangement:

(i)	Axle arrangement	Bo-Bo
(ii)	Traction motor mounting	Fully suspended on bogie frame
(iii)	Brake system	Air, regenerative and parking brake for loco
(iv)	Control circuit voltage	110 Vdc (nominal)

1.3 Important dimensions:

(i)	Total weight		78.0± 1% tones plus max .800 kg including harmonic filter and side buffers
(ii)	Axle load		19.5± 2% tones
(iii)	Unsprung mass per axle		Limited to 2.69 tonnes
(iv)	Wheel Dia.	- new	1092 mm
		-half worn	1054 mm
		-full worn	1016 mm
(v)	Gear ratio		3.941 (67:35:17)
(vi)	Length of loco over buffers		18162 mm
(vii)	Length of loco over headstock		16880 mm

(viii)	Bogie center distance	10200 mm
(ix)	Loco wheel base	13000 mm
(x)	Bogie wheel base	2800 mm
(xi)	Overall width of the body	3144 mm
(xii)	Length of cab	2434 mm
(xiii)	Panto locked down height	4255 mm
(xiv)	Height of C.G. from rail level	1393 mm

1.4 Other salient features:

- 3-phase drive with GTO thyristors and MICAS-S2 microprocessor based control system.
- The design provides for increasing the service speed potential to 200 km/h in future by changing the gear ratio.
- Hotel load winding on loco to feed coach converters.
- Provision for multiple unit operation of two locomotives.

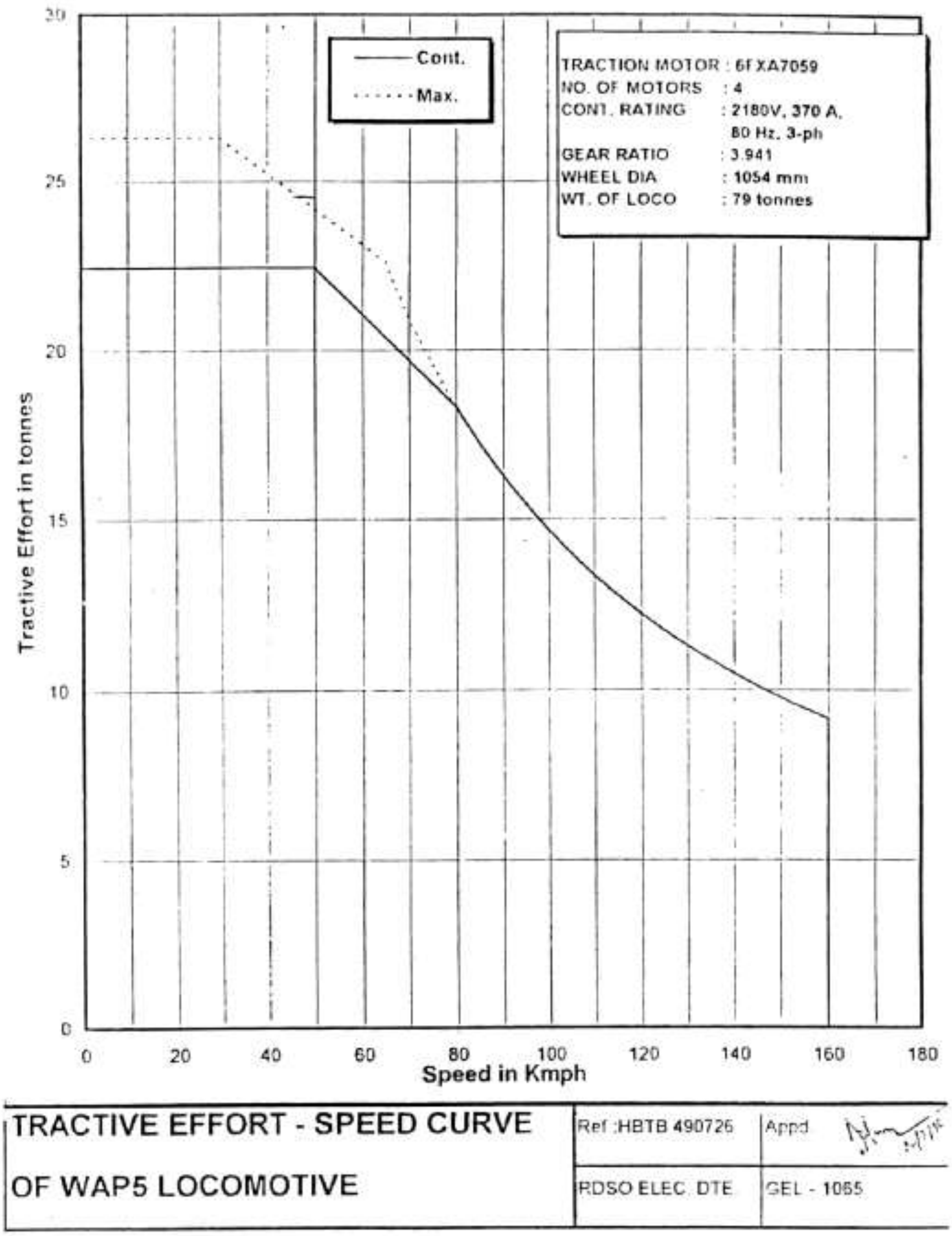
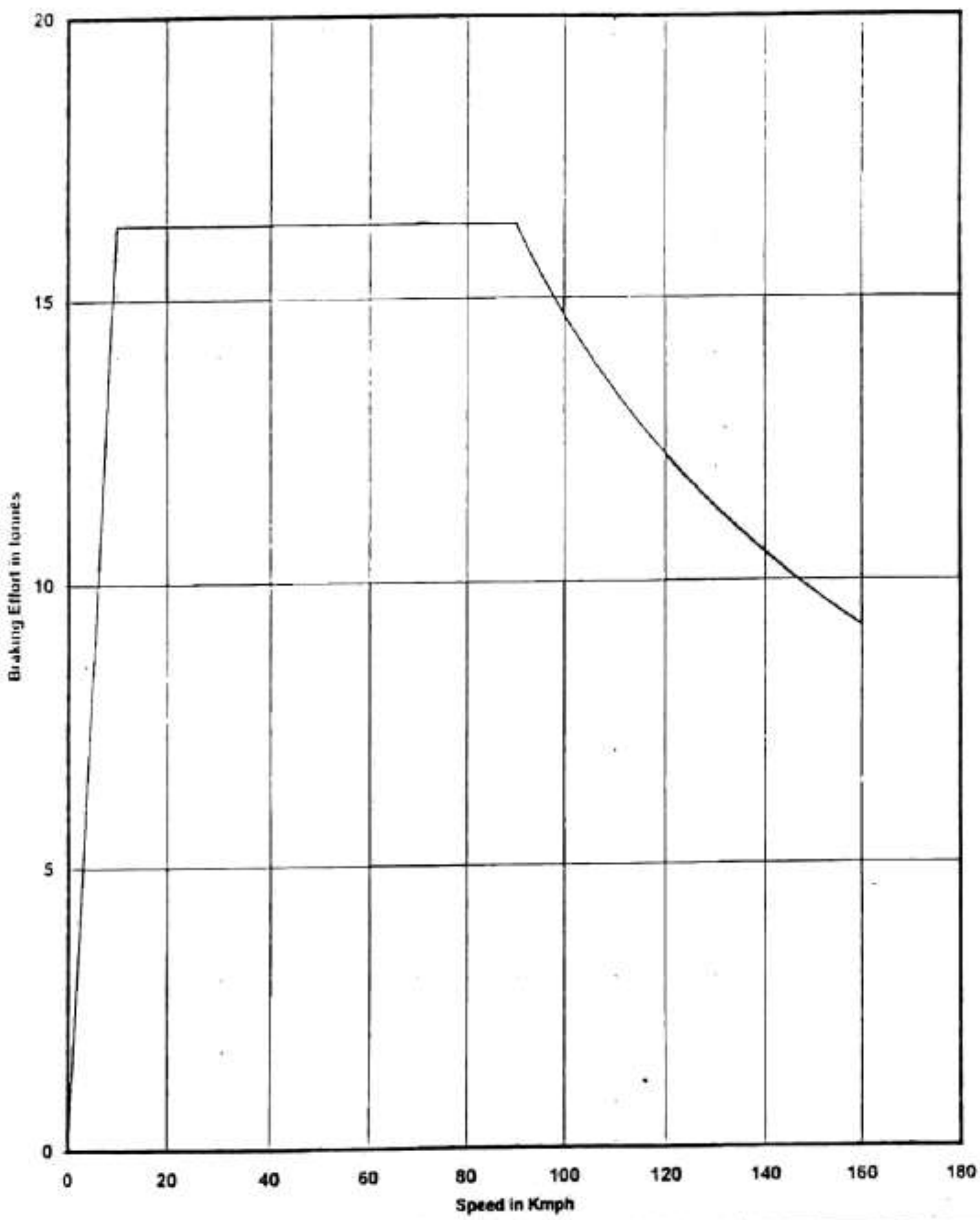

Cont.
Max.
TRACTION MOTOR : 6FXA7059
NO. OF MOTORS : 4
CONT. RATING : 2180V, 370 A, 80 Hz, 3-ph
GEAR RATIO : 3.941
WHEEL DIA : 1054 mm
WT. OF LOCO : 79 tonnes
Tractive Effort in tonnes
Speed in Kmph
TRACTIVE EFFORT - SPEED CURVE OF WAP5 LOCOMOTIVE
Ref :HBTB 490726
Appd
RDSO ELEC DTE
GEL - 1065

Fig. 2.6



BRAKING EFFORT - SPEED CURVE OF WAP5 LOCOMOTIVE	Ref :HBTB 490730	Appd:
	RDSO ELEC. DTE.	GEL - 1066

Fig. 2.7

HAULAGE CAPACITY OF 3 PHASE PASSENGER LOCOMOTIVE

(WITHOUT ACCELERATION RESERVE)

G.R 1:3.92   T.M. 6FXO 7059

SERVICE		GRADE	TONNES AT KMPH (TANGENT TRACK) 20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	START
GOODS SERVICE	4 WHEELER WAGONS	LEVEL																
		1/500																
		1/200																
		1/150																
		1/100																
		1/50																
	BOGIC WAGONS (BOX)	LEVEL																
		1/500																
		1/200																
		1/150																
		1/100																
		1/50																
PASSENGER SERVICE	ICF COACH	LEVEL	← ABOVE 1500 →													1470	1230	ABOVE 1500
		1/500	← ABOVE 1500 →											1470	1250	1065	910	ABOVE 1500
		1/200	← ABOVE 1500 →									1350	1160	995	860	745	645	ABOVE 1500
		1/150	← ABOVE 1500 →								1310	1125	970	840	730	635	550	ABOVE 1500
		1/100	← ABOVE 1500 →					1460	1325	1125	970	840	730	635	555	480	420	ABOVE 1500
		1/50	980	965	955	940	865	780	710	610	525	455	400	345	305	265	230	1010

Fig. 2.8

TECHNICAL PARTICULARS FOR WAG9 LOCOMOTIVE

1.1 Guaranteed performance at 22.5 kV and half worn wheel:

(i)	Starting tractive effort	460kN
(ii)	Continuous rated tractive effort in the speed range of 0-50 km/h	325 kN
(iii)	Continuous rated speed	50 km/h
(iv)	Continuous rated power at wheel rim in the speed range of 80-160 km/h	4500 kW
(v)	Maximum regenerative breaking effort	260 kN (10-62 km/h)
(vi)	Maximum service speed	100 km/h

1.2 Arrangement:

(i)	Axle arrangement	Co-Co
(ii)	Traction motor mounting	Axle hung, nose suspended
(iii)	Brake system	Air, regenerative and parking brake for loco Air brake for train.
(iv)	Control circuit Voltage	110 Vdc (nominal)

1.3 Important dimensions:

(i)	Total weight		123.0 ± 1% tonnes
(ii)	Axle load		20.5 ± 2% tones
(iii)	Unsprung mass per axle		3.99 tonnes
(iv)	Wheel Dia.	- new	1092 mm
		- half worn	1054 mm
		- full worn	1016 mm
(v)	Gear ratio		5.133 (77:15)
(vi)	Length of loco over buffers	20562 mm	
(vii)	Length of loco over head stock	19280 mm	
(viii)	Bogie center distance	12000 mm	
(ix)	Loco wheel base	15700 mm	

(x)	Bogie wheel base	1850 + 1850 mm
(xi)	Overall width	3152 mm
(xii)	Length of cab	2434 mm
(xiii)	Panto locked down height	4255 mm
(xiv)	Height of C.G. from rail level	1349 mm

1.4 Other salient features:

- 3-phase drive with GTO thyristors and MICAS – S2 microprocessor based control system.
- Provision for multiple unit operation of two locomotives.
- Provision for ballasting to increase the loco weight to 135 tones in future.
- The design permits interfacing and provision of "inching control" in future.

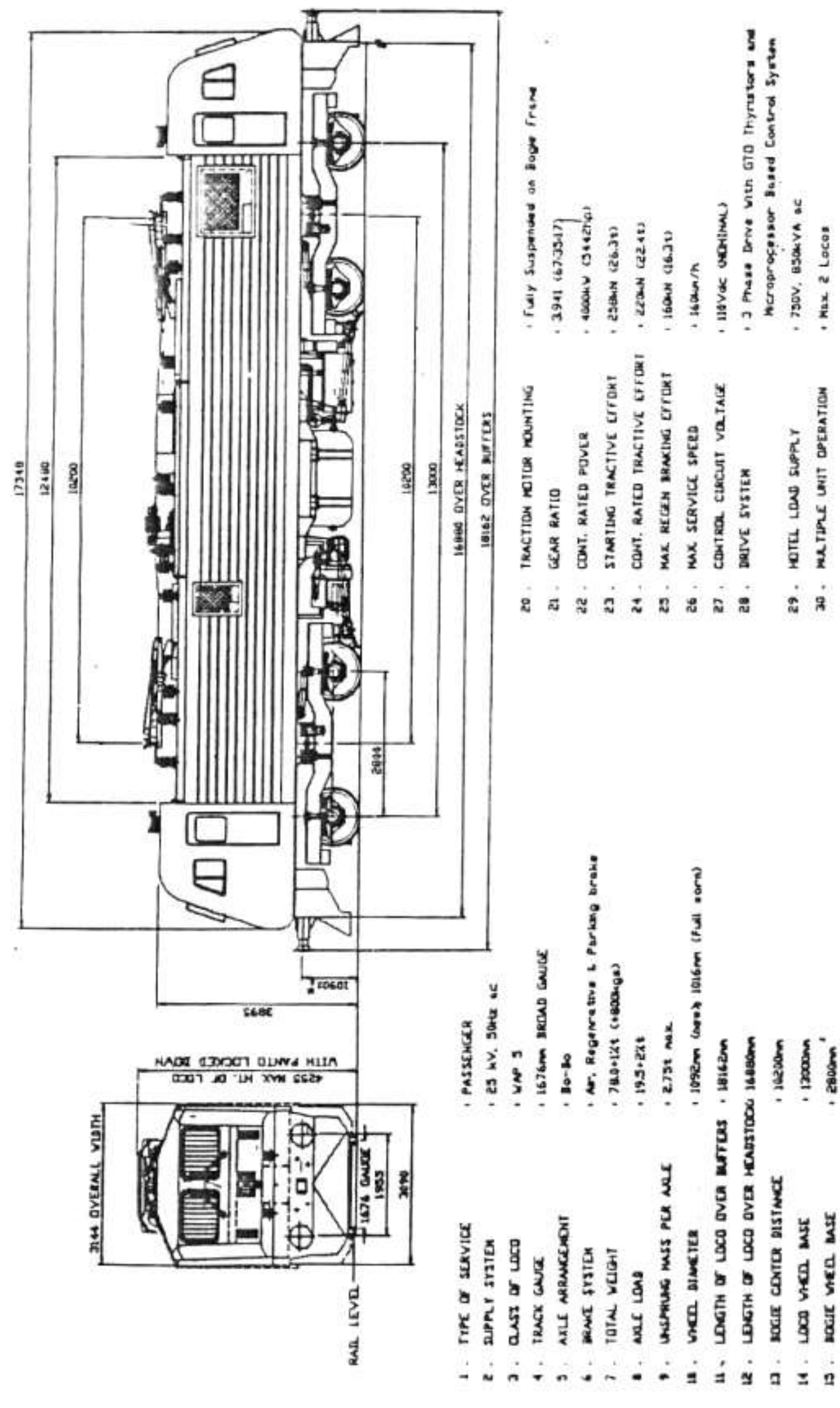
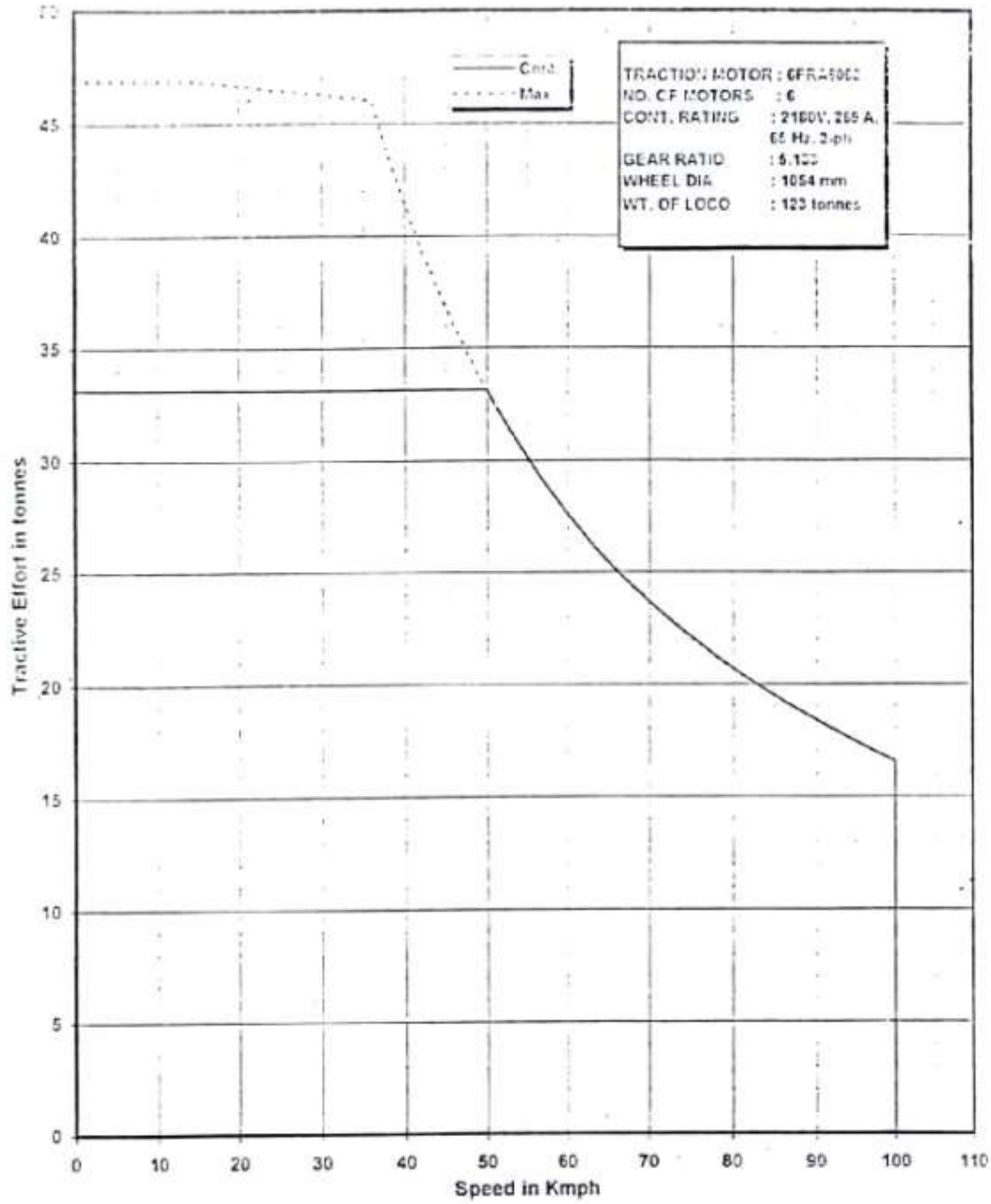

17340
12480
10200
3144 OVERALL WIDTH
4253 MAX. HT. OF LOCO WITH PANTO LOCKED DOWN
3895
1090
RAIL LEVEL
1676 GAUGE
1953
3090
2804
10200
13000
16880 OVER HEADSTOCK
18162 OVER BUFFERS
1. TYPE OF SERVICE : PASSENGER
2. SUPPLY SYSTEM : 25 kV, 50Hz ac
3. CLASS OF LOCO : WAP 5
4. TRACK GAUGE : 1676mm BROAD GAUGE
5. AXLE ARRANGEMENT : Bo-Bo
6. BRAKE SYSTEM : Air, Regenerative & Parking brake
7. TOTAL WEIGHT : 78.0+1t (+800kgs)
8. AXLE LOAD : 19.5+2t
9. UNSPRUNG MASS PER AXLE : 2.75t max.
10. WHEEL DIAMETER : 1092mm (new) 1016mm (Full worn)
11. LENGTH OF LOCO OVER BUFFERS : 18162mm
12. LENGTH OF LOCO OVER HEADSTOCK 16880mm
13. BOGIE CENTER DISTANCE : 10200mm
14. LOCO WHEEL BASE : 13000mm
15. BOGIE WHEEL BASE : 2800mm
16. OVERALL WIDTH OF BODY : 3166mm
17. LENGTH OF CAB : 2434mm
18. PANTO LOCKED DOWN HEIGHT : 4255mm
19. TRACTION MOTOR TYPE : 6FXA 7059
20. TRACTION MOTOR MOUNTING : Fully Suspended on Bogie Frame
21. GEAR RATIO : 3.941 (67:3517)
22. CONT. RATED POWER : 4000kW (5442hp)
23. STARTING TRACTIVE EFFORT : 258kN (26.3t)
24. CONT. RATED TRACTIVE EFFORT : 220kN (22.4t)
25. MAX. REGEN BRAKING EFFORT : 160kN (16.3t)
26. MAX. SERVICE SPEED : 160km/h
27. CONTROL CIRCUIT VOLTAGE : 110Vdc (NOMINAL)
28. DRIVE SYSTEM : 3 Phase Drive With GTO Thyristors and Microprocessor Based Control System
29. HOTEL LOAD SUPPLY : 750V, 850kVA ac
30. MULTIPLE UNIT OPERATION : Max. 2 Locos

Fig. 2.9



TRACTIVE EFFORT - SPEED CURVE	Ref :HBTB 493727	Appd:
OF WAG9 LOCOMOTIVE	RDSO ELEC. DTE	GEL - 1057

Fig. 2.10

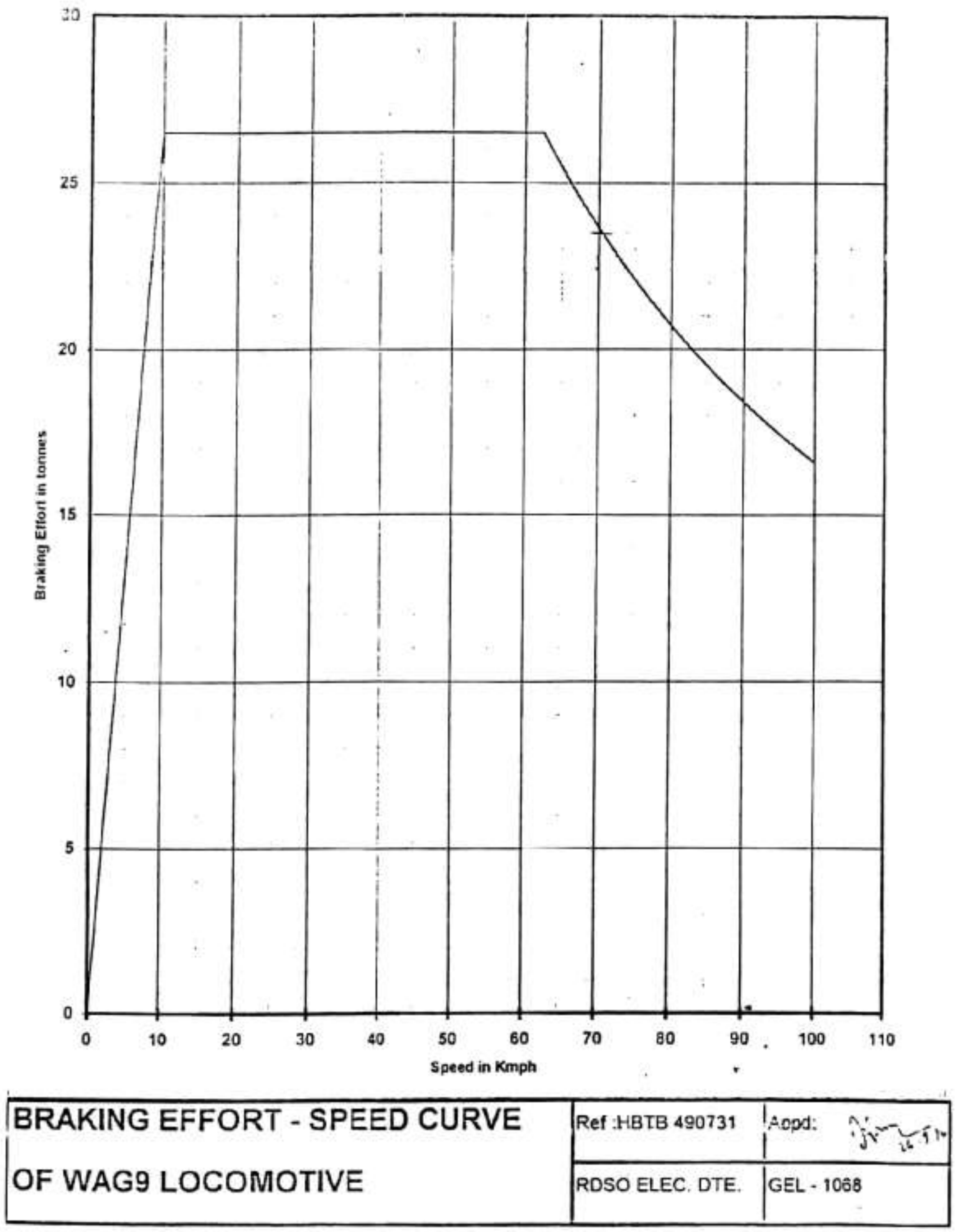

Braking Effort in tonnes
Speed in Kmph
BRAKING EFFORT - SPEED CURVE
OF WAG9 LOCOMOTIVE
Ref :HBTB 490731
Appd:
RDSO ELEC. DTE.
GEL - 1068

Fig. 2.11

HAULAGE CAPACITY OF 3 PHASE FREIGHT LOCOMOTIVE

(WITHOUT ACCELERATION RESERVE)

G.R. 1:5.1   T.M. GFRA-6068

SERVICE		GRADE	TONNES AT KMPH (TANGENT TRACK) 20	30	40	50	60	70	80	90	100	110	120	START
GOODS SERVICE	4 WHEELER WAGONS	LEVEL												
		1/500												
		1/200												
		1/150												
		1/100												
		1/50												
	BOGIE WAGONS (BOXN)	LEVEL	ABOVE 6000											ABOVE 6000
		1/500	ABOVE 6000						4985	4150	3500			ABOVE 6000
		1/200	5060	5060	5060	5060	4045	3325	2780	2365	2040			5060
		1/150	4250	4165	4080	3985	3200	2640	2220	1895	1640			4250
		1/100	2910	2870	2825	2775	2240	1855	1565	1345	1165			3205
		1/50	1455	1445	1435	1420	1140	945	795	680	590			1820
PASSENGER SERVICE	ICF COACH	LEVEL												
		1/500												
		1/200												
		1/150												
		1/100												
		1/50												

Fig. 2.12

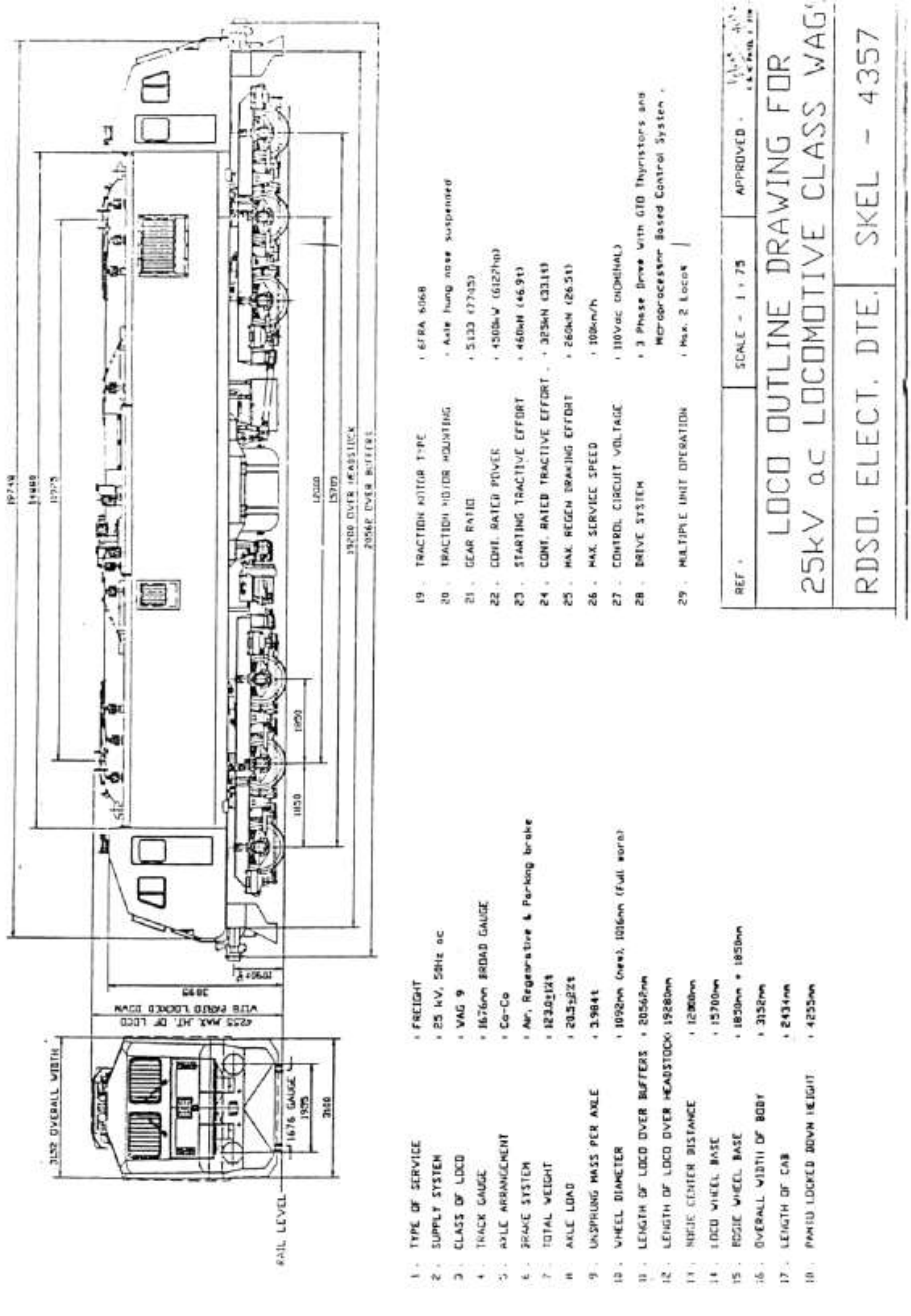

3152 OVERALL WIDTH
RAIL LEVEL
1676 GAUGE
4255 MAX. HT. OF LOCO WITH PANTO LOCKED DOWN
19748
13000
19280 OVER HEADSTOCK
20562 OVER BUFFERS
1830
1850
1. TYPE OF SERVICE : FREIGHT
2. SUPPLY SYSTEM : 25 kV, 50Hz ac
3. CLASS OF LOCO : WAG 9
4. TRACK GAUGE : 1676mm BROAD GAUGE
5. AXLE ARRANGEMENT : Co-Co
6. BRAKE SYSTEM : Air, Regenerative & Parking brake
7. TOTAL WEIGHT : 123.0±1%t
8. AXLE LOAD : 20.5±2%t
9. UNSPRUNG MASS PER AXLE : 3.984t
10. WHEEL DIAMETER : 1092mm (new), 1016mm (Full worn)
11. LENGTH OF LOCO OVER BUFFERS : 20562mm
12. LENGTH OF LOCO OVER HEADSTOCK : 19280mm
13. BOGIE CENTER DISTANCE : 12900mm
14. LOCO WHEEL BASE : 15700mm
15. BOGIE WHEEL BASE : 1830mm + 1850mm
16. OVERALL WIDTH OF BODY : 3152mm
17. LENGTH OF CAB : 2434mm
18. PANTO LOCKED DOWN HEIGHT : 4255mm
19. TRACTION MOTOR TYPE : 6FRA 6068
20. TRACTION MOTOR MOUNTING : Axle hung nose suspended
21. GEAR RATIO : 5.133 (77/15)
22. CONT. RATED POWER : 4500kW (6122hp)
23. STARTING TRACTIVE EFFORT : 460kN (46.9t)
24. CONT. RATED TRACTIVE EFFORT : 325kN (33.1t)
25. MAX. REGEN BRAKING EFFORT : 260kN (26.5t)
26. MAX. SERVICE SPEED : 100km/h
27. CONTROL CIRCUIT VOLTAGE : 110Vdc (NOMINAL)
28. DRIVE SYSTEM : 3 Phase Drive with GTO Thyristors and Microprocessor Based Control System.
29. MULTIPLE UNIT OPERATION : Max. 2 Locos
REF.
SCALE - 1 : 75
APPROVED
LOCO OUTLINE DRAWING FOR
25kV ac LOCOMOTIVE CLASS WAG
RDSO. ELECT. DTE.
SKEL - 4357

Fig. 2.13

3. POWER CIRCUIT DESCRIPTION

(Refer Fig. 3.1 & Fig. 3.2)

The locomotives WAP5 and WAG9 are having 3-phase drive with GTO thyristors and microprocessor based control system. The primary winding of the main transformer is fed from the OHE (25 kV, single phase ac, 50 Hz) through the pantograph (1) and the vacuum circuit breaker (5). Two surge arrestors (9/1 & 9/2) are provided on the roof – one at the pantograph end and the other after the VCB. A primary voltage transformer (6.1) is provided at the primary side of the main transformer (7) to monitor the overhead catenary voltage. Signal from this primary voltage transformer is continuously monitored by the control electronics. In addition to serving other control functions, this signal is used by the control electronics to protect the equipment on the locomotive by tripping off the VCB in case of catenary voltage going out of limits.

The main transformer is a specially built high impedance transformer as compared to those used in conventional locomotives. In addition to the primary winding, there are four traction windings and one auxiliary winding. A harmonic filter winding is also provided which has a filter connected across it to reduce the harmonics. In case of WAP5 loco, one hotel load winding is additionally provided.

Each group of two traction windings feed two 4-quadrant line converters (12/1 & 12/2) connected in parallel. The line converters feed an intermediate circuit (known as DC link) consisting of a series resonant circuit (15.3, 15.4) and DC link capacitors (15.5), which supply power to the drive converter (12/3 + 13/1). The drive converter feeds two traction motors of a bogie in case of WAP5 and three traction motors of a bogie in case of WAG9. The traction motors are instantaneously discharged through the MUB resistor. Firing of the GTOs is controlled by the control electronics.
During regenerative braking, the traction motors are made to act as induction generators by controlling the output frequency to obtain a negative slip value. In the line converter, the resultant 3-phase electrical energy is converted into single-phase energy through the DC link and is fed back to the catenary via the main transformer. The fundamental reactive power flow can be adapted to the line voltage conditions independent of the active power flow, thanks to the 4-quadrant pulse controlled converter. Thus the converter also serves to stabilize the line voltage.

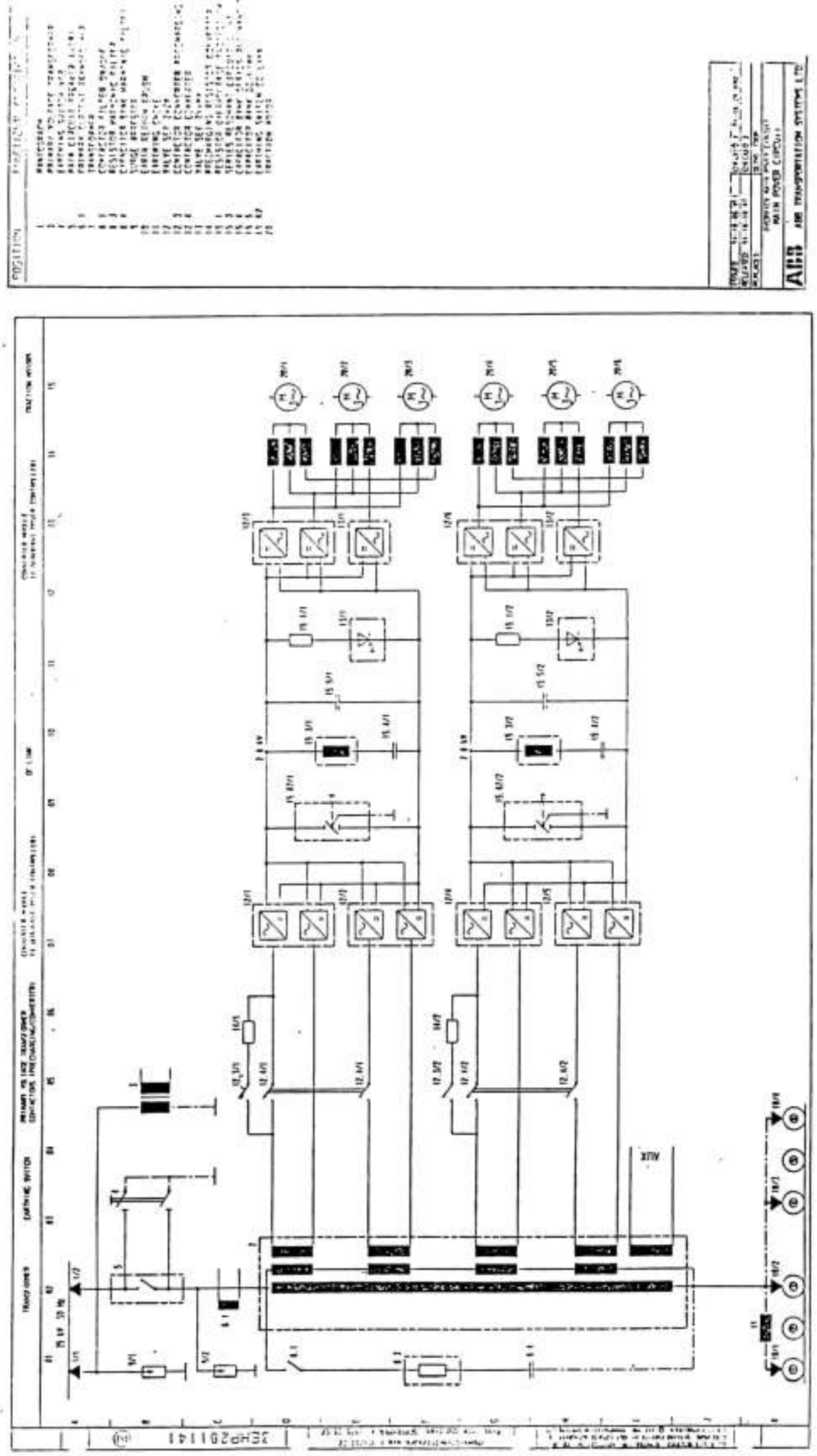


Fig. 3.2 Overview of Power Circiut WAG9

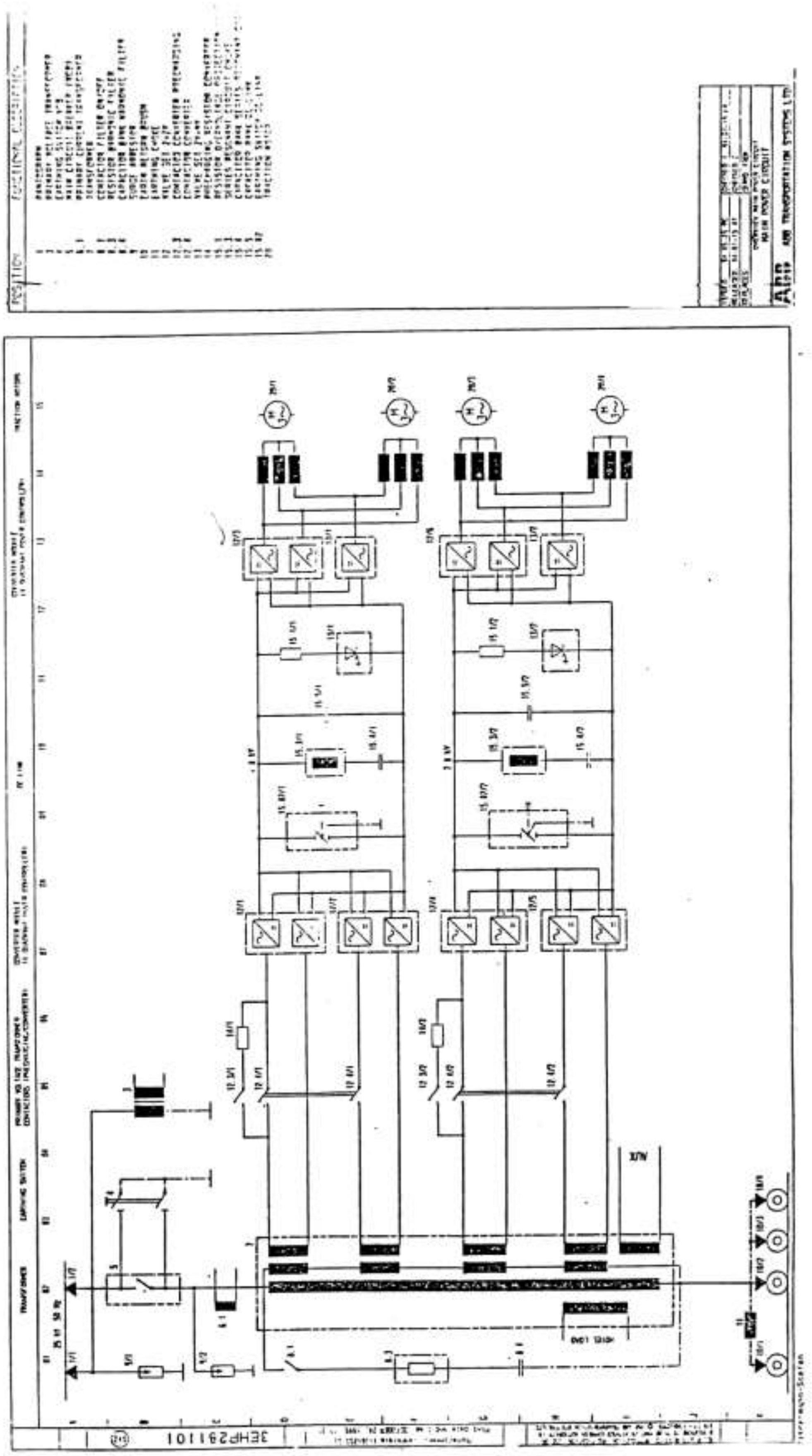


Fig. 3.1 Overview of Power Circuit WAP5

SALIENT DATA OF MAJOR SUBSYSTEMS OF WAP 5 LOCOMOTIVE

EQUIPMENT, TYPE, MAKE AND MAIN RATING / DATA

1.1 Traction motor :

Make : ABB Switzerland — 4 Nos/loco
Type : 6 FXA 7059

	Cont.	Max.	
Voltage phase to phase	2180	2180	V
Current per phase	370	593	A
Frequency	80	160.3	Hz
Output at shaft	1150	1150	Kw
Torque at shaft	6930	9920	Nm.
Speed	1585	3174	rpm.
Cos phi	0.86		

All the above values are given for half worn wheels

Design Speed	3571 rpm
Over speed test speed	3571 rpm
Stator winding Insulation system	Class 200, Veridur (R) system

1.2 Transformer:

Make : ABB, Switzerland — 1 no / loco
Type : LOT 7500
Rating : at 25 kV line voltage

Primary winding	25 kV, 7475 kVA, 299 A	
Traction winding	4x1269V, 4x1449 kVA, 4x1142 A	
Aux. Converter winding	1000V, 334 kVA, 334 A	
Hotel load winding	750 V, 945 kVA, 1260 A	
Filter winding	1154 V, 400 kVA, 347 A	
No load current	0.5A at 22.5 kV	
Series resonant circuit reactor	2x984 A_{rms},2x0.551 mH, linear upto 2x1391A peak	Assembled in transformer
Cooling system	Forced oil cooling using standard mineral oil	Oil type shell Diala DX

Impedances — Traction winding

(Guaranteed value for traction winding inductivity only, others for information purpose)

ex = 59.4%
er = 3.08 %
L = 2.1 mH $\pm$ 15%
R = 34 mΩ

<u>Aux. Converter winding</u>

	ex = 6.68 % er = 1.01% L = 0.5 mH R = 23.7 mΩ	
	Hotel load winding ex = 19.52 % er = 1.85 % L = 0.37 mΩ R = 11 mΩ	
Temp. Rises	Primary	11 K
	Traction	17 K
	Aux. Converter	12 K
	Hotel load	13 K
	Filter	3 K
Temperature	Cu. max.	100° C
	Oil max.	84° C
	Oil mean	82° C

1.3 Power converter:

Make : ABB, Switzerland 2 Nos./ loco
Type : UW 2423 – 2810

(i) 4 Quadrant power converter

Suitable for		
Transformer secondary voltage	2 x 1269 V at 25 kV line voltage	
Frequency	50 Hz $\pm$ 3%	
DC link voltage	2800 V nominal	
Cooling system	Forced oil cooling using standard mineral oil.	Oil type shell Diala DX

(With 8 GTO Thyristors 4.5 kV / 3kA, Toshiba Type SG 3000 GXH 24 or equivalent type and gate units and 8 power Diode type D921S45T Eupec Make or equivalent)

(ii) <u>Motor Inverter</u>

Suitable for		
Motor voltage (phase to phase)	2180 V	
Motor frequency	0…160.3 Hz	
DC link voltage	2800 V (nominal)	
Cooling system	Forced oil cooling mineral oil.	Oil type shell Diala D

(With 6 GTO Thyristors 4.5 kV / 3kA, Toshiba Type SG 3000GXH24 or equivalent type and gate units and 6 Power Diode Type D921S45T Eupec Make or equivalent)

(iii) DC Link Capacitor

Make	:	Condis
Type	:	CDM15230A0815
Rating	:	Capacity : 815 µF
	:	Voltage :2940 Vnom
Bank Capacity	:	11.41 mF

(iv) Instant Voltage Limitation

Make	:	Microelettrica Scientifica, Italy
Type	:	MUB
Voltage	:	2800 V
Current	:	500 A
Containing	-	GTO thyristor and gate units
	-	power diode
	-	power resistor (Microelecttrica)

(With 1 GTO Thyristors 4.5 kV / 3kA, Toshiba Type SG 3000 GXH 24 or equivalent type and gate units and power Diode type D921S45T Eupec Make or equivalent)

(v) Series Resonant Circuit Capacitor

Make	:	ERO
Type	:	ERO – GFP 3.8
Rating	:	560 µF, 2940 V
Bank Capacity	:	4.6 mF (The bank has 8 nos of these capacitors and one adjustable capacitor unit consists of 3 capacitors (280 µF+140µF+140 µF)

SALIENT DATA OF MAJOR SUBSYSTEMS OF WAG9 LOCOMOTIVE

EQUIPMENT, TYPE, MAKE AND MAIN RATING / DATA

1.1 Traction motor :

Make : ABB Switzerland 6 Nos/loco
Type : 6 FRA 6068

3-phase Induction Motor Axle hung nose suspended type

	Cont.	**Max.**	
Voltage phase to phase	2180	2180	V
Current per phase	270	393	A
Frequency	65	132	Hz
Output at shaft	850	850	Kw
Torque at shaft	6330	9200	Nm.
Speed	1283	2584	rpm.
Cos phi	0.88		

All the above values are given for half worn wheels

Design Speed	2842 rpm
Over speed test speed for 2 minutes	3250 rpm
Stator winding Insulation system	Class 200, Veridur (R) system

1.2 Transformer:

Make : ABB, Switzerland 1 no / loco
Type : LOT 6500
Rating : at 25 kV line voltage

Primary winding	25 kV, 6531 kVA, 261.25 A	
Traction winding	4x1269V, 4x1449 kVA, 4x1142 A	
Aux. Converter winding	1000V, 334 kVA, 334 A	
Filter winding	1154 V, 400 kVA, 347 A	
No load current	0.5A at 22.5 kV	
Series resonant circuit reactor	2x984 A_{rms}, 2x0.551 mH, linear upto 2x1391A peak	Assembled in transformer
Cooling system	Forced oil cooling using standard mineral oil	Oil type shell Diala DX
Impedances (Guaranteed value for traction winding inductivity only, others for information purpose.)	Traction winding ex = 59.4% er = 3.08 % L = 2.1 mH $\pm$ 15% R = 34 mΩ	

	Aux. Converter winding ex = 6.68 % er = 1.01% L = 0.5 mH R = 23.7 mΩ	
Temp. Rises	Primary	11 K
	Traction	17 K
	Aux. Converter	12 K
	Hotel load	13 K
	Filter	3 K
Temperature	Cu. max.	100°C
	Oil max.	84°C
	Oil mean	82°C

1.3 Power converter:

(Similar to WAP5 locomotive)

4. POWER CONVERTER

INTRODUCTION

The three phase voltage required for operating the traction motors is generated on the vehicle by means of two traction converters connected between the vehicle's main transformer (single phase) and the traction motors.

To control the tractive or braking effort, and hence the speed of the vehicle, both the frequency and the amplitude of the three-phase converter output voltage are continuously changed according to the demands from the driver's cab. This allows continuous adjustment of the driving or braking torque of the traction motors, which means that the driving speed changes smoothly.

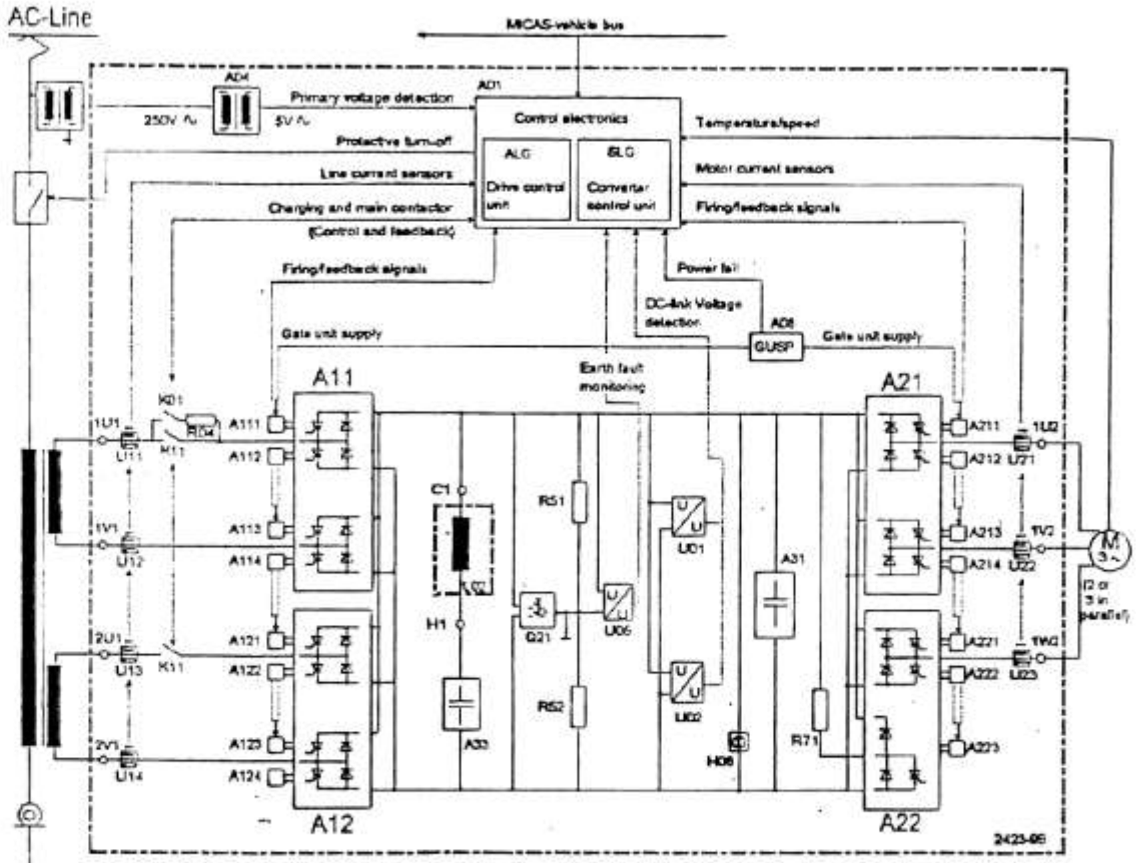
When braking electrically the traction motors act as generators. In the converter the resulting three-phase electrical energy is converted into single-phase energy, which is fed back into the line (regenerative brake).

OVERVIEW: STRUCTURE AND COMPONENTS OF THE CONVERTER.

(See Fig.4.1)

Line converter

A11, A12…………… Oil – cooled value sets with 2 pairs of arms each, 2xZV24(12)
A111 – A114
A121 – A124………. Gate Units (Forced air – cooling) (227)
K01…………………Charging contactor (12.3)
K11…………………Converter contactor (12.4)
R04…………………Charging resistor (14)
U11-U14……………Current transducers (18.2)



Line converter

Intermediate DC-link

Motor converter MUB-arm

Fig. 4.1

DC –Link

A31…………DC – link capacitor bank (15.5)
A33…………Series resonant circuit capacitor bank (part of the converter block) (15.4)
H08…………Voltage indicator (15.7)
L02…………Series resonant choke (15.3) (outside of the converter block)
Q21…………Earthing switch (15.82)
R51, R52…….Earthing resistors (90.61/90.62)
R71…………Over voltage limitation resistor (15.1)
U01, U02……Voltage transducers (measurement of DC-link voltage) (15.6)
U05…………Earth fault monitoring voltage transducer (89.4)

Motor Converter

A21…………Oil-cooled valve set with 2 pairs of arms ZV24(12)
A22…………Oil-cooled valve set with 1 arm ZV24 for the motor converter and 1 arm MU23 for the MUB (13)
A211- A214
A21-A222……Gate units for the motor converter (228)
A223…………Gate units for the MUB-arm (229)
U21-U23……..Current transducers (18.5)

Additional converter apparatus

A01………..Converter bus station with converter control unit, SLG and drive control unit, ALG (415)
A04………..Primary voltage transformer module (224)
A08………..Gate unit power supply GUSP (219)

ABBREVIATIONS

The abbreviations used in these operating instructions are explained below:

ALG	: Drive control unit
ASR	: Motor converter
BUR	: Auxiliary converter
FLG	: Vehicle control unit
GU	: Gate unit
GUSET	: Gate unit transmitter / receiver test unit
GUSP	: Gate unit power supply
MUB	: Over voltage protection circuitry
NSR	: Line converter
SLG	: Converter control unit
SR	: Converter
Ud	: DC-link voltage
VS	: Valve set

ZK : DC-link
ZP : Pair of arms

MAIN CONSTITUENT PARTS AND THEIR FUNCTIONS

(See main circuit diagram Fig.4.1)

The traction converter is largely a modular construction and consists of the following main functional groups:

- Line converter
- DC – Link
- Over voltage limitation circuitry
- Motor converter

Line converter (NSR)

(A11, A12, A111-A124)

(See main circuit diagram Fig.4.1)

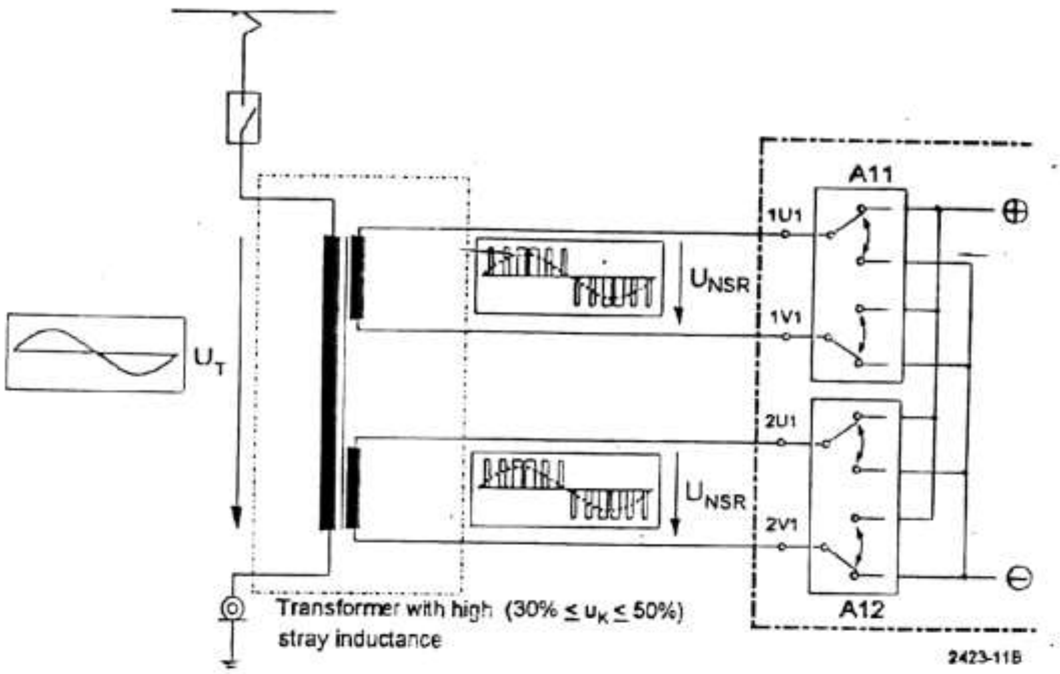
Circuit & Function

The line converter consists of two pulse – controlled single – phase full bridge circuits (A11, A12) which are connected to a transformer secondary winding (terminals 1U1, 1V1 resp. 2U1, 2V1).

The line converter is a self-commutating 4-quadrant converter. The AC terminals of the two bridge circuits (A11, A12) see AC voltages that consist of square–wave pulses of identical amplitude (see fig.4.2). These pulses are produced by pulse– width –modulating the DC–link voltage. The fundamentals of these alternating voltages are at line frequency and form the counter-e.m.f to the two transformer secondary voltages. The converter input current is in quadrature with E_L i.e., voltage across transformer reactor. Since Es is equal to Vector sum of E_L & E_C (see fig. 4.3), it is possible to ensure that I_S is in phase with E_S by changing amplitude and phase of E_C It could be seen that fundamental component of E_C is nothing but modulating wave itself. Its amplitudes and phase angle, referring to the transformer primary voltage, can be changed independently of each other. This allows the adjustment at $\cos\phi = 1$ in either driving or braking mode.

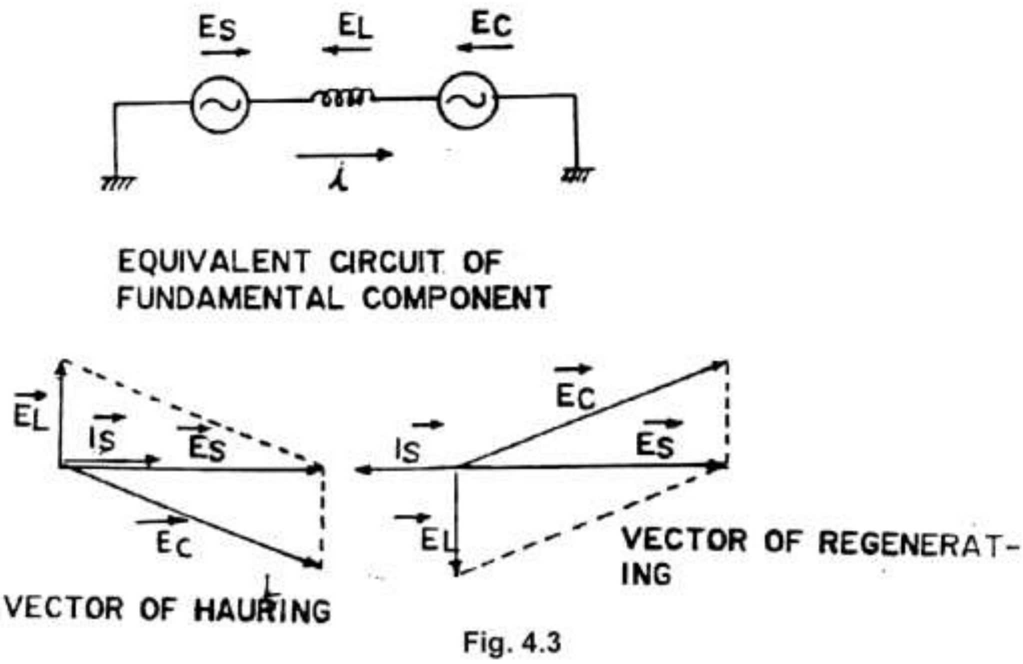
The full-bridge circuit GTOs are switched at a frequency much greater than the line frequency. The switching signals for the four pairs of arms are shifted by 90° (quarter of a switching period) in relation to one another. This ensures that the AC current in the transformer primary winding is almost sinusoidal and that the harmonic currents in the line are kept down to a minimum (for the whole converter operating range).

The line converter maintains the DC –link voltage at a value, which is dependent on the power, direction of energy flow and line voltage.



A11
1U1
1V1
U_{NSR}
U_T
2U1
2V1
U_{NSR}
A12
Transformer with high (30% ≤ u_K ≤ 50%) stray inductance
2423-11B

Fig. 4.2



ES
EL
EC
i
EQUIVALENT CIRCUIT OF FUNDAMENTAL COMPONENT
EL
IS
ES
EC
VECTOR OF HAURING
IS
EC
ES
EL
VECTOR OF REGENERAT-ING

Fig. 4.3

Main constituents parts

The two converter bridges A11-A12 each consist of two bipolar switches. Two GTO – thyristors arms and two diodes, connected in anti – parallel, realize each bipolar switch. These two pairs of arms together with their snubber circuit components are housed in a square aluminium tank and form a so-called valve set (A11 and A12). Such a valve set is oil – filled and cooled by forced oil circulation. The four gate units do not belong to the valve set. They are, however, placed in their immediate vicinity.
The line converter input currents are measured by means of the current transducers U11, U12 resp. U13, U14. Their output signals are sent to the converter controller in the drive control unit (ALG).

DC-link

(L02-A33, Q21, R51-R52, U05, U01-U02, Ho8, A31, R71-A22)
(See main circuit diagram Fig.4.1)

Function

The DC-link connects the line converter to the motor converter. Primarily, it serves to compensate both periodic and non-periodic power differences between the motor-side and line-side terminals of the traction converter.

Such power differences occur on the one hand as relatively low frequency pulsations caused by the single-phase circuit of the line converter. On the other hand they may occur as irregular transient surges produced by sudden disturbances of the power equilibrium between the motor side and line-side of the converter, e.g. due to pantograph bounce, wheel spin etc. It is not possible to completely avoid these transient power differences but they can be minimized. It is a characteristic of the circuit that the power equilibrium after a disturbance cannot be instantaneously recovered, there is a certain delay.

Absorption circuit

(A33-LO2)

The periodic pulsation in the DC-link occurs because the fundamentals power in a symmetrically loaded three-phase system (traction motor system) is constant, whereas the fundamental power in a single-phase system pulsates at double the line frequency.

Referring to the DC-link currents of the converter, this means that the DC-link is fed from the line converter with a pulsating current at double the line frequency, whereas the motor converter draws almost pure DC-current from the DC-link.

The A33-L02 series resonant circuit serves to filter out the current at double the line frequency. It must therefore be tuned to this frequency.

DC-link capacitor (ZK)
(A31)

The DC-link capacitor is used to cater to non-periodic power differences between the motor and line sides of the converter. It also absorbs the harmonic currents produced by both the line converter and the motor converter (frequency higher than double the line frequency).

The DC-link capacitance is rated in such a way that the DC-link voltage remains as constant as far as possible under all operating conditions and that there are no inadmissible fluctuations with regard to the operation of the motor converter.

Over voltage limitation circuit MUB
(R71-A22)

If the capacitance of A31 is not sufficient to prevent the DC-link from sudden and inadmissible high transient overvoltages the R71 overvoltage limitation resistor is almost immediately connected across the DC-link by the firing of a GTO in the A22 valve set. The GTO is fired as soon as a certain overvoltage threshold is reached. After the overvoltage has decayed, the GTO is turned OFF again.

Overvoltages in the DC-link may occur due to:

- ☞ Wheel spin
- ☞ Pantograph bounces
- ☞ Detuned (defective) series resonant circuit (L02, A33)

The MUB-circuit also serves to discharge the converter DC-link if the vehicle is put out of operation (powering-down). Valve of the MUB-resistor is 2.5 mΩ. The temperature of the MUB-resistor is monitored in the control electronics by a thermal model.

Furthermore, the DC-link also contains the following measuring, monitoring and protective functions:

- ☞ DC-voltage measurement, transducer U01, U02 for converter control
- ☞ Voltage indicator H08 and converter earthing switch Q21
- ☞ Earth fault monitoring system (U05, R51 + R52)

Motor converter (ASR)
(A21, A22, A211-A222)

Function

The motor converter consists of a pulse-controlled three-phase bridge circuit (valve set A21, A22), which is connected to the DC-link. On the AC-side, it is connected to the three motor stator windings (connected in start). All 2 resp. 3 motors are connected in parallel.

Each of the three pairs of arms of the three-phase bridge circuit (two of them in A21, one in A22) generates an AC-voltage from the DC-link voltage. This AC-voltage consists of square pulses of constant amplitude. Both the fundamental frequency and the amplitude of the alternating voltage can be changed continuously and independent of each other. These 3 voltages appear at the converter output terminals 1U2, 1V2, and 1W2. Their fundamentals are shifted against each other b by 1/3 period (120°) and from the phase voltages of the traction motor three-phase system.

The torque and the speed of the motors are controlled by continuously changing both the frequency and the amplitude of the fundamentals of the pulse-shaped motor-phase voltages.

In motoring mode (driving mode) the fundamental frequency of the motor terminal voltage is higher than the frequency corresponding to the motor speed (positive slip), resulting in a positive motor torque.

During braking, the fundamental frequency of the motor terminal voltage will be lowered below the frequency corresponding to the motor speed, resulting in a negative slip and therefore producing a braking torque.

The whole control range of the motor voltage is subdivided into three smaller ranges i.e., (indirect self-control), TB_DSR (direct self control), or "tolerance band control" as well as square-wave operation or "field-weakening"-DSR, characterized as follows:

ISR (indirect self control)

The ISR-range covers the range from standstill (motor voltage = 0) up to approx. 30% of the nominal voltage and type frequency (resp. type speed) of the motors.

In this range, the relationship between the motor voltage amplitude and frequency remains roughly constant. This is achieved using the pulse-width-modulation method. The motors are constantly magnetized at nominal induction and can be loaded with the nominal torque over the whole ISR-range.

The GTO-switching frequency is constant over the whole ISR-range. Therefore, the motor voltage per half-wave consists of a variable number of pulses having the same amplitude but differing widths.

TB-DSR (tolerance band control)

The TB-DSR covers the range from approx. 30% up to 98% of the nominal voltage and nominal frequency (resp. nominal speed) of the motors. Over this range the motors are fully magnetized and therefore they can be loaded with the full torque (see Fig.4.4).

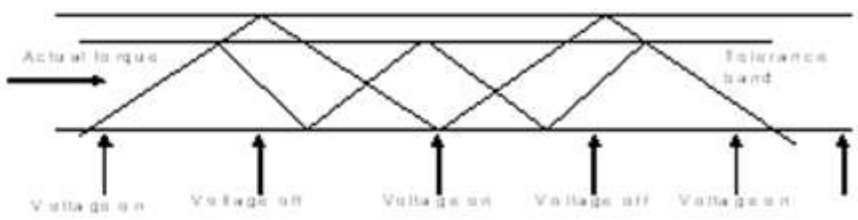


Fig. 4.4

The torque, however, is no longer controlled to an average value but to a set value. The difference between actual torque and set value must always lie within a preset tolerance band whose width is determined by the admissible GTO-switching frequency. Thus, the motor converter is always operated with the largest possible switching frequency, resulting in the smallest possible torque pulsations.

"Field weakening"-DSR (square-wave operation)

The "field weakening" range is the region between the nominal speed (nominal voltage) and the maximum speed of the traction motors.

Over the whole field weakening range the amplitude of the motor voltage is kept at its maximum value. Only the frequency is changed. This has the effect that the motor flux and pullout torque are inversely proportional to the frequency.
The line-line motor voltage in square-wave operation is formed by one voltage pulse per half-wave.

TRACTION CONVERTER CONTROL BY THE CONTROL ELECTRONICS

(See main circuit diagram Fig. 4.1)

The traction converters serve to provide continuous and utmost automatic control of both speed and torque of the three-phase induction motors.

The demands from the driver's cab, such as driving or braking, and the relevant driving speed are converted into the voltage, current and frequency values required on the traction motor side by means of the control electronics and the converter power electronics.

The traction converters of a vehicle are exclusively controlled by the central vehicle control unit (FLG) and the individual converter control units (SLG) as well as the relevant drive control units (ALG).
The converter has no hand-operated component except the earthing switch Q21.

Basic structure of the control electronics

The control electronics is fully based on microprocessors, connected to each other via a data bus system (MICAS vehicle bus). Each vehicle contains a vehicle control unit (FLG). Each converter is controlled by a converter bus station. The A01-converter bus station contains both the converter control unit (SLG) and the drive control unit (ALG), which is controlled by the former. Furthermore, the ALG is also equipped with controllers, one each for the line converter and the motor converter.

Motor converter (ASR) control

Depending on the demands made in the driver's cab and the instantaneous speed of the vehicle, the FLG calculates the required tractive or braking effort. The demanded torque is sent to converter bus station via the vehicle data bus.

The SLG compares the demanded torque from the FLG with the effective load torque calculated in the ALG. The demanded torque for the ALG is determined from the difference between these two values.

The ALG determines the required firing and turn-off pulses for the GTOs on the basis of the demanded torque. The pulses are sent to the gate-units (A211-A222) via fiber optics. The outputs of the gate-units are at high potential.

The actual firing and turn-off pulses for the GTO-thyristors are only generated in the Gate Units (GU). The Gate Unit Power Supply A08 (GUSP) provides the Gate Units with the required energy.

Line converter (NSR) control

The line converter is also controlled by the ALG. The ALG controls the line converter in order to maintain a constant DC-link voltage. This DC-link voltage is reduced, if the needed power is below the rated value. Hence, the loading of the line converter has to correspond to the loading of the motor converter. Therefore the flow of active power on both sides of the traction converter is of the same value and direction (driving, braking).

MONITORING OF GTO – Thyristers

The GTO-thyristors are not only controlled by the drive control unit (SLG, ALG) and Gate Units but are also monitored (GTO feedback signals). This ensure for example that a GTO is only fired if the necessary conditions are fulfilled, and that the converter is immediately shut down (or not powered-up) when a GTO fails.

Additional functions performed by the vehicle control unit, converter control unit and drive control unit (FLG, SLG, ALG)

Apart from the control functions described above, the vehicle control unit and the converter control units fulfill numerous additional functions. The following functions are important for the converter:

☞ Automatic powering-up and powering-down of both the vehicle and the converter according to the selections from the driver's cab.

☞ Monitoring of various variables (limit values).

AUTOMATIC SYSTEM TESTS

The converter is regularly and automatically tested by the control electronics. This takes place when the vehicle is first powered-up and whenever the converter is powered-up again, e.g. after a protective shut-down during driving mode.

The functional test consists of two parts, the OFF-LINE TEST and the ON-LINE TEST.

The OFF-LINE test is performed before any turn-ON (the converter being de-energies). The ON-LINE test, however, is carried out during the charging of the DC-link as well as during the operation.

OFF-LINE TEST

The OFF-LINE TEST tests the following functions (amongst others):

- ☞ The current transducers (U11-U23) by means of simulated actual value signals (test windings).
- ☞ The comparators for the various protection thresholds.
- ☞ The power supplies for the gate units and the control electronics.

ON LINE TEST

The ON-LINE TEST tests the following functions (amongst others):

- ☞ That the K01 charging contactor closes.
- ☞ That the DC-link voltage is reached within a predetermined time.
- ☞ That the K11 main contactor closes.
- ☞ That the actual value signals of the voltage transducers (U01, U02) are correct (plausibility test).
- ☞ That the MUB is ready for operation.

During operation, different states and values, which allow the release of the GTO firing pulses, are continuously (ON-LINE) monitored.

Amongst others they are

- ☞ The position of the vehicle main circuit breaker, the K01 charging contactor and the K11 main contactor.
- ☞ The pressure and the temperature in the oil cooling system.
- ☞ The converter DC-link voltage.
- ☞ The current and voltage transducers (plausibility test).
- ☞ The gate unit supply voltages.

The ON-LINE test is only initiated when the OFF-LINE test is successfully complete.

CONVERTER TURN-ON/OFF

(So called powering-up and powering-down)

Powering-up

(See main circuit diagram Fig.4.1)

When powering-up the vehicle, the converter is powered-up after the OFF-LINE test. For this purpose the K01 charging contactor is closed, so that the converter DC-link is precharged through the R04 charging resistor and the diodes in the A11 valve set. Immediately afterwards the K11 main contactor is closed.

Subsequently, the GTO-thyristors' control pulses for the line converter are released and approx. 200 ms later those for the ASR (motor converter).

The conditions for control pulse release are:

- ☞ Closed vehicle main circuit breaker.
- ☞ Converter powered-up (i.e., OFF-LINE and ON-LINE test OK).
- ☞ Gate unit supply (GUSP) OK.
- ☞ Driving direction switch (reversing switch) set to "forward" or "reverse".
- ☞ DC-link charged.

Powering-down

The converter is powered down if:

- ☞ The vehicle is put out of operation.
- ☞ The converter protection (steps 4 or 5) has reacted.
- ☞ The line voltage is too low for a considerable time.

When powering-down

- ☞ The demanded torque is reduced to zero.
- ☞ The firing pulses of both the line and motor converter are inhibited.
- ☞ Main circuit breaker is opened.
- ☞ The K11 main contactor is opened, and
- ☞ The MUB is turned ON (DC-link is discharged).

CONVERTER PROTECTION

(See main circuit diagram Fig.4.1)

Various conditions during converter operation (wheel spin, pantograph bounces, overload) as well as errors in the control electronics may endanger important components of the converter, especially the power GTOs.

In order to prevent this and to affect the converter normal operation as little as possible a five-stage protection concept is used, whose individual stages are described below.

Protection stages

Protection stage 1: Monitoring of the minimum switching times of the GTO-thyristors and mutual interlocking of the gate units of a GTO-thyristor pair of arms:

To ensure the safe function of the converter, when it is alternately switching the plus or minus pole of the converter DC-link to the relevant converter terminals (alternate firing and turning OFF of the GTO-thyristors in a ZP), it is absolutely necessary that minimum turn ON and OFF times are observed including the minimum change-over time of the GTO-thyristors. These times are monitored by the control electronics.
A further step to avoid shorting the DC-link is to interlock the firing signals for the two GTO-thyristors of a pair of arms. A firing command is only released if the neighbouring GTO has safely turned off.

<u>Triggering</u>:

Protection stage 1 responds as soon as the converter reaches its control limits.

<u>Effect on the operation</u>:

Normal operation is maintained. The diagnostic system will indicate a fault.

Protection stage 2: <u>Power and current set value limitation</u>:

In order to prevent the converter from thermal overloading, it is important that certain current limits on both the line side and motor side are not exceeded. For this reason, the current and torque set values required by the converter control circuits are limited.

<u>Triggering</u>:

Protection stage 2 responds either if the overhead line has under voltage or if the motor converter is operated with motor fundamental frequencies that are below
1.1 Hz.

<u>Effects on the operation</u> :

Reduction of the motor torque. No fault is indicated.

Protection stage 3: Instantaneous voltage limitation MUB **:**

Normal operation is transiently affected but maintained. No fault is indicated.

Protection stage 4: **Full reduction of load :**

(Controlled reduction of the motor torque to zero)

To reduce the power flow in the converter as quickly as possible, but without disturbing the power equilibrium between line and motor converter (otherwise there is a danger of overvoltages in the DC-link), the torque of the driving motors is quickly and continuously reduced to zero (ramp function). Subsequently, all the GTO-thyristors of both the line and motor converters are turned off.

Triggering:
Protection stage 4 responds if:

- ☞ The plausibility test of the current and voltage transducers indicates a fault (either thermal drifts or defective transducer).

- ☞ The MUB – resistor overheats.

- ☞ Either the cooling medium temperature is too high or the inlet pressure is too low.

- ☞ The converter control circuits attain an abnormal state (e.g. a GTO-thyristor can not be fired).

Effects on the operation:
The converter is turned off and turned on again, provided it has passed the off-line test. If the test, however, is not successful, the converter will automatically be powered down, which means that it is completely shut down. The DC-link will be discharged.

Protection stage 5: **Immediate converter shut-down:**

(Opening the vehicle main circuit breaker and firing the MUB)

The converter is fully shut down without delay. For this purpose the MUBs are fired by means of a continuous pulse, all the GTO-thyristors of both line and motor converter are turned off and the vehicle main circuit breaker is opened.

Triggering:

Protection stage 5 responds, if:

- ☞ The maximum admissible DC-link voltage is exceeded despite activation of the MUB (protection stage 3).
- ☞ The MUB (protection stage 3) responds several times in a row.
- ☞ The maximum admissible current is exceeded at one of the power terminals of the converter.
- ☞ The gate units of a pair of arms signal either an inadmissible switching state or a defective GTO-thyristor.
- ☞ The DC-link voltage inexplicably drops below its minimum admissible value.
- ☞ Either the gate unit power supply or the supply for the control electronics fails

Effect on the operation

After vehicle shut-down the converter undergoes an OFF-LINE test. It the test is not successful, it remain shut shown.

Behavior in case of line under voltage during operation

If during operation the line voltage drops below the minimum allowable value. The motor converter and then immediately afterwards, the line converter are turned off (or vice versa depending if the converter is in motoring or braking mode). In the blocked state, the DC-link voltage gradually drops. If the line voltage returns inside the tolerance range before the DC-link voltage has decreased too much, the firing pulses are again released. If however the line voltage remain below the minimum value for more than approximate10 seconds, the converter will be powered down. Once the line voltage has recovered, the normal powering-up process will be initiated.

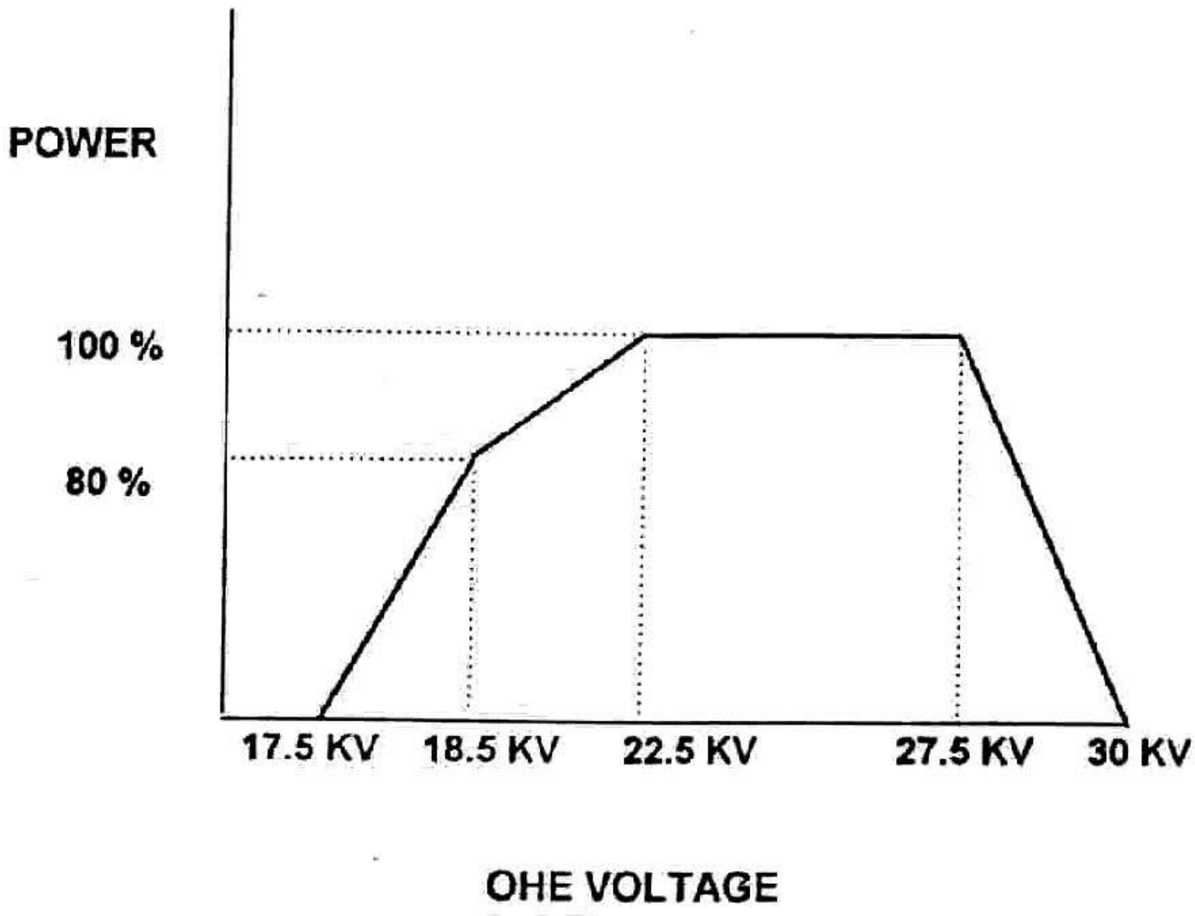


Fig . 4.5

5. AUXILIARY CIRCUIT DESCRIPTION

The auxiliary circuit in WAP5 and WAG9 locomotives has single phase as well as 3-phase auxiliary motors. The circuits feeding the single phase machines and 3-phase machines are distinctly separated although they are fed from one and the same auxiliary winding (1000V) of the main transformer.

SINGLE PHASE CIRCUIT

The single phase auxiliary circuit is shown in Fig.5.1. An auxiliary transformer to give 415V and 110V AC output steps down the auxiliary winding voltage.

The following loads are connected in the 415V AC circuit:

- ⇨ Machine room blowers.
- ⇨ Scavenge blowers for machine room blowers.
- ⇨ Cab heaters.

Loads connected to the 10V AC circuit are:

- ⇨ Cab fans.
- ⇨ Blowers for cab heater.

The 415V and 110V AC auxiliary circuits energized as soon ad VCB is closed. The machine room blowers cool different electronic cubicles in the locomotive in addition to provide for pressurisation of the machine room. For working control electronics a machine room temperature below 70°C is to be ensured. In peak summer periods, if the locomotive with all the doors and window closed is kept under the sun for a long time, there is a possibility that the machine room temperature exceeding 70°C. Provision of a "cooling mode" operation in the control circuit facilitates raising of pantograph and closing of VCB in such an eventually without intervention of control electronic. The machine room blower starts working to bring down the machine room temperature after which the locomotive can be operated in the normal "driving mode".

3-PHASE CIRCUIT

The overview of the 3-phase auxiliary circuit is shown in Fig.5.2 for running the 3-phase auxiliary motors, WAP5 and WAG9 locomotives are equipped with 3-phase static auxiliary converters to supply the auxiliary machines of the locomotive. The static auxiliary converter is very different in principle, construction and operation from the conventional Arno Converter. Since there are no rotating parts as in the Arno Converters, these converters have less wear and tear, thus making it almost maintenance free.

CIRCUIT DESCRIPTION

The load distribution among the BURs is such that required redundancy is achieved by automatically switching load from one auxiliary converter to another in case of failure of any one auxiliary converter. BUR1&2 feed variable voltage and variable frequency supply to the traction motor bowers; oil cooler blowers and its scavenger blower of bogie1 & bogie2 respectively. BUR3 feeds a fixed frequency supply to the two compressor motors and two converter and transformer oil pumps. In addition to that, BUR3 also feeds the battery charger.

For traction motor blowers, oil cooler blowers and their scavenge blowers, the speed is controlled in three steps (17Hz, 33Hz & 50Hz) by the control electronics depending on the temperature of the traction motors / cooling oil sensed by temperature sensors in traction stator and in oil cooling circuit. BUR3, on the other hand, is operated at a fixed frequency of 50Hz to feed the drive motors of the main compressors, oil pumps in addition to the battery charger. The output voltage of Bur3 varies a little around 415V depending on the battery charging requirement. However, whenever a compressor starts, the output voltage and frequency of BUR3 are reduced to near zero and then ramped upto the full values to achieve a soft start of the compressors. Load changeover from one auxiliary converter to another in case of isolation of any one auxiliary converter to another in case of isolation of any one auxiliary converter is done automatically by the auxiliary converter electronics with the aid of electro-pneumatic contactors. If BUR1 fails and gets isolated, BUR2 feeds the auxiliaries for ventilation of both the bogies up to a maximum frequency limited to 42Hz. If BUR2 fails & gets isolated, BUR1 feeds the auxiliaries for ventilation of both the bogies up to a maximum frequency limited to 42Hz. If BUR3 fails and isolated, BUR2 feeds the compressor motor, oil pumps and the battery charger at affixed frequency of 50 Hz and BUR1 feeds the auxiliaries for ventilation of both the bogies up to a maximum frequency limited to 42 Hz.

As shown in Fig.2, under normal operation, contactors 52/1, 52/3 52. ½, 52/5 are closed and contactors 52/2, 52/4, 52.1/1 are open. When BUR1 is isolated, contactors 52/4, 52/1, 52/3 and 52.1/2 are closed and 52/5, 52/2 and 52.1/1 are open. When BUR2 is isolated, contactors 52/5, 52/4, 52/3 and 52.1/2 are closed and 52/1, 52/2 & 52.1/1 are open. When BUR3 isolated, contactors 52/2, 52/4, 52/5 & 52.1/1 are closed and 52/1, 52/3 & 52.1/2 are open.

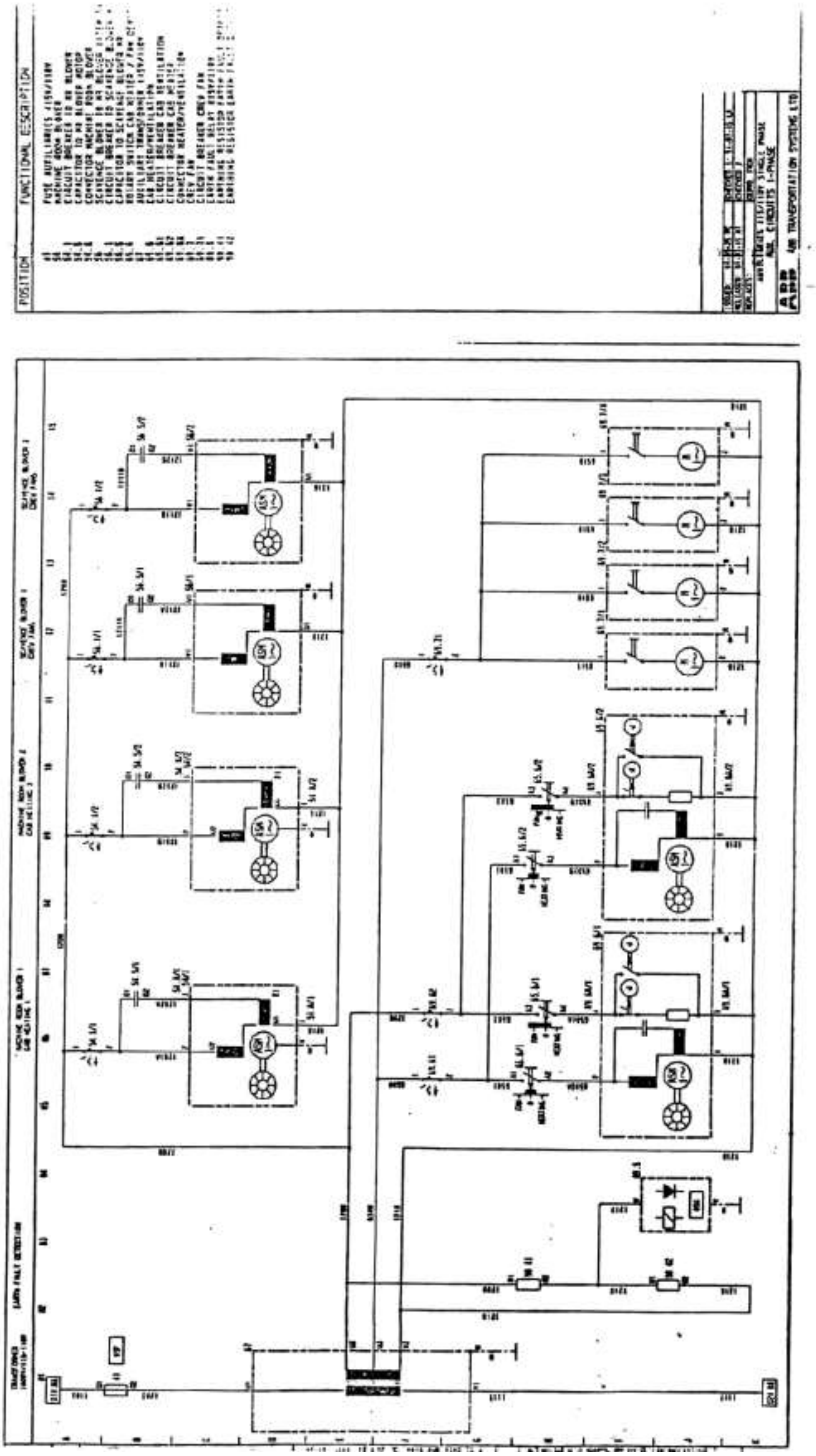


Fig. 5.1 Single Phase Auxiliary Circuit

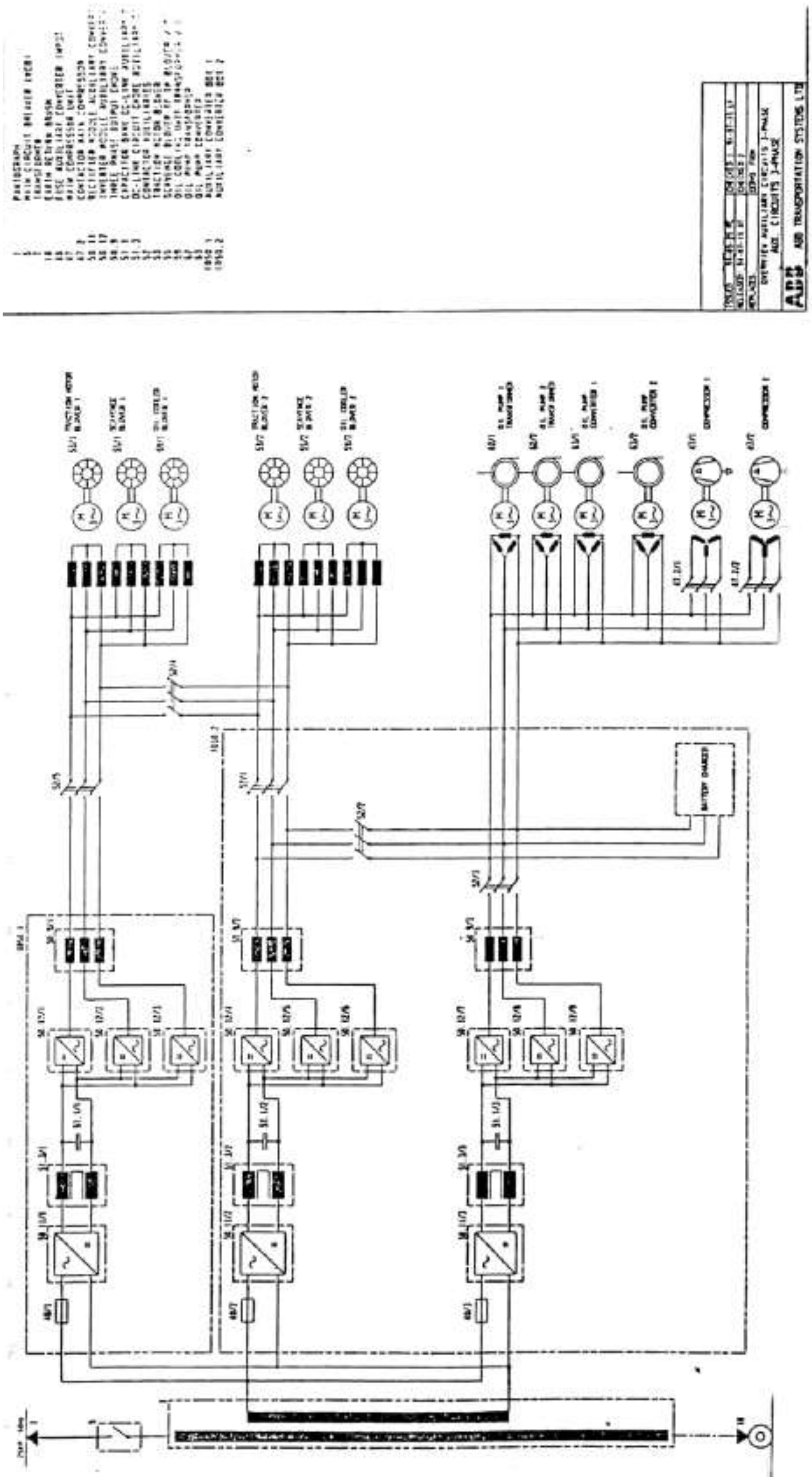


Fig. 5.2 Overview of Three Phase Auxiliary Circuit

6. AUXILIARY CONVERTER

1.0 INTRODUCTION

Each locomotive is equipped with two boxes enclosing the static auxiliary converter system.

1. BOX1 containing BUR1
2. BOX2 containing BUR2 & BUR3 and battery charger, which may be, fed from one of the two converters and which may be considered to be a functional part of the converter system.

Fig.6.1 shows the converter function within the locomotive and Fig 6.2 the essential parts of the auxiliary converter and battery charger.

Three auxiliary converters are designed for connection to the auxiliary services winding of the main transformer. Each converter is rated for 100 KVA output and has short circuit proof three-phase output at 415 V. The output frequency of converter BUR1 & BUR2 is variable from 0 to 50 Hz while BUR3 gives fixed frequency output at 50 Hz.

The battery charger is supplied from the converter BUR3. In case of the fault in the converter, BUR2 will feed the battery charger. The battery charger with a rated output of approx. 111 V charges the locomotive batteries and supplies the low voltage loads. The low voltage output is electrically insulated from the input and from the three-phase output.

The converters are provided with external forced convection cooling (5 m/sec approximately). Thermostats are provided inside the box. When the temperature goes above 50°C, fans run until temperature decrease below 35°C.

Both boxes and three phase output chokes are mounted in the machine room of the locomotive. The intermediate chokes are incorporated in the main transformer tank for convenience and in order to save weight.

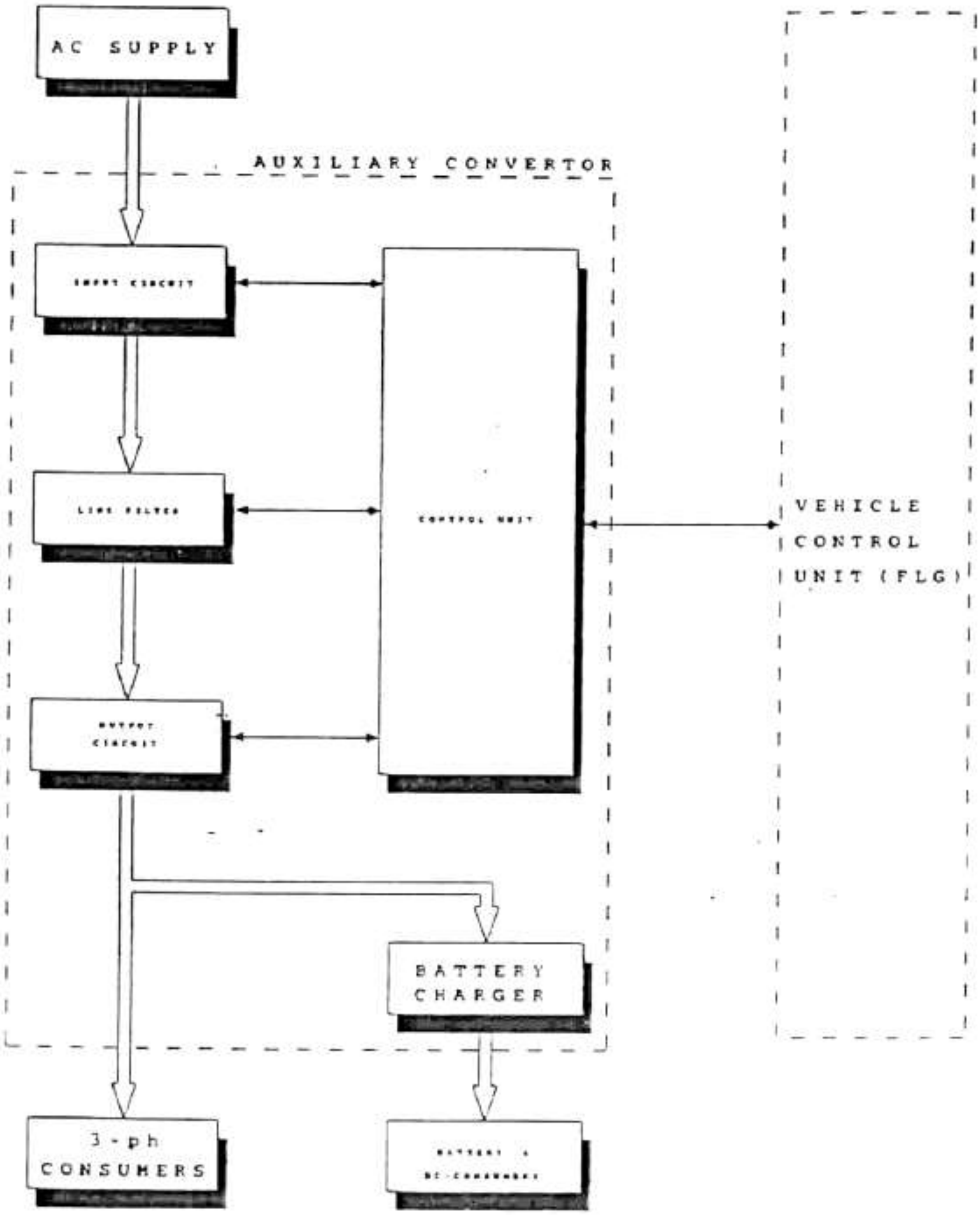

AC SUPPLY
AUXILIARY CONVERTOR
VEHICLE CONTROL UNIT (FLG)
BATTERY CHARGER
3-ph CONSUMERS

Fig. 6.1

TECHNICAL DATA

Input

Supply voltage	: 1000 V AC +200 V -300 V
Apparent power	: 100 KVA
Current (r.m.s.)	: 150 A (100 KVA and 700 V)
Frequency	: 50Hz + 3%
Rated insulation voltage	: 1200 V
Test voltage (50Hz/60 sec)	: 4250 V

Intermediate circuit

Voltage	: 550 VDC
Rated current	: 155 ADC
Short term overload	: 190 ADC
Rated insulation voltage (capacitor)	: 900 V
Test voltage (50 Hz/60 sec)	: 2600 V

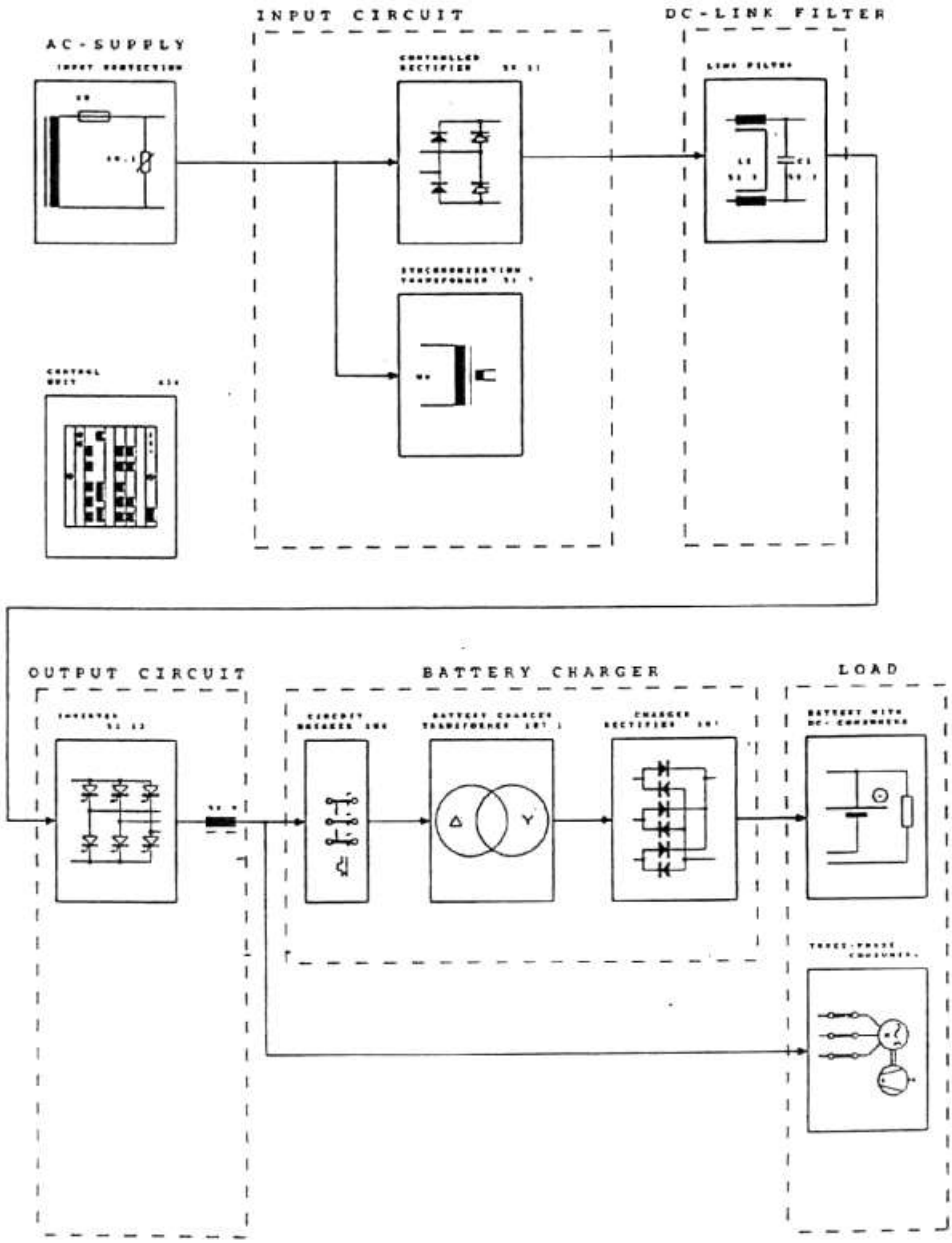

INPUT CIRCUIT
DC-LINK FILTER
AC-SUPPLY
OUTPUT CIRCUIT
BATTERY CHARGER
LOAD

Fig. 6.2

2.3 Output

		AC	DC
Rated voltage (fundamental r.m.s)	:	415 V	---
(DC voltage)	:	---	111 V
Rated frequency (BUR1 & 2)	:	50 Hz	---
(BUR3)	:	50 Hz	---
Rate current			
(AC includes battery charger)	:	140 A	---
Max. battery charger current			
(only battery)	:	---	80 A
(user + battery)	:	---	110 A
No. Of poles (conductors)	:	3	3
Rated insulation voltage	:	900 V	150 V
Test voltage (50 Hz/60 sec)	:	2600 V	1500 V

2.4 Control unit

Supply voltage:		77..137.5 V (operating range)
Power consumption	:	120 W

2.5 Thermal losses and cooling by forced air

Thermal losses at rated power

Box1	:	2 KW
Box2	:	5 KW
Ventilator supply voltage	:	36….56 V
Ventilator power losses	:	5 W
Air rate	:	5 m/sec

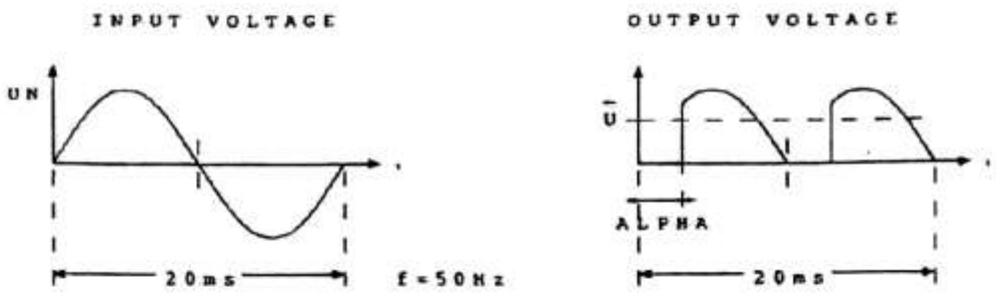


Fig. 6.3

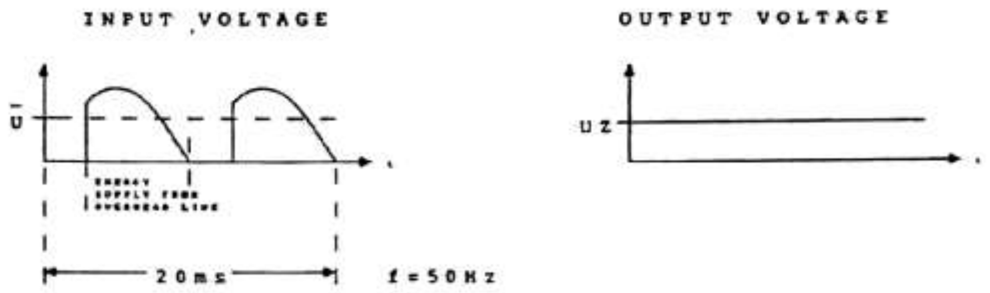


Fig. 6.4

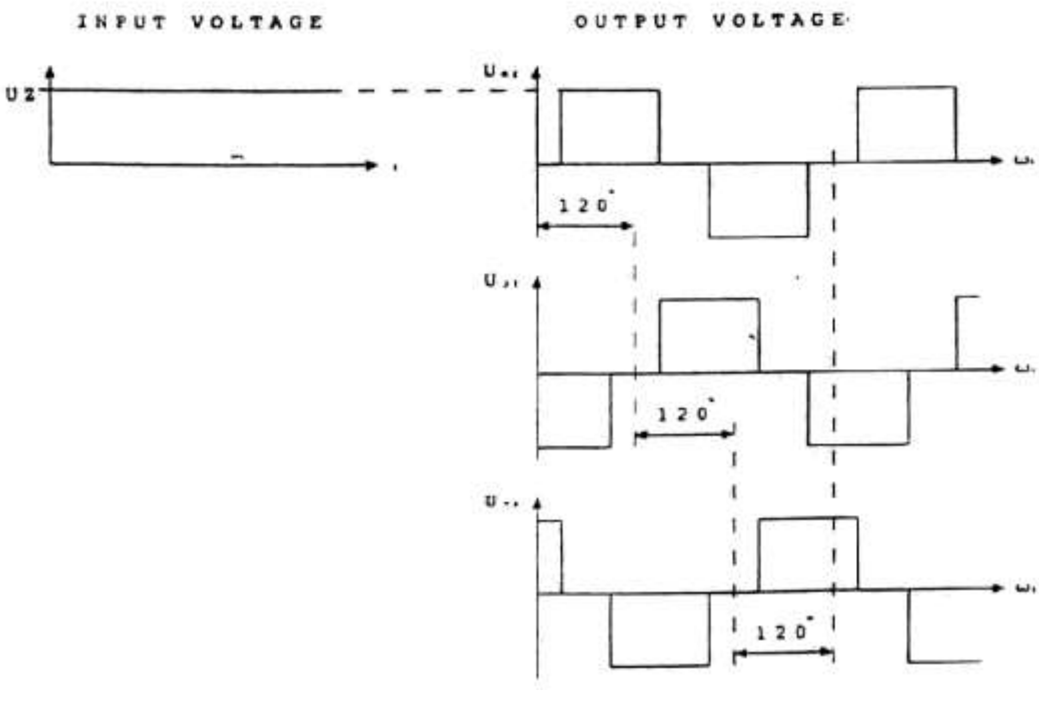


Fig. 6.5

3.0 CIRCUIT DESCRIPTION

The main parts of the converter are:

- The half controlled rectifier bridge [50.11]
- The intermediate filter (inductor [51.3] and capacitor [51.1])
- Three inverter legs, connected as three-phase inverter [50.12]
- The electronic control unit [426]
- The three phase output inductor [50.9]
- The battery charger (three phase transformer [107.1] and rectifier [107])

The other components serve to detect the actual values required to control the process and to ensure that the necessary operating condition are maintained for reliable operation of the power electronics.

3.1 Rectifier

The half controlled asymmetrical type GTO rectifier is used. The rectifier converts AC to DC and maintains output dc voltage of approx. 550 V. The input & output voltage waveforms are shown in fig.6.3 and currents through devices are summarized in fig.6.7.

Average value of rectifier output voltage:

$$U2 = \frac{\sqrt{2}}{\pi} \times Un_{rms} \times (1 + \cos \alpha)$$

The active power transmitted through the converter amounts to

P = UZ x IZ, IZ being the average value of the link filter current.

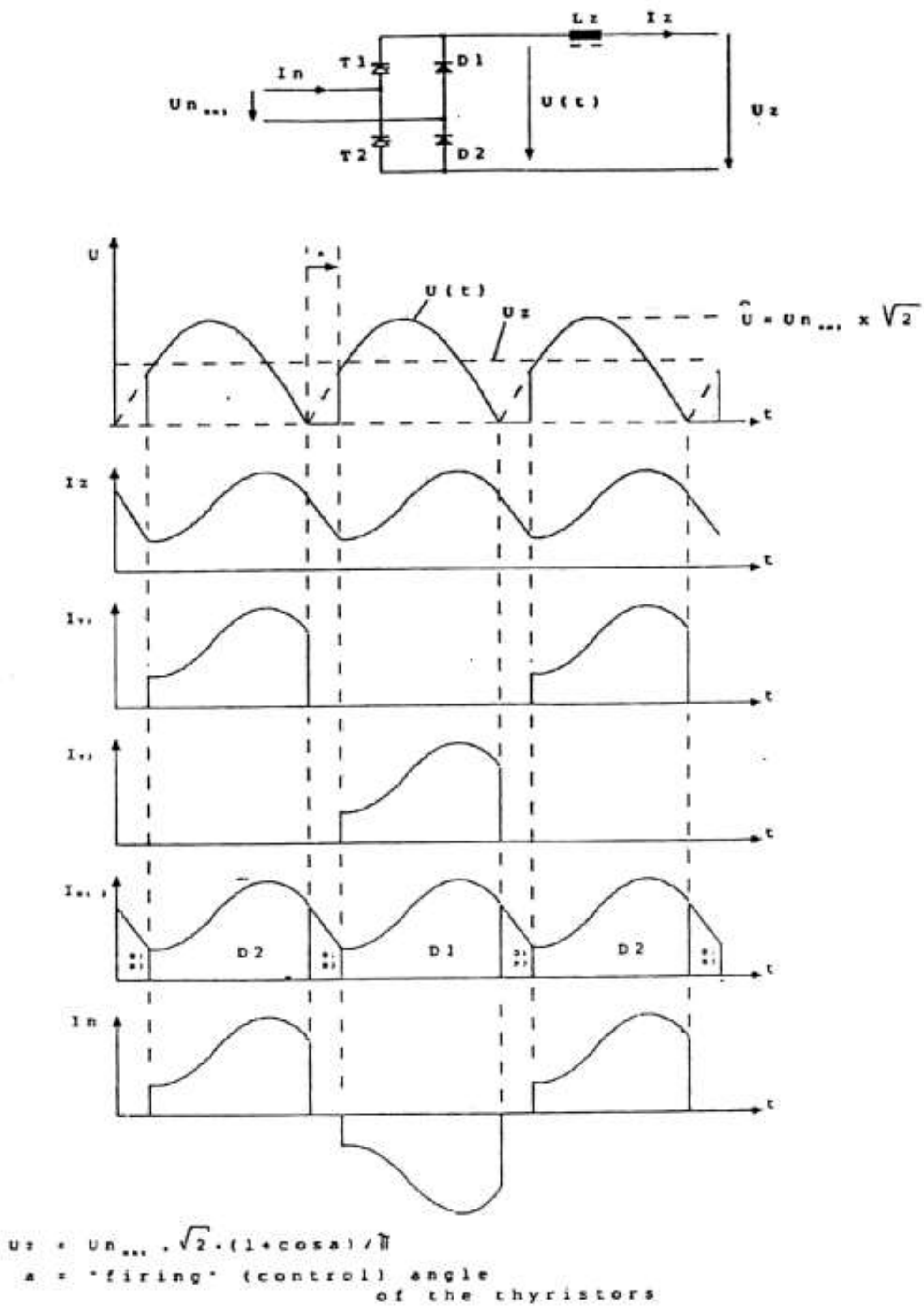

Lz
Iz
In
T1
D1
T2
D2
U(t)
Uz
U
u(t)
Uz
t
Iz
In
D2
D1
Uz = Un... . √2 . (1+cosa)/π
a = "firing" (control) angle
of the thyristors

Fig. 6.6

3.2 DC link filter

DC link filter consists of intermediate circuit reactor and capacitor.

The intermediate circuit reactor smoothes the pulsating energy flow from the input rectifier and supplies DC current (IZ) with superposed ripple. The choke is equipped with two coils in order to keep voltage spikes away from the inverter and the connected load.

The intermediate circuit capacitor (CZ) absorbs the component of the current, with little fluctuation in terminal voltage. In addition, CZ represents the low impedance voltage source, essential for functioning of three phase inverter. CZ also supplies the magnetization current to the inductive load.

The intermediate circuit capacitor consists of 2-stage series circuit of 6 parallel-connected electrolytic capacitors each. The voltage across the series connected stage is balanced with resistors. These are dimensioned so that the current passing through them is several times larger than the capacitor leakage current and they thereby determine the voltage sharing. At the same time they act as discharge resistors.

Fig.(4) shows the voltage waveforms across the filter input and output.

3.3 Three phase inverter

The three-phase inverter consists of three single-phase inverter modules. They generate a three phase AC voltage from the intermediate circuit DC voltage by being approximately switched ON and OFF Fig.5 shows the switching sequences of the three modules is steady state conditions.

The rectangular output voltage of inverter may be represented as an infinite sum of sine waves as follows:

$$U(t) = UZ \times [(\sqrt{6} \times \sqrt{2}) / (\pi \times n)] \times \Sigma \sin (n \times 2\pi f_1 \times t)$$

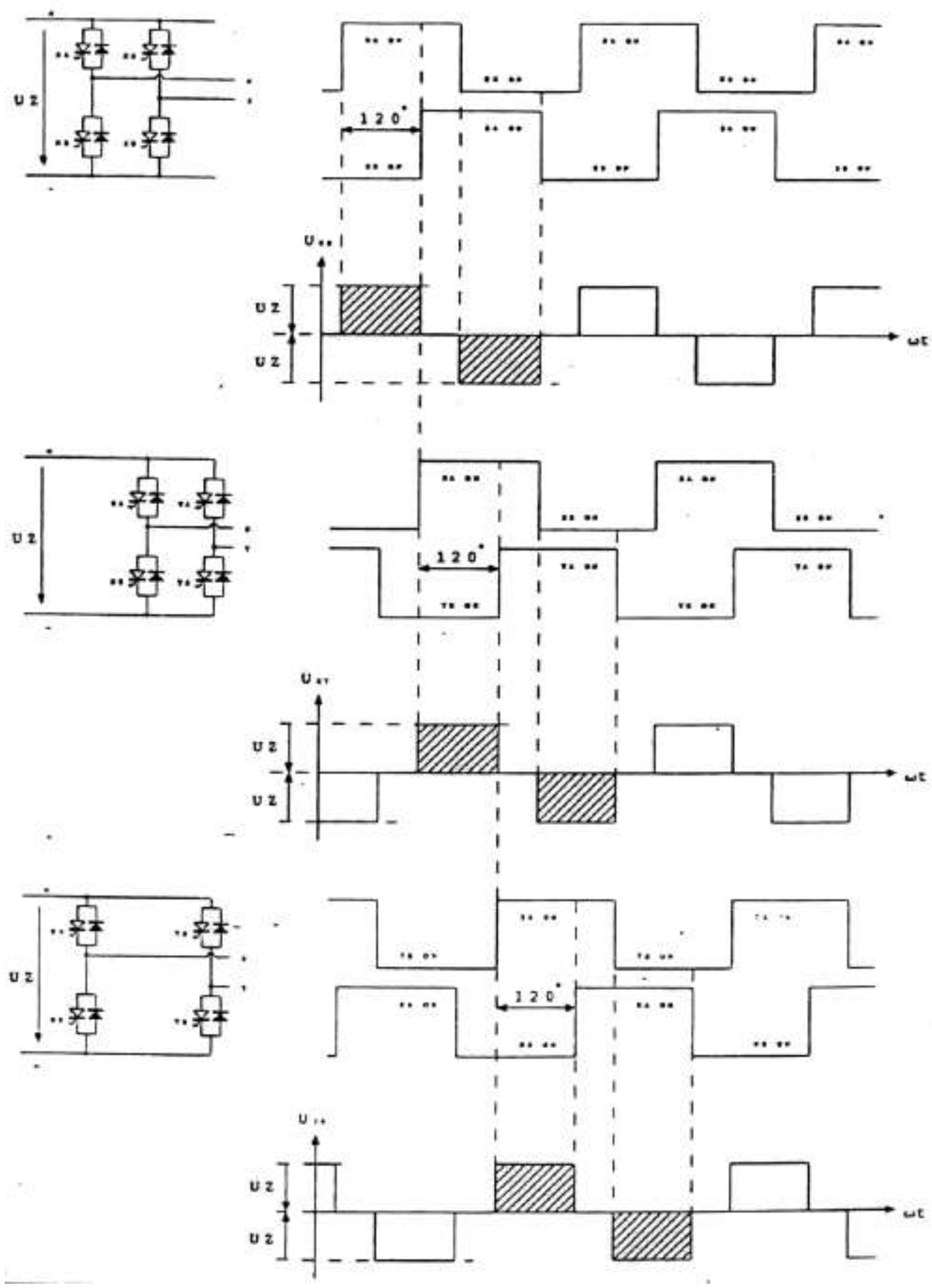


Fig. 6.7

With f_1 = inverter frequency as understood conventionally fundamental component
and n being 1,5,7,11,13,17….(= 6k ±1, k = 1,2,3,4……)

The shaft power of motor is function of fundamental component

$$U_{1rms} = UZ \times \frac{\sqrt{2}}{\pi}$$

In case of resistive loads, the heating will be function of total rms value.

$$V_{(total)\ rms} = UZ \times \sqrt{2/3}$$

In steady state operating conditions, both frequency and amplitude of output voltage correspond to set point, while in dynamic conditions these values can be set away from the reference value by PWM for better control of the process.

3.4 Three phase inductors

The inductor slightly attenuates harmonics but mainly provides the converter with the required capability of withstanding load short – circuits.

3.5 Battery Charger

The diode bridge (107) rectifies the voltage supplied from one of the auxiliary inverter through 107.1 A capacitor of 2.2 mF located on 107 smoothes the charger voltage and limits the transient voltage rise when some major load is switched off. The current transducers 107.2 and 107.3 transmit the actual current values to the control unit of inverter BUR2 while the transducers located on the charger module transmit the same values to inverter BUR3 (normally supplying the battery charger) control unit (Ref. Fig. 6.8).

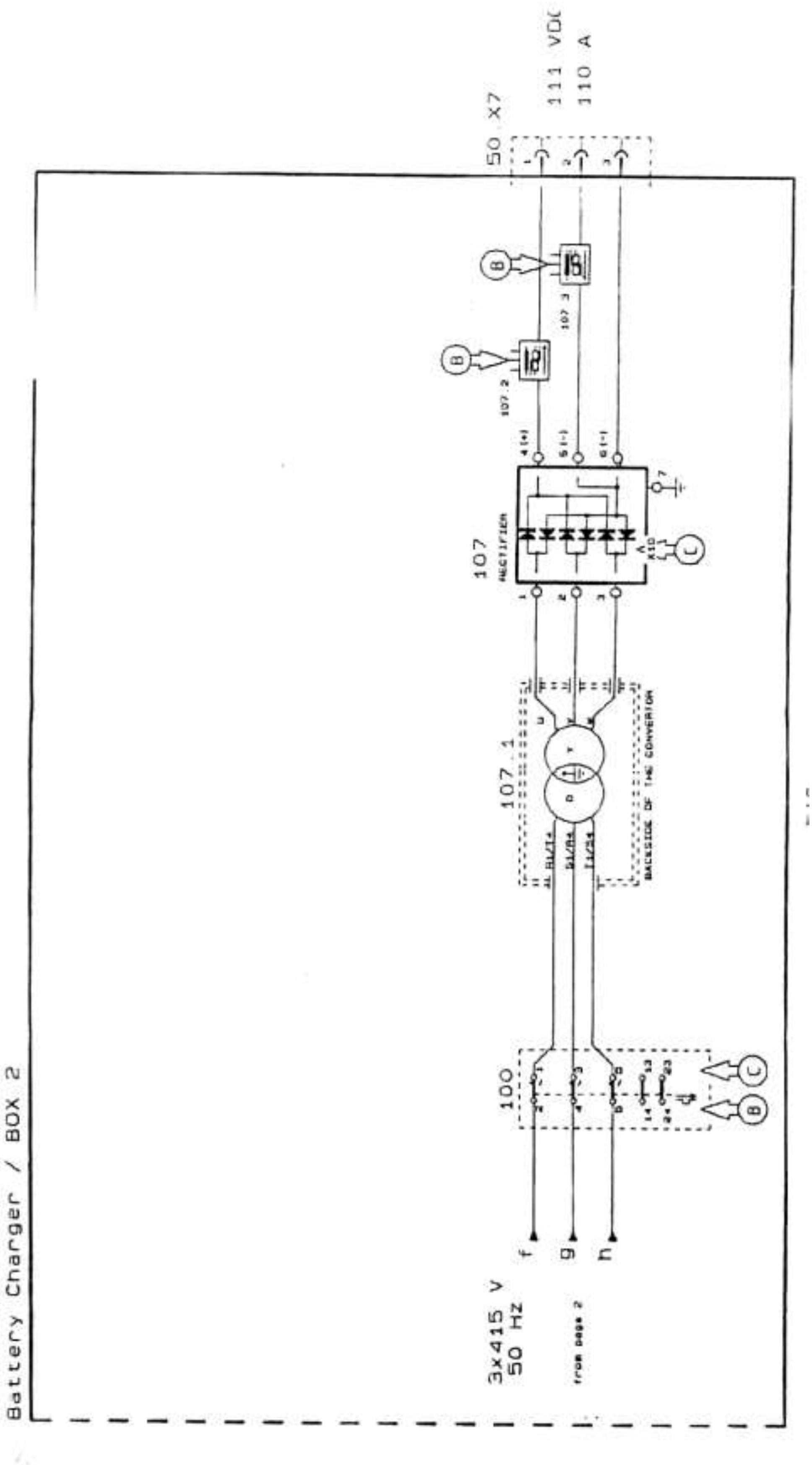

Battery Charger / BOX 2
3x415 V
50 Hz
from page 2
f
g
h
100
107.1
BACKSIDE OF THE CONVERTER
107
RECTIFIER
107.2
107.3
50 X7
111 VDC
110 A

Fig. 6.8

3.6 Protective devices

I. Battery charger circuit breaker [100] – The battery charger is protected against overload by magnetic circuit breaker 100. the breaker isolates the battery charger from the inverter output through magnetic tripping in case of short circuits inside the battery charger. The converter need not be switched off and locomotive can continue to run until the battery capacity is exhausted.

II. Input fuse [40] – The fuse protects from serious consequential damage, which result in the event of failure of power components in the rectifier bridge or defects of the regulation or the actual value monitoring.

III. Surge arresters [40.1] – The surge arresters protect the semiconductors of the rectifier bridge [50.11] from over voltage spikes.

IV. Damping filter RC [49.2/49.1] – The small filter is intended to limit the rate of rise of voltage spikes in order to avoid spurious thyristor firing.

3.7 Measurement devices

I. Input voltage measuring transformer. It provides the electronic control unit with information about amplitude and phase of input.

II. Voltage transducer. It is used to measure intermediate circuit voltage.

3.8 Auxiliary Converter control unit

It handles all control and electronic protection functions. The control unit communicates with the vehicle control unit (FLG) via MVB optical bus.

<u>The rack contains</u>:

☞ A power pack with electrical insulation between input and outputs, which converts the battery voltage varying over a wide range into the various stabilized voltages e.g. $\pm$24 V for gate unit supply, $\pm$15 V for analog circuit and transducer supply and $\pm$5 V for digital circuit. All voltages have a common ground.

☞ The microprocessors unit including binary input / output card. This unit provides the regulation of the link voltage (i.e., it controls the input rectifier) and of the battery voltage. It is in charge of the higher-level protective functions, of the contactor control and of the communication with the FLG.

☞ The bus interface board converting the electrical signals elaborated by the microprocessor unit into the optical ones and vice-versa.

7. CONTROL ELECTRONICS & VEHICLE DIAGNOSTIC SYSTEM

The Control electronics used in WAP5 and WAG9 locomotives is known as MICAS–S2 (Micro Computer Automation System Series 2). MICAS–S2 is a process oriented, distributed control system optimized for the application on electric traction vehicles. It consists of a number of devices for signal input / output, signal processing and communication systems to exchange data between bus stations (control units). A man-machine interface for the operating system as well as aids for planning, commissioning and maintenance of an installation is also provided.

FIELD OF APPLICATION

The MICAS-S2 control system is mainly used in electric traction vehicles, such as locomotives, multiple unit trains, tramways and trolley buses. A modern transportation system has high demands on the vehicles. Thanks to its modularity, MICAS-S2 can be adapted to the various requirements.

There are three hierarchical levels in the MICAS traction control system (Fig.7.1) train control, vehicle control and drive control level.

The train control level coordinates and controls coordination of several similar traction vehicles (multiple traction), interfacing to brake systems and much more. It is the train control level that converts the driver's commands (e.g. set speed) into commands for the individual vehicles. These commands are passed on to the vehicle control level for execution.

The vehicle control level is responsible for all the vehicle functions. It converts the commands of both the train control level and the driver into actions (contactor control, EP-valves etc) and gives feedback about important events or operating states. To allow the driver to concentrate on his most important task, i.e. observing the track and signals, the vehicle control level automatically reacts as far possible on all events occurring during operation.

The third hierarchical level is the drive control level. It receives the set value of the tractive effort required from the vehicle control level and controls the power converters in such a way that the motors will deliver the required torque.

MICAS-S2 comprises components for all the three hierarchical levels. Thus all requirements demanded for modern vehicle can be met such as:

* Full integration of all control system tasks for a train.
    - Measuring and conditioning of process values.
    - Control of all functions.
    - Drive control.
    - Power supply.
    - Data exchange between sub-systems of a vehicle and between several vehicles.

- Supervision on inadmissible operating condition.
- Protection of components and vehicles.

* Integrated diagnosis to support both operation and maintenance.
* Safe operation (inherent or user configurable redundancy of the control system)
* Easy vehicle maintenance due to high modularity and availability of components.
* Efficient vehicle production with extensive test of preassembled modules before integration in the vehicles.

*Possibility to adapt to changing needs during the whole life time.

CHARACTERISTICS

The MICAS–S2 control system takes charge of all tasks necessary for operating,, monitoring and maintaining vehicles. Furthermore, because of it structure and modes of operation it offers exceptional advantages for both the vehicle manufacturer and the customer.

- Internationally standardized data transfer according to IEC TC9 WG22 (Train Communication Network, MICAS Vehicle Bus and Train Bus).
- Self-diagnosis of all the devices with centralized processing and the degree of fault tolerance can be widely adapted to requirements regarding availability and safety.
- Simple configuring and programming of an installation thanks to powerful and user-friendly software tools (Mic Tools).
- Uniform interface between software and data transfer systems.
- Access to all devices via MICAS vehicle Bus for commissioning and maintenance.
- Integration of third-party systems (electronic modules of other manufacturers) into a MICAS-S2 installation.
- Extensive protection against electromagnetic interferences.

Communication is one of the most important functions of a distributed control system Requirements for data transfer between the control electronics component of a vehicle are quite different from the data exchange between different vehicles. Therefore MICAS-S2 includes various data transfer systems that offer optimum adaptations such as the Train Bus, the MICAS Vehicle Bus and the Parallel buses. Data between up to 62 vehicles can be exchanged by the Train Bus. It is possible to control one or several traction vehicles (multiple traction commuter train). The Train Bus flexibly adapts to any configuration alteration of a train. Mixed trains with vehicles having no interface to the Train control bus are possible.

The MICAS Vehicle Bus is optimized for the transfer of real-time process values. The cyclic data transfer according to the broadcast principle allows a very efficient utilization of the transmission capacity available. Cycle times between 1 ms and 1024 ms are possible. Upto 127 devices can be connected to a bus. Considerable noise immunity is obtained by linking the modules with fibre optic cables.

The Parallel bus (AMS-Bus) is used to control input/output devices in subracks.

Another very important function of MICAS-S2 is the drive control electronics. Asynchronous motors mainly used in modern traction vehicles are very dynamically controlled due to the stator-flow-oriented torque control process (direct and indirect self control). This results in maximum adhesion utilization, optimum comfort and minimum wear. Traction vehicles equipped with MICAS-S2 drive control offer universal application both in pulling heavy goods trains or in front of fast passenger trains.

HANDLING

MICAS-S2 offers uniform user-friendly tools for the design, commissioning and maintenance staff. The Mic Tools package presents a wide variety of programs to fulfill most of their tasks.

User programs for general control tasks are programmed in the process oriented Function Block Language (FUPLA). FUPLA is a programming tool using graphic symbols called function blocks. This makes it very simple to write, test and document programs for the automation of process.

The shielded subracks, the protective circuits in the electronic modules as well as the shielded cables for analog process signals guarantee and optimum safety of operation even in very harsh environments close to strong sources of electromagnetic radiation. Internal signals and the supply voltages are wired via the rear rack connectors in wire wrapping technique and with back planes.

For the remote bus of the MICAS Vehicle Bus and the signals to the power converters fibre cables with ST bayonet connectors are used.

PROGRAMMING

The Software required to use the MICAS-S2 control system can be divided into three groups.

- Programs in the control system processors that are independent of the application (operating system firmware).
- Programs for the project specific task of the control system (user programs for control tasks, diagnosis, visualization).
- Programs for the planning of installations, i.e., to write the project specific software as well as for testing, commissioning and maintenance purposes (Mic Tools).

DIAGNOSIS CONCEPT

As part of the distributed control system the MICAS-S2 diagnosis has a decentralized structure. The diagnostic messages are produced by the computers involved in the process and transmitted to the diagnostic computer. The later is equipped with an expert system which evaluates and stores the incoming messages.

Special functional blocks in the Function Block Language (FUPLA) are intended to produce the diagnostic messages in the computers. Therefore the programmer can define which disturbances will cause a diagnostic message to be sent.

The diagnostic messages of the different devices are evaluated by an expert system. The system processes the incoming messages by means of pre-defined rules considering the present operating state of the system. If a failure occurs the driver is given hints on a driver's cab display whether to maintain or to re-start operation. The maintenance staff can be provided with additional information in order to accelerate trouble shooting.

MICAS-S2 also comprises programs to test modules and for the commissioning of vehicles. Automatic testing of single racks as well as of complete pre-produced modules is possible. The temporal behaviour of process variables can be registered if necessary for a longer period time.

With a workstation (a Personal Computer with an additional equipment) users have access to any device connected to the MICAS Vehicle Bus. Check of correct function, trouble shooting, installation of new program versions and so on are possible without interfering with the hardware.

MECHANICAL DESIGN

For the modules in 6U double-height Eurocard format (6U=233.35*220mm) the subracks are configured, manufactured and wired in different widths according to the project need. They include one or several processors, input/output boards, bus couplers and one or more power supplies (Fig.7.2). For protection against electromagnetic interferences the subracks are usually integrated into shielded cases.

Devices with a special format (e.g. Compact Unit alphanumeric display) are not designed for mounting into subracks.

The process signals are connected to the modules by means of front connectors. Common DB9, DB15 and DB25 type connectors according to DIN 41652 are almost exclusively used for process signals.
The incoming messages are processed by the expert system on the diagnostic computer. The expert system reaction on message is programmed by means of the Action Diagnostic Language (ADL). Earlier messages or current operating states can be considered as well to take the appropriate conclusion from a certain diagnostic message. One of the possible conclusions of the

expert system may results in a message output to the vehicle driver. The diagnostic computer passes the message on the visualization controller (Vico). The latter transmits the message to the alphanumeric display in the driver's cab.

The diagnostic computer is nor involved in the process control. This allows the system to be operated without diagnostic computer. Furthermore the diagnostic computer has no influence on functions important for the vehicles safety and therefore, redundancy is not required.

IMPLEMENTATION ON WAP5/WAG9 LOCOMOTIVE

The vehicle control scheme in WAP5/WAG9 loco integrates MICAS-S2 based software and conventional hardware (such as relays, auxiliary contactors etc) for obtaining the desired control functions. It is not proposed to describe the complete control schematic of these locos in this document. The detailed schematics are given in ABB's drawing No. 3EHP 281105 and the software specification is given in ABB document No. 3EHP 541681. After software specification is finalized the logical functions to be performed by software are written as "function groups". Each function group comprises of functional segments written in a graphical language (FUPLA). When all the FUPLA segments are written down, the MICAS-S2 system compiles the program to generate the final vehicle control software. During the design of function groups signal names (variables) are allocated including inputs from the control circuit hardware and these signals are approximately indicated in the control circuit schematics. The control software for converter control are written using FUPLA, 'C' and assembly language programming, but these are covered in Drive Control Software. For the appreciation of how the software and hardware are integrated in the vehicle control scheme, the pantograph control circuit the schematic of which is shown in Fig.7.3 is explained here as an example. The corresponding software specification is given in Annexure 7.1Wire Nos. 2111A and 2111B are at potential of 110V which get supply from the battery circuit and are connected to the spring loaded pantograph switches (129/1&2) of Cab1 and Cab2 respectively. If the driver drives from Cab 1 and pushes the switch 'UP' of 129/1, then battery feed takes the path through 2333A, 123/3 (blocking diode which is provided to block the reverse flow), 2319,2309A, 2300 to 412.QJ. The dotted box 412.QJ, which is an auxiliary control processor board and a part of the Central Electronics – 2 represents that it receives a digital input (#) and actives a PCB-mounted relay. The output is in the form of a normally closed contact. The opening of this contact is done through the software by processing the pantograph disable digital signal in the HBB2(Aux. Cubicle Control) processor. Normally closed contact of 412.QJ and 412.JJ can be forced open in certain conditions like software mismatch, MCE fatal, VCB stuck in 'ON' position etc. thereby disconnecting the feed to the coil of 130.1. So in normal pantograph 'UP' operation of 129/1 switches, the 110V control signal passes through 412.QJ (explained earlier) and 412.JJ (a software function of STB2 low voltage cubicle processor) to energise the auxiliary contactor coil (130.1) of pantograph and its N/O contact (130.1) connected between wire Nos. 2064 & 2302 closes. Once this contact is made, feed is maintained through wire No.

2062, 2061A, 2063, 2061A to energize EP valve (130/2) of pantograph Cab2 side. Thus, pantograph Cab2 side is raised. In case the driver drives from Cab2 then 110V control feed takes the path through electronics 412.QG and EP valve (130/1) is energized and pantograph Cab1 side is raised. Closing of contactor 130.1 is maintained by continuing the feed for energisation of auxiliary contactor coil (130.1) through the path 2064, 2319, 2309, 2300, 2315 and 2301. Status of the pantograph is monitored by the electronics 412.LD and 412.QD.

There are two pressure switches of pantographs 130.4/1 is for monitoring the air pressure for pantograph 1. Similarly 130.4/2 is for pantograph 2. If the air pressure falls below 2.5 kg/cm^2, 130.4 opens out and corresponding signal is processed by the control electronic 412.QA. The pressure switches (130.4/1 and 130.4/2) are monitored by the Central Electronics-2 (412) through the auxiliary cubicle processor (HBB2) boards 412.QA connected to wire No. 2307 and 412.QA connected to wire No. 2308 which gives the message to the drivers display unit (DDU). Similarly the status of the auxiliary contact pantograph (130.1) is monitored by 412.LD and 412.QD. To energise the EP valve 130/2 and 130/1 for raising the pantograph, it is required to close the contact of 412.LJ or 412.QG. These processors 412.LJ and 412.QG take a digital signal by logical “AND”ing the signals of 412.QA & 412.LJ for pantograph 2 and 412.QA & 412.QD for pantograph 1 respectively. During ‘Cooling Mode’ the electronics is in the off state. So raising the pantograph in cooling mode through electronics 412.LJ and 412.QG is not possible because output of 412.LJ and 412.QG are normally open contacts. If driver raises the pantograph from Cab 1 then the feed to the EP valve 130/2 is made through 2111A, contact 130.1, 2103A, 126.6 (safety relay control electronics ‘ON’ which is open in driving mode and closed in cooling mode), 2104A, blocking diode 123/2,2105A, 2107A and 2106A. Similarly if the driver raises the pantograph from Cab 2 the feed to the EP valve 130/1 is made through 2111B, 130.1, 2103B, 126.6, 2104B, 123/2, 2105B, 2107B & 2106B.

The rotary pantograph selection switch (129.1) has got 3 positions (I, AUTO, II). I represents pantograph Cab1 side, II represents pantograph Cab2 side and AUTO represents automatic selection, i.e., if Cab1 is activated pantograph Cab2 side will be raised and if Cab2 is activated pantograph Cab1 side will be raised on pushing ZPT switch (129/*) to ‘UP’ position.

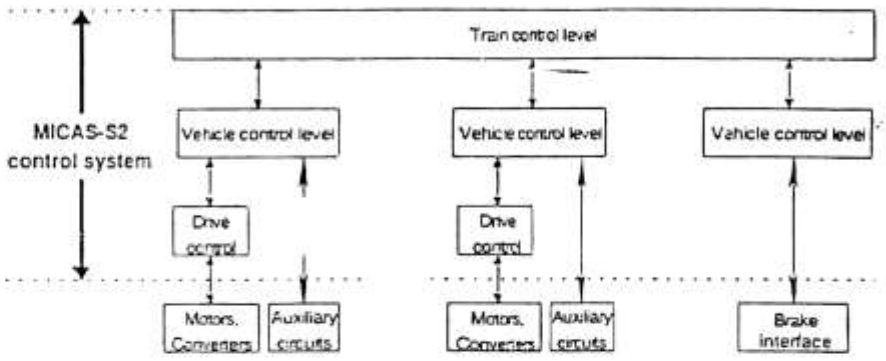


Fig. 7.1 Hierarchical Levels in MICAS Traction Control System

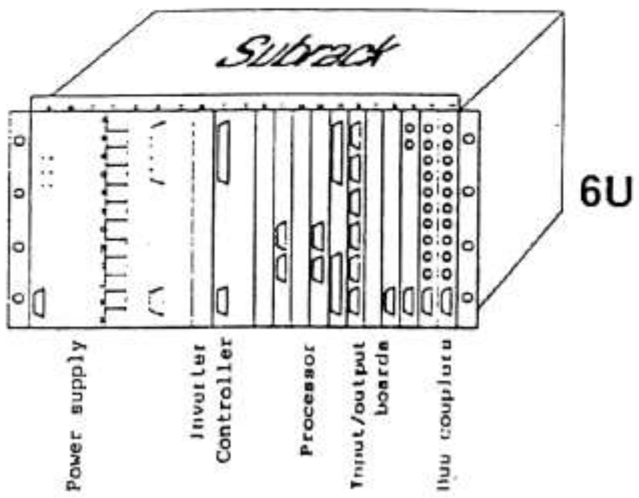


Fig. 7.2 Mechanical Design of Controal Electronics Module

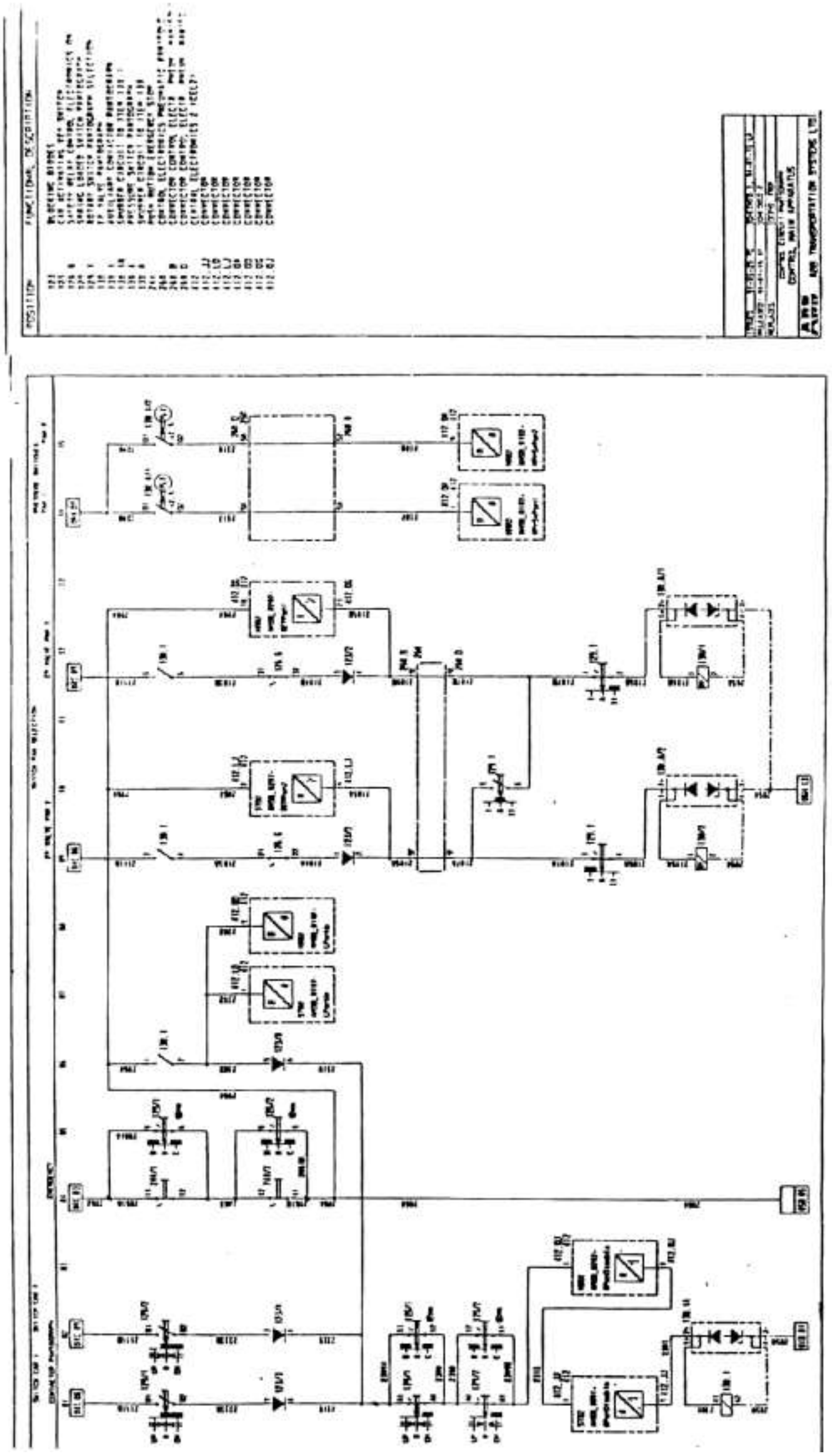


Fig. 7.3 Schematic of Pantograph control Circuit

Annexure 7.1/1

SOFTWARE SPECIFICATION OF PANTOGRAPH CONTROL CIRCUIT

2.2.4 Pantograph	
2.2.4.1 Pantograph section	
n2241.01f	The rotary switch for pantograph {05A, 129.1) has the following 3 positions: Pos. “I” Pan above cab1 is selected Pos. “AUTO” Pan above the inactive cab will be selected automatically. Pos. “II” Pan above cab2 is selected.
n2241.02i	The rotary switch is located in the machine room. The selection is hardwired and without MCE control. Only if the pantograph selector is in Pos. “AUTO” then the MCE selects the pantograph, otherwise the selected pan (rotary switch Pos. “I” or Pos. “II”) will raise independently of the selection by the MCE. Multiple unit → 284.01f
2.2.4.2. Raise and lower pantograph	
n2242.01f	To handle the pan there is a spring loaded switch (129) with 3 positions Pos. “UP” Raise Pan (spring loaded) Pos. “O” Neutral Pos. “DN” Lower Pan (spring loaded)
n2242.02i	Both EP valves {05A, 130} to raise the pan are controlled either by the MCE (key switch in Pos. “D”) or by hardware (cooling mode)
n2242.03f	The driver gives the command to raise the pan with a short push to Pos “UP” of the spring loaded switch (129)
	He gives the command to lower the pan with a short push to Pos “DN” of the switch.
n2242.04f	The pulse generated in the “UP” position energises the auxiliary contactor pantograph {05A, 130.1}. The contractor has different effects depending on mode of the locomotive.
	Cooling mode Contactor {130.1} raise the pantograph above the unoccupied cab
	Driving mode: Contactor {130.1} transmit the command of the driver to the CEL
n2242.05i	The auxiliary compressor secures enough air pressure to raise the pantograph→ 2.5.4 Auxiliary compressor.
n2242.06f	The pan should be able to be lowered by the driver in each situation without any risk of damages to the loco.
n2242.07f	It shall be possible to raise the pan at any speed→ 277.02 Neutral section
n2242.08f	The MCE shall lower the pan and over write the driver’s command “pan up” with “pan down” by de-energising the auxiliary contactor pantograph {05A, 130.1} in the following way: - Key switch in Pos. “O” - Emergency stop push button (06B, 244) - Fatal mode of MCE (loco dead)
n2242.09f	The pan is not lowered automatically in case of the catenary voltage exceeding the upper line voltage.
n2242.10f	Each pan is monitored by a pressure switch {05A, 130.4} VCB open : After the driver’s wish to raise the pan, the driver will be informed by a message on the diagnosis display, that the pan is raising. As long as the air pressure of the pan is not ok, the VCB will be disabled. If the pantograph air pressure will not be ok after 20sec, a fault message will be displayed. VCB closed: In case of low pressure with 2 sec delay at raised pan, VCB will be opened and a priority 1 fault message is displayed. The time delay shall be settable during commissioning.
n2242.11f	If HBB2 isolated, the pan 1 is not available and the pressure switch of pan 2 is not monitored.

ABB	ABB Transportation System Ltd	3 EHP 541 891

Responsible department	Take over department	Revision	Doc-type	File No.
BEF3		A*	SOS	

Proposed	Checked	Approved	Language	Page
95-04-20 W. Hemmann	95-04-21 Ph. Weber	95-04-21 W. Jaun	en	1/9

Vaid tor.	Derived From	Replaces	Classify no.	File
IR WAP 5/WAG9				P541891.DOC

Vehicle Control Software

IR WAP5/WAG9
Design FG 31 – Pantograph Control

Table of Contents

31.1 Purpose

This FG controls and monitors the pantograph \(pans) in the driving mode. In the cooling mode all pan functions are hardwired.

31.2 Reference Documents

[1]	3EHP 541 681	Vehicle Control Software – Specification
	2.2.4	Pantograph selection
	2.8.4	Pantograph (Multiple operation)
	2.8.13	Trailing mode
[2]	3EHP 541 681	Control main apparatus
	05A	Control circuit pantograph

31.3 Processor and Clusters

All processors containing this function group are listed below:

Processor	Description
HBB2	Pan 1 control
STB2	Pan 2 control

31.4 Normal Functionality

31.4.1 General Information

FG31 is divided in four parts :

- Pan up/down wish generation
- Collection of pan up conditions
- Collection of pan down conditions
- Pan control and supervision

31.4.2 Redundancy

Pan 1 is controlled and monitored by HBB2 and pan 2 by STB2. The pan selection logic, which runs simultaneously in FG31 of HBB2 and STB2, selects the pan to be raised. If one processor fails, the other one will raise the connected pan independently of the pan selection logic.

31.4.3 Pantograph selection

With the ‘Pan Selection’ switch ([2], {5A, 129.1}) it is possible to force a pan selection ([1], 2.2.4.1)

- Position “I”	The pan above cab 1 will be raised (hardwired)
- Position “II”	The pan above cab 2 will be raised (hardwired)
- Position “AUTO”	Depending on the parameter (PA 31_P3102 – PanselecSM) in the pan selection logic of FG31

The following table is valid if the ‘Pan selection’ switch is in the “AUTO” position and the loco in the single operation mode:

Parameter name	Value	Description
PA31 – P3102 - PanSelecSM	1(default)	The pan above the unoccupied cab will be raised
PA31 – P3102 -PanSelecSM	2	The pan above the occupied cab will be raised

31.4.4 Pan up/down wish generation

The pan up/down logic in the driving mode is partly hardwired ([2], 05A)
To generate a pan up wish (LpanUp = 1) following conditions must be fulfilled:

- The ‘Pan disable’ contactor must be deenergised (BpanDisable = 0)
- The ‘Emergency stop’ push button ([2], 05A, 244/1 or 244/2}) is released in the activated cab (hardwired : [2], {05A, 125/1 or 125/2})
- The driver pushes the ‘Pan up’ push button in the activated cab (hardwired: [2], {05A, 129/1 or 129/2})

If all these conditions are true, the pan wish logic is in the self hold mode.

The self hold logic can be manually released (Lpanup = 0) by one of the following actions:

- The driver pushes the ‘Pan down’ push button in the activated cab (hardwired: [2] {05A, 129/1 or 129/2})
- The driver pushes the ‘Emergency Stop’ push button in the activated cab (hardwired: [2], 05A, 244/1 or 244/2})

The self hold logic can be released by the software if the ‘Pan disable’ contactor is energised (BpanDisable = 1)

31.4.5 Collection of pan up conditions

In order to raise a pan following requirements must be fulfilled:

- The driver generates a Pan up wish (LpanUp = 1)
- The MSC (master state chart) node has to be 550: ‘Pan enable’ (BPanUpMSC = 1)
- The pan selection logic selects the connected pan (the pan above the unoccupied cab is raised) or the other processor which should raise the pan is isolated

31.4.6 Collection of pan down conditions

There are three groups of pan down conditions:

- Pan down without disturbance
- Protective pan down
- Pan disable

• Pan down without disterbance:
  - The driver generates a pan down wish (LpanUp = 0)
  - The driver switches the ‘Cab activation’ key switch to “0” (Mtrain Occup = 0)
    In these cases of controlled Pan down commands, the VCB will be opened first (BVCBOffDem = 1)

• Protective pan down:
  - The driver pushes the ‘Emergency stop’ push button (hardwired : [2], {05B, 130.1})
  - The VCB is stuck on (MVCBStuckOn = 1)

- Pan disable
  (These signals prevent from raising the pan)
  - The MSC node is lower than 504 (no cab occupied) or 600, 601, 612 or 613 (loco shut down nodes; BPanDnMSC = 1)
  - Subsystem 01 (main power) is isolated

  In the above cases the 'Pan disable' contactor will be energised (BpanDisable = 1) to inhibit any wish to raise the Pan.

31.4.7 Pan Control and Supervision

This part of FG 31 performs following tasks:

- Raises or lowers the selected pan according to the pan up and down conditions, the pan down conditions always have the higher priority
- Supervises the selected pan (see 31.6)

31.4.8 Simulation mode

In the simulation mode (Bsimulation = 1) the pan will not be raised physically. A special signal (BpanUp) is sent to both SLGs to simulate catenary voltage

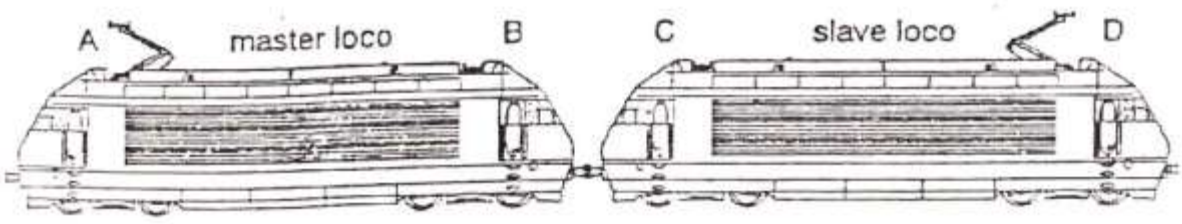
31.5 Multiple Control

31.5.1 Normal operation

The pan up/down generation is working on the master loco only. The up or down wish is transmitted over the Trainbus to the slave loco ([1],V284.02f). If both 'Pan selection' switches ([2], {05A, 129.1}) are in the "AUTO" position then it depends on the parameter (PA31 – P3102 – PanSelecMM) in the pan selection logic of FG31 which pan will be raised. There is a signal from the Trainbus logic (Mside2Con) to detect on which side the loco is coupled.

The following table is valid if both 'Pan selection' switches are in the "AUTO" position and the locos are in multiple operation mode:

Parameter name	Value	Description
PA31_P3102 -PanSelecMM	1(default)	The most distant pans are raised (pan A and D)
PA31_P3102 -PanSelecMM	2	The two most furthest parts from the occupied cab are raised (pan B and D)
PA31_P3102 -PanSelecMM	3	The two pans in driving direction are raised (pan A and C)



31.5.2 The master loco is in trailing mode

Only the pan up/down wish generation is working on the master loco. All other functions are only active on the slave loco. The ‘Pan disable’ contactor on the master loco is controlled by FG31 on the slave loco (13-BpanDisable). The pan selection is the same as in the normal mode (see 31.5.1).

31.6 Disturbances

Since the pan selection can be manually forced, both pressure switches ([2], {05A, 130.4/1 and 130.4/2}) have to be monitored within FG31 because the software cannot detect which pan is actually raised. If one pan is raised and both pressure switches are open for longer than 2 seconds (the value can be set during commissioning: PA31_P3104-PanPresDel) the VCB will be opened and a priority 1 fault message will be displayed ({1},n2242.10f).

31.6.1 HBB2 fails

If HBB2 fails, the HBB2 and Subsystem 14 will be isolated as soon as the driver presses the ‘Fault acknowledge’ push button. If the driver has been driving from cab 2 the driver has to change cab. From cab 1 pan 2 will be selected, which will be raised with a command from STB2.

31.6.2 STB2 fails

If the driver is driving in cab 1 and the STB@ fails, pan 1 should be raised by HBB2 after pressing the ‘Pan up’ push button. In order to make this functionality possible, the pan wish self hold logic must be released by FG31 in HBB2.

31.6.3 Disturbance handling in multiple operation

If there is a shut down on the master loco (BPanDnMSC = 1) the driver’s wish to raise the pan will be reset. This will cause a pan down wish on the slave loco and thereby the pan is lowered on the slave loco as well. After the fault handling and a renewed pan up wish from the driver, the selected pan will be raised on the master and on the slave loco.

If there is a shut down on the slave loco, the selected pan will be lowered on the slave loco but the pan on the master loco will stay raised. After the fault handling the selected pan will be raised automatically because the wish to raise the pan is still active from the master loco.

31.6.4 Disturbance handling in trailing mode

If there is a protective shut down on the slave loc, the selected pan will be lowered on the slave loco and the wish to raise the pan will be reset on the master loco. After the fault handling and a renewed pan up wish, the selected pan will be raised on the slave loco.

31.7 Interface

Below is a complete list of all input and output signals of this function group, ordered by cluster

31.7.1 FG 31 Implemented in HBB2

Cluster Task: 100 ms

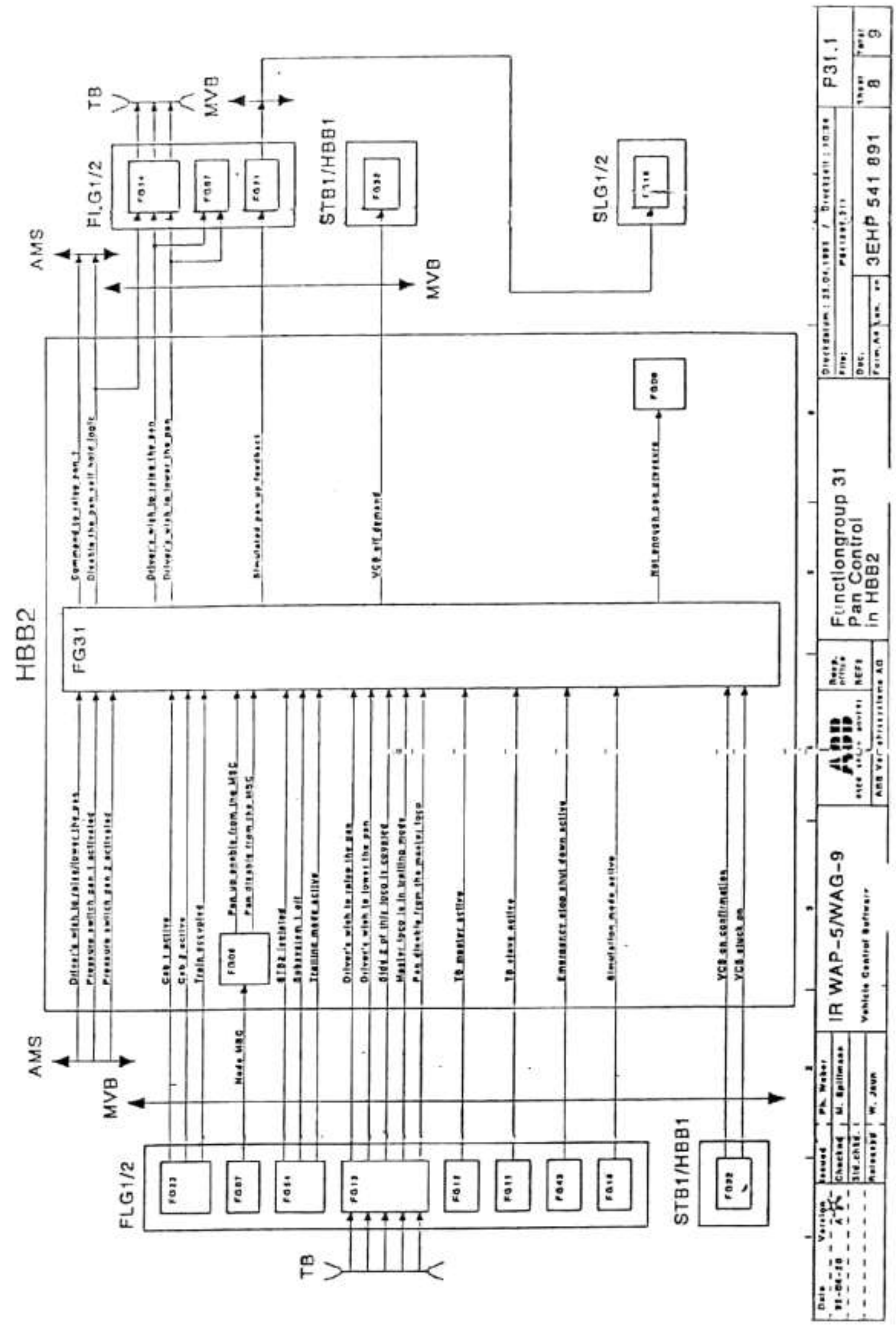
Name	Type	I/O	Bus type	From/To	Description
01-LPanUp	BIT	IN	AMS	{05A,130.1}	Driver’s wish to raise/lower the pan
13-LpanUpWish (M- >S)	BIT	IN	TB	HBB2,FG31 STB2,FG31	Driver’s wish to raise the pan from the master loco
13-LpanDnWish (M- >S)	BIT	IN	TB	HBB2,FG31 STB2,FG31	Driver’s wish to lower the pan from the master loco
23-MCAb1Active	BIT	IN	MVB	FLGM,FG23	Cab1 active
23-MCAb1Active	BIT	IN	MVB	FLGM,FG23	Cab2 active
0895-BpanUpMSC	BIT	IN	INT	FG08	Pan up unable from the MSC
0895- Bpan DnMSC	BIT	IN	INT	FG08	Pan down command from the MSC
11-MTbMastActv	BIT	IN	MVB	FLGM,FG11	This loco is the slave loco in the multiple operation and the Trainbus master is active
12-MTbSlaActv	BIT	IN	MVB	FLGM,FG12	This loco is the slave loco in the multiple operation and the Trainbus slave active
13-Mside2Con	BIT	IN	TB	FLGM,FG13	Side 2 on this loco is coupled to the other loco
54-BSTB2-Off	BIT	IN	MVB	FLGM,FG54	Processor STB2 isolated
23-MtrainOccup	BIT	IN	MVB	FLGM,FG23	Train occupied
43-MemgStopShDn	BIT	IN	MVB	FLGM,FG43	Emergency stop shut down
32-MVCB On	BIT	IN	MVB	HBB1,FG32 STB1,FG32	VCB on confirmation
32-MVCB Stuck On	BIT	IN	MVB	HBB1,FG32 STB1,FG32	VCB stuck on
54-BsubS01-Off	BIT	IN	MVB	FLGM,FG54	Subsystem 01 isolated
18-Bsimulation	BIT	IN	MVB	FLGM,FG18	Simulation mode is active on the loco
54-MtrailMode	BIT	IN	MVB	FLGM,FG54	The master loco is in trailing mode
13-MtrailMode (M→S)	BIT	IN	TB	FLGM,FG54	The master loco is in trailing mode
13-BpanDisable (S→M)	BIT	IN	TB	HBB2,FG31 STB2,FG31	Pan disable from the slave loco. Only valid if the master loco is in trailing mode
01-MPrSwPan1	BIT	IN	AMS	{05A,130.4/1}	Pressure switch pan 1 activated
01-MprSwPan2	BIT	IN	AMS	{05A,130.4/2}	Pressure switch pan 2 activated
31-BVCBOffDem	BIT	OUT	MVB	HBB1,FG32 STB1,FG32	VCB off demand
31-LpanUpWish (M→S)	BIT	OUT	MVB TB	FLGM,FG07 HBB2,FG31 STB2,FG31	Driver’s wish to raise the pan

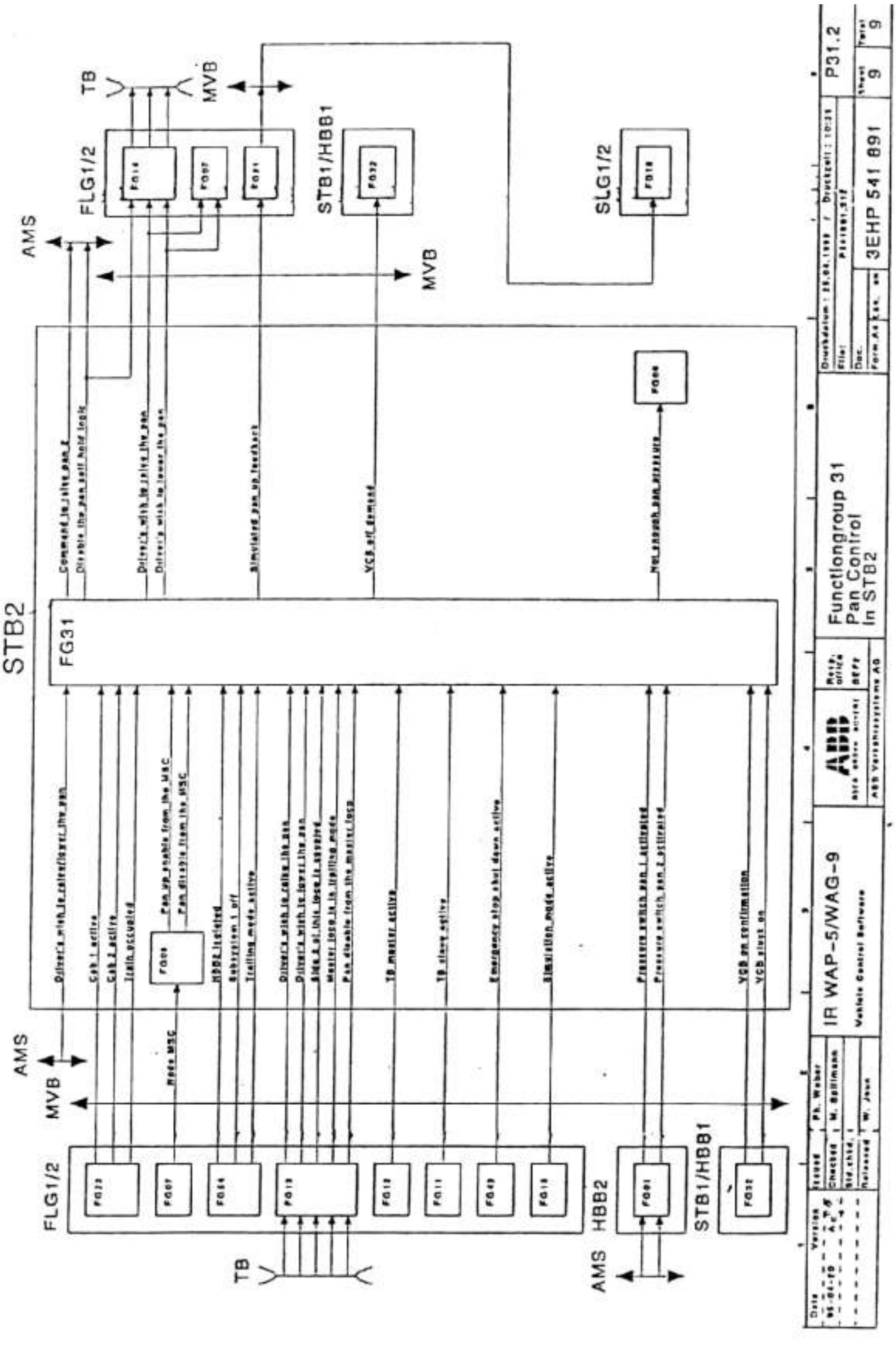
31-LpanDnWish (M→S)	BIT	OUT	MVB TB	FLGM,FG07 HBB2,FG31 STB2,FG31	Driver’s wish to lower the pan
3104-BEPPan1	BIT	OUT	AMS	{05A,130.A/1}	Command to raise pan1
31-BpanDisable (S→M)	BIT	OUT	AMS TB	{05A,130.1} HBB2,FG31 STB2,FG31	Releases/disables the pan self hold logic
3103-Mpan1NoPres	BIT	OUT	INT	FG06	Pan 1 has not enough pressure Disturbance with VCB off and priority 1 fault massage
31-BPanUp	BIT	OUT	MVB	FLGM,FG21 SLGA,FG18 SLG2,FG18	Simulated pan up feedback in orer to simulate catenary voltage in the SLGs. Only valid in the simulation mode

31.7.2 FG 31 Implemented in STB

Cluster Task : 100 ms

Name	Type	I/O	Bus type	From/To	Description
01-LPanUp	BIT	IN	AMS	{05A,130.1}	Driver's wish to raise/lower the pan
13-LpanUpWish (M- >S)	BIT	IN	TB	HBB2,FG31 STB2,FG31	Driver's wish to raise the pan from the master loco
13-LpanDnWish (M- >S)	BIT	IN	TB	HBB2,FG31 STB2,FG31	Driver's wish to lower the pan from the master loco
23-MCAb1Active	BIT	IN	MVB	FLGM,FG23	Cab 1 active
23-MCAb1Active	BIT	IN	MVB	FLGM,FG23	Cab 2 active
0895-Bpan UpMSC	BIT	IN	INT	FG08	Pan up unable from the MSC
0895-Bpan DnMSC	BIT	IN	INT	FG08	Pan down command from the MSC
11-MTbMastActv	BIT	IN	MVB	FLGM,FG11	This loco is the slave loco in the multiple operation and the Trainbus master is active
12-MTbSlaActv	BIT	IN	MVB	FLGM,FG12	This loco is the slave loco in the multiple operation and the Trainbus slave active
13-Mside2Con	BIT	IN	TB	FLGM,FG13	Side 2 on this loco is coupled to the other loco
54-BSTB2-Off	BIT	IN	MVB	FLGM,FG54	Processor STB2 isolated
23-MtrainOccup	BIT	IN	MVB	FLGM,FG23	Train occupied
43-MemgStopShDn	BIT	IN	MVB	FLGM,FG43	Emergency stop shut down
32-MVCB-On	BIT	IN	MVB	HBB1,FG32 STB1,FG32	VCB on confirmation
32-MVCB StuckOn	BIT	IN	MVB	HBB1,FG32 STB1,FG32	VCB stuck on
54-BsubS01-Off	BIT	IN	MVB	FLGM,FG54	Subsystem 01 isolated
18-Bsimulation	BIT	IN	MVB	FLGM,FG18	Simulation mode is active on the loco
54-MtrailMode	BIT	IN	MVB	FLGM,FG54	The master loco is in trailing mode
13-MtrailMode (M→S)	BIT	IN	TB	FLGM,FG54	The master loco is in trailing mode
13-Bpan Disable (S→M)	BIT	IN	TB	HBB2,FG31 STB2,FG31	Pan disable from the slave loco. Only valid if the master loco is in trailing mode
01-MPrSwPan1	BIT	IN	AMS	{05A,130.4/1}	Pressure switch pan 1 activated
01-MprSwPan2	BIT	IN	AMS	{05A,130.4/2}	Pressure switch pan 2 activated
31-BVCBOffDem	BIT	OUT	MVB	HBB1,FG32 STB1,FG32	VCB off demand
31-LpanUpWish (M→S)	BIT	OUT	MVB TB	FLGM,FG07 HBB2,FG31 STB2,FG31	Driver's wish to raise the pan
31-LpanDnWish (M→S)	BIT	OUT	MVB TB	FLGM,FG07 HBB2,FG31 STB2,FG31	Driver's wish to lower the pan
3104-BEPPan1	BIT	OUT	AMS	{05A,130.A/1}	Command to raise pan1
31-BpanDisable (S→M)	BIT	OUT	AMS TB	{05A,130.1} HBB2,FG31 STB2,FG31	Releases/disables the pan self hold logic
3103-Mpan1NoPres	BIT	OUT	INT	FG06	Pan 1 has not enough pressure Disturbance with VCB off and priority 1 fault massage
31-BPanUp	BIT	OUT	MVB	FLGM,FG21 SLGA,FG18 SLG2,FG18	Simulated pan up feedback in order to simulate catenary voltage in the SLGs. Only valid in the simulation mode


HBB2
FG31
FLG1/2
STB1/HBB1
SLG1/2
AMS
MVB
TB
Functiongroup 31
Pan Control
in HBB2
IR WAP-5/WAG-9
3EHP 541 891
P31.1


STB2
FG31
FLG1/2
MVB
AMS
TB
HBB2
STB1/HBB1
SLG1/2
IR WAP-5/WAG-9
Functiongroup 31
Pan Control
In STB2
3EHP 541 891
P31.2

8.**PNEUMATIC SYSTEM**

WAP5/WAG9 locomotives are provided with a pneumatic system integrated with electronic controls supplied by M/s Davies & Metcalfe. The systems provided in WAP5 and WAG9 locomotives are similar except for some minor differences owing to the difference in the brake riggings provided in the Bo-Bo (WAP5) and Co-Co (WAG9) bogies and arrangement of main reservoirs.

Description of Air Supply, Distribution and Brake Control Equipment

Equipment fitted in the WAP5 Bo-Bo Passenger Locomotive are shown on Scheme B1685 given at Annexure 8.1 and all reference numbers used in the description given below are those listed in the document B1685PL1 given at Annexure 8.2. The schematics and parts list for WAG9 locomotive are given at Annexure 8.3 and Annexure 8.4 respectively.

Air Supply

There are two 2A320D electrically driven air compressors (20) which feed out through flexible hoses (18) and (19) and through two compressor check valves 11 into the main reservoir system. There is a safety valve (10) in each of the compressor legs to protect the system in the event of a check valve blockage and there is an unloader valve (12) also in each leg. The unloader is operated from an electro-pneumatic valve (33) mounted on the brake frame. Once through the compressor check valves the compressors feed through a single water separator (87), which is fitted with an auto drain valve. This auto drain valve is operated from the same signal line that operates the unloader valves (12). Having passed through the water separator the air passes into two main reservoirs (89) and (110) both fitted with a manual drain cock (90) and an auto drain valve (124). The auto drain valves are also operated from the signal that operates the unloader.

Having passed through the two main reservoirs which will allow further condensate to be extracted from the air, the air flow is a via a vented isolating cock (13) into the twin tower air dryer (77) which gives a significant dew point depression to the air passing into the locomotive, through the final filter (15) which removes any of the dust which can be created from the air dryer desiccant and then the air passes through an isolating cock (14). There is another isolating cock (14) which is intended to be wired closed and only used to by pass the air dryer if there is any significant problem with that unit. This portion of the main reservoir circuit has the main reservoir system safety valve (39) and the two compressor governors (35) and (36), (35) being for operation of a single compressor in alternating mode between 10 kg/cm^2 and 8 kg/cm^2 and compressor governor (36) being for operation of both compressors between 7.5 kg/cm^2 and 10 kg/cm^2. The low main reservoir governor (37) is also in this part of the circuit and is used to interlock with traction in the event of the main reservoir pressure falling below its set point.

The main reservoir supply splits at this point one leg passing through check valve (91) into another 240 litre main reservoir (89) fitted with a manual drain cock (90) only. This leg continues through an isolating cock (94) and into the brake frame via port U where it passes through an in line filter (138) before splitting and feeding the pilot supply for the direct brake isolating valves (115), the pilot supply for the brake cylinder cut out valve (52), the main reservoir supply for the direct relay valve (58) and the main reservoir supply for the blending valve (55). There is a test point 40 in the section of the main reservoir supply where the two legs split. The other leg is the main reservoir feed to the brake frame through port W. This feed passes through an in line filter (138) before splitting to various locations within the brake frame.

One of these splits passes through the duplex check valve (92) into the main reservoir equalizing pipe portion of the circuit. The main reservoir equalizing pipe is the through pipe which connects the main reservoir from one locomotive to another via hose and coupling (95) and end cock (96). The connection between the main reservoir equalizing through pipe and brake frame is via port X and this then passes through an in line sieve (138) into the passage work fed by the duplex check valve (92). The duplex check valve allows the main reservoir equalizing pipe to feed via a simple check valve into the locomotive main reservoir supply within the brake frame and to the third main reservoir (89) through check valve (91). This direction of flow through the duplex check valve has virtually no restriction and allows one locomotive to feed the main reservoir system with another in the event of a failure of the compressor system on that locomotive. It also enables air to be fed from the slave locomotive in a multiple consist to the lead locomotive if there is a heavy demand for air rather than the lead locomotive having to cope solely with that air demand. From the main reservoir to the main reservoir equalizing pipe however, the duplex check valve is set up at 5 kg/cm^2 such that the main reservoir pressure has to be at or above the set pressure before the valve will feed any air. This is to ensure that the locomotive retains air in the main reservoir system in the event of a burst main reservoir equalizing pipe hose or other problem in that portion of the system.

The main reservoir equalizing pipe within the brake frame feeds three independent parts of the circuit. The first is a “break-in-two” protection valve 46 which is open, connecting the direct brake valve on the lead locomotive to the direct brake pipe or connecting the direct brake pipe on the slave loco to the direct brake relay valve when main reservoir equalizing pipe pressure is present but shuts off this connection in the event of a “break-in-two” to ensure that it is possible to make a directed brake application on the locomotive once the “break-in-two” has occurred.

The second is the brake feed pipe regulator (137) and relay valve (93). The regulator is used to set the pressure to the control part of the relay valve at 6 kg/cm^2 and the relay valve feeds out the large volume of air required at 6 kg/cm^2 level via isolating cock (136), port B of the brake frame to the brake feed pipe which is a through locomotive pipe and feeds the brake feed pipe on any two pipe trailing stock. The connection to other locomotives or trailing stock is made via hose and coupling (101) and end cocks (102) within the brake frame downstream of the brake feed pipe isolating cock (136) there is a test point (107) and a pressure switch (34).

The third area that the main reservoir equalizing pipe feeds within the brake frame is the sanding equipment. There is a direct feed taken to the pilot supply of the four sanding EP valves (73) and the choked supply via choke (171) through to reservoir (170) and then via two legs each with an isolating cock (134) to two of the four sanding valves per leg. The sanding EP valves feed out via ports C and D to the number 1 end leading no.1 bogie and the number 1 end leading the no.2 bogie respectively. The other leg sanding valves feed out vi ports E and F to the number 2 end leading no. 1 bogie and the no. 2 end leading no. 2 bogie respectively. The arrangement of choke (171) and reservoir (170) is there to ensure that when the sanding valves are operated there is arush of air to start the sand moving in the sand injectors (103), the rush of air coming from the air stored in the reservoir (170) and subsequent sanding is carried out by the steady flow of air passing through choke (171). In this way the equipment ensures that the sand sitting in the nozzle of the injector is moved so that flow can commence and a steady sand application made in a controllable fashion.

External to the brake frame the main reservoir equalizing pipe is used to provide the feed to the antislip valves (65). The anti-slip valves are utilized when and axle set(s) slips and the slip is not able to be corrected by the traction control equipment. The antislip valve is energised and rapidly puts air into the brake cylinders feeding into the break cylinder circuit via as double check valve (66). The anti-slip valve is designed to give a rapid build-up of brake cylinder pressure, typically in the order of one second and have a long release time typically 20 to 30 seconds in order that the power can be re-applied with some degree of brake application still present. The main reservoir equalizing pipe is also taken into each cab via an inline strainer (129) to provide the air supply to the wind screen wipers via vented isolating cock (130) and the air supply to the horns via vented isolating cock (120). The horn supply is taken to a two way horn valve (123), one on the driver's and one on the assistant driver's desk, each valve feeding the two horns (1) and (2), one operated in the forward direction and the other in the rearward direction of handle movement.

Automatic Brake System

The main reservoir supply from port W is utilized by the flow meter (42) to supply air to the direct brake valves (112) in each cab via port H on the brake frame and to the E70 brake unit (29). Whenever there is a demand of air from either the direct brake or more importantly the E70 unit there is a pressure differential set up across the flow meter which results in a reduction in pressure in the signal line from the flow meter to the flow meter valve (43). The flow meter valve (43) is in effect a pneumatic amplifier having high gain so that with a small pressure change from the Venturi there is a large pressure change in the output pipe from valve (43) to port M on the brake frame and hence to the flow meter gauges. Also on the output line from valve (43) is a pressure switch (44), which senses when there is a high flow demand. The flow meter valve (43) also utilizes main reservoir air from port W.

The control of the automatic brakes via the E70 brake control unit (29) in charging and varying the brake pipe pressure is described in D&M catalogue A658/2 which also describes the interaction with the automatic brake controllers (111). This catalogue immediately follows this overall system description. The brake pipe output from the E70 unit is taken via isolating cock (70), which has auxiliary switch contacts. These switch contacts are made when the isolating cock is closed to indicate if the cock is closed inadvertently during operation or as an indication that the brake pipe will not charge when taking control of a locomotive. The brake pipe passes out of the brake frame via port AA to connect to the through automatic air brake pipe. This is taken to other locomotives and to trailing coaches (or wagons) via hose and coupling (97) and end cock (98). There are test points (118) in the automatic air brake pipe. There is a connection taken from the automatic air brake through pipe into each cab which connects to the assistant driver's emergency cock (113) and to a large bore exhaust valve (116) which is pilot fed from the automatic brake controller (111). This gives two direct means of applying emergency brake from the cab either by the automatic brake controller or from the assistant driver's cock. Within the brake frame the air brake pipe is taken to a port on the distributor (49) and also to the brake pipe is taken to a port on the distributor (49) and also to the brake pipe governor (pressure switch) (69) and via emergency (vigilance) cock (74) to the emergency vigilance exhaust valve (71). The brake pipe governor is used to signal to the traction equipment that an emergency brake application has been made. The emergency (vigilance) exhaust valve (71) is controlled by the EP valve (72) in turn being controlled by the vigilance device (176) emergency push buttons in the cab or over speed switch. If the EP valve (72) de-energizes, an emergency brake application is made via the exhaust valve 71 exhausting the air brake pipe through exhaust port 7. The EP valve (72) takes its air supply from the main reservoir port W within the brake frame. The emergency (vigilance) cock (74) also has auxiliary switch contacts so that an alarm is raised if this isolating cock is closed.

The distributor (49) responds to the variations in pressure in the brake pipe by comparing them with the control reservoir within the unit (49). A distributor supplies a signal proportional to the fall in the brake pipe via the dynamic brake cut out EP valve (52) to a volume reservoir (53), test point (75) and via double check valve (54) to the relay valve (57). The relay valve is an amplifier taking the signal from the distributor and increasing it in the ratio of approximately 1.44 to 1 and passing this signal out via port A on brake frame to the brake cylinders. There is a pressure switch 80 which is used for vigilance suppression together with the test point (61) on the output from the relay valve (57). The dynamic brake cut out EP valve (52) is utilized when there is a dynamic brake present of greater than 10 kN, being energised to prevent the output of the distributor passing to the relay valve. This prevents any duplication of braking effort of both dynamic and automatic air brakes on the locomotive. Additionally, on the distributor (49) there is an EP valve and limiter, which allows the driver to operate a push button (PVEF) in the cab and remove the automatic air brake application on the locomotive. This allows the driver to make a train brake application via the automatic air brake pipe but remove the locomotives proportion of this, allowing the train to brake the locomotive. This is inoperative when an emergency brake application is made, thus ensuring that a locomotive brake application will occur if an emergency brake application is made following a full services application where this feature has been used to remove the locomotive brake application.

The air supply for the distributor (49) and the automatic brake relay valve (57) is taken from the auxiliary reservoir (51), fitted with a manual drain valve (90), which is external to the brake frame and connected via port J. The auxiliary reservoir (51) is charged from the main reservoir connection at port W via check valve (106). When the locomotive is being hauled dead, as part of the train, and not connected to another locomotive via the main reservoir equalizing pipe the auxiliary reservoir can be charged from the brake pipe which enters the brake frame at port K. The dead engine cock (47) has to be turned from its normal closed position to be open and allow the brake pipe pressure to feed via check valve 48 into the auxiliary reservoir.

Parking Brake

The release air for the spring applied parking brake is taken from the auxiliary reservoir (51) via reducing valve (114), latched solenoid valve (30) and via choke (31) though port N via the bogies hoses (104), bogie to actuator hoses (183) to the spring brake port on the disc brake actuators (108). The reducing valve (114) limits the maximum pressure that the spring brake release cylinder will have supplied to it. The latched solenoid valve 30 enables the driver to apply and release the parking brake on both the lead and the slave locos in a multiple consist from the drivers cab. There are also manual push buttons on the latched solenoid valve (30) so that in addition to being able to be controlled electrically from the cab, it can be manually operated to apply and release the parking brake provided there is air pressure on the locomotive. The choke (31) ensures that in the event of a burst hose in the parking brake feed, that the loss of air from the auxiliary reservoir s restricted. The parking brake is supplied with its release air from the auxiliary reservoir so that when the locomotive is being hauled as a dead loco the brake pipe feed into the auxiliary reservoir can thus be used to ensure that the parking brake is also released. There is a pressure switch (32), which indicates whether the parking brake is applied or released.

Brake blending

The locomotive has the facility to blend the dynamic and air brakes. This facility will be used, in practices, to apply the air brakes to the same level as the dynamic brakes in the event of a dynamic brake failure. The EBC/5 blending value (55) responds to the signal from the dynamic brake equipment, which indicates the level of air brake, required and feeds out via check valve (54) to the relay valve (57), which supplies the air for the brake cylinders. There is a test point (56) which can be used to check the output of the blending valve (55).

Direct Brake

The direct brake valves (112) take their air supply from port H on the brake frame. The direct brake isolate valves (115) on the brake frame are energized to close. On the lead loco the direct brake isolate valve is de-energised for the particular cab which is switched on and the direct brake valve input via either port V or port O is taken into the frame, passed by the de-energised isolate valve (115) to the direct brake relay valve (58). There is a test point (119) provided in the feed to the brake frame in order to test the output pressure from the brake value in addition to feeding the relay valve (58) the direct brake valves also feed out via a "break-in-two" protection valve (46) through port L on the brake frame to the direct brake pipe which is a through pipe on the locomotive passing out to adjacent locomotives working in multiple via hose and coupling (99) and end cock (100). On the trailing locomotive, feed in from the direct air brake pipe is taken in through port L on the brake frame passed via the "brake-in-two" protection valve (46) to the direct brake relay valve (58). The direct brake isolate valve (115) are both energized on the trailing loco and prevent any air being passed out to the direct brake valves in the cabs and hence allow the direct brake on the trailing locomotive to be applied.

Brake Cylinder Feeds

The direct brake cylinder pressure is taken from the brake frame at port Y having come from the direct brake relay valve (58), with test point (76) in that portion of the circuit and feeds down to each bogie via a bogie hose protection choke (67) through a double check valve (66), which interfaces with the anti-slip valve and another double check valve (66), which interfaces with the automatic air brake application. The air then passes via a vented bogie isolating cock (63) through the bogie hose choke (105) and then to the service brake portion of the two service / parking brake actuators (108) via the actuator hoses (148) and to the two service actuators (109) also via actuator hoses (184). The actuators operate through the right hand and left hand caliper sets (149) and (150) onto the brake discs (148). There are also wheel tread conditioning units (147) which are operated from the same air supply that operates the service brake cylinders.The automatic air brake application is supplied from port A on the brake frame and comes from the automatic air brake relay valve (57) and out to each bogie via bogie hose protection choke (62) and then through the double check valve (66) to go into the main bogie air supply pipe that is common with direct brake and anti-slip brake feeds. Down stream of bogie isolating cock (66) there is a connection taken off for the brake cylinder pressure switch 64 and the connection to the cab gauge (131).

Pantograph Equipment

The pantograph air supply air supply for normal operation comes from the main reservoir connection at port W on the brake frame. This is taken up via check valve (25) into the pantograph reservoir (22) and is the pilot supply for the two-pantograph EP valve (6). The air also passes via vented isolating cock (5) out via port Q to the main circuit breaker (4). The air passes to the pantographs via the Kabba key switch cock 38 via the two pantograph EP valves 6, vented isolating cock (8) and existing the brake frame via ports S for the no.1 end and R for the no.2 end pantograph (3). There is a throttle valve 80 between the air supply from the brake frame and the pantograph itself. There is a pressure switch (9) in between the vented isolating cock (8) and the port from the brake frame (S/R) which supplies a signal to the ABB central electronics to indicate the status of air supply to the pantograph.

There is an alternative means of providing air for the pantograph if the locomotive has been stabled for some time and there is no main reservoir air present at port W. An auxiliary compressor (78) controlled via pressure switch (26) supplies air via flexible hose (17) and into the brake frame at port P. The air then passes via a centrifugal strainer (84) through check valve (24) and into the pantograph reservoir (22) and the remainder of the pantograph circuit. The pressure switch (26) acts as a compressor governor for the auxiliary compressor ensuring it does not operate when the main reservoir pressure has exceeded the pressure switch maximum setting. There is also a test point (27) in the pantograph circuit to enable the various settings to be checked. Additionally, between selections switch (85) is described within the electrical description within the D&M catalogue M366/BEM.

Auxiliary Air Supplies

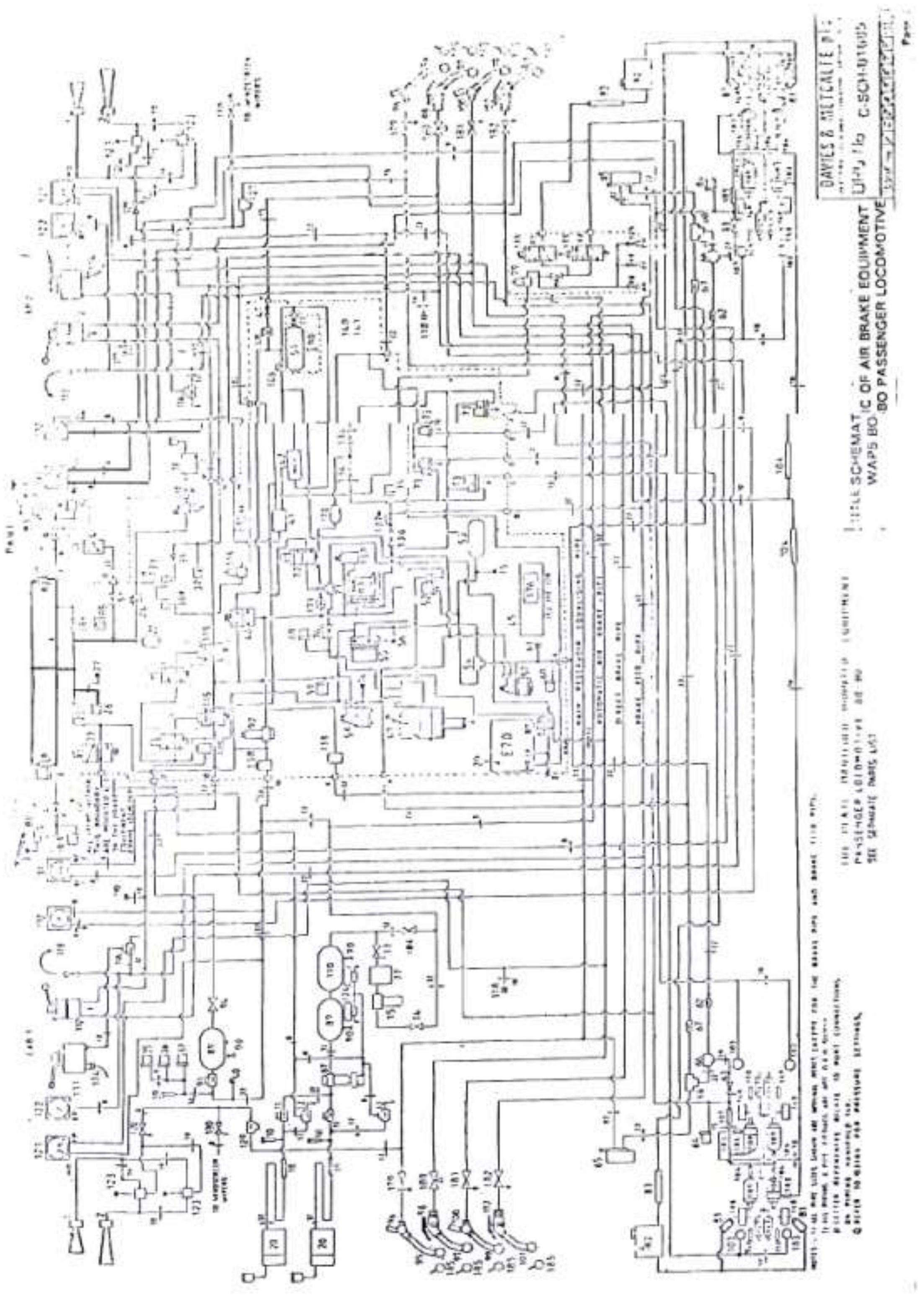
There is an additional sub-manifold bolted to the rear of the brake frame on the left hand side which takes its main reservoir air supply from that coming in at port W and passes through a reducing valve (79) and go into four isolating cocks. The isolating cocks (68), (88) and (125) supply air to the various electrical cubicles for the traction control equipment. The isolating cock (86) supplies air to two EP valves (135) for the flange lubrication equipment. The air from these EP valves passes out from port EE for the No.2 end and FF for the No.1 end and pass through flexible hose (83) to the flange lubrication pump (82). This supplies the lubricant via nozzles (81) to the external axle sets of the bogie.

Cab Instrumentation

There are four cab gauges provided in each driver’s cab to provide indication for the driver. Gauge (121) indicates the main reservoir pressure of the input to the brake frame at port W and the brake feed pipe pressure which is the air supply pipe for trailing vehicles. Gauge (122) shows the pressure in the brake pipe. Gauge (131) show the pressure in the brake cylinders down stream of the bogie isolating cocks for both bogie1 and bogie2. Gauge (132) is the flow meter gauge and gives the differential reading between the main reservoir pressure at port W on the brake frame the output from the flow meter valve (43) hence giving an indication of the air requirement to the automatic air brake pipe. Thus the flow meter gauge will give an indication if for any reason there is a heavy flow demand such as that caused by a “break-in-two” of the train.

End Connection Protection

Dummy couplings (185) are provided to house the coupling head of the hoses and couplings (96), (97), (99) and (101) when they are at the end of the locomotive which is not coupled. Vented isolating cocks are provided in board of the headstock to enable the four through pipes on the locomotive to be isolated in the event of damage to the end cocks on the external headstock. These cocks are all vented and will vent the headstock side of the pipe. The brake pipe isolating cock has a full bore vent thus ensuring that should it inadvertently be closed on a trailing locomotive the leading locomotive will be unable to create brake pipe pressure or be unable to create a brake pipe pressure or be unable to create a brake pipe pressure on the locomotives or the train.



Schematic of Air Break Equipment WAP5 BO-BO PASSENGER LOCOMOTIVE

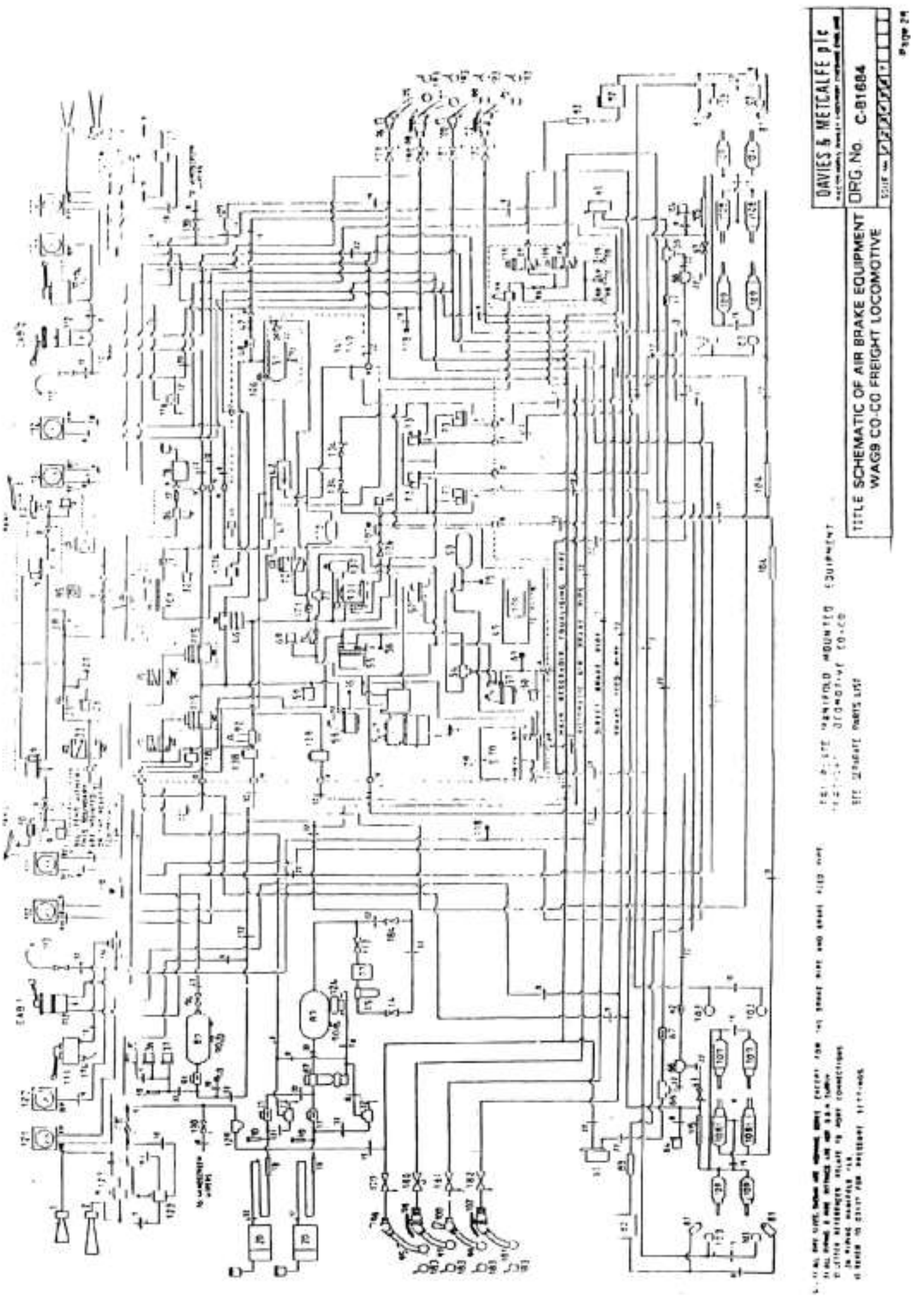
Annexure 8.2

REF	DESCRIPTION	QTY.
1	AIR HORN	2
2	AIR HORN	2
3	PANTOGRAPH	2
4	MAIN CIRCUIT BREAKER	1
5	ISOLATING COCK 3/8” VENTED	1
6	SOLENOID VALVE (PANTOGRAPH)	2
7	-	-
8	ISOLATING COCK 3/8” VENTED	2
9	PRESSURE SWITCH PANTOGRAPH	2
10	SAFETY VALVE ¾”	2
11	COMPRESSOR CHECK VALVE1-1/4”	2
12	UNLOADER EXHAUSE VALVE 1”	2
13	LATCHED ISOLATING COCK 1-1/4”VENTED	1
14	ISOLATING COCK 1-1/4”	2
15	FINAL FILTER	1
16	-	-
17	AUXILIARY COMPRESSOR DELIVERY HOSE	1
18	COMPRESSOR DELIVERY HOSE	1
19	COMPRESSOR DELIVERY HOSE	1
20	MAIN COMPRESSOR WITH MOTOR	2
21	-	-
22	PANTOGRAPH RESERVOIR 5 LITRE	1
23	SAFETY VALVE ¼”	1
24	COMPRESSOR CHECK VALVE ½”	1
25	CHEK VALVE ½”	1
26	AUXILIARY COMPRESSOR PRESSURE SWITCH	1
27	½” TEST POINT (VENTED PLUG)	1
28	-	-
29	E70 EQUIPMENT MANIFOLD ASSEMBLY	1
30	LATCHED SOLENOID VALVE (PARKING BRAKE)	1
31	CHOKE	1
32	PARKING BRAKE PRESSURE SWITCH	1
33	EP VALVE UNLOADING	1
34	BRAKE FEED PIPE PRESSURE SWITCH	1
35	COMPRESSOR PRESSURE SWITCH	1
36	COMPRESSOR PRESSURE SWITCH	1
37	LOW MAIN RESERVOIR PRESSURE SWITCH	1
38	KABA-KEY COCK	1
39	SAFETY VALVE ¾”	1
40	½” TEST POINT	1
41	-	-
42	VENTURE VALVE	1
43	FLOW METER GAUGE RELAY VALVE	1
44	VENTURI VALVE PRESSURE SWITCH	1
5	ELECTRONICS ENCLOSURE	1
46	BREAKAWAY PROTECTION VALVE	1
47	TOWING COCK 3/8”	1
48	CHECK VALVE WITH STRAINER ½”	1
49	DISTRIBUTOR DMD3	1
50	-	-
51	BRAKE SUPPLY RESERVOIR 240 LITRES RIGHT HAND	1
52	BRAKE CUT OUT VALVE	1
REF	**DESCRIPTION**	**QTY.**

53	CAPACITY RESERVOIR 5 LITRES	1
54	DOUBLE CHECK VALVE ½”	1
55	EBC/5BLENDING UNIT	1
56	½” TEST POINT (VENTED PLUG)	1
57	D2 RELAY VLVE (AUTOMATIC BRAKE)	1
58	D2 RLAY VLVE (DIRECT BRAKE)	1
59	DIRECT BRAKE PRESSURE SWITCH	1
60	VIGILANCE PRESSURE SWITCH	1
61	½” TEST POINT (VENTED PLUG)	1
62	CHOKE 3/16” BORE	2
63	ISOLATING COCK 34” VENTED	2
64	BRAKE CYLINDER PRESSURE SWITCH	2
65	ANTI SPIN VALVE	2
66	DOUBLE CHECK VALVE ¾”	4
67	CHOKE 3/16” BORE	2
68	ISOLATING COCK 3/8” (TRACTION CONVERTER 2)	1
69	BRAKE PIPE PRESSURE SWITCH B.P.G	1
70	E70 BRAKE PIPE ISOLATING COCK WITH SWITCH 1-1/4”	1
71	EMERGENCY EXHAUST VALVE	1
72	EMERGENCY EP VALVE	1
73	SANDING VALVE	4
74	EMERGENCY /VIGILANCE ISOLATING COCK WITH SWITCH 1-1/4”	1
75	½” TEST POINT (VENTED PLUG)	1
76	½” TEST POINT (VENTED PLUG)	1
77	TWIN TOWER AIR DRYER WITH PRE-COALESCER	1
78	AUXILIARY COMPRESSOR	1
79	PRESSURE REGULATOR ½”	1
80	THROTTLE VALVE	2
81	FLANGE LUBRICATION CONTROL	4
82	GREASE PUMP WITH RESERVOIR	2
83	FLEXIBLE HOSE 3/8”	2
84	CENTRIFUGAL STRAINER WITH DRAIN COCK ½”	1
85	PANTOGRAPH SELECTION SWITCH	1
86	ISOLATING COCK 3/8” (WHEEL FLANGE LUB)	1
87	OIL SEPARATOR / DRIP CUP WITH AUTO DRAIN VALVE	1
88	ISOLATING COCK 3/8” (FILTER CUBICLE)	1
89	MAIN RESERVOIR 240 LITRES LEFT HAND	2
90	DRAIN COCK 3/8”	4
91	CHECK VALVE 1-1/4”	1
92	DUPLEX CHECK VALVE 1-1/4”	1
93	PRESSURE CONTROL VALVE	1
94	LATCHED ISOLATING COCK 1-1/4”	1
95	HOSE AND COUPLING 1” (M.R.E.P)	2
96	END COCK 1” RH	2
97	HOSE AND COUPLING 1-1/4” R.H BRAKE PIPE	2
98	END COCK 1-1/4”	2
99	HOSE AND COUPLING 1-1/4” L.H	2
100	END COCK 1”	2
101	HOSE AND COUPLING 1-1/4” L.H FEED PIPE	2
102	END COCK 1-1/4”	2
103	SANDER NOZZLE	8
104	HOSE	2
105	HOSE	2

REF	DESCRIPTION	QTY.
106	CHECK VALVE 1”	1
107	½” TEST POINT (VENTED PLUG)	1
108	COMBINED BRAKE CYLINDER/PARKBRAKE UNIT WITH SLACK ADJUSTER	4
109	BRAKE CYLINDER WITH SLACK ADJUSTER	4
110	MAIN RESERVOIR 240 L RIGHT HAND	1
111	DRIVERS BRAKE CONTROLLER	2
112	DRIVERS DIRECT BRAKE VALVE FDI	2
113	ISOLATING COCK 1-1/4” (EMERGENCY)	2
114	PRESSURE REGULATOR ½”	1
115	DIRECT BRAKE EXHAUST VALVE	2
116	EMERGENCY EXHAUST VALVE 1-1/4”	2
117	-	1
118	½” TEST POINT	2
119	½” TEST POINT	2
120	ISOLATING COCK 3/8” VENTED	2
121	DUPLEX PRESSURE GAUGE (F.P-M.R)	2
122	PRESSURE GAUGE BRAKE PIPE	2
123	2-WAY HORN VALVE	4
124	AUTO DRAIN VALVE	2
125	ISOLATING COCK 3/8” (TRACTION CONVERTER 1)	1
126	-	-
127	-	-
128	-	-
129	AIR LINE SIEVE 3/8”	2
130	ISOLATING COCK 3/8” VENTED	2
131	DUPLEX PRESSURE GAUGE (B.C1-B.C2)	2
132	FLOW METER GAUGE	2
133	-	-
134	ISOLATING COCK 3/8” VENTED	2
135	EP VALVE	2
136	ISOLATING COCK 1-1/4”	1
137	PRESSURE REDUCING VALVE	1
138	AIR LINE SIEVE 1” (IN LINE)	3
139	-	-
140	BRAKE FRAME INTERFACE MANIFOLD	1
141	BRAKE CONTROL EQUIPMENT RACK	1
142	-	-
143	-	-
144	-	-
145	-	-
146	-	-
147	WHEEL TREAD CONDITIONERS	8
148	BRAKE DISC	8
149	BRAKE CALIPERS STANDARD (RH)	4
150	BRAKE CALIPERS SPB (LH)	4
151	-	-
152	-	-
153	-	-
154	-	-
155	-	-
156	-	-
157	-	-
158	-	-
159	-	-
160	-	-
161	-	-
162	-	-
163	-	-

REF	DESCRIPTION	QTY.
164	-	-
165	-	-
166	-	-
167	-	-
168	-	-
169	-	-
170	CAPACITY RESERVOIR 5 LITRE	1
171	CHOKE	1
172	37 WAY FREE SOCKET (CUSTOMER)	1
173	19 WAY FREE SOCKET (CUSTOMER)	1
174	19 WAY FREE SOCKET (CUSTOMER)	2
175		
176	VIGILANCE CONTROL EQUIPMENT	1
177	-	-
178	19 WAY FREE SOCKET (CUSTOMER) VIGILANCE	1
179	ISOLATING COCK VENTED ¾"	2
180	ISOLATING COCK VENTED 1-1/4"	2
181	ISOLATING COCK VENTED ¾"	2
182	ISOLATING COCK VENTED 1-1/4"	2
183	HOSE 3/8"	2
184	HOSE ½"	8
185	DUMMY COUPLING	8



Schematic of Air Break Equipment WAG9 CO-CO FREIGHT LOCOMOTIVE

Annexure 8.4

REF	DESCRIPTION	QTY.
1	AIR HORN	2
2	AIR HORN	2
3	PANTOGRAPH	2
4	MAIN CIRCUIT BREAKER	1
5	ISOLATING COCK 3/8” VENTED	1
6	SOLENOID VALVE (PANTOGRAPH)	2
7	-	-
8	ISOLATING COCK 3/8” VENTED	2
9	PRESSURE SWITCH PANTOGRAPH	2
10	SAFETY VALVE ¾”	2
11	COMPRESSOR CHECK VALVE1-1/4”	2
12	UNLOADER EXHAUSE VALVE 1”	2
13	LATCHED ISOLATING COCK 1-1/4”	1
14	ISOLATING COCK 1-1/4”	2
15	FINAL FILTER	1
16		
17	AUXILIARY COMPRESSOR DELIVERY HOSE	1
18	COMPRESSOR DELIVERY HOSE	1
19	COMPRESSOR DELIVERY HOSE	1
20	MAIN COMPRESSOR WITH MOTOR	2
21		
22	PANTOGRAPH RESERVOIR 5 LITRE	1
23	SAFETY VALVE ¼”	1
24	COMPRESSOR CHECK VALVE ½”	1
25	CHEK VALVE ½”	1
26	AUXILIARY COMPRESSOR PRESSURE SWITCH	1
27	½” TEST POINT (VENTED PLUG)	1
28	-	-
29	E70 EQUIPMENT MANIFOLD ASSEMBLY	1
30	LATCHED SOLENOID VALVE (PARKING BRAKE)	1
31	CHOKE	1
32	PARKING BRAKE PRESSURE SWITCH	1
33	EP VALVE UNLOADING	1
34	BRAKE FEED PIPE PRESSURE SWITCH	1
35	COMPRESSOR PRESSURE SWITCH	1
36	COMPRESSOR PRESSURE SWITCH	1
37	LOW MAIN RESERVOIR PRESSURE SWITCH	1
38	KABA-KEY COCK	1
39	SAFETY VALVE ¾”	1
40	½” TEST POINT	1
41	-	-
42	VENTURE VALVE	1
43	FLOW METER GAUGE RELAY VALVE	1
44	VENTURI VALVE PRESSURE SWITCH	1
5	ELECTRONICS ENCLOSURE	1
46	BREAKAWAY PROTECTION VALVE	1
47	TOWING COCK 3/8”	1
48	CHECK VALVE WITH STRAINER ½”	1
49	DISTRIBUTOR DMD3	1
50	-	-
51	BRAKE SUPPLY RESERVOIR 240 LITRES	1
52	BRAKE CUT OUT VALVE	1
53	CAPACITY RESERVOIR 5 LITRES	1
54	DOUBLE CHECK VALVE ½”	1
55	EBC/5BLENDING UNIT	1
56	½” TEST POINT (VENTED PLUG)	1
57	D2 RELAY VLVE (AUTOMATIC BRAKE)	1

REF	DESCRIPTION	QTY.
58	D2 RLAY VLVE (DIRECT BRAKE)	1
59	DIRECT BRAKE PRESSURE SWITCH	1
60	VIGILANCE PRESSURE SWITCH	1
61	½” TEST POINT (VENTED PLUG)	1
62	CHOKE 3/16” BORE	2
63	ISOLATING COCK 34” VENTED	2
64	BRAKE CYLINDER PRESSURE SWITCH	2
65	ANTI SPIN VALVE	2
66	DOUBLE CHECK VALVE ¾”	4
67	CHOKE 3/16” BORE	2
68	ISOLATING COCK 3/8” (TRACTION CONVERTER 2)	1
69	BRAKE PIPE PRESSURE SWITCH B.P.G	1
70	E70 BRAKE PIPE ISOLATING COCK WITH SWITCH 1-1/4”	1
71	EMERGENCY EXHAUST VALVE	1
72	EMERGENCY EP VALVE	1
73	SANDING VALVE	4
74	EMERGENCY /VIGILANCE ISOLATING COCK	1
75	½” TEST POINT (VENTED PLUG)	1
76	½” TEST POINT (VENTED PLUG)	1
77	TWIN TOWER AIR DRYER WITH PRE-COALESCER	1
78	AUXILIARY COMPRESSOR	1
79	PRESSURE REGULATOR ½”	1
80	THROTTLE VALVE	2
81	FLANGE LUBRICATION CONTROL	4
82	GREASE PUMP WITH RESERVOIR	2
83	FLEXIBLE HOSE 3/8”	2
84	CENTRIFUGAL STRAINER WITH DRAIN COCK ½”	1
85	PANTOGRAPH SELECTION SWITCH	1
86	ISOLATING COCK 3/8” (WHEEL FLANGE LUB)	1
87	OIL SEPARATOR / DRIP CUP WITH AUTO DRAIN VALVE	1
88	ISOLATING COCK 3/8” (FILTER CUBICLE)	1
89	MAIN RESERVOIR 450 LITRES LEFT HAND	2
90	DRAIN COCK 3/8”	4
91	CHECK VALVE 1-1/4”	1
92	DUPLEX CHECK VALVE 1-1/4”	1
93	PRESSURE CONTROL VALVE	1
94	LATCHED ISOLATING COCK 1-1/4”	1
95	HOSE AND COUPLING 1” (M.R.E.P)	2
96	END COCK 1” RH	2
97	HOSE AND COUPLING 1-1/4” R.H BRAKE PIPE	2
98	END COCK 1-1/4”	2
99	HOSE AND COUPLING 1”	2
100	END COCK 1” L.H.	2
101	HOSE AND COUPLING 1-1/4” L.H FEED PIPE	2
102	END COCK 1-1/4”	2
103	SANDER NOZZLE	8
104	HOSE	2
105	HOSE	2

REF	DESCRIPTION	QTY.
106	CHECK VALVE 1”	1
107	½” TEST POINT (VENTED PLUG)	1
108	COMBINED BRAKE CYLINDER/PARKBRAKE UNIT WITH SLACK ADJUSTER	4
109	BRAKE CYLINDER WITH SLACK ADJUSTER	4
110	-	1
111	DRIVERS BRAKE CONTROLLER	2
112	DRIVERS DIRECT BRAKE VALVE FDI	2
113	ISOLATING COCK 1-1/4” (EMERGENCY)	2
114	PRESSURE REGULATOR ½”	1
115	DIRECT BRAKE EXHAUST VALVE	2
116	EMERGENCY EXHAUST VALVE 1-1/4”	2
117		1
118	½” TEST POINT	2
119	½” TEST POINT	2
120	ISOLATING COCK 3/8” VENTED	2
121	DUPLEX PRESSURE GAUGE (F.P-M.R)	2
122	PRESSURE GAUGE BRAKE PIPE	2
123	2-WAY HORN VALVE	4
124	AUTO DRAIN VALVE	2
125	ISOLATING COCK 3/8” (TRACTION CONVERTER 1)	1
126	-	-
127	-	-
128	-	-
129	AIR LINE SIEVE 3/8”	2
130	ISOLATING COCK 3/8” VENTED	2
131	DUPLEX PRESSURE GAUGE (B.C1-B.C2)	2
132	FLOW METER GAUGE	2
133	-	-
134	ISOLATING COCK 3/8” VENTED	2
135	EP VALVE	2
136	ISOLATING COCK 1-1/4”	1
137	PRESSURE REDUCING VALVE	1
138	AIR LINE SIEVE 1” (IN LINE)	3
139	-	-
140	BRAKE FRAME INTERFACE MANIFOLD	1
141	BRAKE CONTROL EQUIPMENT RACK	1
142		
143		
144		
145		
146		
147		
148		
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160		

REF	DESCRIPTION	QTY.
161		
162		
163		
164		
165		
166		
167		
168		
169		
170	CAPACITY RESERVOIR 5 LITRE	1
171	CHOKE	1
172	37 WAY FREE SOCKET (CUSTOMER)	1
173	19 WAY FREE SOCKET (CUSTOMER)	1
174	19 WAY FREE SOCKET (CUSTOMER)	2
175		
176	VIGILANCE CONTROL EQUIPMENT	1
177		
178	19 WAY FREE SOCKET (CUSTOMER) VIGILANCE	1
179	ISOLATING COCK VENTED ¾"	2
180	ISOLATING COCK VENTED 1-1/4"	2
181	ISOLATING COCK VENTED ¾"	2
182	ISOLATING COCK VENTED	2
183	DU MMY COUPING	8

9. BOGIE DESIGN FEATURES

The bogies of WAP5 and WAG9 locomotives, designed by M/s ABB Henschel, Germany and manufactured in ABB's factory in Australia, incorporate many modern design features.

BOGIE OF WAP5 LOCOMOTIVE

The WAP5 locomotive is equipped with 2-axle bolster less Bo-Bo bogies with fully suspended traction motor to reduce unsprung mass. General arrangement of the bogie is shown in Fig.1. The bogie has two stages of suspension. The loco body rests on two pairs of secondary helical springs located on bogie long beams. The bogie frame is supported on primary helical spring, resting on the axle boxes. Transverse flexibility between car body and bogie is provided by the flexi-coil action of the secondary helical springs.

Hydraulic dampers are provided in vertical and lateral modes at secondary stage between underframe and bogie frame and in vertical mode in primary stage between axle box and bogie frame to reduce vibrations of the locomotive body. Two dampers provided between loco body and bogie has a special design to give constant damping force in longitudinal mode. One damper is provided on each traction motor to cushion the lateral motion of the motor. Traction links are provided between bogie frame and axle boxes for transfer of traction forces from axle to bogie frame. Traction and breaking forces are transmitted from bogie to underframe through low traction bars. Connection of the traction bars towards the middle of the underframe is aimed to improve the riding behaviour in the cab.

The WAP5 loco is equipped with the following pneumatic breaking systems: Automatic train brake, Direct loco brake, parking brake and Anti spin brake. As with the tractive effort, braking effort is transmitted to the bogie frame by the axle journal boxes and guide rods and from the bogie frame to the locomotive by the traction rods. The locomotive is provided with disc brakes for improved braking performance required for high-speed operation.

Fully suspended traction motor have been provided to reduce unsprung mass and improve the riding at high speeds. The smaller wheelbase of the 2-axle bogie and flexi-float suspension arrangement help improve curving behaviour and permit the negotiation of curves at higher speeds.

BOGIE OF WAG9 LOCOMOTIVE

The three axle, three motor Co-Co bogie assembly, is one of the major parts of the WAG9 locomotive. Two bogie assemblies support the entire weight of the locomotive and provide a means for transmission of the tractive effort to the rails. General arrangement of the bogie is shown in Fig.2.

The bogies are designed to withstand the stresses and vibrations, resulting from normal rolling stock application. An important function of the bogie is to absorb and isolate shocks caused by vibration in the track bed. The suspension system minimizes the transmission of the shocks to the locomotive underframe.

The traction motors are suspended in the bogie frame and on the individual axles. The motors transmit their energy to the driving axles. The motor transmits their energy to the driving axles through a gearbox mounted on the driving axles. The force from the driving axles is transmitted to the contact point between the wheel tread and the rail. Traction force is, in turn transmitted through the axle journal boxes and the guide rods to the bogie frame. The low traction bar, connected between the bogie transom and the car underframe, transmits the tractive forces to the car body.

The WAG9 loco is equipped with the following pneumatic braking system: Automatic train brake, direct loco brake, Parking brake and Anti spin brake. As with the tractive effort, braking effort is transmitted to the bogie frame by the axle journal boxes and guide rods and from the bogie frame to the locomotive by the traction rods.

Isolation and absorption of shock loads and vibration is performed by the primary and secondary suspension. Movement between the car body and bogie is smoothly controlled by the primary and secondary suspension. Although the springs permit pre-movement in any direction lateral buffers and dampers limit the amount and rate of lateral movement. Rebound limit change and vertical dampers limit the amount and rate of the vertical rebound of the locomotive car body. Yaw (longitudinal) dampers control the car body pitch rate. Guide rods control the fore and aft movement between the axles and the bogie frame while the link rod controls the fore and aft movement between the bogies and the locomotive car body.

The primary suspension located between the axles and the bogie frame is provided by twin coil springs on the axle journal box fore and aft of the axle line. Vertical hydraulic dampers are used to dampen the rebound rate of the springs. This “Flexicoil” arrangement permits lateral movement of the axle. Guide rods connected between the axle journal boxes and bogie frame provides longitudinal control on the axle, and the transmission of tractive and braking effort to the bogie frame. Spheribloc rubber bushes in the guide rods allow the axle lateral movement without undue restriction.

Secondary suspension is also provided by coil springs and vertical hydraulic dampers located between the bogie frame and the locomotive underframe on each side of the bogie. The weight of the locomotive car body is carried by the secondary suspension springs. The “Flexi Float” arrangement of the secondary suspension allow the locomotive car body to move both laterally and vertically within certain limits relative to the bogies.

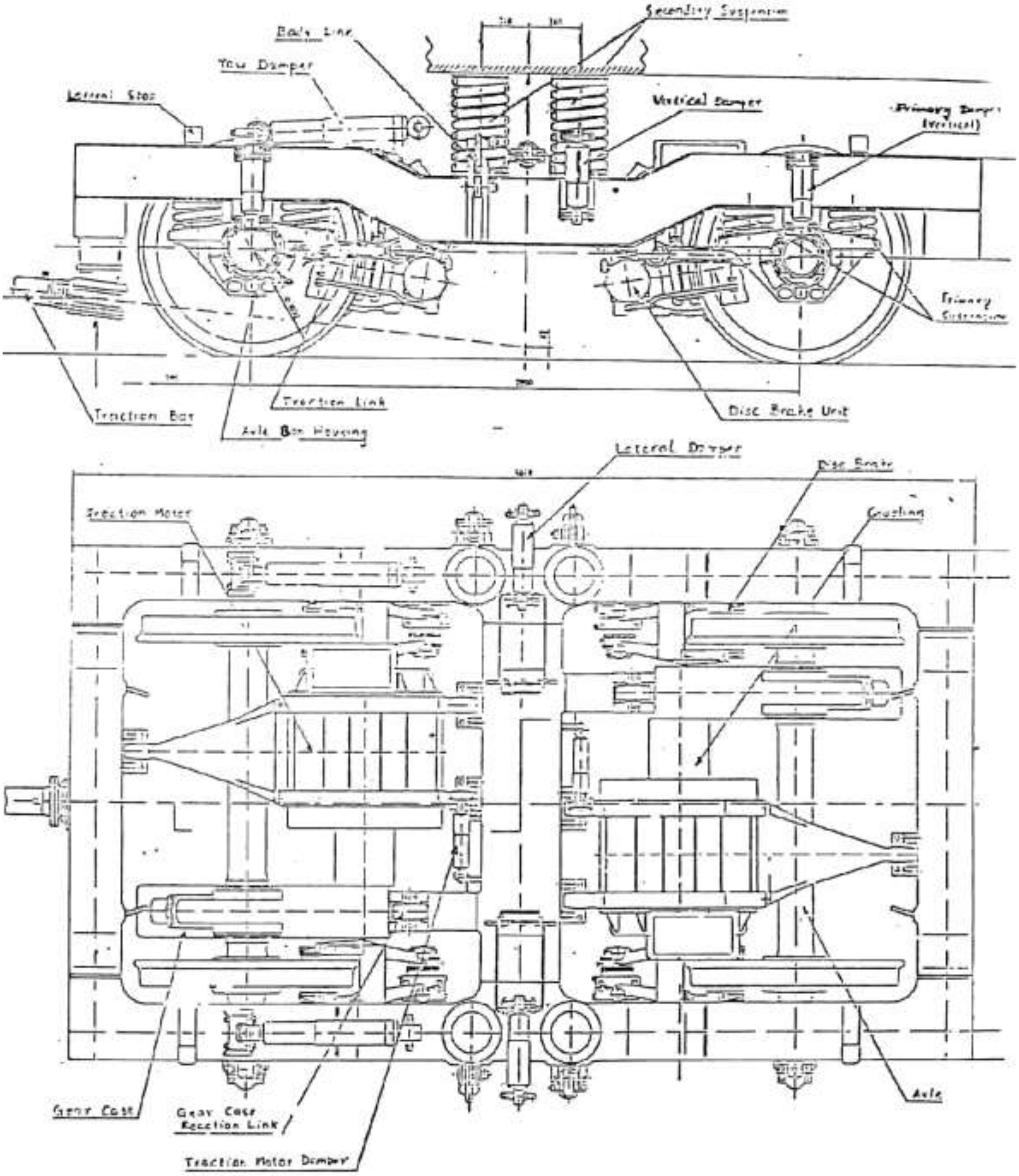

Fig. 9.1 General Arrangement of Bogie WAP 5 LOCOMOTIVE

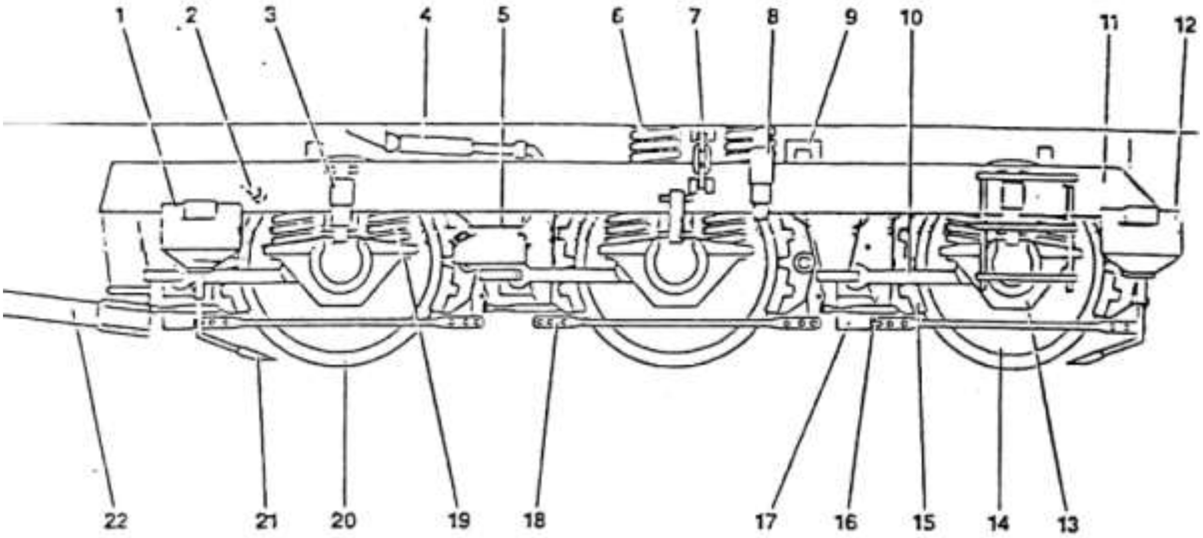

Fig. 9.2. **GENERAL ARRANGEMENT OF BOGIE WAG9 LOCO**

1	Sanding box
2	Wheel flange lubrication reservoir
3	Primary suspension damper
4	Secondary suspension yaw damper
5	Wheel flange lubrication reservoir
6	Secondary suspension spring
7	Safety chain
8	Secondary suspension vertical damper
9	Horizontal damper
10	Wheel set guide
11	Bogie frame
12	Sanding box
13	Wheel set
14	Wheel
15	Brake blocks
16	Brake lever
17	Brake cylinder
18	Brake rod
19	Primary suspension spring
20	Wheel flange
21	Sanding pipe
22	Traction link

10. COMPARATIVE OPERATING PERFORMANCE

Due to their superior TE-speed characteristics and adhesive qualities, the WAP5 and WAG9 locomotives exhibit superior performance as compared to the existing locomotives of IR. Comparative operating performance date for WAP5 locomotive are shown in Table 10.1

	WAP1	**WAP3**	**WAP4**	**WAP-5**	**WAP-6**
Capacity on level	22 coach at 130 km/h	22 coach at 130 km/h	26 coach at 130 km/h	26 coach at 135 km/h	26 coach at 130 km/h
				18 coach at 160 km/h	9 coach at 160 km/h
Capacity on 1/200 grade	9 coach at 130 km/h	9 coach at 130 km/h	12 coach at 130 km/h	16 coach at 130 km/h	12 coach at 130 km/h
HP Output	3800	3800	5000	5400	5000
Max. Service speed in km/h	130	160	140	160	160
Cont. speed km/h	72	72	73	50	73
Axle load (t)	18.05	18.25	19.0	19.5	18.86
Unsprung mass per axle (t)	3.71	3.71	4.22	2.69	4.3
Max. starting TE(t)	22.49	22.49	30.8	26.3	30.8
Continuous TE	13.8 at 72 km/h	13.8 at 72 km/h	19.0tat 73 km/h	22.4 t at 50 km/h	19.0tat 73 km/h

Table 10.1 Comparative operating performance data on passenger locomotives

Table 10.2 Comparative operating performance data on fright locomotives

	WAG5H	**WAG7**	**WAG7H**	**WAG6C**	**WAG9**
Cont. horse power at rail (HP)	4200	5000	5000	6050	6122
Max speed potential (km/h)	80.0	100.0	100.0	100.0	100.0
Cont. speed (km/h)	52.0	50.0	44.0	51.1	50.0
Axle Load (t)	21.0	20.5	22.0	20.5	20.5
Upsprung mass per axle (t)	4.3	4.3	4.3	4.7	3.99
Maximum T.E (t)	36.0	42.0	45.0	45.0	46.9
Cont. T.E. (t)	21.8	27.0	30.8	32.0	33.1
Max. electrical braking effort (t)	20.0 Between 27-36km/h (Rheo)	20.0 Between 27-36 km/h (Rheo)	20.0 Between 27-36km/h (Rheo)	20.0 Between 27-36km/h (Rheo)	20.026.5 Between 27-36km/h (Rheo)

Balancing speed with 4700t BOXN load (km/h)

Grade	Curvature	No. of loco(s)					
Level	2°	1	72	87	79	92	>100
1 in 200	2°	1	*	*	*	30	30
		2	53	68	68	80	82

1 in 150	2°	2	42	58	58	70	70
1 in 100	2°	2	*	*	40	53	53

* Unable to haul

Table 10.2 Comparative operating performance data on fright locomotives

In addition to being able to give a higher balancing speed for freight trains, the WAG9 locomotive owing to availability of higher starting tractive effort, thanks to better adhesion, shows distinct advantage over other types of locomotives in respect of starting capability for freight trains.

Table 10.3 Comparative starting capabilities of freight locomotives

GRADE	NUMBER OF LOCOS REQUIED FOR STARTING									
	4700 t BOXN					5055 t BOXN				
	WAG 5H	WAG 7	WAG 7H	WAG 6	WAG 9	WAG 5H	WAG 7	WAG 7H	WAG 6	WAG 9
1 in 400	1	1	1	1	1	1	1	1	1	1
1 in 300						2				
1 in 200	2	2					2	2	2	
1 in 150			2	2	2					2
1 in 125										
1 in 100						3				
1 in 80	3						3			
1 in 70		3	3	3				3	3	3
1 in 60					3	4				

Table 10.3: No. of locomotives required for starting freight trains

HIGHLIGHTS ON HAULAGE CAPABILITIES

(i) The total running time of existing HWD-NDLS Rajdhani Express will reduce by about 30 minutes if run by a WAP5 loco at existing booked speed.

(ii) If full speed potential of WAP5 loco is utilized (i.e., booked speed 150 km/h), the total running time of existing HWH-NDLS Rajdhani Express will reduce by about 1 hr. 15 mins.

(iii) If existing total running time is to be kept as it is with existing booked speed, the HWH-NDLS Rajdhani Express can be theoretically enhanced to a 29-coach train if hauled by a WAP5 loco.

(iv) The running time between NDLS-JHS for existing 9-coach Shatabdi Express will get reduced by about 12 mins. if hauled by a WAP5 loco with enhanced booked speed of 150 km/h.

(v) Another 5 coaches can be added to the existing 9-coach NDLS-BPL Shatabdi Express without losing on the total running time between NDLS-JHS if hauled by a WAP5 loco at the existing booked speed.

OPERATIONAL ADVANTAGES

(i) The WAP5 loco is equipped to provide a power of 850 kVA at 750 V, 1-phase for supply to the coaches. Once suitable coaches are developed, requirement of power cars (End-on generation) will come down.

(ii) 3-phase locomotives are known to have a higher reliability. In addition, on-board fault diagnostics system on the WAP5/WAG9 locomotives will reduce trouble-shooting time on line.

(iii) With the use of WAP5/WAG9 locomotives, electrical power can be returned back (regeneration) to the OHE supply during braking. Energy savings to the tune of 20-30% have been experienced in electrified railways abroad.

(iv) 3-phase locos operate at near unity power factor. Consequently, payment of penalties to the power supply authorities due to poor power factor will be minimized. Another advantage of improved power factor is that a lower OHE conductor size is required to run the 3-phase locos as compared to conventional locos or alternatively, more number of locomotives can be accommodated in the same feeding zone.

(v) Due to the PWM converter technique adopted, harmonic interference caused by 3-phase locos is much less compared to thyristor locos. Consequently, scope of introducing sophisticated track signaling equipment for enhanced safety in train operation is increased.

MAINTENANCE ASPECTS

(i) Much lower maintenance requirement of 3-phase locos due to absence of commutator and power contactors is well known. As a result, not only the maintenance cost will be low but also higher availability on line is expected.

(ii) Due to use of an induction motor, the unsprung mass in 3-phase locomotives is quite low. For example, the unsprung mass in WAP5 loco is 2.69 tonnes compared to 4.2 tonnes in case of WAP4 loco. In addition to giving better riding qualities, the WAP5/WAG9 loco will be much kinder to the track. As a result, the disturbance to track geometry is minimized and wear or rails and wheels is also reduced.

11. <u>AC DC 3-phase EMUs</u>

Since inception, several technical inputs have been incorporated in EMU stocks which were air brake system, improved design of traction motors, Thyristors control, fluorescent lights and improved fans etc. These changes improved the reliability and performance of the EMU stocks. However, the basic drive running the trains continued to utilize DC series motors. The presence of commutator and brushes impose severe limitations on the use and reliability of the traction motors. The main reason behind the use of DC traction motors has been its high starting torque and easy speed control. The ac induction motors were handicapped on account of absence of these characteristics. With the advent of modern power electronics technology, it is now possible to achieve high starting torque and better speed control with 3 phase AC induction motors and variable voltage variable frequency (VVVF) control. 3 phase EMUs offer remarkable benefits like energy saving, low maintenance cost, higher reliability etc.

These EMUs can be used under both AC as well as DC traction, which will be beneficial in meeting the requirement for DC-AC conversion work, in suburban areas of Mumbai.

THE ADVANTAGES OF 3-PHASE DRIVE WITH GTO THYRISTORS OVER THE CONVENTIONAL TECHNOLOGY ARE:

- It enables energy efficiency
- It provides stepless control thereby increasing passenger comfort.
- Better adhesion between wheel and rail due to smooth control.
- Due to digital electronic control the flexible operation wide range of diagnostic features and very compact size of equipments.
- Robustness and reliability with a low maintenance requirement.
- High power to weight ratio.
- High voltage, low current operation.
- Inherent regenerative braking capability.
- Unity power factor in AC traction.

SPECIAL FEATURES OF 3-PHASE AC-DC EMUs:

- Use of GTO based traction converter and inverter with VVVF control for 3-phase traction motors.
- Increase power with 3-phase induction motor of same size as existing DC motor – 240 kW as against 187 HP of DC EMU & 224HP of AC EMU.
- Roller bearings axle suspension there by reducing maintenance requirement compared to DC motors with sleeve type axle suspension bearing, which calls for frequent maintenance. Also, the life of roller bearings is more than 3 times that of sleeve bearings and the operating performance is superior.
- Coil suspension on existing rake and air suspension on bogie increasing riding comfort as well as better control of bogie parameters under varying load conditions.
- Regenerative braking – 30 to 35% saving in energy in addition to reduction in wheel and brake shoe wear there by reducing maintenance requirement.
- Auto sensing of OHE and selection of AC or DC mode.
- All auxiliary machines working on 3-phase, 415 volts AC supply including drive motor for air compressor, which will reduce maintenance requirement.
- PLC based control for traction and auxiliary circuits including protection which will be more reliable compared to the relay based system presently in use.
- IGBT based Static battery charger.
- The light and fans work on 141 volts AC as compared to 110 volts DC on the existing stock. AC fans are maintenance free compared to the DC fans which need frequent attention to carbon brushes.

Introduction to solid state switching circuits:

Reduction of system losses is one of the major achievements resulting from the use of solid – state power devices. As an example, the induction motor is known for its low efficiency at light loading conditions. To reduce its losses, the terminal voltage of the motor should be reduced during no load or light load conditions. This can be achieved by using an auto transformer equipped with control mechanisms for voltage adjustment. This is an expensive option that also requires much maintenance. An alternate method is to use a power electronic circuit designed to control the motor voltage. This option is often much cheaper and more efficient. In addition, system efficiency will be enhanced.

Insulator Gate Bipolar Transistor (IGBT)

Bipolar transistors are devices with relatively low losses in the power circuit (Collector circuit) during conduction period; due to their relatively low forward drop VCE when closed. Bipolar transistors are also more suitable for high switching frequencies than SCRs, bipolar transistors have very low current gains at the saturation region (when closed). Thus the base currents are relatively high, which makes the triggering circuits bulky, expensive and of low efficiency. On the other hand, MOSFETs are voltage – controlled devices that require very small input current. Consequently, the triggering circuit is much simpler and less expensive to build. In addition, the forward voltage drop VDS of a MOSFET is small for low voltage devices. At this voltage level, the MOSFET is a fast switching power device. Because of these features, MOSFETs replace bipolar transistors in low voltage applications (<200V).

In high voltage applications, (>200 V) both the bipolar transistor and the MOSFET have desirable features and drawbacks. Combining these two in one circuit enhances the desirable and diminishes the drawbacks. The MOSFET is placed in the input circuit and the bipolar transistor in the output (Power circuit). These two devices can now be included on the same wafer; the new device is called the IGBT i.e., the IGBT has high input impedance as in MOSFET and low on state power loss as in BJT.

2. Gate Turn Off Thyristor (GTO)

A GTO Thyristor is a pnpn device, which can be triggered on like an ordinary SCR by application of a small positive gate current pulse but has the capability of being turned off by a negative gate current pulse of proper amplitude. A GTO thus combines the merits of conventional thyristor and high voltage switching Thyristor. No forced commutation circuitry is required for GTOs. Hence, inverters using GTOs are compact and cheap. However, gate turn off current is high (typically ¼ to 1/5). Thus 4000 volts, 3000 A GTO may need 750 A gate current to turn it off. This facility permits construction of Inverter circuits without bulky and expensive forced commutation components used in ordinary Thyristor circuits. Further GTO has higher switching speed than the conventional Thyristor or power MOSFETs.

Turn off action:

When a negative bias is applied at the gate, excess carriers are drawn from the base region of the NPN transistor and collector current of the PNP transistor is diverted into the external gate circuit. Thus the base drive of NPN transistor is removed and this action removes the base drive of PNP transistor and finally stops the conduction.

Protection of dv/dt and di/dt.

To protect a power electronic device against excessive di/dt and dv/dt, a snubbing circuit must be used. The function of this circuit is to limit the current and voltage transients. The circuit is composed of a source voltage, a load and an SCR. The circuit has a snubbing inductance Ls to limit the di/dt in the current path. It also contains an RC circuit to limit the dv/dt across GTO.

Power Converters:

The power converters driving the traction motors consists of

1. Controlled rectifier (Line Converter)
2. DC Link
3. Inverter (Drive Converter)
4. Controllers (Micro processor)

1. **Line Converter :** It provides constant dc output required for inverter operation. It has GTO or IGBTs as switching devices, which can operate on all four quadrants. It controls phase angle of voltage and current and make current in phase with voltage so that unity power factor can be achieved.

2. **DC Link :** It is a link between Converter and Inverter. It comprise of L-C filter to smoothen ripples and a capacitor to provide constant input to inverter, in case of power failures (intermittent), panto bouncing, neutral section etc. It has got an over voltage protection (MUB), a resistance and a Thyristor connected across the DC link.

3. **Inverter:** It provides variable alternating voltage nd currents at desired frequency and phase for the control of AC Induction motors. There are two types of Inverter available viz.,

- Voltage source Inverters
- Current source Inverters

In traction duty, voltage source inverters are used. Because of low internal impedance, the terminal voltage of a voltage source Inverter remains substantially constant with variations in load.

4. **Controllers :** The controllers embody the control laws governing the load and motor characteristics and their interaction. To match the load and motor though the power controllers, the controller controls the input to the power controller.

Description of Electrical Power Scheme

(Schematic Circuit)

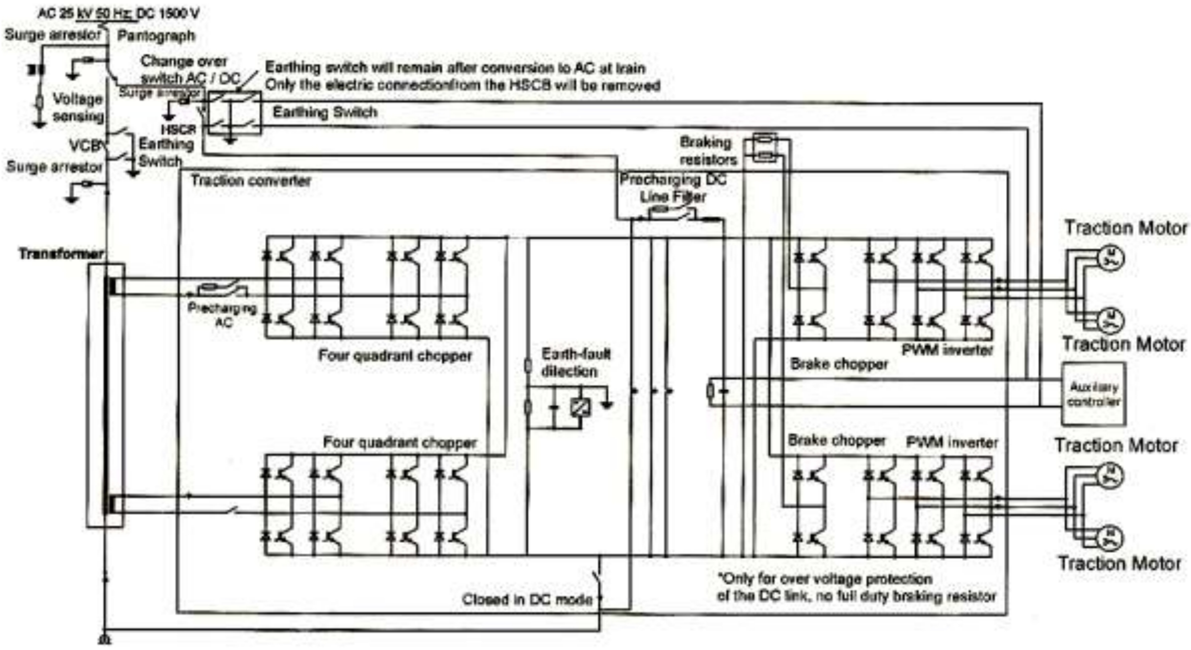

Fig. 11.1

The overhead supply of 1500 V DC or 25 KV AC is connected to the traction system through a common single pantograph.

The power supply collected by pantograph is fed to three equipments.

a) Main Lightening arrestor which protects the entire power circuit from damages due to natural lightening affecting the OHE in the section.

b) A fail safe High Voltage Detection Device (HVDD) detects the line voltage and regulates the HVCC and MVCC accordingly.

c) The High Voltage change over switch (HVCC), which connects the pantograph either to 25 KV AC or 1500 V DC circuit of motor coach.

When the OHE supply is AC, the HVCC take the position on AC side. On closing the vacuum circuit breaker (VCB), 25 KV AC is fed to main traction transformer which in turn will step down the voltage to 1473 volts and feed to medium voltage change over switch (MVCC). A separate surge arrestor ACSA is provided to arrest the surges at primary winding of main traction transformer.

When the OHE supply is DC, the HVCC takes the position on DC side. On closing the DC Circuit Breaker, 1500 V DC is fed to Medium voltage change over switch (MVCC). A separate surge arrestor DCSA is provided between HVCC and DCCB to arrest surges developed while working on DC mode.

L1 inductor, C1 capacitor and R1 resistor forms DC line filter to dampen various harmonics developed while working in DC mode.

The MVCC also has two positions. When OHE supply is AC, MVCC connects the single phase 1473 volts AC supply to Line converter. When OHE supply is DC, MVCC connects the 1500 volts DC supply to Line converter.

The Line Converter is common for both the OHE supplies which can be 25 KV AC or 1500 V DC supply. The line converter receives the input supply from medium voltage change over contactor which is either 1473 volts single phase AC supply received from secondary of traction transformer or 1500 V DC supply received from DCCB. The Line Converter coverts it to stabilized 2200 volts DC supply and feeds mainly to following three equipments:

a) 3-Phase Traction Inverter: The Traction Inverter inverts the 2200 volts DC Power to 3-phase Variable Voltage Variable Frequency and feeds 4 nos. of traction motors connected in parallel. Three phase Squirrel cage Induction Motors are used as traction motors.

b) Diverting Chopper: The diverting chopper comes into function whenever the DC link voltage exceeds above preset voltage. The diverting chopper also helps in providing dynamic brakes when the train is in regenerative braking mode and the OHE turns non receptive. Such dynamic brakes are in function for a short duration till the change over takes from regenerative braking to electro pneumatic braking.

c) Down Chopper: It converts the 2200 volts DC to 530 volts DC and feeds to following three equipments:

i) 20 kVA dedicated inverter for Main Compressor Motor.

20 kVA Inverter converts 530 volts DC to 3-phase 415 volts AC.

ii) 50 kVA Inverter

50 kVA Inverter inverts 530 volts DC to 3-phase
415 volts AC, and feeds auxiliary transformer.

The Auxiliary Transformer has two secondary windings.

a) One supplying 415 volts 3-phase AC to Auxiliary Machines

b) Second supplying 220 Volts 3-phase AC to Lights and Fans in coaches. The load of lights and fans are on single phase of
140 volts evenly distributed across each phase and neutral.

iii) 7 kW Battery Charger.

7 kW battery charger converts 530 volts DC to 110 volts DC for charging batteries and feeding control supply.

Driving cab component description

The main components in driving cab of AC DC BHEL EMU are as follows:

Drivers control equipment

The components mentioned in the following paragraph are available for the driver to control the train:

Driver's Panel

<u>Drivers Control Switch (DCS)</u>

The drivers control switch is used for switching the train on and enabling the functions of the master controller.

<u>Switch Panel (BL key panel)</u>

There are two rows of switches in switch panel.

The first row consists of following switches:

a) Shunting Switch
b) Pantograph Up
c) Pantograph Down
d) Train Off
e) Entering Neutral Section
f) Fault Reset
g) VCB / DCCB Trip
h) VCB / DCCB Set

The second row consists of the following switches:

a) Lamp Test

b) Spare

c) Spare

d) Spare

e) Spare

f) Parking Brake ON / OFF

g) Spare

h) Spare

Master controller cum Brake Controller

The traction / brake controller is used for distributing the traction / braking torque request from the motorman to the train. This controller has 16 positions:

- One (1) emergency brake position (EB)
- Seven (7) brake positions (BP1, BP2, BP3, BP4, BP5, BP6, BP7)
- One (1) coasting position (C)
- Seven (7) traction positions (TP1, TP2, TP3, TP4, TP5, TP6, TP7)

Dead-man switch

The function 'dead man' is incorporated in the traction / brake controller. To assure the driver is capable of driving the train an action form the driver is necessary to be able to power the train. To activate the dead-man the throttle handle must be turned for approximately 5 degrees when the mode selector is in forward or reverse position.

Mode selector

The mode selector is used for distributing the driving direction from the driver to the train. This mode selector has 3 positions:

- Forward (F)
- Neutral (N)
- Reverse (R)

By moving this selector, a driving direction is chosen. This direction is only accepted by the drive control electronics when the train is not moving.

Fault Indication Panel

There are eight indications on Fault indication panel, they are as follows:

a) General Fault
b) E.P. Brake Fault
c) Parking Brakes Applied
d) C jumper Continuity
e) OHE 'ON' Indication
f) Guard's supply 'ON' Indication
g) Master controller in Coasting Position
h) Brakes Not Released

Pneumatic Brake Controller

It has 4 positions:

1. Release / Running position
2. Lap
3. Auto
4. Emergency

The brake controller is used as a back up to brake the train. In normal operation all brake controllers in the train are in the running position. When a brake controller is not in the running position it is not possible to drive at a speed higher than 5 km/h.

Driver's Display Unit

Configuration screen – Present date, time, vehicle status, vehicles present, EP status.

F1 – Message presentation screen – Fault messages can be read.

F2 – Start trip screen driver ID, Route ID, edit the data.

F3 – End trip screed – continue or End – Enter – you will get trip details.

F4 – Total screen – indicates line voltage, line current, speed, energy consumed / energy saved / mileage etc.

F5 – Maintenance screen – Password is required to give reset.

General Fault (Red) indication:

When DCS is switched ON, it will illuminate and go after 10 sec., indicating that DCS is switched ON and LV supply is available.

How to handle in case of faults:

- Faults or malfunction of parts of the Traction and Auxiliaries will be indicated by the **General Fault** light.
- The display will show the reason of the fault.
- In case of a **WARNING** the fault light will be OFF after accepting the message.
- In case of **WARNING,** there is no loss of performance. The maintenance staff should be informed to solve the problem after service.
- In case of a **MINOR FAULT** performance can be less but traction power and Auxiliaries are still available.
- In case of **TRACTION FAULT** traction power and ED brake will be lost on the motor coach with the fault.
- In case of **OFF** traction, ED brake and Auxiliaries will be lost. Lights, fans for passengers and 110 volt control power will be fed from adjacent motor coach.
- The driver can try to reset the fault via the button **FAULT RESET** (for at least 1 sec) only in case the fault has disappeared a reset will lead a reapplying of power.

<u>How to read Message in DDU</u>

Press F1, then

i. If fault / warning message appear, then read it and press **ENTER** for next message(s).

ii. If DDU shows that **All messages accepted,** then press CLR and read message and press **ENTER** for next message(s).

<u>How to give Fault Reset</u>

Important : Fault reset can be given from **Fault Reset** toggle switch in BL-box after inserting BL-key. Since at a time only one BL key can be inserted, so **Fault Reset** should be given from the motorman's DTC.

i. In DTC D-Cab press **Fault Reset** toggle switch in BL box for 2 seconds.

ii. In M / ch D-cab **Ensure that all MCBs above Brake Controller are in ON position.**

Instructions for maintenance reset:

CAUTION:

i. **Maintenance reset should not be given without advice of shed (PPIO).**
ii. **Ensure that all MCBs above Brake Controller are in ON position.**

Steps for giving maintenance reset:

i. Switch On DDU by switching ON display toggle switch in driver's desk. Observe status of motor coach; OK or OFF
   a) If coach is OK, maintenance reset is not required
   b) If coach is OFF, then proceed as follows –
   - At next stoppage of train bring panto down by rotating the **Panto valve Kaba Key** (Blue Key) anti-clockwise.
   - Press F5
   - Press 2000
   - Press 1 and keep it pressed for 15 seconds
   - Press **ENTER**

ii. Wait for 30 seconds
iii. Then read fault messages by pressing F1
iv. The ensuring that train is halted, raise the pantograph by rotating clockwise the **Panto Valve Kaba Key.**
v. Read status of that vehicle (coach) **OK** or **OFF.**
vi. Before leaving motor coach ensure that DDU is switched OFF.

Component codes for AC – DC EMUs

2 13 k 6

First digit indicates the type of coach :

1 stands for DTC
2 stands for MC
3 stands for TC

Second digit indicates function of the component :

11 – HVS – High Voltage System
12 – Static converter/battery

Charger /Auxiliaries

13 – LVS – Low Voltage System
15 – TRC – Traction Control
16 - -VHC – Vehicle Control
21 – General Equipment and PLC
23 – Position Detection

34 – VIS – Vehicle Information System

Third digit indicates component codes:

A – Converter/Inverter Module

B – Speed probe

C – Capacitor

D – Diode

E – Heating element

F – Safety device (Fuse/MCB/LA/Over load element)

G – Battery

H – Indication lamp

K – Contactor/Relay

L – Inductor

M – Motor

P – Panel meter

Q – Circuit breaker

R – Resistor

S – Switch/Push button

T – Transformer

U – Transducer/Measuring device/Sensor

V – Power Electronic device/Component

W – Current Collector

X – Connector

Y – Magnet valve

Z – Filter Circuit

Fourth digit indicates Sr. No. of the item.

Auxiliary machines : There are 18 aux. machines in AC/DC EMU.

Sr. No.	Description	Qty.	Motor No.	Contactor
1	Inductor vessel fans	2	M1 & M2	213 K1 & K26
2	Bleeder motor	1	M15	213 K2
3	HT Room fans	2	M16& M17	213 K3 to K8
4	HEX cubicle fans	2	M16 & M7	213 K9 to K14
5	TFP radiator fans	4	M1 to M4	213 K15 & K16
6	TFP cooling pump	1	M5	213 K17
7	LCD cubicle fans	2	M11& M12	213 F10 & 213 F11
8	Aux. Inv. Cubicle fan	2	M13& M14	213 F12 & 213 F13
9	LCD oil pump	1	M9	5.5 kVA Inv.212 A1
10	Fan for cooling oil pump	1	M10	213 F9

Relays used in light & Fan circuits :

213 K18 - light & Fan selection to & from left side of motor coach

213 K19 - light & Fan selection to & from right side of motor coach

213 K 20 – Self motor coach supply

213 K30 – Power supply in motor coach OK

213 K 21 – Input supply (110V) from either side M / Ch

213 K 22 – Output supply (110V) to either side M / Ch

213 K 23 – 100% light ON

213 K 24 – 50% light ON

213 K 25 – Fans ON

213 K 33

213 K 34 – Lights OFF

213 K 35 – Fans OFF

Technical Data of Electrical equipments :

1. Traction Transformer:

Continuous rating : 1312 kVA

Turns ratio : 17:1

Primary voltage : 22.5 kV, 25 kV

Sec. Voltage : 1326 V, 1473 V

2. Traction converter / inverter / aux. converter :

1. Line Converter :

	AC Mode	DC Mode
Input Voltage	1326 V AC	1500 V DC
Input Current	900 Amps	900 Amps
Output Voltage	2200 V DC	2200 V DC
Output Current	525 Amps	525 Amps
Power rating	1200 kW	1200 kW

2. Inverter:

Input Voltage	2200 V DC
Input Current	460 Amps
Output Voltage	1950 V AC
Power rating	1520 kVA

3. Aux. Down chopper:

Input Voltage	2200 V DC
Output Voltage	530 V DC
Cooling Medium	MIDEL Synthetic Ester

3. Traction Motor :

	Continuous	1 hour rating
Power	295 kW	362 kW
Voltage	1669 Volts	1669 Volts
Current	136 Amps	163 Amps
Speed	1259 rpm	1249 rpm
Max. service speed	2750 rpm	
Gear ratio	16:69	

Traction Faults for which reset can be given :

Auto reset	Maintenance reset	Fault reset
12,13,14,15,16,17, 18,19,28,42,45,46,51, 52,53,55,56,57,58,59	30,33,36,37,41	7,8,9,10,11,20,21,22, 23,24,25,26,27,29,31, 32,38,39,44,47,48,49, 50,54,60,83,96,98
Reset to be given through laptop 86,87,88 & 89 – temperature sensors for traction motors 1,2,3 & 4 90,91,92 & 93 – speed sensors for traction motors 1,2,3 & 4		

Message Details

10. Traction Fault - Inductor vessel fan 1 failing
11. Traction off - Both Inductor vessel fans failing
12. Traction off - Inductor temp. too high.
13. ED – Brake off - Inductor temp. high.
60. Traction fault - Inductor fan 2 not working

14. Traction and Aux. Off- TFP temp. too high.
15. Traction and Aux. Off- TFP failure.
17. ED-Brake off - TFP temp. high.
18. Warning - TFP oil level low.
19. Traction and Aux. off - TFP oil no circulation (No oil cooling)

21. Warning - HT Room fan high speed failing.
22. Warning - HT Room fans both speed failing.
23. Warning - HT Room fans low speed failing.
24. Warning - HT Room temp. too high.

25. Traction Off - HEX fans high speed failing.
26. Traction and Aux. Off- HEX fans both speed failing.
27. Warning - HEX fans low speed failing.
28. Traction and Aux. Off- HEX cubicle temp. too high.
39. Traction and Aux. Off- Pantograph control failing.
49. Traction and Aux. Off- Aux. on chopper failing.
50. Traction & Aux. Off - Internal Electronics problem.
51. Traction & Aux. Off - Control Air pressure too low.
52. Warning - LCD oil pump fan failing.
53. Warning - cooling fan – converter & Aux. Inv. Failing.

55. ED-Brake Fault - TM temp. high.
56. Traction fault - TM temp too high.
57. Traction fault - Traction/Conv. /Braking res. temp. high.
58. Traction fault - Traction Conv./Br. Res. temp. too high.
59. Traction & Aux. off - Traction converter temp. too high.
71. Warning - TFP temp. too high.
76. Warning - TFP temp. high.
77. Warning - OHE voltage too high.
83. Warning - No oil cooling transformer.
79. EP fault - EP brake pressure MC too low.
80. EP fault - EP brake pressure DTC/TC too low.
81. EP fault - EP brake pressure MC not released.
82. EP fault - EP brake pressure DTC/TC not released.
84. MR Pressure - Main compressor manually off.
85. No Traction - BP Pressure too low.

Frequently coming message Nos.

2,8,16,20,33,37,44,50,54,60,61,84 & 85

Type of fault	Fault messages	AR	MR	FR
Warning	18 – low oil level in TFP			
	62 – TFP failing			
	71 – TFP temp. too high			
	76 – TFP temp. high			
	21- HT Room fans Hi-speed failing			X
	22 – HT Room fans both speeds fail			X
	23 – HT Room fan low speed failing			X
	24 – HT Room Temp. too high			X
	27 - HEX fans low speed failing			X
	52 - LCD pump fan failing	X		
	53 - Cooling fan for converter & Aux. Inverter failing	X		
	43 – PLC Battery low	X		
	34 – Internal problem PLC prog.			
	40 – Line converter inhibited			
	63,64,67,68,69 & 72 – Internal Electronics problem			
MF	16 – Compressor OLR tripped			X
Minor	42 – Battery Charger failed			X
Failure	44 – Compressor Inverter failed			X
	45 – Position detection failed	X		
EDF	13 – Inductor temp high	X		
ED	17 – TFP temp. high	X		
Brake	55 – Traction motor temp. high	X		
Off				
Type of fault	**Fault messages**	**AR**	**MR**	**FR**
TF	10 - Inductor fan 1 failing			X
Traction	60 - Inductor fan 2 failing			X
Off	11 – both inductor fans failing			X
	12 – inductor temp. too high	X		

	25 – HEX. High speed failing			X
	48 – Traction fault			X
	56 – traction motor temp. too high	X		
	57 – traction Converter/Breaking res. temp. high	X		
	58 - traction Converter/Breaking res. temp. too high			
	85 – BP low			
	65,66 – Internal Electronics problem			
Off Traction & Aux. Off	9 – oil pump inverter failure			X
	14 - TFP temp. too high	X		
	15 - TFP failure	X		
	19 - No oil cooling TFP	X		
	20 – 50 kVA Inv. failure			X
	26 - HEX both speed failed			X
	28 - HEX. cubicle temp. too high	X		
	29 - AC line contactor failing			X
	32 – DCLC failing			X
	30 – DCCB failing		X	
	41 – VCB failure		X	
	31 – Line over current DC mode			X
	38 – Line over current AC mode			X
	33 – HVCC failed		X	
	37 – MVCC failed		X	
	36 – DCCB/VCB failed by MDC		X	
	39 – Panto control failing			X
	49 – Aux. Dn. Chopper failing			X
	50 – Control Electronics problem			X
Type of fault	**Fault messages**	**AR**	**MR**	**FR**
Off Traction & Aux. Off	51 – Control air pressure too low	X		
	54 – Traction fault			X
	59 – Traction Converter temp. too high.	X		