A Review on Charging Infrastructure for Electric Transit Buses

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ABSTRACT:
The Electric transit buses (ETBs) are the main source for public transit to get the cleaner environment. The ETBs have gained popularity around the globe since the last decade. The ETBs are 14 % of the total transit buses around the world. The ETBs are heavy EVs and need more power to charge the high capacity batteries. The batteries used in these buses have the energy capacities between 80 kWh to 550 kWh. Such high capacity batteries take more to get charged. In order to increase the adoption of ETBs, a suitable number of high power dc charging infrastructures need to be installed in various main cities of the nations. The ETBs can operate with battery alone or fuel cell or combination of these two. Such ETBs are named as battery electric transit bus (BETB), fuel cell electric transit bus (FCETB) and hybrid electric transit bus (HETBs). As of 2020, out of total ETBs around the globe, 70 % are HETBs, 20 % are FCETBs and 10 % are BETBs. In this paper, the key parameters and comparison among these three batteries are shown. The major EV market holders are China, US, Europe and japan. The charging protocol used in the US and Europe is combined charging system. The charger capacity has reached up to 500 kW as of 2020. With such high power chargers it takes only less than half an hour to charge the high power batteries.

KEYWORDS: EV Charging, EV Power Conditioning for Charging, Converter Topologies for EV Charging, Battery Charging, Power Conditioning of EV Charging Systems.

1. INTRODUCTION

It is expected that by 2050, almost 70 % of the world population would be in the urban areas. So, the urban transit is a primary challenge. Transit buses (TBs) have gained much popularity around the world due to the cost effective alternative to the urban rail transport. Approximately one TB replaces 30 cars on the roads. Buses are the major alternative for various low income people, who do not drive, older generation, people living in remote areas and physically disabled people. There are many countries in the world that are majorly running diesel transit buses (DTBs) for public transport purpose. The China is the most populous country in the world (1.44 billion as of August, 2020) and absolutely need more transit buses to carry out the passengers of various rural and city areas. Based on the statistics provided by the china transport authority in the month of August, 2020 there are total 23 million diesel transit buses (DTBs) running on the roads of china [1]. On the other hand, India is the second most populous country in the world (1.38 billion as of August, 2020). According to the data provided by an international Association of Public Transport of Indian country, the city and intercity transit buses carries 68 million passengers daily. As per the survey conducted by the state road transport undertakings (SRTU) there are approximately 3 million DTBs on the roads of various cities and rural areas of the Indian country [2],[3].

The TBs are of four types include, diesel transit buses (DTBs), natural gas transit buses (NGTBs), diesel hybrid transit buses (DHTBs) and electric transit buses (ETBs). The usage of DTBs is one of the major causes of air pollution in the cities. Out of various combustion products (NO_x, CO_2, HC, CO,) released by DTBs, NO_x is the most dominant. The NO_x released by a 231 kW, 1275 Nm DTB tested in a city travel route is 8.73 gm/km. whereas other gases were CO_2-1.57 kg/km, HC- 0.07 gm/km, CO-2.12 gm/km[39]. NOx gases are the main cause for acid rains and destruction of forests. As per the WHO statistics in 2020, globally one in eight deaths is due to the air pollution. The CO_2 emissions of various transit buses are shown in the Fig.1.

Worldwide there are approximately 6 million city transit buses in operation and out which only 0.43 million buses are of electric transit buses (ETBs) (just 13 % only). See Table 1. The primary cause for least adoption of ETBs are their cost, the ETBs are 3 to 4 times costlier than conventional DTBs [5]. However the ETBs have several benefits like low noise,

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minimum greenhouse gas emissions and better living atmosphere. [6]- [9]. It is worth emphasizing here that the city in china called Shenzhen has 16,500 ETBs (100 % of TBs) running on the roads as of August 2020. The Shenzhen bus group has claimed that they could reduce the CO_2 emissions by 4, 40,000 tonnes and could conserve 1, 60,000 coal per year. Also they claimed that the recharge time for ETB battery is 5 hours and the bus has driving range of 250 km. [10].

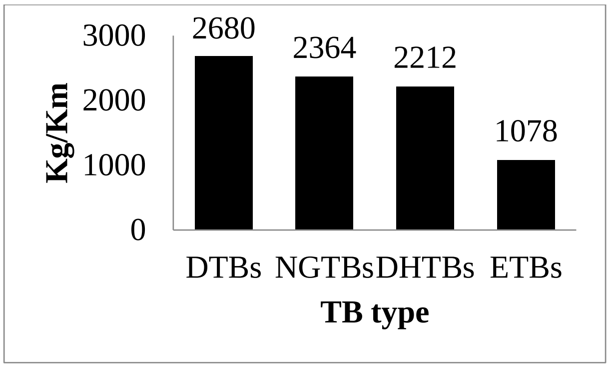

Fig. 1. CO_2 emissions by various types of transit buses.

Table 1. Statistics of ETBs (1000 buses minimum).

S. No	Country	No of DTBs	No of ETBs	% of ETBs
1	China	23,00,000[1]	4,21,000	18.30 %
2	India	16,00,000[2]	5000	0.3125%
3	Europe	8,92,861[40]	4000	0.4479%
4	US	10,00,000[57]	2500	0.25 %

The world's leading ETB manufacturers are Yutong (China), BYD (China), Ankai (China) Dongfeng (China), KingLong (China), Hengtong (China), Zhongtong (China), Sunwin (China),Tatamotors (India), AshokLeyland (India), JBM (India), PMI (India), Poterra (North America), VDL (Netherlands), Volvo (Sweden), Solaris (Europe), Ebusco (Netherlands), Higer (China), Scania (Germany), and Alstom (France). Out of all these, the Yutong and BYD are the major suppliers and they have supplied the ETBs to many countries like United States, japan, India, Chile and Britain. This paper discusses the classifications of ETBs in the second section. The modern buses are manufactured in three categories, battery electric buses, fuel cell electric transit buses and hybrid electric transit buses. Also the study compares these bus technologies by considering various technical parameters into consideration. Section 3 of the paper discusses the most coming technologies adopted in United States, Europe, Japan and China. The study also shows the various CHAdeMO charging protocols and their electrical power ratings. The highest power rating available for ETB charge is CHAdeMO with 600 kW. Section 4 of the paper discusses the various charging infrastructures for electric transit buses. The conductive and inductive charging infrastructure are compared with respect to their advantages and disadvantages. The overhead charging can be done in two ways, off board top down pantograph and on – board bottom up pantograph methods, both of these methods are compared with respect to their benefits and drawbakc. The individual benefits of each type are presented. The study also shows the technical specifications of the various bus models of BYD group buses. Almost all the types of the BYD buses prefer Lithium-ion phosphate bus type. Further, the current progress made in wireless charging is shown in this section. There are certain barriers to adopt the ETBs. The barriers are grouped into technical, financial and institutional type. Finally section 5 presents the current status of electric bus market in china. The china is leading bus manufacturer with selling capacity of 18000 per annum.

2. TYPES OF ELECTRIC TRANSIT BUSES

The ETBs are generally classified based on the usage of electrical energy sources and storages methods. Given as follows

a) Battery Electric Transit Buses (BETBs)
b) Fuel Cell Electric Transit Buses (FCETBs)
c) Hybrid Electric Transit Buses (HETBs)

a) Battery Electric Transit Buses: BETBs stores the complete electrical energy requirement for the bus in the battery. Based on the range and charging schemes, theses buses can be grouped into opportunity charging and overnight charging type. The former type can be rapidly charged at the charging stations (only 5 mins) after running a short range of 30-70 km [41]. The later type is slowly charged overnight and has long range. The range of the bus depends on the battery capacity. High capacity or low capacity batteries may be used. High capacity battery can give high range but increases the cost and weight. The low capacity battery provides less range and need more CI at various locations on routes to charge them frequently, which can further add to the CI cost. The cost of BETBs is nearly double as that of DBs. Specifically, the overnight BETBs are expensive than opportunity BETB. Mostly used battery types in BETBs are lithium ion types, like lithium nickel cobalt manganese, lithium titanate, lithium iron phosphate. The bus manufactures BYD and Volvo uses lithium iron phosphate, Poterra prefers lithium titanate and VDL bus uses lithium nickel cobalt manganese type.

b) Fuel Cell Electric Transit Buses: FCETBs stores the hydrogen fuel in cylinders and converts the chemical energy stored in hydrogen into electricity. The purified hydrogen is filled in the cylinders and fitted on the roof of the bus. Fuel cells (FCs) provide high energy efficiencies due the less operating temperatures. The FCETBs are often operated along with batteries and ultracapacitors to have additional benefits like, improved performance, lower size of FC stack, long range and reduced cost. FCETBs are expensive to operate (running cost) over lifetime when compared with other ETBs but slightly economical when compared with DBs. [42],[43]. However the purchase price of the FCETBs are 2.5 times greater than the DBs.[44]-[47]. Also, the kerb weight of the FCETBs are nearly 2.5 tonnes more than DBs. Despite the high cost of these buses, there is a growing interest towards the development due to various benefits like, long range, quick refueling time, zero local emissions and no CI requirement. FCETBs can run for 350 km range with 56 kg of hydrogen stored capacity and equivalent to 565 liters of tank space. Whereas the DBs need only 200 liters of fuel tank to run 350 km range. The current refueling rate achieved at the hydrogen refueling stations for theses buses is 5 kg/ min, in other words the bus can run for 400 km with a refueling time of 10 minutes, which is faster than the recharge time of the batteries in BETBs.

Fig. 2. Rooftop hydrogen storage on the FCETBs (source Sealord photography on Smugmug).

c) Hybrid Electric Transit Bus: HETBs runs with both IC Engines and electric motor. IC engine is powered y diesel and electric motors are powered by battery. These are the most common type of buses in operation. The components are connected three configurations, series, parallel and series parallel. Series configuration is preferred for low speed operation and parallel configuration is preferred for high speed operation. The current electric bus market around the globe prefers 70 % of the HETBs designs of parallel configuration and the rest 10 % series and 20 % series parallel configurations [50]. HETBs are economical when compared to BETBs and FCETBs but 50 % more costly than DBs. However, the maintenance cost of the HETBs is lower than DBs and more expensive than BETBs and FCETBs [49]. Also, HETBs have less running cost due to higher fuel efficiency. At the early stage of electric bus market in 2012, the global share of ETB purchases were 90 % - HETBs, 6% BETBs and 4 % FCETBs. After 4 years from there, the ETB procurements were changed to 78%-HETBs, 7% BETBs and 14 % FCETBs. Now in 2020, ETB market has focused more on FCETBs due to the various benefits of these FC devices. Current ETB bus market has 73 % HETBs, 8% BETBs and 19 % FCETBs. [51]

Table 2. Comparison among ETBs and DBs [27],[34] [38]

Parameters	**BETBs**	**FCETBs**	**HETBs**
Range	Reasonable but small	Higher compared to BETBs	Almost similar to DBs
Refueling capability	Expensive and easy	Expensive and difficult	Economical and easy
Kerb weight	Heavier than DBs and HETBs (since batteries are heavy) but lighter than FCETBs	Heavier than DBs, HETBs and BETBs, due to hydrogen cylinders	Little heavier than DBs but lighter than BETBs and FCETBs
Purchase price	1.5 times of DBs price	2 times of DBs price	4 times of DBs price
Operating and Maintenance cost	Lower than DBs, HETBs and FCETBs	Higher than DBs, BETBs and HETBs	Lower than DBs but higher than BETBs and much higher than FCETBs
Infrastructure cost	Much higher than DBs but lower than FCETBs	Much higher than all types of TBs	Little higher than DBs but lower than BETBs and FCETBs.
Energy efficiency	450 % higher than	150 % higher than	100 % higher than

	DBs	DBs	DBs

3. MOST COMMON CHARGING TECHNOLOGIES WORDWIDE

The charging technologies for ETB are not universally common throughout the world. It varies from country to country; each country has own standards for the ETB chargers. The charging standards and technologies for ETBs differ with their type of electricity transfer (Conductive or inductive), output power type and range (AC or DC), communication and protection capabilities. The equipment used to charge a battery of an electric vehicle is universally known as electric vehicle supply equipment (EVSE) or simply called as a charger. The charging technologies around the world cannot be compared altogether due to the lack of unique universal standards of the EVSE. Absolutely, the design parameters of the EVSE depends upon the individual nation's power grid design and charging requirements of EVs. It is worth knowing the various charging standards followed by the countries prominent in EV market. The charging standards of US, Europe and China are presented here.

a) **US:** The US National Electric Code Committee has set certain detailed standards for EVSEs for EVs. As shown in Table 2. The charging schemes for EVs are categorized into three levels, Level 1, Level 2 and Level 3. Level 1 and Level 2 are AC type and use single phase voltage power supply available at home and commercial buildings. On the other hand, Level 3 use three phase AC voltage or DC power supply. The combined charging system (CCM) protocol is commonly used in Europe and US countries. All in single easy usage is key benefit of CCS protocol. The CCS is universally accepted by many EV companies. They have 1-phase ac charging with type 1 and type 2 inlets, 3-phase ac charging with type 2 inlet and high power(> 350 kW) dc charging with dedicated pins via combo 1 and combo 2. They stand as competitors for CHAdeMo (Japanese) GB/T(Chinese) Tesla super charger(Tesla sole proprietary).

Table 2. ETB charging standards in US[23].

Charging levels	**Voltage rating (V)**	**Current range(A)**	**Power range(kW)**
Level 1	120	15-20	1.4 - 2.4
Level 2	240	20-100	4.8 - 24
Level 3	480 V	60-400	50 - 350 kW

b) **Europe:** The European electricity industry has set their own charging standards as shown in Table 3. It has four modes of charging schemes. First three modes are suitable with 1-phase or 3 phase power supplies and whereas mode 4 is a dc fast charging. The Mode 1 charging is at only home and commercial buildings and not much preferred standard. This is a slow charging process and can the power socket gets heated during the long time charging. Mode 2 and 3 are reasonably preferred to charge the EVs. These standards define safety and communication related to charging process.

Table 3. Charging standards in Europe[22].

Modes	**Details**	**Voltage rating (V)**	**Maximum current (A)**	**Power range (kW)**
Mode 1	House hold AC charging (slow)	250/480	16	3.7 - 11
Mode 2	AC charging with safety	250/480	32	7.4 - 22
Mode 3	AC Charging with safety and communication between charger and vehicle	250/480	32	14.5 - 43.5
Mode 4	DC fast charging	600	400	38-170

c) **China and Japan:** Chinese electricity council and japans CHAdeMo both contributes to set up a common charging standard for all the EVs. Initially the China adopted the European charging standards as shown in Table 3. From 2018 onwards, the China and Japan allied together to create a common standard.

Fig. 3. Photograph showing the collaboration between Japan and China on 28th April 2020(Source: Electrek).

CHAdeMo is the top association to manufacture DC fast chargers; there are 50 manufacturing companies throughout the globe. The CHAdeMo has both countries together released a new charging standard CHAdeMo.3 for charging the ETBs quickly. The CHAdeMO.3.0 protocol is DC charger with the power rating of 500 kW and maximum current rating of 600 A.

Table 4. CHAdeMO charging protocols [21].

CHAdeMO Protocols	Released year	Power rating kW	Maximum Current (A)	Voltage rating (V)	Details
CHAdeMO 0.9	2010	62.5	125	500	Most popular dc fast charging in the world
CHAdeMO 1.0	2012	62.5	125	500	Enhanced Vehicle protection, compatibility and reliability
CHAdeMO 1.1	2015	62.5	125	500	Emergency stop button and dynamic change of current during charging.
CHAdeMO 1.2	2017	200	400	500	First high power charger with protection against excess temperature, overload protection, fault detection availabilities
CHAdeMO 2.0	2018	400	400	1000	Quick charging for trucks and ETBs
CHAdeMO 3.0	2020	500	600	833 V	Quick charging for trucks and ETBs
CHAoji	Announced &Expected in 2021	900	600	1500	Ultra Quick charging for trucks and ETBs

4. CHARGING INFRASTRUCTURE FOR ELECTRIC TRANSIT BUSES

The key points to be considered to deploy more ETBs on roads are the development of adequate and efficient charging infrastructures (CI) and power conditioning systems (PCSs) for ETBs. The technical challenges with CI for ETBs are design, construction, maintenance and operation [36]. An efficient and reliable CI for ETBs at short distance is need of the hour to open the doors for huge number of ETBs on the roads [37]. There are currently four charging options available to recharge the batteries of ETBs which are plug-in charging, overhead charging, induction charging and battery swapping. The plug in type and overhead charging can together be called as conductive charging schemes. The plug-in type is designed for fast charging of ETBs and has various benefits like less CI expenditure, robust, stable, reliable and user-friendly. The overhead charging schemes are of two types. First, off-board top down pantograph (OBTDP) and second is on-board bottom up pantograph (OBBUP) [11]-[15]. The OBTDP method is a scheme of opportunity charging ETBs charged in regular intervals. The duration of the charging the batteries depend on the traffic, driving distance, climate condition and the size of the battery. The OBBUP method of is also an opportunity charging scheme, the bottom up pantograph is mounted on the roof of the ETBs, the bus driver charges the battery by raising the pantograph to the DC power supply catenary wires and the pantograph is lowered after finishing the charging procedure.[16]-[21]. The charging stations are located at few bus stands around the cities and it is almost impossible to have at every bus stand. The careful study is required for selection of placement of the charging stations [22-33]. The key challenges with conductive charging schemes are charging time, time lapse in standing the queue of various buses and availability of charging station with in the range. [34]

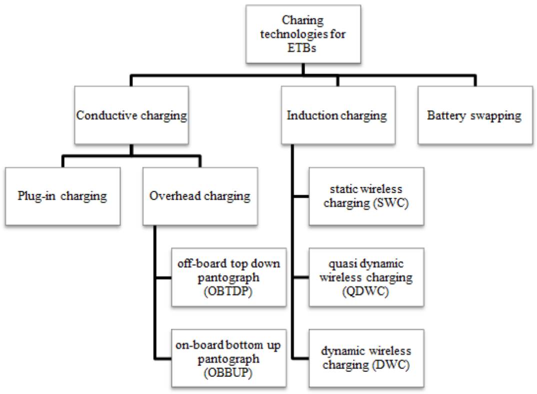

Fig. 3. Charging schemes for ETBS.

The drawbacks of conductive charging can be overcome by an inductive charging scheme for ETBs. It is also called as wireless charring. This method charges the battery of ETBs by transferring the power from an inch of distance. An extensive research has been conducted to increase the air gap distance to 1 m. The ETBs need high power and hence transferring power to the high power battery from distance is a huge challenge nowadays [35]. The wireless charging is classified into three methods, Static Wireless Charging (SWC), Quasi Dynamic Wireless Charging (QDWC) and Dynamic Wireless Charging (DWC). These methods have got certain advantages over conductive charging like, shock free, easy installation, less charging time, increased driving range and less battery size. In this paper, the various methods of conductive and wireless charging schemes are reviewed and recent advancements are given. The plugin types of charging with various connectors are suitable to charge the low power rating batteries installed in EV cars.

4.1. OVER HEAD CHARGING FOR ETB

There are two types of charging facilities available for any ETBs, on route charging (opportunity charging) and overnight charging. In the former type, the buses are charged during the operation on the bus running routes with a high power charging capacity between 150 kW to 600 kW. In the later type, the buses are charged during non-running conditions at night time with low power ranges (50 kW-150 kW). The on route charging schemes can be of direct plug-in (for small buses) or pantograph (for heavy 40 ft bus) or inductive or battery swapping. Again the pantograph types are two, OBTDP and OBBUP type. These two are further explained as follows.

A) OBTDP CHARING INFRASTRUCURE

In OBTDP scheme, the ETB does not need to carry any power electronic converter for charging the batteries. The pantographs with a certain dc power levels are located along the road side, the bus stops at an appropriate place as indicated by the mark on the roads. The pantographs moves down on the terminals of the ETB battery and charge them. The charging duration depends on the charger capacity, driving distances, traffic congestion, size of the ETB battery and climate condition. The ETBs should have contact rails, Wi-Fi antenna, switch gear and control units to satisfactorily get charged from OBTDP charging scheme. There are many but Siemens and ABB companies are well known to facilitate these charging schemes. Both ABB and Siemens have charging capacity ranges between 150 to 600 kW.

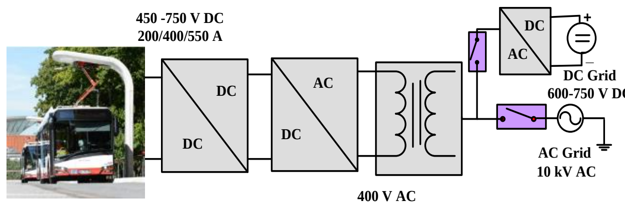

Fig.4. OBTDP charging infrastructure connected with charging station supplied by ac and dc grids.

Fig. 4 shows the complete charging infrastructure of an OBTDP type. The required power for charging the batteries are obtained from AC or DC grids. In the case of AC grid power supply, a transformer is used to step down the high voltage level 10 kV of AC grid to 400 Vac as input to the ac-dc converter (rectifier). The DC voltage output of the rectifier is further increased by using a dc-dc converter. The battery sizes of ETBs are generally high and nearly vary the power ranges between 60 kWh to 550 kWh, with a typical capacity of the ETBs ranges from 200 kWh to 300 kWh. All city ETBs have high power ranges and shuttle, trolley buses adopt low ranges of battery capacity. For example the various ETB models of Chinese bus manufacturers and suppliers company BYD are compared in Table 5 and photographs of each compared model are shown in Fig. 5 for the necessary understanding. As shown in Table 5, the battery size will depends upon the passenger capacity and length of the bus. A 45 feet double decker shown in 5 (a) and 60 feet electric transit bus models needs same battery size of 446 kWh with a charging capacity of 200 kW(Own BYD charger). Whereas the 23 feet electric motor coach model needs a battery size of 121 kWh with a charging capacity of 40 kW(Own BYD Charger).

Table 5. Battery charging details of BYD ETBs [46].

Fig No	**Bus model**	**Battery type**	**battery size**	**charging capacity of CHAdeMO 3.0**	**charging time with CHAdeMO 3.0**	**Max power**
5 (a)	45′ DOUBLE DECKER ELECTRIC BUS	LIP	446 kWh	500 kW	50 mins	180 kW× 2
5 (b)	35′ DOUBLE DECKER ELECTRIC BUS	LIP	313 kWh	500 kW	37 mins	180 kW× 2
5 (c)	40′ Electric Motor Coach	LIP	352 kWh	500 kW	42 mins	180 kW× 2
5 (d)	35′ ELECTRIC MOTOR COACH	LIP	313 kWh	500 kW	37 mins	180 kW× 2
5 (e)	23′ ELECTRIC MOTOR COACH	LIP	121 kWh	500 kW	14 mins	150 kW× 2
5 (f)	60′ ELECTRIC TRANSIT BUS	LIP	446 kWh	500 kW	50 mins	180 kW× 2
5 (g)	35′ ELECTRIC TRANSIT BUS	LIP	266 kWh	500 kW	32 mins	150 kW× 2
5 (h)	30′ ELECTRIC TRANSIT BUS	LIP	215 kWh	500 kW	25.8 mins	90 kW× 2

Fig. 5. Photographs of BYD bus models a) 45′ double decker electric bus b) 35′ double decker electric bus c) 40′ electric motor coach d) 35′ electric motor coach e) 23′ electric motor coach f) 60′ electric transit bus g) 35′ electric transit bus h) 30′ electric transit bus (source: en. BYD.com)

B) OBBUP CHARGING INFRASTRUCTURE

In this overhead charging scheme, the power supply available from the grid is directly connected to the on-board charger terminals to charge the HV battery of ETB. The bus needs to be equipped with the necessary power electronic converters to convert the ac power from grid to the dc power required to charge the battery or on the other case the DC catenary wires are directly available at charging stations and bottom up pantograph is raised to collect the dc power required to charge the batteries. Fig 6 shows the block diagram of the OBBUP charging infrastructure. The ac-dc converter has a front end rectifier, power factor correction circuit (to improve the grid side power factor) and dc-dc converter to boost the output voltage of the front end rectifier to the voltage needed as that of ETB battery. The DC catenary wires with 750 V are directly available at the charging station. The ETB is driven underneath the bipolar catenary wires and the bus driver raises the pantograph up to the catenary and starts charging procedure. There are various companies like CCS, CHAdeMO, GB/T, Tesla, Siemens, ABB and many more are available around the globe which provides OBBUP opportunity charging. For example the Siemens company provide 750 V dc power input through bipolar catenary wires with charging power range of 60 kW or 120 kW. They also provide the ac power with 400 V and 63 A. The ABB also provides this kind of charging with a power ranges 150 kW to 400 kW.

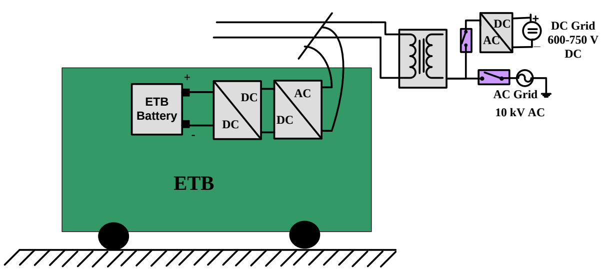

Fig. 6. Block diagram of the OBBUP charging infrastructure with on board power electronics system.

4.2. Wireless Charging for ETBs

Usually the ETBs return to bus depot center for parking at night times, the overnight charring of the ETBs are done by using plug-in or overhead charging schemes. There are various drawbacks of plugs in charging schemes like slow charging, vandalism, whether damage and risk of electric shock. Next, in addition to the above mentioned drawbacks, the overhead charging systems again need frequent maintenance due to the involvement of moving parts and also adds to the extra cost. The wireless charging schemes are completely hand free and no action is required by the driver to charge the battery of ETB and takes lesser space (1/3 of battery in EV charged with plugin type) compared to the plugin and overhead charging schemes and also the weight of the vehicles also gets reduced. The buses can move the passengers throughout a day without the range concern. The cost of charging infrastructure for wireless charging is almost 30 % of what is spent on plugin and overhead type charging schemes.[56] The wireless technology transfers power to a receiver mounted on the ETB undercarriage bus through the air from an embedded transmitter placed in the pavement. It uses electromagnetic field principle to transfer the power. The transmitter pads are located at various bus stops, highways and traffic signals to continuously charge the ETBs during running conditions. There are three types of wireless charging systems, static, quasi dynamic and dynamic methods [52]. Static method is used widely at bus depots, quasi dynamic method is used to charge the buses at traffic lights and bus stops and the dynamic method provides an a continuous charging under runner conditions of the bus in a specified electrified lanes. Also, the dynamic charging allows using smaller battery capacity and increases the driving range of the ETB [53]. The comprehensive study on wireless power transfer and comparative study is presented in [54].

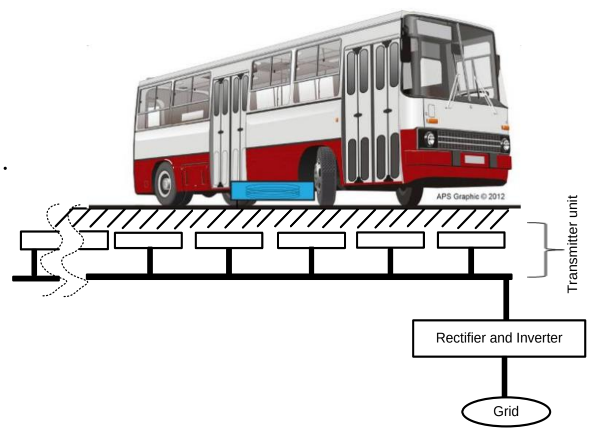

Fig. 7. Outlne digram of wireless charging system for electric transit bus(Image courtesy: America Phisical Society).

The wireless charging scheme involves with basic elements power transmission system and pick up system. The power transmission system transfers the power to the receiver from grid using electromagnetic principle and consists various elements in it like transmitter unit, powered track and power supply unit. Whereas, the pickup system in the ETB receives power from the transmitter unit and it has a pick up unit placed at the bottom of ETB surface, also it has a rectifier circuit to provide dc power to the battery.

4.3. Current Progress in Wireless Charging of ETB

a) **WAVE :** The Wirelss Advance Vehcile Electrificaton (WAVE) is US based compnay and offers the wiress charing for heavy commerical vehicles from power ranges 50 kW to 250 kW. They provide an exptreme fast charging for ETBs using 250 kW multiple wireless chargers. The WAVE has got various branches across the country. They provide charing facilities to various transit authorities like Utah, Monterey Salinas, McAllen Metro and AVTA. The US based public tranist Antilope Valley Transity Auhtoriy AVTA(Antilope Valley Transmit Authoority) buses are charged by these WAVE wireless charing systems. The AVTA buses have smaller batteries, lighter weight, high passenger capacity and longer range due to 100 % electrification of routes with wireless charing. They also serve BYD buses [55].

b) **WiTricity:** The name is derived from the statement "Wireless Electricity", Wi from Wireless and Tricity from Electricity is taken up and formed as a new name WiTricity. WiTricity started in 2007 and the charging principle is resonant charging. This company was started by Marin Soljačić who is professor in department of physics, Massachusetts Institute of Technology (MIT), US. The two resonance objects exhanges the energy between them when they operate at same resonat frequency, the principle employed in wireless power transfer by WiTricity. They provide the wireless charing to the ETBs with the power ranges more than 11 kw.

c) **Momentum Wireless Power:** Momentum Wireless Power is an US based company located in Wenatchee city, washington, US. The charging services to the ETBs were statrted since March 2018. The principle used is the resonant magnetic induction. This wireless charging sytem is of modular type and has 4 modules with 50 kW each. Total 200 kW is available to charge the ETB batteries. The bus is charged for every 7-10 mintes in a hour. For example, the BYD K9S bus with battery size of 266 kWh has the driving range of 145 miles with a single charge of 7-10 mins. The ultimate advantage of this wireless charging is the avalability of periodic on route charing facility, which adds to the unlimited driving range. Recently they have developed the 300 kW wireless charing stations.

4.4. Barriers to Adopt the ETBs

ETBs are two to three times costlier compared to the conventional DBs. The Chinese city Shenzhen operates 99 % of their total buses with electric buses. The city runs around 16 thousand electric buses on their roads. These buses are costly and why does someone prefer these buses? The important reason one should look for is the reduction in CO_2 emissions and lesser long term ownership cost. A case study in Izmir, Turkey was conducted on 20 ETBs and 20 DBs operated in parallel. They observed that, operating the 20 ETBs led to the fuel cost reduction of 84 % and 60 % reduction in maintenance cost when compared to DBs. Also, the CO2 emissions in the city are reduced by 420 tons per annum.

After conducting the rigorous literature survey on the ETB market and based on the comprehensive report submitted by World Resource institute (WRI), the main barriers to adopt the ETBs by the transit agencies can be grouped into the three categories

1) Technological
2) Financial
3) Institutional

4.4.1.Technological barriers

The technical barriers comprises of ETBs is related with the three categories vehicle and energy storage technologies, agencies and operators, grid and charging infrastructure.

A) **Bus procurement and energy storage technologies:** The lack of technical information about the electric bus technology and their adoption is the main barrier. Many of the transit agencies of various cities does not know the actual benefits of ETB technology and no awareness on environmental, health, and long term economic benefits due to ETBs. Many transit agenesis are also worried about the life time of ETBs and performance of old ETBs. Battery recycles and disposing issues are the other reasons. The ETBs are limited to electrified routes, hence the range is a critical limitation observed by many transit operators. The battery performance variation during cold and hot temperatures is also a major barrier to the wide adoption of the ETBs. The cold temperatures often slow down the reaction rate and also extra power is required for heating systems. Similarly, hot temperatures aids to the faster discharge of batteries and also the air conditioners and other cooling devices are necessarily supplied by the on-board battery, which further tax the range of the battery. The design flaws of the bus is the another important barrier to be considered. The procurement process of the ETBs through tenders and finding the suitable manufacturer is difficult.

B) **Agencies and operators:** Most of the transit agencies and operators do not awareness to start the ETB project. Lack of planners to procure, operators to drive, technicians to service, and electrician to install the charging infrastructure. As saving environment is a global concern, every transit agencies and operators of various nations should be called together for meeting and needs to openly discuss and share the various issues like, design of suitable guide books on adoption of ETBs, how to start ETB project, range, charging limitations, how to train the drivers, how to train the electricians and how to minimize the cost etc..

C) Grid and charging infrastructure: Grid stability is one of the barriers to implement the ETBs. The batteries of ETB have higher storage capacity between 100 kWh to 400 kWh. Consistent electricity needs to supply by the grid to charge the batteries fully. The bus fleets are connected to a substation to receive power supply. If the substation is failed due to grid instability, the whole bus fleet remains charge less. A suitable smart charging infrastructure is essential to charge the batteries quickly. A charging infrastructure needs upgrade and agencies should constantly adopt the smart and economical charging methods for ETBs. The variation in charging standards is also one of the key barriers to adopt the ETBs.

4.4.2. Financial barriers

High capital cost is main barrier for mass production of the ETBs. High capital cost is due to usage of high capacity energy storage systems and high rated on board power electronic components. Due to these high up front cost, financing is difficult. The buses are operated either through operating lease (monthly payment for using the operating the bus) or capital lease (mortgage basis). Typically the cost of ETB is 2 to 3 times higher than the DB. The capital cost varies with the location, type of manufacturer and vehicle specifications. Quoting the exact price of the ETB may be a difficult idea, but the cost varies approximately from $ 300,000 to $ 900,000. In addition to the procurement of ETBs, the financial challenges are also faced in constructing and maintenance of charging infrastructure. The charging infrastructure expenses are outside the purview of transit agencies. The capital cost includes various parameters like, procuring charging station and preparation work (substation transformers, underground power supply and excavating concrete).

4.4.3. Institutional barriers

The ETB manufacturers are limited to certain cities only. There are certain barriers between the overseas manufacturer and local transit agencies. The key barriers are high tariff cost, spare parts arrival delay, bus procurement delay, and international bureaucracy dealings. Another barrier is the difficulty in removing the current stock of DBs in operation. The Contractual lock in period of the current operating buses is not allowing the transit agencies to look for the ETBs. Some transit agencies often set up a long term contract with the bus manufacturers. For example, a transit agency has 20 years of contract with a manufacturing company let's say, 2010-2030. So, till 2030, the agencies may not have obligation to electrify their bus service. Another key barrier faced by the bus operators at the agency level is the lack of support from the national and local government. The politicians and other key stake holders are not much aware of the ETBs and their benefits. If a current government approves the electric bus fleet, the next upcoming government with new administration may stop the project. Also, the selection of site for charging infrastructure and bus depots is a major barrier seen by many transit agencies.

5. RECENT DEVELOPMENTS IN GLOBAL ELECTRIC BUS MARKET

China is the leading manufacturers and operators of ETBs in the world. Based on the available records, there are 4, 21,000 ETBs running on the china roads as of October 2020. As per the recent reports released by the industry experts, the china manufactures approximately 9500 buses with in one month duration. Schenzen, China is one and only city in which, entire bus fleet is gone electric. There are 17000 electric buses running as of October 2020. It has taken almost 10 years to transform the city into whole electric powered bus fleet. The deputy general manager of Shenzhen Bus Company says that the achievement was possible with the support and funding by the Chinese government. Each bus is fitted with 7 cameras and power by GPS network. The buses move around 2 million passengers per day. The buses are operated for only seven years and retire later. Due to COVID-2020, the selling of ETBs in china has dropped to only 8394 units. The number of buses sold in 2019 year was 18232. The domestic bus market leaders in china are Yutong, BYD, Zhontong and Winnerway. Yutong is standing as the top bus manufacturing company in china. All most 90 percent of the electric buses in china use permanent magnet synchronous motor with the power range from 200 hp to 300 hp. The motors are supplied by the batteries of charging capacity ranges between 150 kWh to 300 kWh. Many of the bus markets are supported by the subsidies provided but the Chinese government. Based on the length of bus, the ETBs are grouped into three categories, large bus (10 m-12 m), medium bus (8 m -10 m) and small bus (5 m to 8 m). The bus type could any of the following type, BEV, PHEV, HEV or FCEV. The BYD electric buses have been supplied in dozens of countries including the major counties United States, japan, India, Chile and Britain. 50 % of the electric buses running on the Indian roads were supplied by BYD Company.

Recently, the Chinese company Youtong has launched ZK6907H ETBs in June 2019. It has four models namely, T7 3.5 T, U10, L4 and F8. The North America's ETB manufacturers NFI (New Flyer Infrastructure) group is the world's largest double decker electric bus manufacturer which works in alliance with BYD and ADL (Alexander Dennis Limited). ADL provides the light weight chassis and outer body to the NFI and BYD supplies the electric power train.

6. CONCLUSIONS

The electric transit buses play major role in reducing the greenhouse gas emissions in the various cities of the nations. The governments of individual nations should support the transit agencies to manufacture the ETBs at larger rate. The key barriers to adopt the electric buses were technical, financial and institutional. All these barriers need to be carefully looked up and the transit and agencies and operators need some best support in developing the new modern ETBs in the market. The china is leading manufacturers of the ETBs with 421000 buses which is 18.30 % of the total buses. The other countries should take china as reference and one should move towards to reach the goal. In this regard, the china deserves great respect as they are moving fast towards the electric bus fleet. The environmental protection is the universal issue and each country is equally responsible to achieve the reduced global emissions. The author hopes that the technical information given in this document may help the readers to purse their research study on the electric buses. The fundamental details of battery electric bus, fuel cell electric transit buses, and hybrid transit buses were given. The compassion among the various bus types were shown based on several parameters like range, refueling, kerb weight, cost and efficiency. It is clear from the study that the hybrid operation of the buses aids to better range and economy. Further, the most common charging topologies of the used worldwide were presented. There is no unique chairing standard followed commonly. It varies country to country. The battery capacities of the ETBs usually range between 50 kWh to 300 kWh. The CHAdeMO protocol has the highest charging power capacity of 600 kW. This is the most suitable charging stations for ETBs. Furthermore, the charging infrastructures for ETBs were clearly emphasized as the main study. The various advantages and disadvantages of conductive, inductive and battery swapping technologies were given. It has been shown that the inductive charging scheme has various benefits up on the conductive type like; shock free, neat appearance, less space, less costly, more flexible and low battery capacity requirement. The current progresses in the wireless technologies in the world were presented. The brief background and technical details various modern wireless chairing companies, WAVE, WiTricity and momentum wireless power were briefly described. The current bus market of china has been briefly reviewed and presented.

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