Simulation Based Analysis of Load Flow and Grid Design for Electric Vehicle Charging: Bangladesh Chapter

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***Abstract*—** The purpose of this paper is to build up a reference grid for a specific region in Dhaka, the capital city of Bangladesh. In order to gain the in depth knowledge of this reference grid, a case study has been done. As the prime concern is the integration of IPT (Inductive Power Transfer) lead transportation system to reduce traffic deadlock, a thorough sensitivity analysis has been done in this paper under SIMULINK environment. Also Load flow analysis and other calculations have been done during research period. This paper will provide a substantial view of reference distribution network in urban area and pave the way to pursue further research as well.

***Keywords*—** SIMULINK, SOC, FFT, THD.

I. Introduction

DHAKA, the capital of Bangladesh is one of the most populous cities in the world. Traffic congestion is a common phenomenon now a day. To reduce this congestion several attempts has been taken already. Policy makers strive to reduce fuel consumption and pollution as well. In order to fulfill these aims new technologies have been thoroughly considered and rolled out like: Plug-in Hybrids Vehicles (PHEV) and Electric Vehicles (EV) on the street of Dhaka city. Some models are already proposed for purchase, and more are slated for use in near future. Gaining mass-market adoption of any new product in Bangladesh, especially EV, brings new challenges in the automotive sector as well as electric power system engineering. Inductive Power Transfer or IPT – is an energy transfer system which has recently been considered and proposed for electric vehicles that works by magnetic resonance coupling. The system consists of two main components: a primary coil, which is connected to the electricity grid via an in feed converter, and a pickup coil integrated in the floor of the bus. This technology permits an efficient, automatic, contactless transfer of energy [1]. IPT is convinced that short but regular charging is the way to go. The battery is usually fully charged overnight and then topped up as necessary and as possible over the course of the day at suitably equipped stops, generally by about 10–15%, depending on how long it stays at the stops [1]. Bus travel is one of the most common and versatile modes of public transportation in Dhaka city and the market is experimenting with alternatives to combustion-driven vehicles – but few of these approaches offer a sustainable solution to our dependence on fossil fuel and most come at a high price – both literally and in terms of inconvenience. More often, they involve serious compromises to vehicle availability, service reliability, aesthetics or resources (e.g. battery swapping, requiring extra fleet vehicles or turning to conductive charging). In essence, these solutions address the key issue of making the electric bus market competitive and attractive especially in Bangladesh.

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II. Motivation Of The Grid Design

Traditional distribution systems are designed to deliver power from the transmission networks to local loads. This type of power supply get changed due to the integration of EV (Electric Vehicle), DG (Distributed Generation), which can supply the local loads directly and may reverse the power flow direction by injecting power to the transmission networks. Such a change may significantly influence the voltage profile, reliability and planning, power losses, power quality, protection of the distribution system [2]. Also with the rapid development of IPT driven vehicle in the urban area, it's very important to analyze the load flow and grid integration of these electric vehicles. Normally in the urban places, where these public buses usually go, are of highly dense populated area including residential, commercial and industrial structures. In order to ensure a secure, reliable and economic operation of the system, network operators intend to minimize the adverse impacts and to maximize the potential benefits brought by EV. This is normally achieved by optimizing the location and capacity of the distribution system [3]. The distribution grid should be modelled such a way that maximum residential load, the voltages at all points of the network doesn't exceed 10% of nominal assuming residential load only. It needs to keep in mind, the equation for coincidence factor as well.

$$Coincidents\ factor = \frac{Maximum\ diversified\ demand}{Sum\ of\ the\ maximum\ loads}$$

Also, significant deployments of distributed generation like wind and solar creates reverse power flow in distribution networks and that bidirectional power flow can have effects on the quality of power supply and voltage supply. Electric vehicle charging system is controlled by power electronic controller. Converters are coupled to grid via a single or three phase connector. Electric vehicle represents a larger load than a single house. There is a significant impact on the distribution Grid. And it depends upon the density of their penetration or charging points, charging requirements, time of the day when they are charged. So, for the sound operation of electric vehicle as well as the grid, it's highly recommended to design an optimum distribution grid network model and analyze the load flow.

III. Load Profile in Urban Areas

Load profiles in Dhaka city is the vital one as because most of the industries are built over here as well as a great portion of the population live also in this urban area. So, the average power consumption is very high in Dhaka city. Load profile for a specific urban area shows us how much electricity has been being consumed by the customers throughout a whole day. The hourly electricity consumption (EBE) for any city can be written as

$$E_{BE} = E_{DPC} * f(hour)$$

Where, $\sum_{1}^{24} f(hour) = 1.0$

While E_{DPC} (Daily per capita of energy consumption) can be obtained directly from the Energy information administration, but the hourly profile function is more difficult to obtain. Electric utilities monitor and archive hourly load data for their own service areas but do not generally make these data available [4]. Energy consumption data in a specific area depends upon four criteria [5]-

- Location of the community
- Domestic households information, such as the number of persons in a family, unoccupied period, activity period etc
- Appliance usage information such as usage hours and period.
- House information such as building type.

If all these data and information are available, it will be easy for electricity supplier to predict the likely future development of electricity demand in the whole region.

IV. Distribution Grid System in Bangladesh

The distribution voltage ratings are usually 33kV, 11kV and 400/230 Volts [6]. However in many certain parts, the distribution voltages may include 22kV or 6.6kV.Medium (normally 6 to 60 kV) and low (< 1 kV) voltage grids are summarized as distribution grids [6]. In case of high load density even 110-kV-grids are denoted as distribution grids as well [7]. They are constructed as hybrid networks containing cables and overhead lines. Due to protection of the countryside, less susceptibility to atmospheric disturbances and positive operational experiences plastic cables are more and more applied. The R/X-ratio of cable-based distribution grids ranges from 1 to 3 [8]. For many years the supply voltage for single-phase supplies in the Bangladesh has been 240V +/- 6%, giving a possible spread of voltage from 226V to 254 V. For three-phase supplies the voltage was 415 V +/- 6%, the spread being from 390 V to 440V [15]. Most continental voltage levels have been 220/380V [8].

A. Supply frequency

The Supply frequency of Bangladesh is 50Hz. It may go up 1% or go down 1%. Consumers are required to maintain their load power factor to a minimum of 0.85 for voltage level less than 132 kV and 0.90 for voltage level 132 kV and above [7].

B. Earthing System

Medium voltage (6.6kV up to 33kV)

- 3-phase configuration
- Solidly earthed or impedance earthed
- Overhead lines and underground cable are usually used.
- Low voltage 400/230V
- 3-phase 4 wire system
- Neutral point solidly earthed mixture of overhead lines, underground cables and aerial insulated cables.

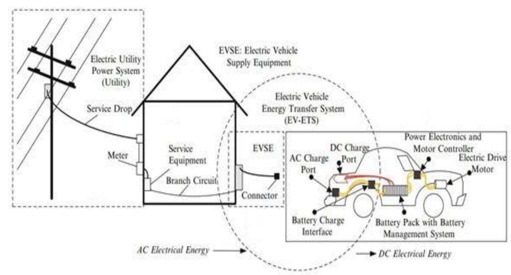

Fig. 1 General outlook of EV charging system [9]

V. EV Configuration of the System

We took the data gleaned from the test to determine whether the batteries installed in the trial buses were the right size for the vehicle, and would also monitor how much stress the electric buses put on the local power grid.

TABLE I
EV and Battery Configuration

Parameter	Detail
Dimension	39.4'L
Capacity	36 seated, 44 standing
Battery Type	Lithium-ion
Battery Capacity	60KWh (Voltage: 660v)
Charging	200KW (Grid connection: AC 400v or DC 750V) using Inductive charging platform
Advertised range	Unlimited en-route

A. Categorization of loads

We have assumed average power demand of several types of building and implement those data on SIMULINK.

TABLE II
ELECTRICAL DEMANDS FOR SEVERAL TYPES OF BUILDINGS

Building Use	**Average Power Demand(W/m2)**
Bank	40-70
Library	20-40
Office	30-50
Shopping Center	30-60
Hotel	30-60
Department Store	30-60
Small Hospital (40-60 bed)	250-400
Hospital (200-500 beds)	50-80
ware house (No cooling)	15-20
Cold store	500-1500
Apartment complex	20-30
Museum	60-80
Parking garage	10
Production plant	30-80
Data center	500-2000
School	20-30
Gym Hall	15-30
Stadium (40k-60k)	70-120
Greenhouse	250-500

In the model, we simulate the total design for two scenarios. One scenario is without a rechargeable battery on the Grid. Another scenario is with a single rechargeable battery on the Grid (MV side). Both scenarios have been operated by using circuit breakers. The forward voltage for AC/DC converter is 660 V as the nominal voltage for the battery is also 660 V. On the other hand, the forward voltage for DC/AC inverter is 10KV. Electric vehicles employ power electronics controllers that interface the vehicle electric power system to the grid. These controllers usually include an on-board AC/DC converter which is coupled to the grid via a single or three-phase connector. The converter can be either a diode bridge rectifier for charging the battery or a switch-mode converter which not only controls the charging of the battery, but is also capable of feeding power from the vehicle to the grid (regeneration). If properly designed and controlled, EVs can provide ancillary services and support the supply network, such as supply/demand matching and reactive power support [10]. This type of operation is part of a new concept in power systems called the ‘smart grid’. EVs may be considered as active loads, increasing the demand on the network during charging, and as generators when operating in regeneration mode [11].

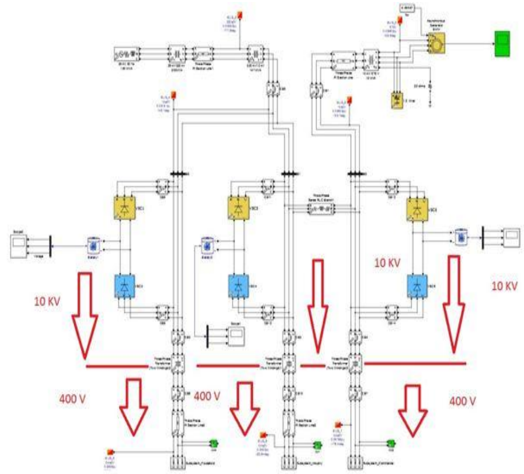

Fig. 2 Simulink Model for distribution grid specific region

VI. RESULTS AND DISCUSSIONS

The First subplot gives the show of three phase voltage and the second subplot gives a glimpse of three phase current whenever a rechargeable battery is not integrated into the medium voltage (MV) grid.

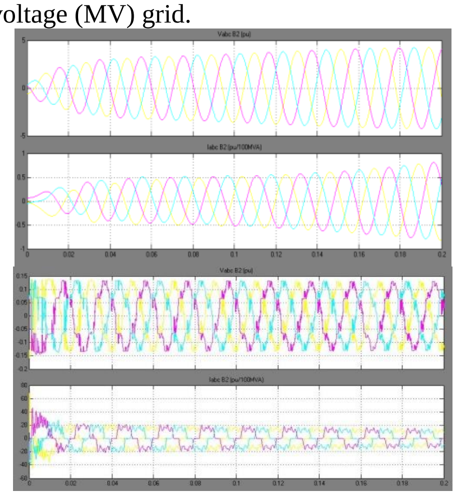

Fig. 3 Voltage and current response

Here also same as before, the first subplot depicts the voltage and second one depicts the current as well whenever a rechargeable battery is connected in to the medium voltage (MV) grid. It’s remarking that both the voltage and current waveforms has been distorted a lot due to integration of power electronics device, such as converter, inverter. Many problems may arise due to this harmonics. These harmonics can cause problems ranging from telephone transmission interference to degradation of conductors and insulating material in transformers. Therefore it is important to gauge the total effect of these harmonics. The summation of all harmonics in a system is known as total harmonic distortion (THD). Massive distortion can increase the current in power systems which results in higher temperatures in neutral conductors and distribution transformers. Higher frequency harmonics cause additional core loss in motors which results in excessive heating of the motor core. These higher order harmonics can also interfere with communication transmission lines since they oscillate at the same frequencies as the transmit frequency. If it is left unchecked, increased temperatures and interference can greatly shorten the life of electronic equipment and cause damage to power systems. While there is actually no national standard dictating THD limits on systems, there are some recommended values for acceptable harmonic distortion. IEEE Standard 519. The limits on voltage harmonics are thus set at 5% for THD and 3% for any single harmonic [12]. It is important to note that the suggestions and values given in this standard are purely voluntary. However, keeping low THD values on a system will further ensure proper operation of equipment and a longer equipment life span. In our grid model, there is a little bit exception as well. The commercial subsystem in our model is directly connected to the 9MW (Asynchronous Motor) wind park and shunt connected to other networks. After integrating the battery the current waveform becomes almost perfectly sinusoidal. The rechargeable battery which has been connected to the grid has a discharge characteristic and it has been shown –

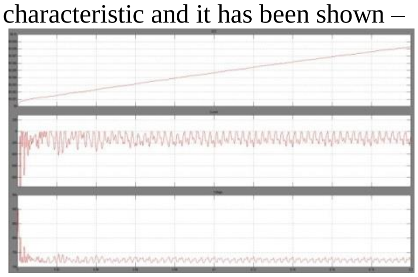

Fig. 4 SOC (State of Charging) of EV

As from the graph, the voltage is very low in the battery output. On the other hand, the current is much higher. SOC (State of Charging) remains within acceptable range. About FFT (Fast Fourier Transform) analysis, the commercial side node shows the lowest total harmonic distortion (THD) at both conditions. After integrating battery charging, THD goes below than previous which is exceptional in other nodes. The graphs have been given –

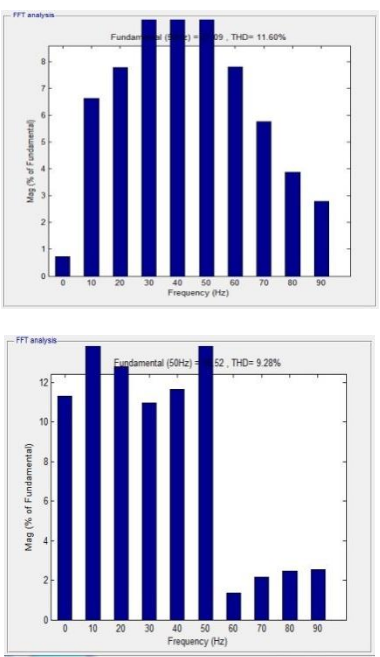

Fig. 5 THD and FFT analysis

VII. Conclusion

The main purpose of this research is to make a reference grid where future research on the IPT (Inductive Power Transfer) and its response on grid can easily be done. We have done a case study on the city of Dhaka in Bangladesh. We have scaled up the load blocks and implement those under SIMULINK environment. Analysis, calculations and discussions have been conducted on the basis of our reference grid model. The developed SIMULINK model of distribution grid design will give designers and engineers the possibility to get a clear view about the grid. The graphics user interface (GUI) will enhance them to undergo several calculations on this grid. Any kind of future test can easily be done on the basis of our grid model. Even other software designs can also be integrated into this SIMULINK model by several interfaces. Many challenges still exist to EV's large scale implementation in Dhaka city. The access to the charging stations are still limited and large capital investment is required for developing a public charging infrastructure. Furthermore, EVs require to the grid during their charging a power as higher as the recharge time want to be short. Therefore, an uncoordinated charging of a huge number of EVs can have a negative impact on the grid operation, in terms of power outages, voltage fluctuations, harmonics pollution and so on [13,14]

References

[1] www.conductix.de
[2] Determining the Impact of Distributed Generation on Power Systems: Part 1 - Radial Distribution Systems; Philip P. Barker, Robert W. de Mello (Power technologies.
[3] Stochastic modeling and analysis of power system with renewable generation by Peiyuan Chen, department of Aalborg University, Denmark.
[4] A top–down methodology for developing diurnal and seasonal anthropogenic heating profiles for urban areas by David J. Sailora,*, Lu Lu
[5] A method of formulating energy load profile for domestic buildings in the UK, Runming Yao, Koen Steemers; University of Cambridge
[6] Radial Distribution Test Feeders Distribution System Analysis subcommittee report, IEEE
[7] Tenaga Nasional Berhad, Electricity Supply Application handbook , Page7,8 and 23
[8] Electricians guide fifth edition by John whitfield, chapter 1 (http://www.tlc-direct.co.uk/Book/1.1.htm)
[9] Electric Vehicle Battery Technologies Kwo Young, Caisheng Wang, Le Yi Wang, and Kai Strunz; Chapter 2
[10] European Commission "European Smart Grids Technology Platform: Vision and Strategy for Europe's Electricity Networks of the Future", EUR22040, 2006
[11] Impact of Electric Vehicles on Power Distribution Networks, Putrus G. A. Suwanapingkarl P. Johnston D. Bentley E. C. Narayana M; Northumbria University, Newcastle, UK
[12] Total Harmonic Distortion and effects in electrical power systems, Associated power technology
[13] EV fast charging stations and energy storage technologies:A real implementation in the smart micro grid paradigm, paradigmD. Sbordonea, I. Bertinib, B. Di Pietrab, M.C. Falvoa, A. Genoveseb, L. Martiranoaa; University of Rome Sapienza
[14] The Impact of Charging Plug-In Hybrid Electric Vehicles on a Residential Distribution Grid; Kristien Clement-Nyns, Edwin Haesen, Student Member, IEEE, and Johan Driesen, Member, IEEE
[15] www.bpdb.gov.bd
[16] Peak Demand Charges and Electric Transit Buses, White Paper; U.S. Department of Transportation Federal Transportation Agency Prepared by: Ted Bloch-Rubin, Jean-Baptiste Gallo & Jasna Tomić

[17] Watt per square foot based on IEEE standard 241-1990

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