Head on Generation (HOG) - A step towards energy efficiency

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Abstract

Indian Railways imported 22 WAG9 locomotives and 11 WAP5 locomotives from M/s. ABB, Switzerland in 1996-97. Later on Chittaranjan Loco Works (CLW) started the production of WAP-7 locomotive. The WAP-7 is actually a modified version of the WAG 9 freight locomotive with modified gear ratios. A hotel load winding in locomotive transformer of WAP5 and WAP7 locomotives has been provided to cater the hotel load supply to the coaches through hotel load converter. Different power generation schemes are being used on IR to cater hotel load requirements of the mail/express trains. The most common schemes being used presently are Self Generation (SG), where the train has few air conditioned coaches and End on Generation (EOG), where the train has all air conditioned coaches such as Rajdhani, Shatabdi and Duronto trains.Railway Board had issued instructions vide letter No 95/elec(G)/114/13 Pt dtd. 25/10/07 for implementation of HOG scheme by manufacturing of 3 phase electric loco with IGBT technology having minimum 2x500 KVA hotel load converters on loco and one under-slung DA set in SLR for Rajdhani/Shatabdi trains. This paper discusses the challenges faced in the regular operations of the converters fitted in the WAP-7 locomotive with the Shatabdi LHB coaches. This paper also discusses the benefits of the HOG and suggests future course of action.

1. Preamble

Indian Railway is manufacturing 3-phase electric locomotives at Chittaranjan locomotive works (CLW) i.e. WAP5, WAP7 and WAG9 locomotives. These locomotives take power from OHE through pantograph to traction transformer. Traction transformer of WAP5 and WAP7 is provided with a hotel load winding to cater for the power supply to coaches (also referred to as Hotel Load).

With the technological up-gradation and continuous advancements in the field of power electronics, control system and power supply systems, Indian Railways has decided to adopt an energy efficient power supply system for power supply to the coaches referred to as Head On Generation (HOG) for Rajdhani/Shatabdi trains, presently having “End on Generation” (EOG) system. LHB type of coaches are best suited for adoption of “Head on Generation” (HOG) scheme as the rake integrity with these coaches is expected to be maintained due to the specific design of their inter vehicle mechanical coupling.

Railway Board had issued instructions vide letter No 95/elec(G)/114/13 Pt dt 25/10/07 for implementation of HOG scheme by manufacturing of 3 phase electric loco with IGBT technology having minimum 2x500 KVA hotel load converters on loco and one under-slung DA set in SLR for Rajdhani/Shatabdi trains.CLW prepared specification (No. CLW/ES/03/IGBT/0490) for development of 2x500 kVA hotel load converter for WAP-7 locomotives with traction transformer (LOT 7500) having 01 single phase hotel load winding.

Meanwhile CLW has turned out first HOG based electric loco No. 30277 (WAP7) in the month of July'2010 having M/s Siemens make 2X500 KVA Hotel Load Converter installed in the locomotive with single hotel load winding transformer (LOT-7500). This locomotive is in regular train service in 12005/06 NDLS-KLK Shatabdi Express since 21.02.2011 over Northern Railway. Till now 04 nos. of WAP7 locomotives have been provided with 2x500 KVA Hotel LoadConverters (loco no. 30277, 30365, 30406 fitted with M/s Siemens make converter and 30375 of M/s Medha make converter). These are working in NDLS-CDG Shatabdi and NDLS-KLK Shatabdi Express trains.

2. End on Generation System

In EOG system, the electrical load (i.e. load of lights, fans and air conditioning, pantry etc. referred to as "Hotel Load") in the coaches of Rajdhani and Shatabdi Express trains are fed from the power cars placed at either ends of the rake. Each power car is installed with 2 Diesel Alternator (DA) sets generating 3-phase (4 wires) power supply of 750 Volts 50 Hz and the same is transmitted to entire rake through two parallel cables feeders termed as *Feeder-A* and *Feeder-B*, running through the whole length of the train. This electric power supply is tapped at each coach through a 50 KVA transformer in Conventional Coaches and 60 KVA transformers in LHB coaches and is converted to 415 volt for feeding the equipment working at this voltage and further transformed down to 110-volt AC single phase for feeding the equipment working at that voltage.

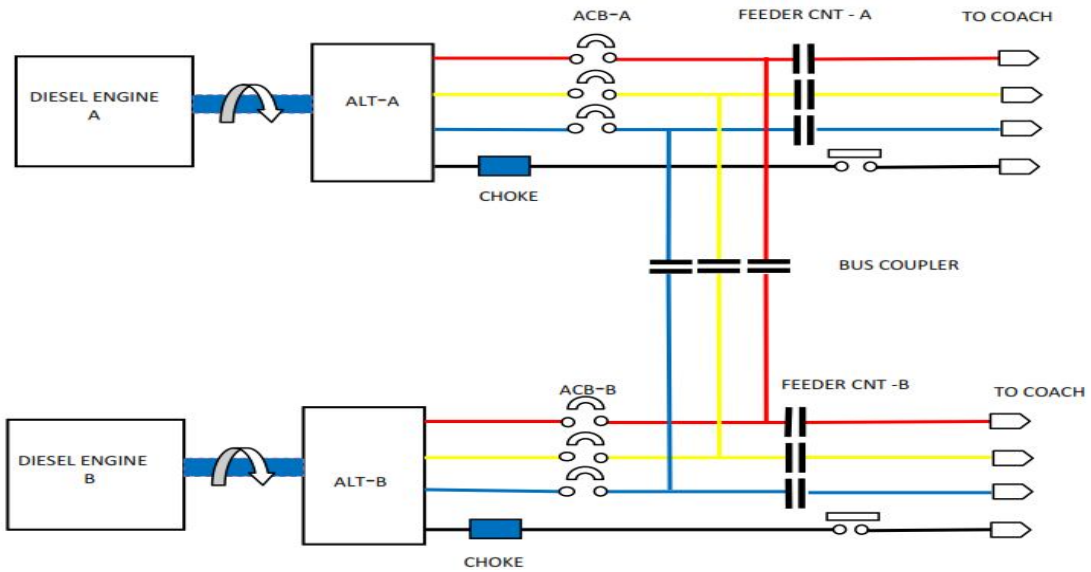


Figure - 1: Power car block diagram with EOG supply

415 V, 3-phase supply is directly used for compressor motors, the condenser fan motors and heaters installed in the evaporator. The evaporator blower motor is fed at 110V, 3-phase ac. 110V ac supply is also provided for lamps and fans by connecting them between line and neutral on the secondary side of this transformer. Since the power cars are placed at either end of the rake, the system is termed as End on Generation (EOG).

3. Head on Generation System

In HOG scheme, power is fed from the electric locomotive to the train to cater for the Hotel Load of the train. In electric locomotives, power is taken from the OHE through pantograph to traction transformer of the locomotive which is provided with a hotel load winding of 945 kVA, at nominal voltage of 750 V single-phase, which varies with the OHE voltage variations. This 750 Volts single-phase supply is fed to Hotel Load Converter, which gives 750 Volts 3-phase 50 Hz supply as output, for feeding the hotel load of the train.

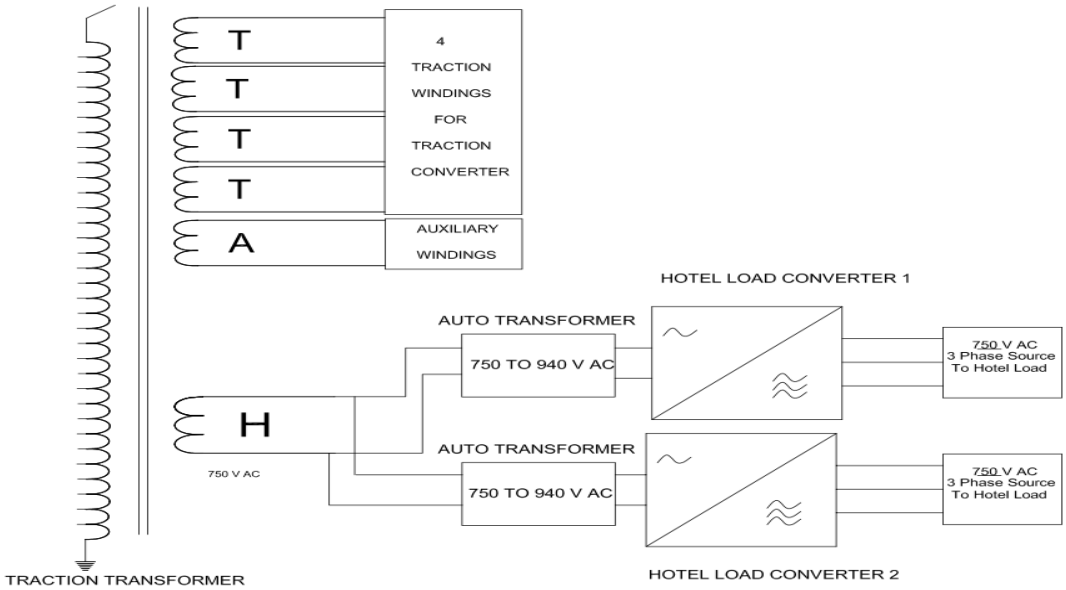


Figure - 2: HOG schematic with single hotel load winding in loco transformer

The three phase output supply of the hotel load converter i.e. HOG system is transmitted to both the feeder of the existing EOG train through IV coupler.

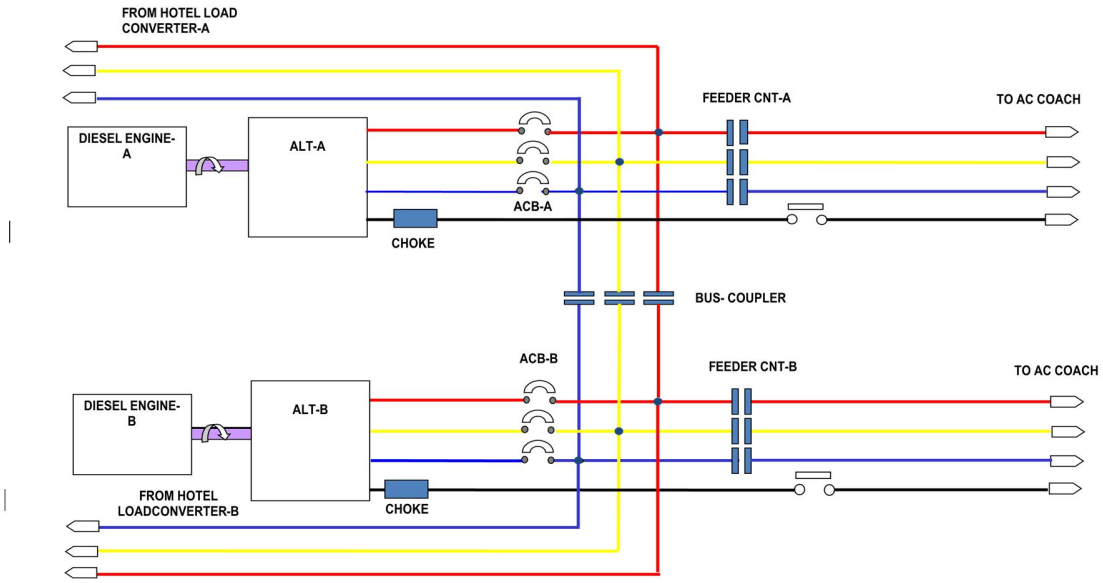


Figure - 3: Power car block diagram with HOG supply

4. Reduction of harmonics in HOG output voltage

With this single hotel load winding of traction transformer (LOT 7500), there were failures reported of 60 kVA coach transformer, 100 VA coach transformer and other coach equipments. This issue was discussed in detail in the meeting held at RB on 16.06.2015. During the course of discussion, it has been brought out that harmonics of 2400 V (peak) between Line to Earth in converter output with traction transformer having single hotel load winding is main cause of these failures. Manufacturers has pointed out that harmonics can be restricted by providing external R-C filter circuit on the power supply of the converter but this scheme is not workable in the present schematic (Figure-2) due to flow of circulating current between the converters as both the hotel load converters are fed from the single hotel load winding of traction transformer (LOT 7500).

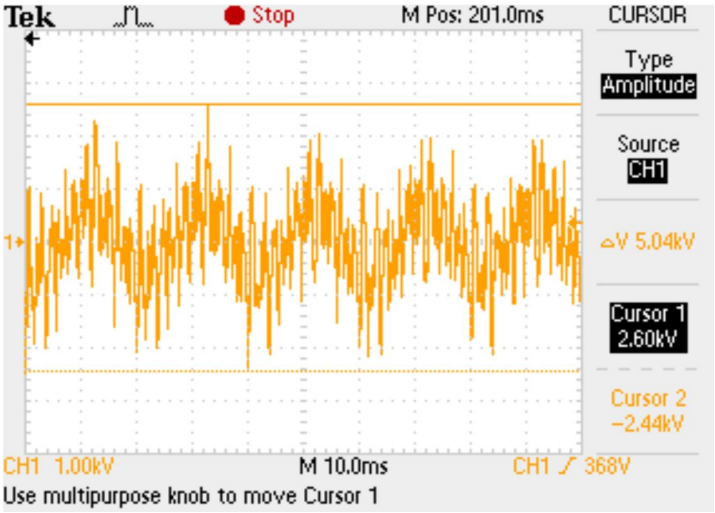


Figure - 4: Output Line to Earth voltage waveform of HOG with single hotel load winding

To restrict the Harmonics content from the HOG supply, provision of external R-C filter has been introduced. This scheme is working in the modified traction transformer (7775 kVA) with provision of two separate hotel load winding input supply scheme. Newly designed M/s Hi-Volt make modified loco traction transformer (7775 kVA) having two independent hotel load windings of 2x622.5 kVA, 960V i.e. separate winding for each converter was fitted in loco no. 30365 at ELS/GZB of NR. In this locomotive, M/s Siemens make 2x500 kVA hotel load converter has been provided. M/s Siemens has provided external R-C filters to reduce Line to Earth voltage harmonics in output of the hotel load converter.

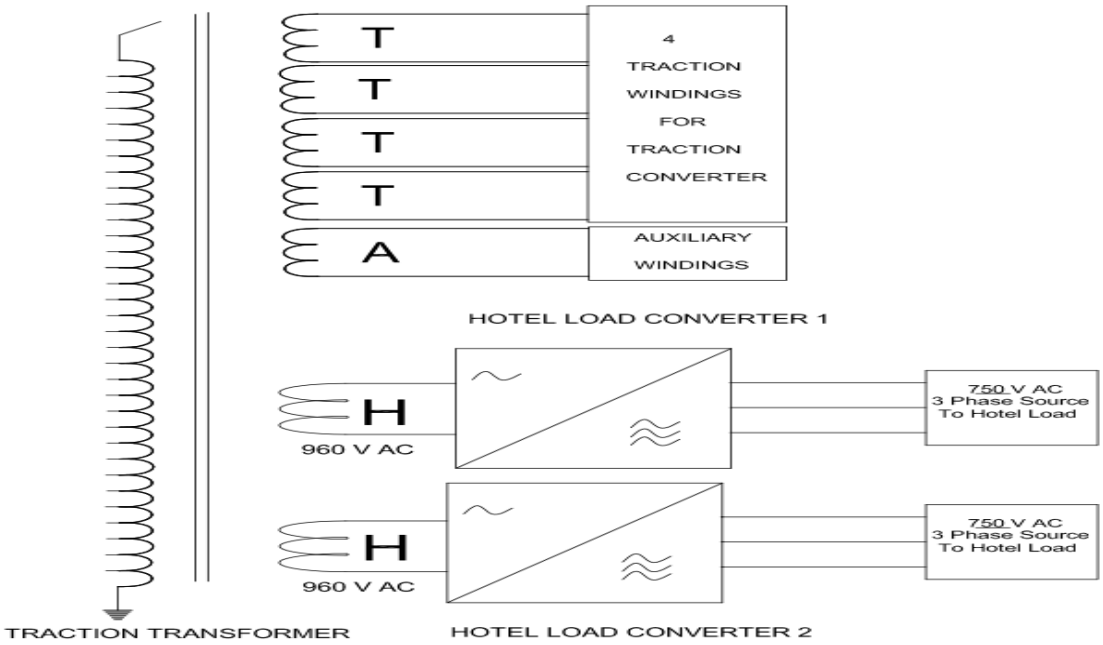


Figure - 5: HOG schematic with modified loco transformer (7775 kVA)

The voltage waveform of HOG power supply captured on CRO during stationary trial on 07.09.15 were examined and it has been noted that voltage waveform between Line to Earth of HOG supply is almost sine wave with a peak of around 700V.

The Voltage waveform captured earlier of HOG power supply with hotel load winding transformer indicates Line to Earth peak voltage 2400V.

The comparison of Line to Earth voltage waveform with dual winding transformer along with hotel load converter with external RC filter and hotel load converter with single winding transformer is appended below:

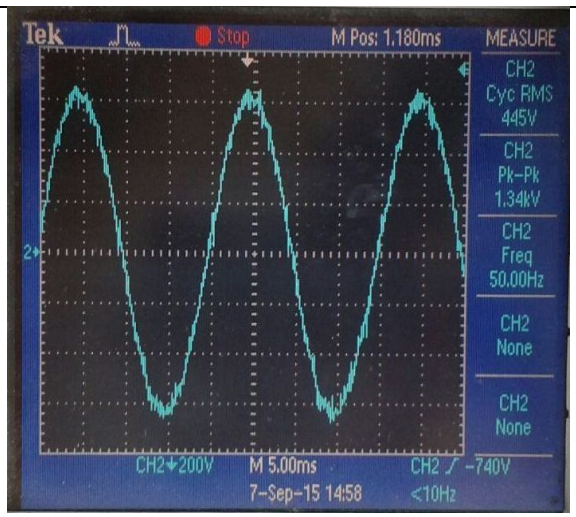
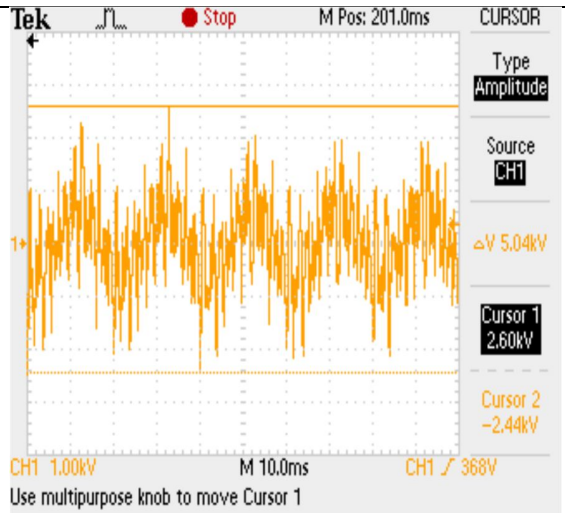
L-E voltage waveform with dual winding transformer (with external RC filter)	L-E voltage waveform with single winding transformer
	

Figure - 5: Comparison of L-E waveform with existing and modified loco transformer

From the above, it can be noted that voltage spikes between Line to Earth in HOG power supply has been reduced from 2400 V to 700 V with provision of two independent hotel load winding transformer and external RC filter in the converter supply.

Measurement of Line to Earth voltage of hotel load supply of loco no. 30365 was measured in train no. 12046 (CDG-NDLS Shatabdi Express) in running and stationary conditions. The results of the trial were found satisfactory and no major change in waveform between Line to Earth Voltage was noticed.

5. Development of HOG for WAP5 locomotives

CLW has prepared specification (No. CLW/ES/03/IGBT/518, Rev. 'B') for development of composite converter i.e. Traction Converter and Hotel Load Converter in single cubicle. IGBT based composite converter to be used in Bo-Bo locomotive shall have two line converters, a DC link and two drive side converters to feed independently two traction motors of 1150 kW capacity in Bo-Bo WAP5 types locomotives and a separate hotel load converter fed from the hotel load winding of traction transformer. The proposed composite converter shall be designed and accommodated within the space available on the WAP-5 locomotive. The composite converter having both traction converter and hotel load converter shall be in same cubicle. The composite converter, output contactors and filters shall preferably fit in the existing foot print of the GTO converter. However additional space of approximate 300 mm lengths available between the converter and machine room blower can be utilized for this purpose keeping maintainability of the converter and machine room blower in view.

The hotel load converter will have output of 750 V, 3-Phase 50 Hz supply which is required for feeding the coach load of the train through Inter Vehicular Coupler (IVC). Hotel load inverter output will further be stepped down to 415 V, 3-phase AC by existing transformers provided in every coach. This electrical power will be used to operate the lights, fans, air conditioning, water raising apparatus, etc of the coaches and the pantry car equipments.

The existing three phase traction motors 6FXA 7059 will be retained and transformer LOT 7775 KVA as per CLW specification No. CLW/ES/3/0660 with latest alteration with two separate hotel load windings each capacity of 622.5 kVA, 960 V will be used for input supply of hotel load converters. Two series resonant chokes available in the transformer also will be used.

CLW is in the process of procuring composite hotel load converter by floating development tender.

6. Analysis of Energy Efficiency of HOG

The trials have established the efficacy of working of HOG scheme on IR. Head on Generation is a superior means of meeting electrical power requirement in coaches and is utilized in developed countries. It overcomes the limitations of the SG and EOG systems. It is very economically advantageous in operation.

The saving in operation with HOG system against EOG system underlined in tables given below:

6.1 Operation cost saving in NDLS-KLK Shatabdi Express (12005/06): Total cost of 137.70 Lacs can be saved annually by regular operation on HOG system.

Table - 1

S N	Scheme	Energy cost per unit (Rs.)	Total hotel load (KW)	Total hotel load Considering duty cycle 70% of the load	Total time (Run time + pre-dreparture time+ Post arrival time)	Units spend in a trip of 5.0 hrs (kWH)	Total energy cost of hotel load in one trip	Total energy cost of hotel load in one round trip i.e. daily (Rs.)	Total annual energy cost of hotel load (Lacs Rs.)
1	EOG	14.86	636.4	445.48	5.0 hrs	2004.66	29789.248	59578.4952	217.46
2	HOG	6.36	545.4	381.78	5.0 hrs	1718.01	10926.544	21853.0872	79.76
Saving									**137.70**

**Considering cost of HS Diesel '51.00 Rs/Liter' accordingly diesel energy cost Rs. 14.86/KWH*

6.2 Operation cost saving in NDLS-CDG Shatabdi Express (12045/46): Total cost of 121.47 Lacs can be saved annually by regular operation on HOG system.

Table - 2

S N	Scheme	Energy cost per unit (Rs.)	Total hotel load (KW)	Total hotel load Considering duty cycle 70% of the load	Total time (Run time + pre-dreparture time+ Post arrival time)	Units spend in a trip of 4.5 hrs (kWH)	Total energy cost of hotel load in one trip	Total energy cost of hotel load in one round trip i.e. daily (Rs.)	Total annual energy cost of hotel load (Lacs Rs.)
1	EOG	14.86	553.4	387.38	4.5 hrs.	1743.21	25904.101	51808.2012	189.10
2	HOG	6.36	462.4	323.68	4.5 hrs.	1456.56	9263.7216	18527.4432	67.63
Saving									**121.47**

**Considering cost of HS Diesel '51.00 Rs/Liter' accordingly diesel energy cost Rs. 14.86/KWH*

6.3 Additional earning of revenue per Chair Car (CC) & Executive Car (EC) per year:

In regular practice, 2 nos. of power car equipped with Diesel Alternator (DA) sets placed at either ends of the rake run with every Shatabdi Express. After provision of hotel load converter i.e. HOGs system, there is need of only one power car to be attached with the shatabdi train rake for standby purpose (to use the DA set supply only after failure of HOG supply) only. Another power car can be removed as there is no need of the same with HOG system one power car can take whole load of the shatabdi rake in emergency due to failure of HOG supply system. Meanwhile, one extra passenger coach in place of removed power car can be attached without increasing in train length. By the provision of this extra passenger coach, Railway may increase earning as calculated below.

Table - 3

Train	Coach type	No. of seat	Fare/seat (Rs)	Earning in one trip (Rs)	Earning in round trip (In Rs.)	Annual (365 days) earning (in Lakh Rs.)
Kalka Shatabdi (12005/06)	Executive Car	56	1260	70560	141120	**515.09**
	Chair Car	78	595	46410	92820	**338.79**
Chandigarh Shatabdi (12045/46)	Executive Car	56	1240	69440	138880	**506.912**
	Chair Car	78	640	49920	99840	**364.416**

6.4 Total Earning of additional revenue after provision of HOG

Based on the analysis/calculations done in para - 6 & 7 above; total lump-sum earning may be calculated as below:

(i) In NDLS-KLK Shatabdi Express:

(a) With addition of Executive Car in place of one removed power car in train, total annual earning = (Saving + earning)
= (137.70+ 515.09) Lacs;
= 652.79 Lacs.

(b) With addition of Chair Car in place of one removed power car in train, total annual earning = (137.70+ 338.79) Lacs;
= 476.50 Lacs.

(ii) In NDLS-CDG Shatabdi Express:

(a) With addition of *Executive Car* in place of one removed power car in train, total annual earning = (121.47 + 506.91) Lacs;
= **628.38 Lacs.**

(b) With addition of *Chair Car* in place of one removed power car in train, total annual earning = (121.47+ 364.41) Lacs;

= 485.88 Lacs.

The average cost of one loco sets hotel load converter for WAP-7 locomotive is Rs. 120.00 Lacs only.

7. Conclusion

The main benefits that will accrue with the development of hotel load converter i.e. HOG system is described below:

(i) **Increase in revenue and reduction in operational cost:** Based on the analysis/calculations done in para - 6 & 7 above, IR will be able to earn annually minimum of Rs. 476.50 & Rs. 485.88 Lacs through NDLS-KLK & NDLS-CDG Shatabdi Express respectively by replacing one power car with LHB chair car. The average cost of one loco sets hotel load converter is Rs. 120 Lacs only. In view of this, revenue of IR will be increased by operating more and more LHB based fully AC trains like Shatabdi, Rajdhani and Duronto Express.

(ii) **Pollution free:** In EOG system, there are two types of pollutions - (i) Air pollution due to burn of High Speed Diesel, and (ii) Noise pollution by

DA sets whereas HOG system is totally free from both types of pollutions i.e. air and noise pollutions.

(iii) **Carbon Credits:** Carbon credits can be earned by not emitting the carbon dioxide through burning of high speed diesel into the environment. IR can also sell this carbon credits in international markets.

(iv) **Better reliability** due to reduced number of generating equipment, low maintenance requirement, reduced dead weight as compared to SG and EOG system.