Conference Presentation

Cross impact analysis of vehicle-to-grid technologies in the context of 2030

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Cross Impact Analysis of Vehicle-to-Grid Technologies in the Context of 2030

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***Abstract*—This paper investigates the future of Vehicle-to-Grid technologies to be used in the UK in 2030 using the method of cross impact analysis. The paper describes the procedure of the cross impact matrix generation conducted to produce a multiplicity of scenarios of Vehicle-to-Grid futures. Three consistent scenarios (fossil, average and green) have been chosen for further development, interpretation and analysis to predict the implementation of Vehicle-to-Grid technologies for power grid stabilising and balancing in the future.**

Keywords*—*vehicle-to-grid; electric vehicles; cross-impact analysis

I. Introduction

The global power grid faces a challenging future due to the intensively growing sector of renewable energy. The penetration of variable renewable energy sources increases the decentralisation of the grid requiring it to be more flexible. It is obvious that the future belongs to smart grids where new energy sources and effective management of electricity generation and demand helps to reduce CO2 emissions. Smart grids could revolutionise energy production and support the utility companies to balance the power grid systems using various energy storages. It has been admitted that eclectic vehicles (EV) having a battery energy storage can be used in the future to improve the grid balancing through technology called Vehicle-to -Grid (V2G) as it shown in Fig. 1.

It is observed that an average electric vehicle travels on the road about 5% of the total time, which is very similar to a conventional Internal Combustion Engine (ICE) vehicle. The rest of the time (about 95%) an EV stays at a household or parking location being connected to a power grid to be charged [1]. However, when the vehicle battery is charged an EV can be used as an energy storage device to provide V2G operation. Under V2G mode the EV can return stored energy back into grid to support the voltage and frequency stability, grid control and energy balance in the power system. It can also reduce CO2 emissions and improve the load factor [1], [2].

The present paper investigates the future of V2G technologies in the context of 2030 using methods of cross-impact analysis. It descries the design of cross-impact matrix generating a multiplicity of future scenarios. Three consistent scenarios of V2G in 2030 have been chosen for further development, interpretation and analysis. The analysed V2G scenarios are called Fossil Scenario, Average Scenario and Green Scenario.

II. Cross-Impact Balancses

Scenario techniques are widely used for analysis of possible future events in context of decision making [3]. It provides a view into a time far away from the present day and “analysis of the path that leads to the desired future” [4]. In contrast to prognoses the occurrence of future scenarios can not be forecasted.

Cross-impact methods have been developed in 1960s to generate possible scenarios for further analysis in the areas of politics, economics or technological development [5], [6]. A modern form of the cross-impact analysis is called Cross-Impact Balance (CIB) analysis. This method is characterised by high flexibility, transparency and easy learning.

The procedure of a CIB analysis comprises the following steps:

- Names of the important influencing factors called descriptors;
- Develop possible trends for the descriptors;
- Rate the impact of the descriptors to the other influencing factors from high to low in six grades;
- Calculate with a cross-impact algorithm possible scenarios;
- Interpret the obtained scenarios.

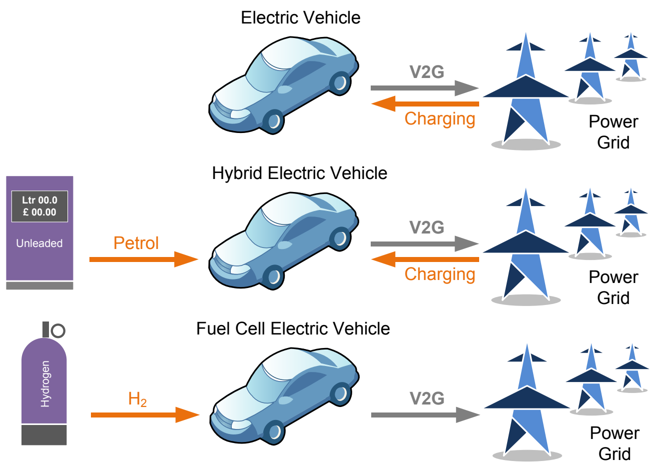

Fig. 1. Vehicle to Grid concept.

Descriptors	Variant 1	Variant 2	Variant 3
Battery technology	A1 Stagnant	A2 Small improvement	A3 Significant improvement
Electric Vehicle Total Costs of Ownership	B1 ICV much cheaper	B2 ICV and EV are equivalent	B3 EV cheaper
Charging Points Infrastructure	C1 Not further enlarged	C2 Enlarged	C3 Available everywhere
Implementation of Smart Grid	D1 Just pilot project	D2 Partially implemented	D3 Fully implemented
Flexible Smart Tariff	E1 Not available	E2 Available at big suppliers	E3 Available
Oil Price compared to 2015	F1 Lower	F2 Stagnant	F3 More expensive
Acceptance of Electric Vehicles	G1 Use in public sector	G2 Partially private and public	G3 Fully accepted
Economical Development	H1 Decreased	H2 Stagnant	H3 Accelerated growth
Average Income	I1 Decreased	I2 Stagnant	I3 Increased
Climatic Discourse	J1 Less important	J2 Important	J3 Much important than in 2015
Governmental Grants	K1 None	K2 Few	K3 Lots
Propulsion Technology	L1 Combustion engine improved	L2 Hybrid technologies in focus	L3 EV is standard
Suppliers Structure	M1 EVs are niche product	M2 Few suppliers	M3 Available everywhere
Mix of Energy Sources	N1 Conventional plants	N2 Well balanced mix	N3 Majority from renewables
Energy Consumption	O1 Decreased	O2 Stagnant	O3 Increased
Grid Expansion	P1 Stagnant	P2 Partially extended	P3 Well extended
Public Transportation	Q1 Less important	Q2 Same level as 2015	Q3 More important
Population	R1 Decreased	R2 Stagnant	R3 Increased

Fig. 2. Descriptors and variants.

CIB method can generate a large number of possible scenarios however just a small number will be consistent scenarios suitable for further development and analysis. The other scenarios containing one or more inconsistent descriptors are defined as inconsistence scenarios.

According the first procedure step, 18 CIB descriptors have been defined to generate V2G scenarios. These are

1. Battery Technology
2. Electric Vehicle Total Costs of Ownership (TCO)
3. Charging Points Infrastructure
4. Implementation of Smart Grid
5. Flexible Smart Tariff
6. Oil Price compared to 2015
7. Acceptance of Electric Vehicles
8. Economical Development
9. Average Income
10. Climatic Discourse
11. Governmental Grants
12. Propulsion Technology
13. Suppliers Structure
14. Mix of Energy Sources
15. Energy Consumption
16. Grid Expansion
17. Public Transportation
18. Population

Cross Impact Matrix	A1	A2	A3	B1	B2	B3	C1	C2	C3
Battery technology									
A1 Stagnant				3	-2	-3	2	-1	-3
A2 Small improvement				2	-1	-2	1	-1	1
A3 Significant improvement				-2	0	1	-2	1	3
Electric Vehicle Total Costs of Ownership									
B1 ICV much cheaper	3	-2	-3				2	-1	-2
B2 ICV and EV are equivalent	-1	1	1				-1	1	-1
B3 EV cheaper	-3	1	2				-1	1	2
Charging Points Infrastructure									
C1 Not further enlarged	1	-1	-1	1	-1	-1			
C2 Enlarged	-1	1	1	1	0	0			
C3 Available everywhere	-1	1	1	1	0	0			

Fig. 3. A fragment of the cross impact matrix.

Every factor from the list has an impact on the future of V2G technology. For example, the battery technology brings a significant impact on both power grid and EV development. A short travelling distance of EVs is the most important issue related to the current state of the battery technology. Therefore, if the technology will be developed and the batteries could store more energy in the future then the travelling range of EV will be extended and the vehicle acceptance will be increased.

At the next step of CIB the descriptors are overviewed and qualitatively rated. Every descriptor has three stages of development. For example, the battery technology could be stagnant (no improvement), improved at a small level or significantly improved to reduce cost of EVs, increase lifetime and the range of travelling. Fig. 2 shows the list of descriptors and three corresponding variants. The descriptor mutual impacts have been rated using seven grades from –3 to 3 as following [7], [8].

+3 = strongly promoting influence;
+2 = moderately promoting influence;
+1 = weakly promoting influence;
0 = no influence;
–1 = weakly restricting influence;
–2 = moderately restricting influence;
–3 = strongly restricting influence.

This procedure initiates generation of a cross-impact matrix. Fig. 3 shows a fragment of the created cross-impact matrix for the V2G analysis. It can be seen that, the descriptor in the row indicates the source and the column the target of an impact. For example, when the battery technology in row A1 is stagnant it has a strong impact (+3) on B1 which means that ICE vehicles are much cheaper in terms of the total costs of ownership (TCO).

After the cross-impact matrix evaluation, three consistent scenarios have been chosen from the multiplicity of obtained scenarios. For example, scenario 1 was defined as a completely consistent where all elements of the scenario form a set of mutual supporting assumptions. Now every descriptor of the

TABLE I. THREE CONSISTENT SCENARIOS

Scenario	**A Fossil Scenario**	**B Average Scenario**	**C Green Scenario**
Battery Technology	Stagnant	Small improvement	Huge improvements
EV TCO	ICEV much cheaper	ICEV much cheaper	EV cheaper
Charging infrastructure	Not further enlarged	Enlarged	Available everywhere
Smart Grid	Just pilot projects	Partly implemented	Full implemented
Flexible Smart tariff	Not available	Not available	Available at big suppliers
Oil Price compared to 2015	More expensive	Stagnant	Lower
Acceptance EV	Use in public sector	Use in public sector	Full accepted
Economical development	Decreased	Accelerated growth	Accelerated growth
Average Income	Decreased	Increased	Increased
Climatic Discourse	Important	Important	Important
Governmental Grants	Few	Few	Few
Propulsion Technology	Combustion engine improved	Hybrid Technology in focus	EV is standard
Suppliers structure	EV are niche product	Few suppliers	Everywhere available
Energy sources	Conventional plants	Well balanced mix	Majority of renewable
Energy consumption	Stagnant	Stagnant	Decreased
Grid expansion	Stagnant	Partly extended	Well extended
Public transportation	Same level as 2015	Same level as 2015	Same level as 2015
Population	Decreased	Stagnant	Decreased

matrix is linked to and affected by other descriptors through the comments. As an example, Fig. 4 shows the comments affecting the oil price descriptor.

Three chosen scenarios described in Table 1 as Fossil, Average and Green show three completely different futures of V2G technology. The next sections provide the interpretation and analysis of each scenario.

III. SCENARIO A (FOSSIL SCENARIO)

Core Idea. The electric vehicle is still a niche product. Although many car manufactures offer EVs, only expensive and premium EVs have batteries providing an acceptable travelling range. The reason why the most of EVs are in the premium sector is the stagnant development of the battery technology keeping very high prices. Vehicles equipped by ICEs are still much cheaper in terms of the TCO. EVs are quite immaterial and bought just by environmentally-conscious consumers having a high income. Therefore, most of the EVs on the road are used in the public sector at pilot programs to promote the electric propulsion technology. The charging infrastructure in the UK is not developed because of lower number of EVs.

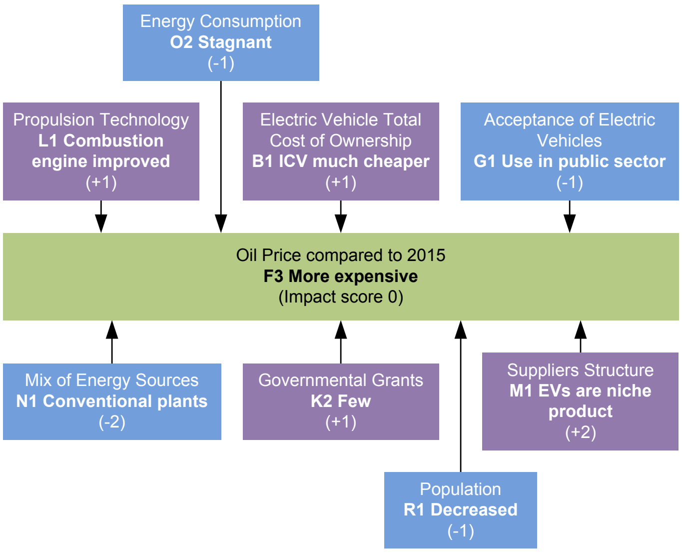

Fig. 4. Influences on the scenario element Oil Price compared to 2015 .

Key factors:

Stagnating battery technology;
Poor charging point infrastructure;
Smart grid has still the project status;
Combustion engines are optimised;
No significant change in the customers behaviour.

Look into 2030. In 2030, in the UK road situation is not changed very much. The traffic volume is slightly increased but the overall population is decreased. Most of cars on the road are still equipped with ICEs although the oil price is increased. Fossil fuel is still affordable because ICEs have been improved. Despite the increase in oil production, the price is still high because of rapidly increased energy demand in Africa and South America. In the UK the energy consumption remains on a similar level as 15 years ago in 2015. The greenhouse effect is still discussed problem but the slight decreasing in economic development and lower average income are putting the other problems in the foreground. The streetscape out of urban areas is dominated by small cars having lower running and maintain cost.

V2G technology is implemented in a very small scale; for example at household microgrid. It is usually used to optimise a household power consumption rather than to support the grid stability. In sum it can be said that the UK in 2030 in the fossil scenario has no room for smart grid and implementation of V2G technology.

IV. SCENARIO B (AVERAGE SCENARIO)

Core Idea. EVs and particularly hybrid EV are populated in the road. Compact and mini electric cars are dominating in the UK cities whereas hybrid vehicles are in use primarily in rural area due to higher travelling range comparing to pure EVs. EVs still have low travelling range because no significant advancements in the battery technology; ICE cars are still cheaper in TCO. The IT-assisted charging connections are partially integrated into smart grid to ensure V2G technology however this technology does not provide effective support to the energy utilities in terms of regulating the energy production and demand.

Key factors:

Strong market share belongs to hybrid vehicles;
Improvements in battery technology (factor 1.5);
No flexible smart tariff;
Stagnating oil price;
Well balanced energy mix;
Smart grid is partly extended;
Stagnating population;
EVs are still more expensive in TCO.

Look into 2030. In 2030s the discussion about electric mobility is important as never before. The streetscape has significantly changed since the last fifteen years and, although the ICE cars still exceed in number, EVs are dominating the cities. The cities were changed in the transport infrastructure; there are lanes reserved for EVs and introduced green badges indicating the CO2 free vehicles provide access to the highly urban areas. EVs have also benefits at parking lots which are cheaper for the green badged vehicles. There are even reserved parking space where only EVs are allowed to park. Most of these reserved parking spaces are equipped by charging points connected to the main power grid. All these charging points are IT-assisted and standardised across the EU.

Due to improvement in the battery technology during the last 15 years, EVs became cheaper and affordable for everyone. But ICE cars are still much cheaper and the fuel price is relatively low. EVs are charged primarily at household locations and at parking places equipped by charging infrastructures. Many EV owners prefer to drive to the transport junctions where they can change the transportation and leave their EVs connected to the grid for battery charging. It is unlikely that EV owners will support V2G technology because of lack of flexible electricity tariffs whereas EV fleets of big companies and public sector can support the power grid through V2G. However the number of EVs is still not enough to provide effective implementation of V2G.

IV. Scenario C (Green Scenario)

Core Idea. In this scenario, the electric mobility has enforced by the way of commercial traffic. There is a rapid expansion of EVs because public authorities support implementation of EVs and electrify their own fleets. In addition there is a policy of city planning which tries to push heavy traffic away from the cities to lower the environmental impacts and the hazardous potential. EV are widely accepted by the normal households because of significant progresses in the battery technology which made the vehicles affordable for everyone. Smart tariffs are available and EVs fully integrated into smart grid. EV market accelerates growth of the UK economy and increase average income of people.

Key factors:

Significant improvements in the battery technology (factor of 4);
Increased average income;
Smart grid is fully implemented;
Excellent charging infrastructure;
Accelerated economic growth;
State is a demand driver;
Demand for small cars.

Look into 2030. British cities in 2030 became less noisy and have no air pollutions. For example, London is much quiet than 15 yeas ago but more active. The streets are full of a variety of mini EVs, mid-class hybrid cars, some conventional powered cars and even electric vans. Even the conventional ICE cars are more environmental friendly and quiet. These achievements have been driven by tightened limits of the CO2 -emissions introduced by the EU. The majority of the first registered vehicles are EVs.

The streetscape in the city centres have been changed: there are much less light delivery vans and no truck with more than 7 tonnes of total weight because they need an individual licence to get access to the city centre. As an alternative to public transportation, there is a broad and efficient functioning car-sharing system to allow every customer to use a vehicle when he/she needs it.

EVs have lower tax, servicing and insurance costs. Criticism like the initial costs, long charging and low travelling ranges have disappeared due to low battery prices and significant advancements in the battery technology.

Most of deliveries and services use EVs. They are accomplished during the regular working hours and the vehicles are charged during the night at the companies depots. An advantage of this overnight charging is that EVs are connected to the power grid and provide V2G operation.

Massive EV fleets in operation bring a number of other economic advantages. One of them is the low battery price; another is the independence on the oil-price. In 2030 the oil-price is lower than fifteen years ago because of decrease in number of ICE vehicles and increase of electricity generated by renewable energy sources. However the price of electricity for EV fleets is cheaper than convention fuel and much stable. Also EV maintenance costs are lower; for example, there are no motor oil changes, emission checks etc. which are a big cost factor for ICE cars with a high mileage.

In 2030 it is popular to leas batteries for EVs. The automotive companies offer a variety of leasing models like billing based on the residual value or mileage, ex- or including integrated car electricity packages, inspection and software services and many other services.

The power grid has dramatically changed comparing to 2015. The grid has extended and improved to allow the customers to be active participants in the grid operation where they are able to control and optimise their electricity usage. The massive extension of renewable energies is implemented into the grid requiring advanced control for coordination of sources and loads. Charging infrastructure for EV is a standard option for any future planning of commercial, industrial and residential areas.

In 2030 the economic traffic is making progress across the country. Most of the governmental fleets are converted into

EVs and profiting from the lower costs of maintenance. Most of the public transport is not pure battery powered, busses are often hybrid models whereas private passenger transport is intensively electrified. Total battery capacity from EVs are significantly enough to provide effective V2G operation to support the power grid stability and balancing.

The utility providers recognise the advantages of big amounts of commercial fleets and are offering smart tariffs where the vehicle owners and the providers profit from. The batteries of EVs used as buffer storage are applied for peak "shaving" in the power grid where the power stored in the batteries is sending back to the grid. The price for energy depends on the demand and is updated in a 10 minute cycle. When the demand and the price is low, the vehicles are charged. If the demand is high the battery is used as power source and supports the grid. The owner of the vehicle gets paid therefor from the power utility. In 2030 there are eight million EVs in the UK which are from time to time connected to V2G system. Majority of EV owners are involved in V2G system offering his battery to the power utility. The batteries are used to stabilise the grid and therefore they are discharged until a selected limit which is normally 10 kWh of residual capacity. This limit allows the owner to use the vehicle in an emergency for at least 50 km. The average EV in 2030 has a 200 kWh battery. If there is only one out of 4 EVs connected to the V2G system offering 190 kWh then there is 380 GWh of energy available to be used for peak "shaving":

$$\frac{8,000,000}{4} \times 190\text{kWh} = 380\text{GWh}$$

V. Conclusion

The number of power sources generated electricity from sun and wind and integrated into the power grid is dramatically increased. This expansion of renewable energies brings an impact on the stability and balancing of the power grid. At the present day, gas powered plants or pumped hydroelectric energy storage systems serve for the grid to provide stability and balancing due to very short response time.

V2G technology converts EV batteries into storage capacity to improve stability and balancing of the grid. In this system, the batteries of EVs act as a buffer storage for the power grid when exceeded power is produced or consumed. V2G concepts were already developed and pilot programs were started. The paper investigates the integration of the EVs into the power grid in 2030.

The method of Cross-Impact Balances have been used for analysis of V2G technology in 2030. This method derived a large number of possible future scenarios of V2G implementation. Three consistent future visions have been chosen for the further development.

Analysis of the key- and impact-factors has shown that the state of development of battery technology is the most important influential factor in electric mobility and consequently in V2G technology. If the decisive progress stays out in this sector as shown in scenario A, there is no space for electric vehicles as buffer storage for the grid. This Fossil Scenario portrays a future in which EVs are not used for V2G technology. Moreover, EVs are not competitive to conventional ICE cars because of large differences in the total costs of ownership.

On the other hand, the Green Scenario demonstrates massive implementation of V2G technology due to significant advances in battery technologies. This scenario states that the number of EVs are dramatically increased and the majority of EV owners allow the power utilities operators use their vehicles as energy buffer storage. It is predicted that in 2030 the total capacity of EV energy storage available for V2G operation is about 380 GWh.

It is important to say that these scenarios are relying on prognoses but there is no guarantee of the accuracy. It is more a question of combining several "What ifs" and can be seen as a projection into the future. Three scenarios are demonstrating the range of developments but they are not intended to make precise forecasts.

References

[1] M. Yilmaz and P.T. Krein, "Review of the impact of vehicle-to-grid technologies on distribution systems and utility interfaces," *IEEE Transactions on Power Electronics*, vol. 28, no. 12, pp. 5673-5689, Dec. 2013.

[2] A. Schuller, B. Dietz, C.M. Flath and C. Weinhardt, "Charging strategies for battery electric vehicles: Economic benchmark and V2G potential," *IEEE Transactions on Power Systems*, vol. 29, no. 5, pp. 2014-2022, Sept. 2014.

[3] J.G. Phillips and T.R. Heidrick, "Technology futures analysis methodologies for sustainable energy technologies," *International Journal of Innovation and Technology Management*, vol. 4, no. 2, pp. 171-190, 2007.

[4] V.A. Banuls and M. Turoff, "Scenario construction via Delphi and cross -impact analysis," *Technological Forecasting and Social Change*, vol. 78, no. 9, pp. 1579-1602, Nov. 2011.

[5] W. Weimer-Jehle, "Cross-impact balances: A system-theoretical approach to cross-impact analysis," *Technological Forecasting and Social Change*, vol. 73, no. 4, pp. 334-361, May 2006.

[6] S.S. Asan, and U. Asan, "Qualitative cross-impact analysis with time consideration," *Technological Forecasting and Social Change*, vol. 74, no. 5, pp. 627-644, June 2007.

[7] M. Godet, "The art of scenarios and strategic planning: Tools and pitfalls," *Technological Forecasting and Social Change*, vol. 65, no. 1, pp. 3-22, Sept. 2000.

[8] A. Hayashi, K. Tokimatsu, H. Yamamoto, and S. Mori, "Narrative scenario development based on cross-impact analysis for the evaluation of global-warming mitigation options," *Applied Energy*, vol. 83, no. 10, pp. 1062-1075, Oct. 2006.