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Impacts of green technologies in distribution power network

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Abstract

Green technologies such as renewable energy resources, Electric Vehicles and Plug-in Hybrid Electric Vehicles (EVs/PHEVs), electric locomotives, etc. are continually increasing at the existing power network especially distribution levels, which are Medium Voltage (MV) and Low Voltage (LV). It can be noted that the increasing level of green technologies is driven by the reduction emission policies of carbon dioxide (CO_2). The green technologies can affect the quality of power, and hence its impacts of are analysed. In practical, the environment such as wind, solar irradiation, temperature etc. are uncontrollable, and therefore the output power of renewable energy in that area can be varied. Moreover, the technology of the EVs/PHEVs is still developed in order to improve the performance of supply and driving systems. This means that these developed can cause harmonic distortion as the control system is mostly used power electronics. Therefore, this paper aims to analyse the voltage variation and harmonic distortion in distribution power network in urban area in Europe due to the combination between wind turbine, hydro turbine, photovoltaic (PV) system and EVs/PHEVs. More realistic penetration levels of SSDGs and EVs/PHEVs as forecasted for 2020 is used to analyse. The dynamic load demands are also taken into account. In order to ensure the accurate of simulation results, the practical parameters of distribution system are used and the international standards such as Institute of Electrical and Electronics Engineers (IEEE) standards are also complied. The suggestion solutions are also presented. The MATLAB/Simulink software is chosen as it can support complicate modelling and analysis.

Key words: *Renewable energy, Electric locomotive, Distribution network, Power quality, MATLAB/Simulink*

1. INTRODUCTION

The electrical energy resources have been evolved over the past decade especially renewable energy resources (green technologies) such as wind turbine, PV system etc. The output power of these technologies is mostly affected by the surrounding environment in that area for instance wind speed, solar irradiation etc. Moreover, these technologies are usually connected to the LV and MV networks via power electronic equipments in order to optimise their output/input power. This means that these equipments cause a non-

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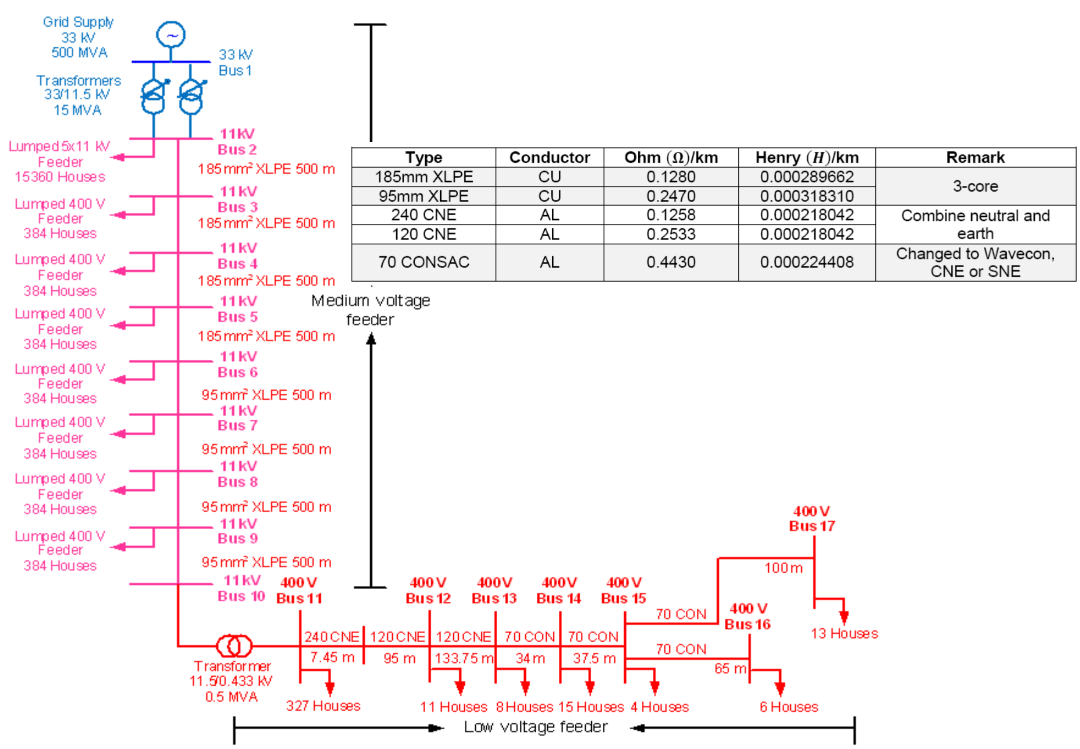
sinusoidal current waveform instead of pure sinusoidal waveform as these equipments behave as non-linear devices. Currently, the penetration levels of the renewable energy resources are considered as a small proportion of the total network generating capacity, hence its impacts on the power network performance are negligible. However, with the increased number of renewable energy resources being connected to the network and increased interest in EVs/PHEVs, it is just a matter of time before their impact will start creating problems in the future power network.

Therefore, the existing typical distribution power network especially in urban area is modelled using MATLAB/Simulink and analysing the impacts of the combined use of wind turbine, hydro turbine, PV system and EVs/PHEVs in 2020, with emphasis on voltage variation and harmonic profiles. The practical parameters of the distribution network, the dynamic demand and Institute of Electrical and Electronics Engineers (IEEE) standard 519 are also taken into account in order to ensure the accurate of the simulation results [1 and 2]. Accordingly, the suggestion solutions are also presented.

2. NETWORK DETAILS

A typical distribution network model (as shown figure 1) connected to the grid at 33 kV is used. The primary substation (33/11 kV) has six 11 kV outgoing feeders, each feeder supplying eight 11/0.4 kV substations. Every 11/0.4 kV substation has four outgoing radial feeders. To simplify the analysis, only one 400 V feeder was modelled in detail. The other feeders were modelled as individual lumped demand/generation connected to the main substation. This resulted in a simpler model of a complex network and relatively faster and computationally less demanding simulation. The simplified distribution network model was validated against an established model [3] to ensure its accuracy.



Type	Conductor	Ohm (Ω)/km	Henry (H)/km	Remark
185mm XLPE	CU	0.1280	0.000289662	3-core
95mm XLPE	CU	0.2470	0.000318310	
240 CNE	AL	0.1258	0.000218042	Combine neutral and earth
120 CNE	AL	0.2533	0.000218042	
70 CONSAC	AL	0.4430	0.000224408	Changed to Wavecon, CNE or SNE

Figure 1. The typical distribution network in the urban area

3. RENEWABLE ENERGY GENERATIONS AND LOAD DEMANDS PROFILES

The 30 minutes data intervals were used for the renewable generations because the energy spectrum of the wind profiles permits operation without lost of accuracy [4]. The average generation profiles of the combination between wind turbine, hydro turbine and PV system in the urban area has shown that the potential highest generation happens in the daytime during 09.00-15.00 (as shown in figure 2).

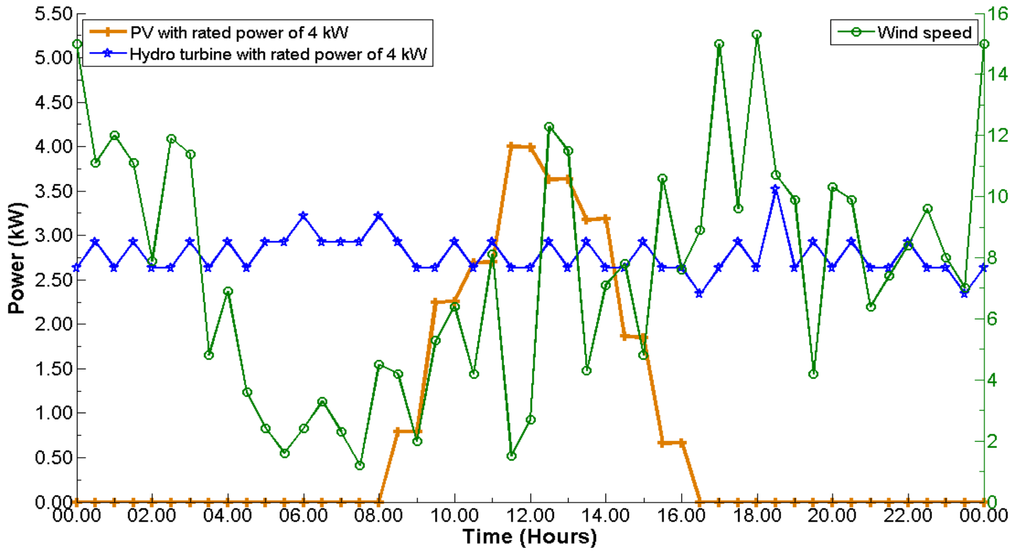


Figure 2. Average generation profile of Small-Scale wind turbine and PV system in countryside area

The daily load demands during summer and winter in the urban area are shown in figure 3. The profiles are varied all the year. These data based on After Diversity Maximum Demand (ADMD) reference to a nominal 100 consumers and measured at a distribution level of outgoing feeder [5]. It can be seen that the most electricity usage is in the daytime (during 08.00-22.00).

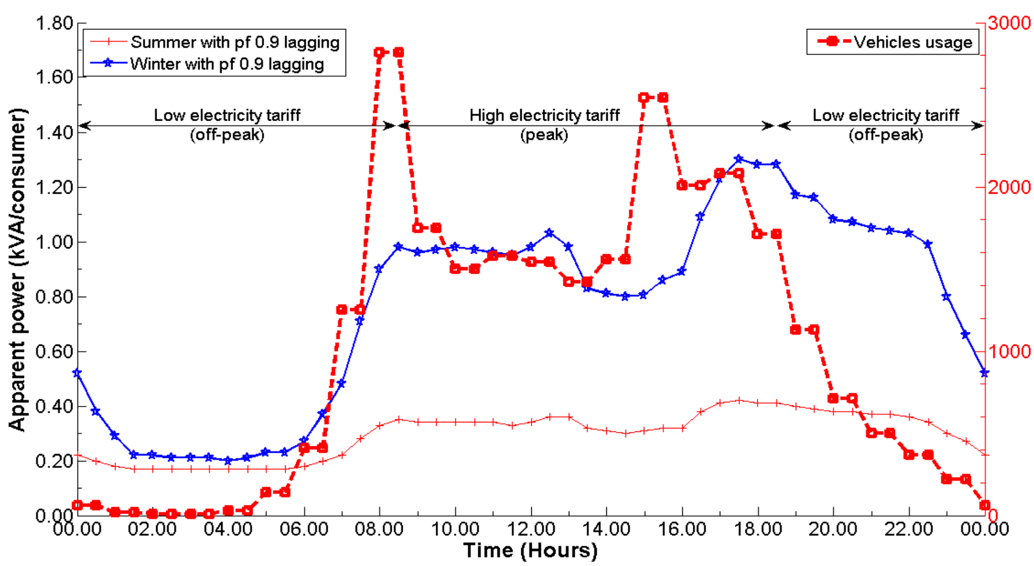


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Figure 3. Average daily load demands in the urban area

In figure 4, 3000 samples of EVs/PHEVs were used to estimate the daily hour usage of private vehicles of EVs/PHEVs [6].

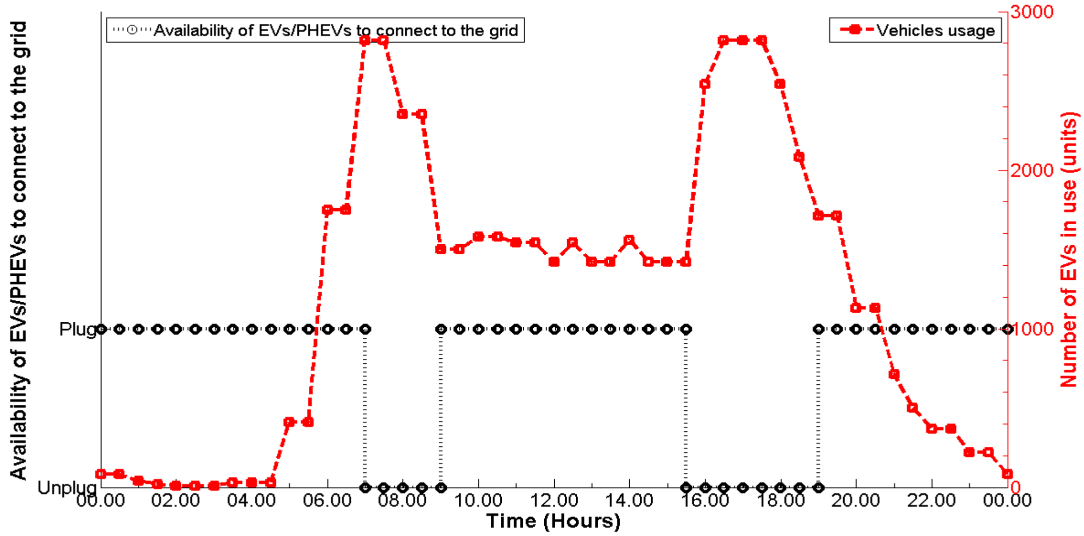

Figure 4. Average daily usages of the EVs/PHEVs

The available connection time and connection time allowances of EVs/PHEVs need to be considered in order to define their demand profile. In weekdays, private EVs/PHEVs are not available for either absorbing or supplying electrical energy at the morning and evening rush hours (approximate 07:00-09:00 and 17:00-19:00). Currently, public parking of EVs/PHEVs allows charging only 4 hours during 08.30-18.30, whereas "Anytime Charging" is allowed in car parks, as shown in figure 5. Standard 3 kW domestic chargers that use 6 to 8 hours (here considers 6 hours) for recharging is also considered [5]. Therefore, the extreme scenarios selected for EVs/PHEVs connection into the network is identified at 19.00-01.00 (connects in charging mode) and 13.30-15.30 (connects in Vehicles to Grid mode; V2G). It is important to note that the EVs/PHEVs owners' are willing to connect their vehicles in V2G mode where the connection tariff is high (during the peak demand).

Figure 5. Connection time allowances of EVs/PHEVs in public parking and car park

4. SIMULATION AND RESULTS

MATLAB/Simulink solver ode23tb, which implements from a multistep of implicit Runge-Kutta formula with a trapezoidal rule (TR-BDF2) is incorporated with Interpolation-Extrapolation technique [7]. Hence, the backward differentiation formula of second order is used to determine the first and second stages. The relative tolerance and absolute tolerance are also set at 0.000001 and 0.0001, respectively. Thus the number of sample data between each point of input data can be defined up to 60 sample data for 1 simulation period. These setting provide fast simulation and more efficiency results.

It must be noted that the model of the ON-Load Tap Changer transformer (OLTC) is slightly different the realistic model as the size of step voltage of the OLTC model is larger than the real OLTC in order to match the step voltage with less tap changer. The results in this paper may include unrealistic transient voltages, which are caused by the sudden connection/disconnection of large numbers of EVs/PHEVs at the same time, and the similar results are shown in references [8-10]. These reasons are explained the abnormal transient voltages in this paper. In practical, the connection/disconnection of EVs/PHEVs to the network would normally take a finite length of time.

The voltage profiles at the far of the feeder of the network in the winter and the summer, without Small-Scale Distributed Generators (SSDGs) and EVs/PHEVs are shown in figure 6. It must be mentioned that the OLTCs use the reference voltage (control) signal from local bus (bus 2) in order to keep the voltage at all buses within the limits. The voltage profiles at the MV network decrease from the main supply substation to the far end of the MV feeder. Then, the voltage level at the LV side of the secondary distribution transformer level is stepped up by transformer ratio of the off-load tap changer transformer. This phenomenon can be explained by the power flow equations.

Furthermore, it can be expected that the penetration levels of green technologies is affected by the characteristics of the network. The number of consumers' on distribution networks with short length feeders is normally higher than the long length feeders, if both networks have the same supply capacity. The long feeder is defined as a feeder extends beyond 15 km radius from a main substation.

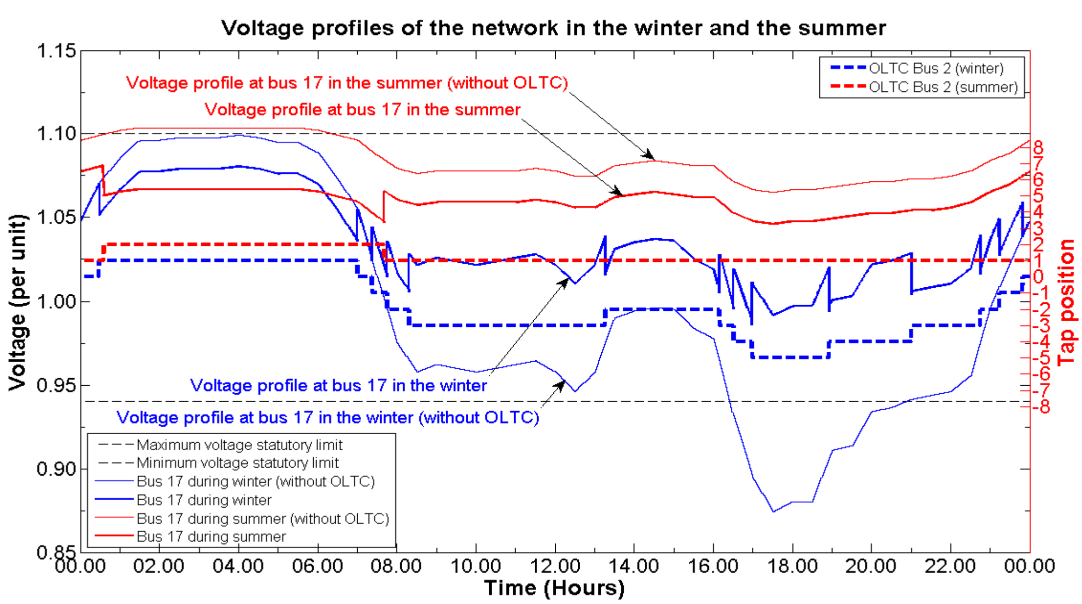

Figure 6. Voltage profiles of the network in the winter and summer without SSDGs and EVs/PHEVs

In addition, more realistic penetration levels of SSDGs and EVs/PHEVs as forecasted for 2020 (which are 7.49 percent of PV, 1.78 percent of wind turbine, 2.54 percent of hydro turbine and 31 percent of EVs/PHEVs) is also used to analyse [5]. In this scenario, it is assumed that SSDGs and EVs/PHEVs are uniformly distributed along the network and that the OLTC control signal is delivered from the OLTC bus.

The network performance for these penetration levels in winter demand profile are shown in figure 7. As can be seen the operation of the OLTCs at bus 2 keep the voltage at all buses within the voltage statutory limits. In figure 8 shown that the voltage profiles during summer at the LV feeder (at buses 11 and 17) exceed the maximum voltage statutory limit of 400 V in the afternoon (during 13.30-15.30) due to the high generation from SSDGs and EVs/PHEVs operating in V2G mode.

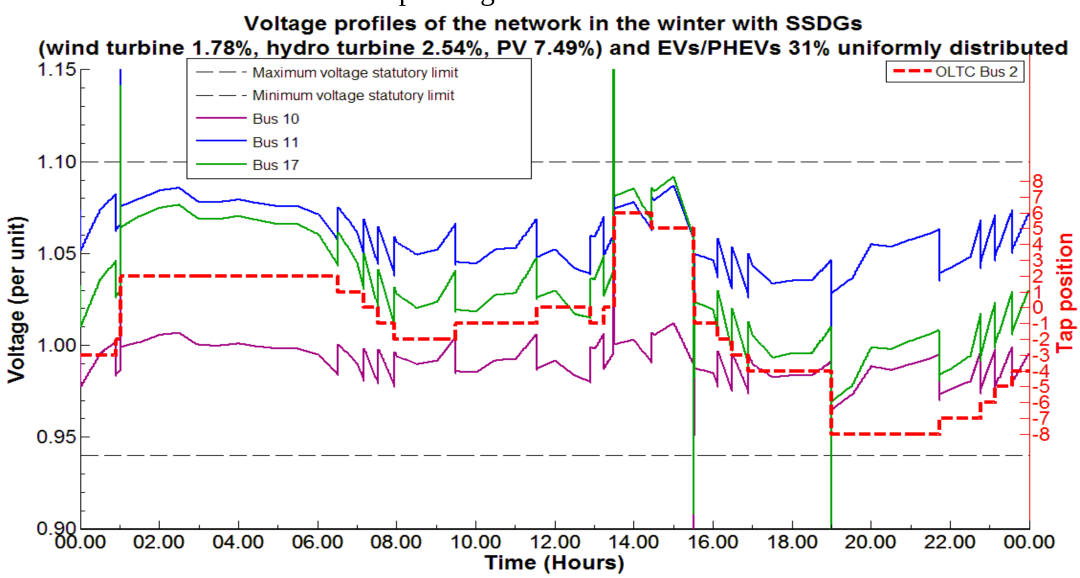

Figure 7. Voltage profiles of the network in the winter with SSDGs and EVs/PHEVs

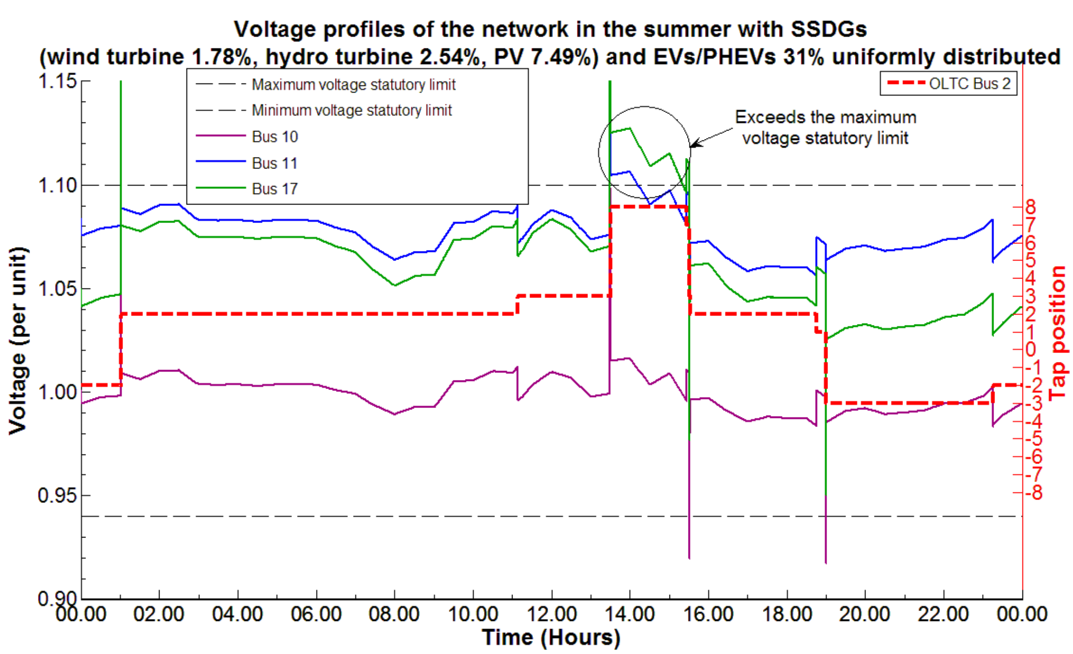

Figure 8. Voltage profiles of the network in the summer with SSDGs and EVs/PHEVs

Most grid interface devices of green technologies use power electronics devices to maximise output power and synchronise to the grid. And hence, this equipment behaves as non-linear loads and the presence of switching power semiconductor elements which usually has a low power factor. When implementing these devices, they distort the waveform which mainly affects power quality by creating high frequency harmonics and transients, which are fed into the grid.

In practice, the PWM full-bridge inverter (shown in figure 9) generates a rapidly switching output (typically 10-50 kHz). The higher in switching frequency bring a resulting improvement in current waveform. Also this switching frequency may be adjusted in phase angle to either lead or lag with respect to the mains phase angle (respect to the grid), which cause real power to either be sent to the grid (phase advance H bridge fundamental) or to charge the battery (phase lag H bridge fundamental). That means it is possible to use the PWM configuration to produce harmonic currents at specified phase angles, allowing cancellation of particular harmonics in the supply [11].

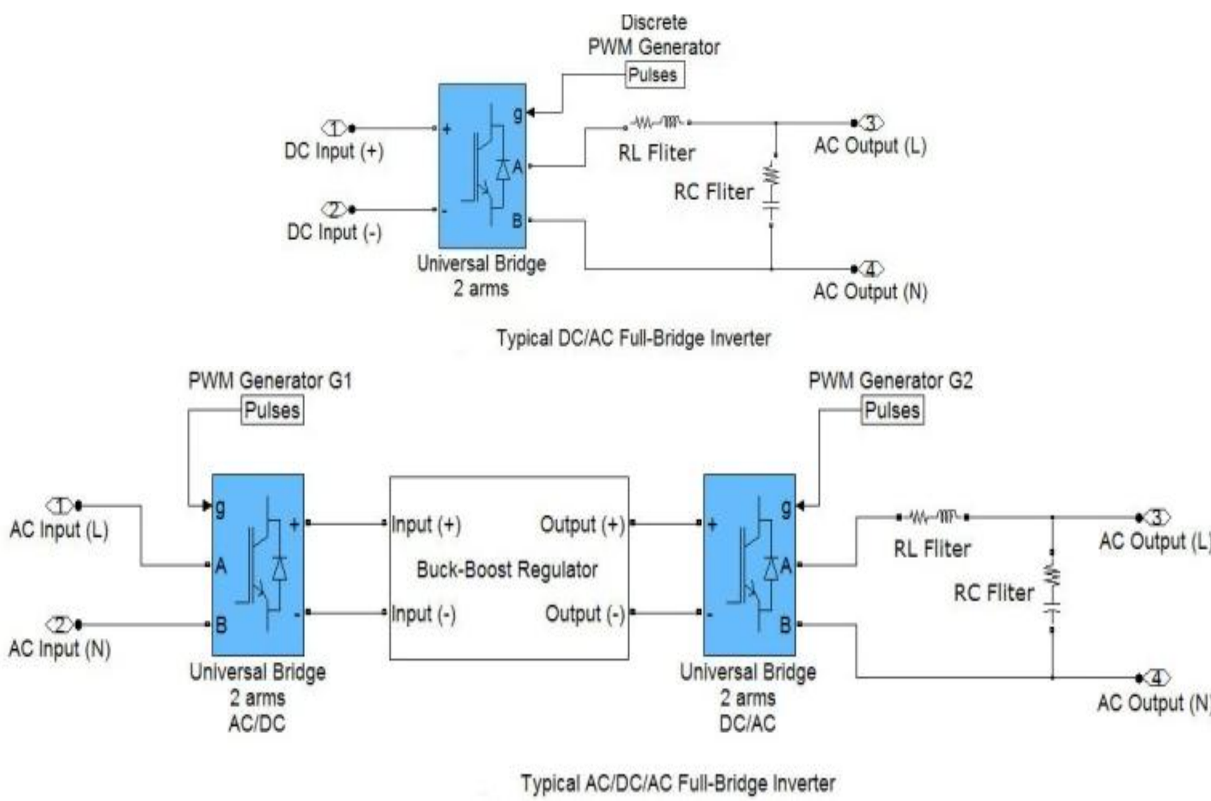

Figure 9. Basic configuration of PWM inverter device

In order to examine the effects of applying a multiplicity of chargers to the system, it was evident that the most pronounced effects would be measured where the system was weakest, i.e. at one of the points furthest from a 11kV/400V distribution transformer. Therefore, the study is made of the relative harmonic distortion levels produced by a PWM inverter. This paper examines the interactive effects of locating a plurality of PWM inverters onto a power system in order to find the effects on the magnitude of each harmonic, whether diminished or augmented, as the number of such converter is increased. A simplified model of inverters was applied to the appropriate point in the system model, and the current harmonic distortion measured via Fast Fourier Transform (FFT) analysis at the input to the relevant bus in each case. Then THD was measured as shown in figure 10.

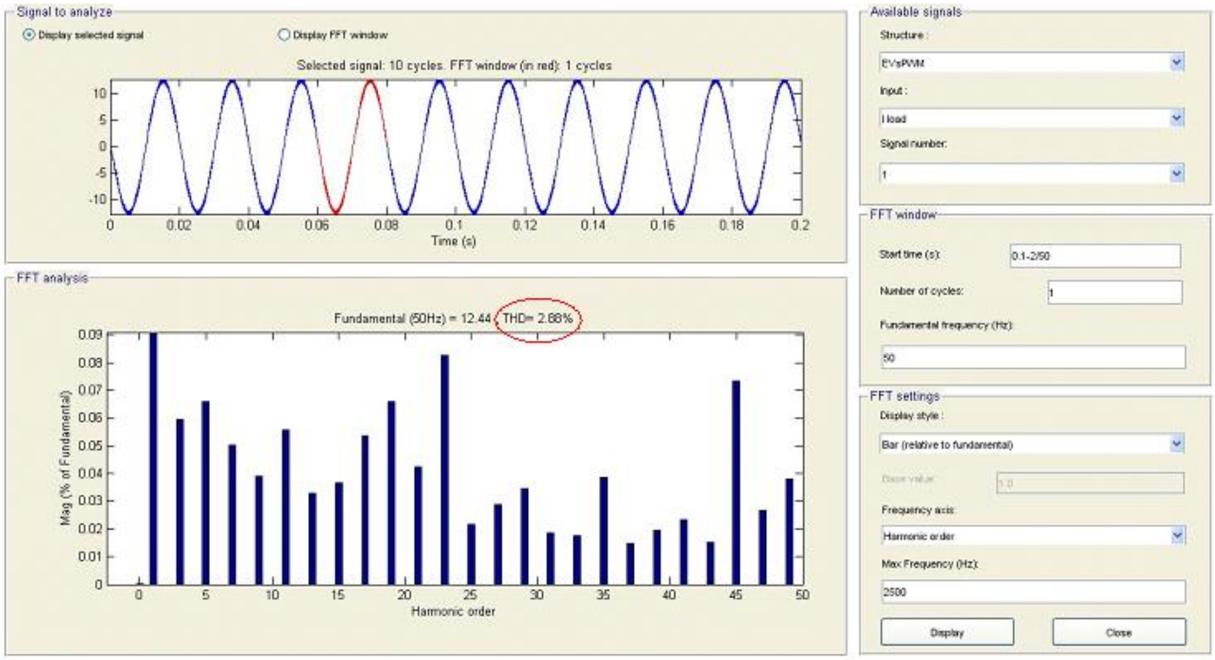

Figure 10. THD profile of at the far end of LV feeder (the weakest point)

As can be seen the reduction in the harmonic current magnitude appeared in the summation of the same type of EVs chargers (identically inverter). These chargers are based on the phase shift types and it can cancel harmonics at the local bus as the firing angle of PWM controller can be adjusted. While, the different type of chargers are independently operated at the same local bus cannot reduce harmonic, and the similar conclusion are also presented in [11 and 12].

5. SUGGEST SOLUTIONS

The output power of micro generators (mainly from renewable energy sources such as small-scale wind turbines, hydro power and photovoltaic) and load demands are always varied due to surrounding environment and consumer behaviour. This may lead to the voltage and frequency in power networks to exceed the statutory limits, practically in weak distribution networks. This paper suggests a concept of a Smart Demand Side Management (SDSM) system, which proposes to deal with supply/demand matching in order to support the network and keep voltage within statutory limit.

The proposed SDSM system makes use of energy storage that is expected to be available in future power networks (including dedicated storage systems and/or EVs/PHEVS, when they are not in use and battery is fully charged/discharged). The priority of this concept (as shown in figure 11) starts from gathering local demand usage via the smart meter. The central data bank will retrieve this data and forward signals to local public EVs/PHEVs charging station to allow EVs/PHEVs to connect (in charging/regenerating modes) into the grid. In practice, the charger controllers of EVs/PHEVs are currently used power electronic controllers such as Pulse Width-Modulation (PWM) inverter. This means that the properly designed PWM inverter can provide ancillary services and support the supply network, such as supply/demand matching and reactive power support. These types of operation would be required in the proposed concept, which is part of Smart Grid.

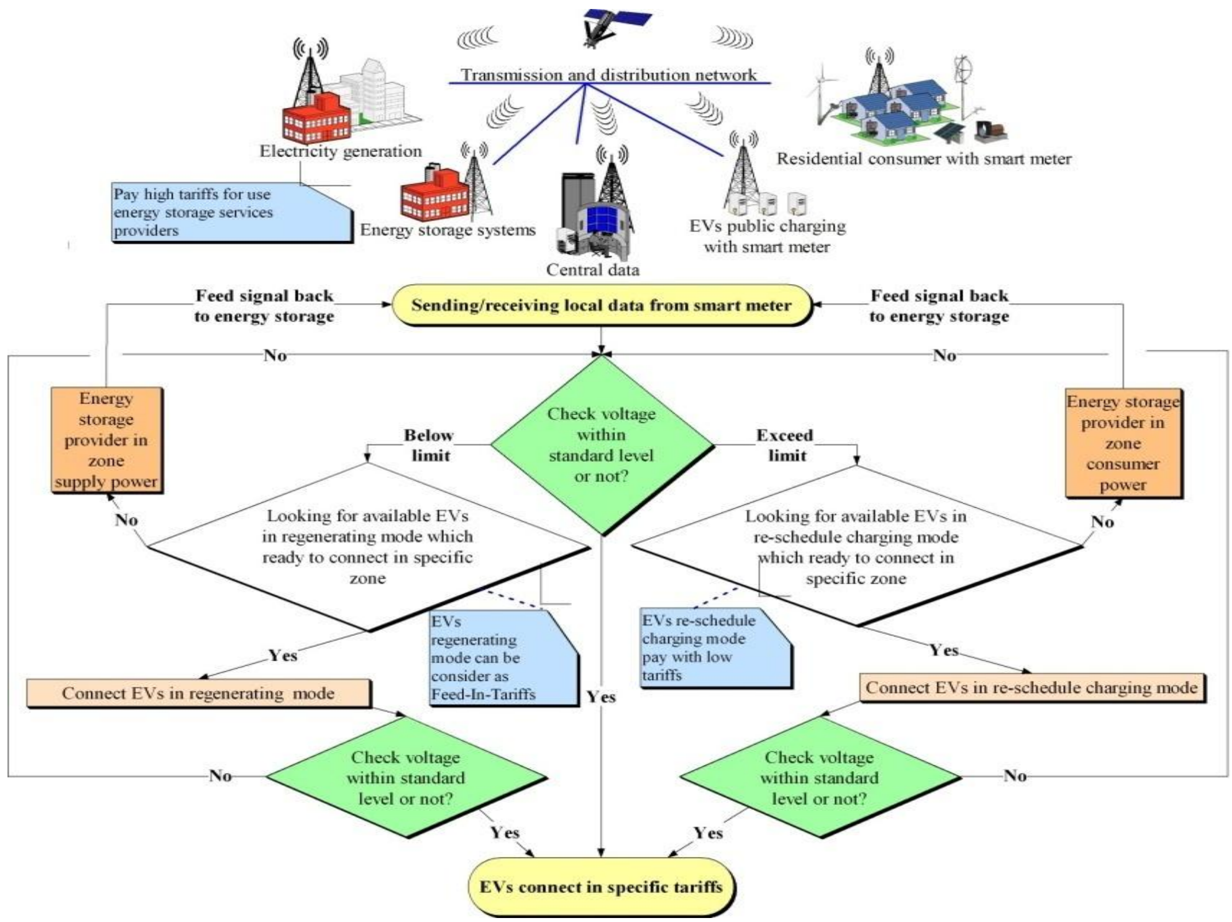

Figure 11. Schematic of the proposed Smart Demand Side Management (SDSM) incorporate with smart meter

The proposed SDMS is also considered to ensure that sufficient power is available at all times, based on a mixture of renewable and conventional energy. In order to achieve this, a number of factors must be taken into account;

- The locations of the generating systems, EVs/PHEVs charging stations and load demands need to be considered as the distance between these will be an important factor in determining the capacity requirements of the distribution network.
- The generating capacity of combinations of various types of generators can often exceed demand which may lead to violation of the maximum voltage statutory limit.
- In considering EVs/PHEVs when they are in use as transport, they are not available for either absorbing or supplying electrical energy. This situation will occur (during the working week) at the morning and evening rush hours (approx. 7:00 a.m. to 9:00 a.m. and 17:00 p.m. to 19:00 p.m. respectively) [13].
- The EVs can be possibly parked at different locations at different times of the day. This may be related to daily variations in energy supply and demand. During the working week, cars will be parked close to the owner's place of work in the daytime and at their home during the night.
- Energy storage systems can be used to store electrical energy, when there is an energy surplus, and return this energy to the grid, when availability is low and/or there is high demand.

6. CONCLUSION

This paper presents the results of an investigation to evaluate some of the effects of renewable technologies deployment on existing power distribution networks. Potential impacts of worst scenario are analysed with emphasis on; the daily profiles of supply/demand depends on the nature of the primary energy source and consumer behaviours'. A computer model of a typical distribution network was developed using MATLAB/Simulink package and analysis of different scenarios were conducted to identify potential impacts of new technologies on the grid.

Recent studies have also shown that the significant deployment of distributed generation creates reverse power flow in distribution networks and that bi-directional power flow can have effects on the quality of power supply and voltage levels. However, this impact can be minimised to a low level and/or a high penetration level of renewable technologies can be allowed to connect to the distribution network by the use of SDMS. In addition, it can improve supply/demand electricity tariff.

Moreover, the significance of Power Quality (PQ) issues does not arise during normal inverter operation. And the most of inverter manufacturer claim that their inverters produce good power quality (mainly with regard to harmonics and power factor). On other hand, the PQ problems occur during some of inverter faults in their operation. It can be noted that such faults would not normally be detected by the inverter over current protection. Then an un-identical type of inverter and the penetration level of inverter faults that can be connected into the distribution network will need to be investigated in future work.

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