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Impact of low-carbon technologies on the power distribution network

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Abstract. Over recent decades, there has been a growing concern about how modern technologies would impact on an electrical grid. Whilst the UK is set to meet the target of 15% energy demand from renewable sources by 2020 to ensure energy security and decarbonisation objectives, there has been a greater concern over how the increasing deployment of low carbon technologies (LCTs) would affect an electrical grid, in particular the residential low voltage distribution network. While LCTs can provide clean energy and decreases the dependence on oil and natural gas stocks, their impact on distribution networks is unknown and the operators are visibly blind as they use a 'fit and forget' approach. Consumers' connections are uncertain and stochastic and the LCT uptake poses a potential threat for distribution network operators. A review is presented in this paper, illustrating the potential impacts the LCTs have on a local electrical grid such as voltage regulation, thermal limits, power quality and harmonics. Potential solutions, such as Deregulation, Soft Open Points, On Load Tap Changer, and Active Power Filter currently available for Distribution Network Operators and power system planners before costly network reinforcement work is undertaken.

1. Introduction

The dynamic role of energy in day-to-day life is irrefutable, with fossil fuel being the primary resource [1]. However, the significant negative impact from this form of energy on the environment is the emission of greenhouse gases like carbon dioxide (CO_2) which lead to the question for policymakers, as to how to ensure low carbon economy. Being eco-friendly and non-depletable, renewable energy has surpassed as the means of energy of choice and various strategies have been implicated for its generation [2]. With an ambitious target for CO_2 reductions, these are leading to more low carbon technology adoption, which threatens the electricity network stability.

2. Literature review

According to the UK Renewable Energy Roadmap [3], renewable sources in the UK needs to contribute 15% to the energy demand by 2020. Significant increment has been seen in energy demand from renewable sources to contribute to energy security and decarbonization objectives. To meet these targets, low carbon technologies (LCTs) development and deployment gain a considerable amount of importance over the past decade. UK has aimed to provide clean energy, decrease the dependence on oil and natural gas stocks and meet the greenhouse gas emission targets of 80 % reduction on 1990 figures by 2050 [4]. To accommodate LCT more efficiently on the electrical grid, DECC and Ofgem are joined together to establish a smart electrical grid which facilitates LCTs in the generation, supply, and consumption, while ensuring the security of supply [5]. This will give the chance for the domestic consumers to get a return on what they generate from their distributed generators.

Recent research studies [6] suggest that LCT growth at the domestic level, may have a deep threat to the UK distribution network, though no certain reports have been recorded due to the consumer's connections are uncertain and stochastic. It is even more challenging to assess the impact of forthcoming scenarios when there is a lack of understanding and monitoring on the LV. Despite many researches [6] emphasized and sited potential solution to such problems, still, uncertainty exists as to what likely to happen in the future to the distribution network notably with respect to the growing electric vehicles (EVs), photovoltaics (PVs) and heat pumps (HPs) at the domestic level [7].

2.1. Electric vehicles

Electric Vehicles (EVs) have been around in the market for over a century since 1990s after the vast development in power electronics, new battery technologies, and advancement in its design and testing [8]. Very soon the importance of EV has been noticed on its low carbon emission making a priority compared to normal Internal Combustion Engines [3]. It is reported in [3] that the government has committed £400 million up to 2015 to support ultra-low emissions vehicles.

Most of the current EV owners find the home to be the most convenient location to recharge their EVs, but their load cumulates in a local domestic area which may cause an increase in the number of voltage violations [8]. According to Dubey [9] the impact is particularly on three areas which are, increases the substation load demand, transformer overheating, and the violation of under-voltage limits, and three-phase power supply unbalance.

2.2. Photovoltaics

Compared to EV, photovoltaics (PVs) system became more popular due to Feed-in Tariff (FiT) scheme which was launched in April 2010 and very soon closed in April 2019 due to the numbers of installations made have exceeded the requirement. This shows the UK is on a fast track to reach the target to reduce carbon emission [10].

Network issues due to the increasing number of PVs was addressed in [11] report as well. It was mentioned that distribution network operators will have to face severe consequence to manage their operation if this issue is not resolved earlier. The impact may occur during the off-peak time as the large number of PVs cumulatively exporting electricity back to the grid would result in voltage violation issues such as the voltage will rise about its threshold which typically regulates within +10% and -6% of 230V phase-neutral. Other issues related are harmonics and power quality [12].

2.3. Heat pumps

The use of heat pumps (HPs) by a Domestic Renewable Heat Incentive (Domestic RHI) scheme would help to reduce its carbon emissions and meet its renewable energy targets stated in [10]. Moving from fossil fuel heating to heat pumps will make a significant amount of reduction in greenhouse gas emission, although the high level of HPs penetration poses a new challenge for the low-voltage networks. Since HPs typically use induction motors the effect could be on power quality which includes voltage variation (dips and surges), harmonics and frequency variation [13].

3. Future prognosis

According to National Grid plc which is multinational company for transmission and distribution of gas and electricity, summaries in their Future Energy Scenarios (FES) [6] about how the energy consumption will take place on their transmission system. These scenarios are credible pathways for the future of energy, from 2018 to 2050 but not considered as a forecast. Four potentials scenarios mentioned in the FES 2018 reports are, Community Renewables (CR), Two Degrees (TD), Steady Progression (SP), and Consumer Evolution (CE). Instead of going into each scenario it is worth looking at analysis made by LCTs on them.

3.1. Expected domestic electricity demand with heat pump
Appliances alone makes up to more than 61% of domestic electricity demand in which Heating accounts for almost a quarter. The significant amounts of electricity for heating is used by traditional heating elements mainly resistive for storage heaters and showers, heat pumps are also used to consume less energy per unit. Domestic electricity demand scenario profile for annual energy demand is being illustrated in figure 1 excluding EVs.

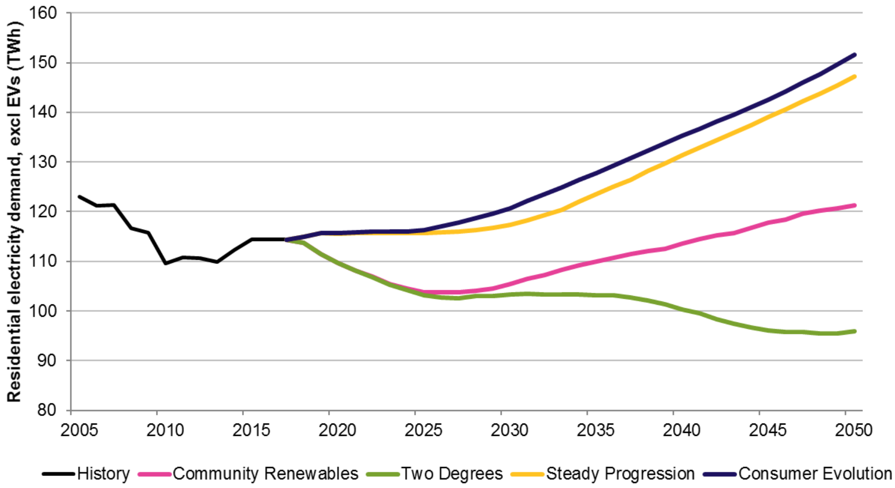

Figure 1. Domestic electricity demand with HP [6]

A high demand rise can be seen in consumer evolution and the steady progression scenarios. In consumer evolution based scenario, the rise is due to the increasing number of heat pumps used at home, whereas, in steady progression based scenario the growth of population exceeds slow efficiency savings. In two degrees scenario, the drop is due to the alternative heating method used such as the hydrogen networks will start and also used improving insulated housing stock whereas in community renewables scenario, the rise after 2030 is due to growth in Air-Source Heat Pump which also mainly depends on at certain times and seasons.

3.2. Expected domestic electricity demand with electric vehicles
Similarly, the electric demand in the transport matters the most when the EVs being charged at a peak time as shown in figure 2. Those four scenarios are made in a way that some have this factor that the avoidance of peak charging such as in consumer evolution and steady progression scenarios the net electric demand for charging EVs went above 13GW and 10GW respectively.

The other two scenarios that is two degrees and community renewables the net demands to charge the EVs rises until it reaches the point when vehicle to Grid (V2G) connections are widely available shows a study line until it drops as the growth in V2G continues and pulls down net peak demand. The net demand is not as steep in community renewables scenario as compare to two degrees because it's considered that in community renewables people are avoiding making charging during the peak time still it is 10 times more than the current consumption.

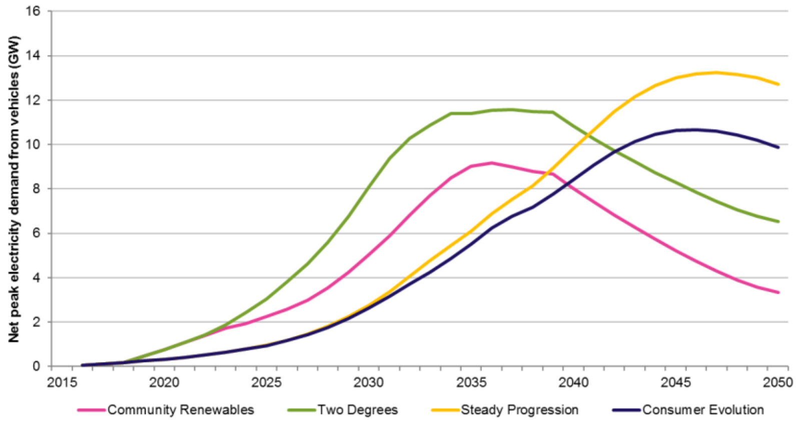

Figure 2. Net peak electricity demand from EV [6]

3.3. Expected domestic electricity demand with photovoltaic

The supply of electricity using micro solar like PVs growth found from FES report is at least doubled from the date till 2050 as confirmed in figure 3. All four scenarios show an increase in the supply due to the reduction in the cost of PVs technology, promotion of these by government policies and the fascination consumers sees from them as they can import less during daytime and export what they save. In community renewables scenarios the solar capacity goes more than 66GW by 2050 from which 33GW is due to micro-solar used at the residential level. The necessity of storage capacity will be significantly observed when PV generates during the day whereas EV charges mostly during the night at home.

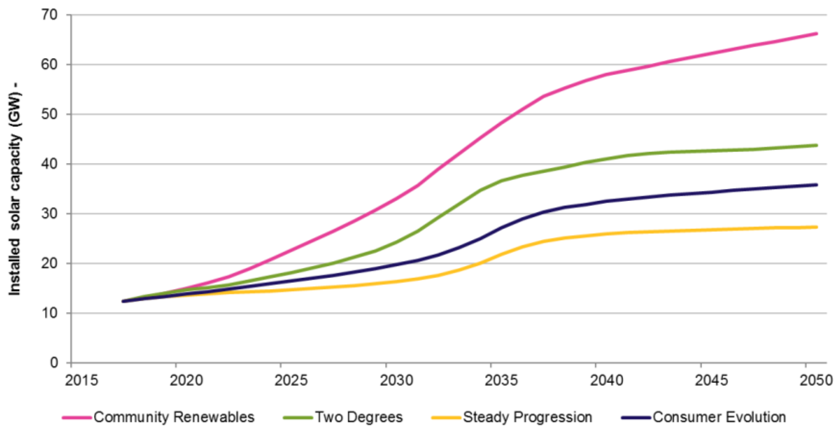

Figure 3. Solar capacity scenarios PV [6]

4. Impact of increased demand & supply

The effect on the low voltage networks are associated to the increasing number of residential demands in electric vehicles, heat pumps and photovoltaics, hence they are outlined. The type of network constraints is illustrated by Fishbone Diagram in figure 4.

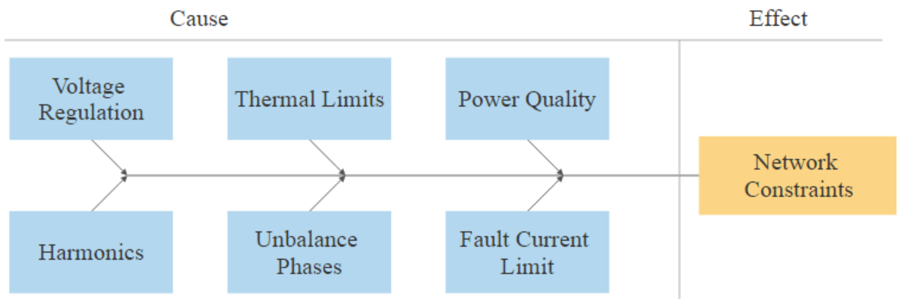

Figure 4. Network Constraints using Ishikawa diagram

The normal voltage needs to be regulated in its range that is +10% and -6% of 230V phase-neutral as illustrated in [14]. When the voltage is not regulated within the limit, a potential threat is generated to the whole low voltage network, since the power could flow in either direction [15]. Due to high PV penetration, the power could flow in the reverse direction causing back feeding, it is a situation where personnel working on equipment may not be aware and this could cause hazardous situation. However, the thermal limit constraint is far greater than the other two because electric vehicle would require high amount of power (typically 3kW or 7kW) which could not be delivered from the existing cables [16]. This also creates the fourth constraint that is imbalance in the phases. Most of the residential units are on single-phase system in the UK and an unbalance condition would occur especially when one of the three loads is either consuming more or in a worst case generating high [15].

Harmonic current or voltage on an electrical system is considered as multiple of the fundamental frequency caused by non-linear electric loads. [16]. Lastly a fault may occur on the load side as a short-circuit or in between two phases which would results in a high amount of current flowing from the power source, hence an uptake of solar panels on the system would require another protection method to disconnect the downstream as well as the fault site [17].

5. Solution to network constraints

Reinforcement of the distribution network is the conventional way to address the issues alleviated by changes in the loads. Some of the options that are classified as a network reinforcement are, increasing the thermal capacity on the network, selecting transformer to accommodate an increase in demand, considering other ways to deliver power instead of using longer routes, building advance substations, and using reactive power compensation techniques. Unfortunately, all these options are costly and disruptive [18].

Table 1. Solutions to list of problems

Solutions	Network Constraints					
	Voltage Regulation	Thermal limits	Power quality	Harmonics	Unbalance phases	Fault current limit
Reinforcement	✓	✓	✓	✓	✓	✓
De-regulation	✓		✓		✓	
SOP	✓	✓	✓		✓	✓
OLTC	✓				✓	
Energy Storage	✓	✓				
APF		✓	✓	✓		

The table 1 shows list of solutions along with their respective problems. Firstly, de-regulation is one of the approach addressing the effect of voltage regulation, power quality and eventually unbalance phases. This concept provides solution by storing energy (which is costly similar to energy storage) and dispatching it when the demand is high [8]. Secondly, soft open points (SOPs) covers all the constraints apart from harmonics. Advantages of SOP is that it can be used for any network system such as radial

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or loop [19]. Thirdly on load tap changer (OLTC) method proposed by [10] can accommodate high PV penetration. This method is effective but costly and mainly applicable to be proposed at the planning phase of the network. Lastly, active power filters (APF) which are widely used to provide a solution to the harmonics issues in the system. Active filters long exist in the literature since the 1970s [20] [21], whereas APF resolves harmonics issues caused by loads of the future.

6. Conclusion

In this paper, a broad review has been presented illustrating various types of impact existing due to the enormous implementation of low carbon technologies, particularly from electric vehicles, photovoltaics and heat pumps. A brief summary is also presented of different solutions available to reduce them including reinforcement, de-regulation, soft open points, on load tap changer, and active power filters. Although the impact is typical for electrical distribution system, their combined effect would require initial assessment of the present system and provide an economical, ecological and sustainable solution.

Analysing the active occupancy, appliance consumption, weather forecast, irradiance, and power consumption would help to predict these types of impact. In future work, we are evaluating the type of domestic loads, creating a technique to implement different types of low carbon technologies into those loads, and developing a forecasting system to analyse such impact effectively.

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