Challenge of Innovative Electric Roadway System Featuring Capacitive Coupling Wireless Power Transfer

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ABSTRACT: This paper reviews worldwide history and recent trend of Electric Road System(ERS) based on DWPT. History of Patent, FS and Evaluation on test course are reviewed covering Europe, England, United States, Korea, China and Japan. Also review current status of standardization and regulatory such as ISO,IEC,SAE,ITU and CISPR. Report on our ongoing challenge plan using test course for innovative ERS featuring Capacitive Coupling DWPT at Fiji-Yoshida city is introduced . Social implementation of DWPT on Public Road at northern area of Mt. Fuji after evaluating using test course will contribute carbon free smart mobility society in the future. It will also contribute the plan of Fujisan railway which was reported by Fujisan railway study committee at Feb.2021. The draft plan of Fujisan railway with no catenary LRT are overviewed.

KEY WORDS: electric vehicle, e-mobility, EV charging, dynamic wireless power transfer, Capacitive coupling , Electric Road System, Standardization, Social Implementation, smart city, Fujisan, LRT, no catenary

1. INTRODUCTION AND BACKGROUND

Wireless Power Transfer(WPT) for e-mobility has been widely developed after report of MIT at 2007. In Japan from 2009 to 2012 METI has arranged technical evaluation program of WPT on Magnetic coupling and also Capacitive coupling type. After 3years deliberation of WG under committee of Radio wave usage environment, April 2016, METI has released technical condition for static WPT for EV under 7.7kW using 85kHz band. At same time Capacitive coupling type WPT under 100W using 400kHz band was also released. From 2021 Capacitive type WPT under 4kW using 6.78MHz band for factory robots is in under deliberation of WG.

International Standardization of ISO/IEC which were started from 2010 and first IS has released 2020 as IEC61980-1 of general requirement. IEC61980-2 for communication control and IEC61980-3 for WPT using magnetic resonance are under FDIS. SAE J2954 standard has also released Oct.2020. Many trial of static WPT for e-mobility has been reported. At 2022, Korea and China OEMs have started to equip static WPT for passenger car.

Along with trials of Static WPT, Feasibility Study (FS) and trials of Dynamic Wireless Power Transfer(DWPT) with Electric Roadway System(ERS) are ongoing. They, on test course and/or public road, have started to realize Carbon Free society. We are now challenging to realize Innovative Electric Roadway System Featuring of Capacitive Coupling Wireless Power Transfer at North Region of Mt. Fuji of Yamanashi Pref. Japan.

2. WORLD TREND OF DWPT

2.1. History of DWPT after 2013

Mr. Takahashi suggested[1)] that the first literature on DWPT idea was US Patent 527.857 at 1894 by M.Hutin and M.Leblanc[2)] almost same time when EV has developed. After then, 1980s PATH(Partners for Advanced Transit and Highway) project[3)] was tried in US. Unfortunately these ideas have not realized enough because of some reason. After 2013, Europe(FABRIC) and Kore(KAIST) re-promote DWPT for future carbon society.

2.1.1 Europe and England

Highway England has reported Feasibility Study Report (FS) at 2015. They announced “England to test charge-as-you-drive 'electric motorways’ ”. Same time Fabric (FeAsiBility analysis and development of on-Road charging solutions for future electric vehicles) project has planed during 2014 to 2018 which was funded under FP7- TRANSPORT of EU and overall budget € 9.09M and EU contribution was € 6.495M . After closing FABRIC, INCIT-EV project (INnovative set of Charging Infrastructures, Technologies) has started from 2020 with € 15M/4 years 32 partners. At Sweden, four demo sites on public roads including

DWPT at Gotland by Electreon are undergoing on electric roadway between airport and city center from March 2020.

At Dec. 2021,Stellantis Group announced their "Arena-del-Futuro", prepared 1km test course , supply power is 1MW and 5G communication system. near Trino Italia They announced overall budget will be € 30bilion until 2025. .

2.1.2 United States

UTAH State university has started their DWPT project at 2015 They prepared Test Course of 409m with 750kW power supply.
ASPIRE (Advancing Sustainability through Powered Infra. for Roadway Electrification) of NSF engineering research center of UTAH State university are testing and evaluating two 100kw receiving module on board and 100kW/m power supply.

2.1.3 Korea and Chinas

KAIST Korea started their evaluation of DWPT for e-BUS OLEV system on public road at Gumi city at July 2013. They established Wipower-one which is specialized in manufacturing wireless charging infrastructures and pickup products.
China has announced their first trial of DWPT at 2016. Also announced at 2022, their practical engineering implementation of high power level DWPT system which power level is 60kW.

2.1.4. Japan

At CEATEC 2014, Prof. Ohira of Toyohashi University of Technology (TUT) and Taisei co. has demonstrated capacitive V-WPT (Via-wheel Power transfer) method DWPT[4]. At 2016 Daihen co. and Prof. Okada of NAIST has prepared oval test course at Oita ushing parallel two line method[5]. At Sept 2022, Mitsui Home Co. and Prof. Fujimoto of Univ of Tokyo has released KOIL test field at Kashiwa City with IWM. Many teams in Japan have evaluating and demonstrating their trial at test site for DWPT. For public road. At March 2022 to demonstrate at show case of Kansai EXSPO 2025, Team of Kansai electric Power and Daihen Co. has evaluated their DWPT system at Maishima Island Osaka.

2.1.5. Study and Evaluation of road structure for ERS

MLIT is supported to improve road structure to implement ERS of different types of DWPT from 2020 to 2022. - Tokyo University of Science based on magnetic resonant and studied Coil burying method and evaluate its character under real road.
-Taisei co. using capacitive method, studied to develop practical system for ERS.

3. STANDARDS AND REGULATIONS FOR DWPT

3.1 Standards Development[6][7]

First NWIP(New work item proposal) for DWPT of IEC has accepted at end of 2019 as IEC63243 and now discussing to prepare CD. NWIP for communication and control of DWPT has accepted 2012 as IEC63381 and also discussing to prepare CD. They are now renamed and merged to IEC-61980-5 and -6. ISO Standards of on-board system are now merging for conductive , wireless and automatic charging for e-mobility to IEC 5474 series. On board system of DWPT for light-duty vehicles will be developed as ISO 5474-4. SAE are also started discussion to develop High power and DWPT standard. SAE J2954 is now expanding high power and DWPT system.

Item	Org.	Activity
International Standards (IS) for System	IEC TC69 WG7	IS;IEC61980-1 ed2 Oct.2020
		IS; IEC61980-2 will be Mid..2022
		IS;IEC61980-3 will be Mid..2022
		WD;IEC61980-4 Under Discuss
		WD;IEC61980-5(IEC63243)Under Discuss
		WD;IEC61980-6(IEC63381) will prerpare
IS for Vehicle	ISO TC22 SC37	IS;ISO19363-2020 at Oct 2020
		CD; ISO5474 series Under Discuss
National Standard	SAE	STD; J2954 202010 at Oct 2020
		WG for High Power ,DWPT are working
	UL	Outline of Investigation; at March 2020
	China GB	GB; 20157675-t339
Freq. Manag.	ITU-R SG1	Rec.SM.2110-1 at Nov.2019
		Pending RR at WRC
EMC	CISPR/B/ WG1 AHG4	CD; CISPR11/FRAG1 ed7 under circulate
Human Safty	ICNIRP	Blue book released April 1998 Revised for 1kHz to 100kHz at 2010
	IEC TC106	TR62905(under 10MHz) at Feb 2018
		PT63184 for Basic Rec under discuss

Table 1 Activity of International Organization (at June 2021)

3.2 Regulations for Safety and Co-existing[8]

It is very important item keeping Safety and Co-existing with other services because the system include air-gap of electro-magnetic energy emission. WPT system should care of near-by emission to care human safety and electro-magnetic emission of unwanted band to avoid serious effect to existing wireless service. Such items for Static WPT with 7.7kW or less power has fixed in Japan. MIAC has announced technical condition for type approval of EV at March 2016.

ITU released recommendation 2110-1 at Oct 2019 which title is Guidance on frequency ranges for operation of non-beam wireless power transmission for electric vehicles to define frequency for Static WPT. The frequency range are listed below. 79-90kHz for WPT-EV.

Frequency range for operation of non-beam WPT systems for electric vehicles

Frequency range	Suitable non-beam WPT-EV
19-21 kHz	Magnetic induction technology or Magnetic resonant technology
55-57 kHz(1)	Magnetic induction technology or Magnetic resonant technology
63-65 kHz(1)	Magnetic induction technology or Magnetic resonant technology
79-90 kHz	Magnetic resonant technology

Table 2 Frequency range of WPT-EV recommended SM2110-1

Frequency range of ISM Band below are also available for WPT and DWPT. Noted A means care of some condition.

6.765 MHz	6.795 MHz	A
13.553 MHz	13.567 MHz	B
26.957 MHz	27.283 MHz	B
40.66 MHz	40.7 MHz	B

Table 3 ISM Bands between 6MHz to 40MHz bands

Considering for Co-existing with existing service and Human Safety issue should be basic for social implementation but still open at this moment. The Co-existing issue for Static WPT-EV is studying and discussing at CISPR of IEC. Fig.1 shows permission levels under 30MHz of I/655/CD. EBU(The European Broadcasting Union) still request to keeping quite low level to avid influence for Broadcasting. This may be one reason why static WPT-EV does not yet in market in EU.

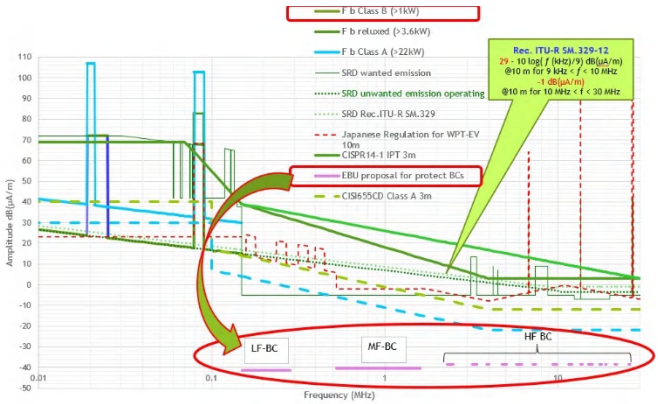

Fig.1 Comparison of permission levels at CISPR (Fig.by Kubota)

On the Human Safety issue ICNIRP has shown its guideline. IEC TC106 are now study and preparing methodology of evaluating human effects.

4. CHALLENGE OF CAPACITIVE COUPLING DWPT

New mobility based on DWPT work with Electric Road System will be one of the effective way to realize Carbon Free Society. Compared to Static WPT, to deploy social implementation, alliance and partnership should be required . Such as Academic, Local Government and private company.

4.1, Partnership agreement with Yamanashi Pref. and TUT[9)]

Fujiwaves Co., Ltd., has established at Feb.2021 to contribute local carbon free smart mobility city area in Yamanashi Pref. and also contribute to realize Fujisan railway for the future.

At Nov.2021 we have agreed partnership with Yamanashi Prf. and Toyohashi University of Technology (TUT).

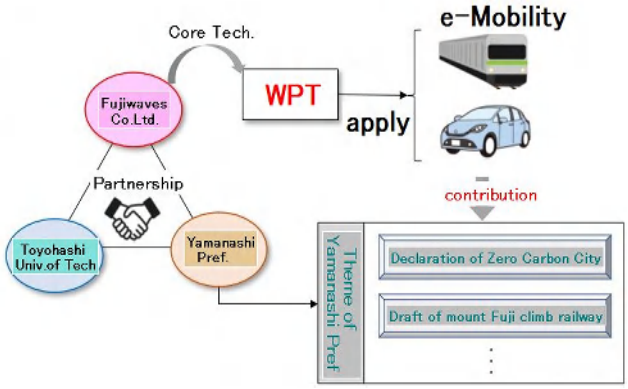

Fig.2 Concept of Partnership (LocalGov. Univ. and private Co.)

Prof. Ohira and his team have completed Test road at campus of TUT using WPT with capacitive coupling and drive a battery-less e-mobility.

NHK World Japan has broadcast at Jan.2023 , topic of science view[10)] including test road at TUT and ongoing plan of test course at Fujiyoshida City.

Fig.3 e-mobility on the electric road at TUT[10)]

Fig.4 electric road with battery-less e-mobility at TUT[10)]

4.2, Partnership agreement with Fujiyoshida city[11)]

Based on the partnership with Yamanashi Pref. and TUT, at Nov 2022, Fujiwaves Co., Ltd., and Fujiyoshida city and Mt. Fuji Springs Inc., have agreed partnership to develop future smart mobility city.

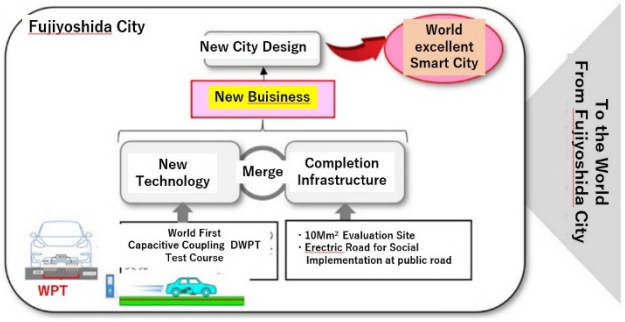

Fig.5 Target of alliance with Fujiyoshida city

4.3 New mobility city plan of Fujiyoshida city, Yamanashi Pref.

The tentative plan for smart mobility city are 4 plans.

1) consolidation of EV test course for Electric Roadway,
2) Implementation and Evaluation for public roads
3) Consolidation package for compact city with smart mobility
4) Complete Disaster prevention base

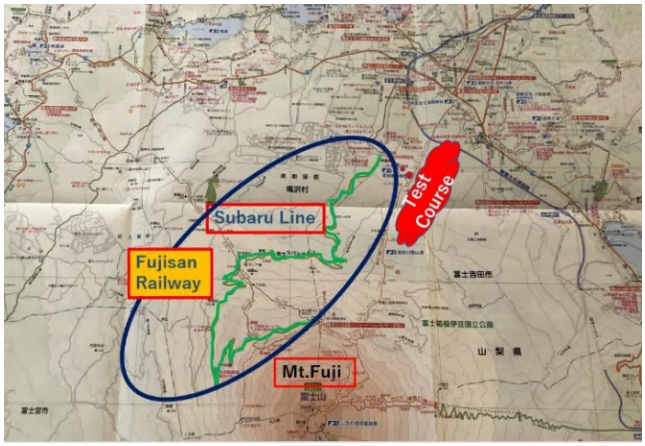

Fig.6 Northern Mt.Fuji area

4.4 Challenge of Capacitive Coupling based DWPT

According to realize smart mobility city of northern area of Mt.Fuji, we have made alliance with Fujiyoshida city and Mt.Fuji Spring Inc. will construct test course .

Following Key items will be evaluated under the test course.

1) To install DWPT system with 20kW to 80kW of 13.56MHZ Capacitive coupling concept.
2) To support safety and harmful with local grid system, we will introduce wide area communication such as Local 5G work with PtoP control such as RFID.
3) To establish Safety for Human and Live matters using Capacitive Coupling based DWPT
4) Evaluate Co-Exist with another wireless service using Capacitive Coupling based DWPT
5) Cost effective for future social implementation
6) Collect Data for implement public roads.

Fig.7 Bird's eye Concept view of planned Test course[10)]

Fig.8 Concept Layout of planned Test course[10)]

4.5. Safety monitoring for DWPT

To support safety and harmful with local grid system, we will introduce wide area communication such as Local 5G work with PtoP control such as RFID.

To apply and deploy Local 5G(4.7GHz) for communication and system control for DWPT will be world first evaluation.

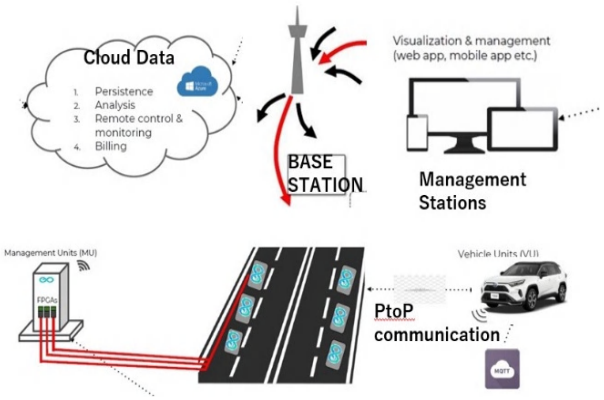

Fig.9 Concept configuration of wide area and PtoP

5. Draft Plan of Fujisan railway study[12)]

Fujisan railway study committee has established at July 2019. Chair is Mr.Mitarai (Keidanren Honorary chairman) . They released draft plan at Feb 8,2021. At that moment Fujiwaves Co., Ltd., has established to contribute the plan in the future.

The report of Fujisan railway study committee showed estimated plan for promotion and expansion visitors to World heritage Mt.Fuji keeping environmental good condition and reduce CO2 emission from ICT vehicles.

The draft has Estimated number of passengers will be 3,000,000 per year and travel time will be 52min for upword, 74min for downword.

Passengers	Per year	3,000,000
Total route length	km	24.2
Up required time	min	52
Down required time	min	74

Table 4 Estimated number of passengers and travel time

The draft report suggested to covert LRT with no catenary type instead of existing SUBARU LINE. Major conditions are listed.

- Route(Subaru Line)
- Length ; 24.2 k m(to 5th station)
- Height ; 2,305m～1,088m
- Slope; max 8.0%, mean slope 5.0%

Table 5 Major conditions of Subaru Line

They also has reported image of LRT Train and Track

Fig.10 Image of LRT without catenary

- Image LRT Track

Fig.11 Image of LRT replaced existing ICT automobile

They have prepared preliminary design for railway design. Double track layout on existing Subaru Line is considered and studied at the draft plan.

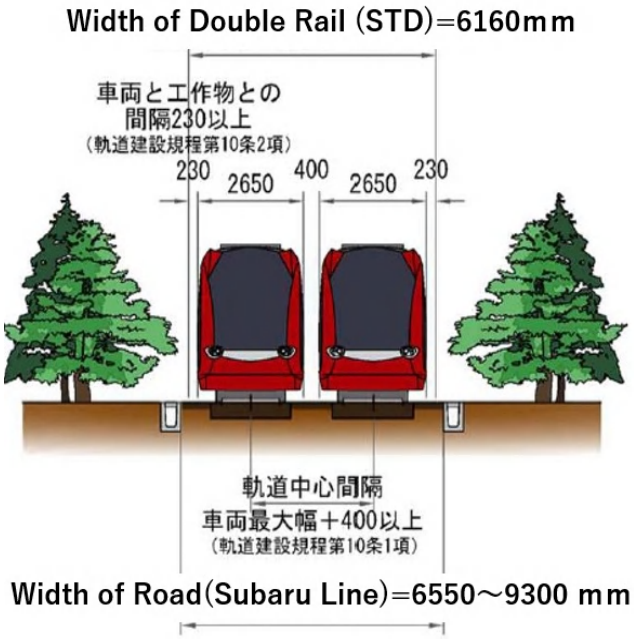

Fig.12 Propose Railway design (Cross section)

6. CONCLUSION

Our Plan for Challenge of Innovative Electric Roadway System Featuring Capacitive Coupling Wireless Power Transfer at Northern area of Mt. Fuji has reported. Yamanashi Pref. will be expected to open new page of DWPT system and Carbon Free Society near future in the world utilizing Capacitive coupling method. Also to realize Safety and convenient social deployment of Electric road system with DWPT, we will evaluate Local 5G work with PtoP control.

We expect our challenge for smart e-mobility will open next challenge for Fujisan Tozan railway without catenary. Those will open new ages of carbon-free society and also visitors convenient of World Heritage Mt.Fuji in the future.

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