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Analysis of the Impact of Electric Vehicle Charging Station on Power Quality Issues

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Abstract: Although, number of Electric Vehicles (EV) in Bangladesh are limited compared to conventional vehicles but in near future, expecting that the EV penetration will be increased significantly. Owing to environmental & socio-economic benefits with reduction of fossil fuel use, EV markets are expanding. These EV have a major impact on the power gird & distribution networks and due to the consequences of huge power demand to recharge their batteries. Large number of EV charging station when integrates with the utility grid, it produces harmonics, affect the voltage profile, finally affects the power quality. In this paper, the impact of electric vehicle charging station in Bangladesh on power grid and distribution networks is analyzed in terms of power demand, harmonics, Voltage sag & swelling and transformer power loss. Also, the mitigation technique for reducing power quality disturbances is analyzed in this paper.

Keywords: Electric Vehicle (EV), Power Quality, Harmonics,Electric Vehicle Charging Station

I. INTRODUCTION

Electric Vehicle is comparatively new concept in the transportation sector. Due to several benefits i.e. less environmental pollution, cheaper mode of transportation, use of less petroleum, EV becomes very much attractive now-a-days. There are mainly three types of electric vehicle available in world-wide i.e. Plug-in-hybrid electric vehicle (PHEV), Hybrid electric vehicle (HEV) and Battery electric vehicle (BEV). Like other developed country, use of EVs like Easy bike, auto-rickshaw and electric bike in Bangladesh are also increasing rapidly and it is more than 7.28% of the total registered vehicle up to March 2018 [1].

All of these vehicles are using electric motor to run these vehicles with the energy from batteries. According to the newspaper, EV penetration in Bangladesh requires more than 450 MW of electricity daily [2]. The huge power demand creates a serious problem with the existing demand. Charging of EV requires high power and large time but theirrange is not satisfactory. In addition, there is no sufficient charging station in Bangladesh. Thus, the EV owner has to charge their batteries from residential connection illegally which becomes a cause of system loss in the power sector. To promote EV penetration, it is necessary to establish sufficient charging stations located at various suitable places[3]. EV batteries may operate from a single phase or three phase supply system. Because of wide availability of single supply points, EV chargers are connected with this system. However, three phase supply system gives larger power with fast charging. These EV chargers are basically power electronic converter similar to non-linear load. This non-linear characteristic of EV charger can produce harmonics in the current and affect the voltage profile of the power network [4]. High non-linear loading can be a cause for nonlinear voltage drop and thus voltage waveform might be distorted. On the other hand, non-linear load can affect the performances of distribution transformer by increasing power losses in the winding and thereby reducing its power output [5]. Thus, EV chargers when integrated with the power grid or distribution network, it hampers the power quality.

In this paper, impact of EVs on the power distribution network is analyzed by MATLAB simulation. This paper presents harmonics and voltage profile along with the losses of distribution transformer when overloading with EV chargers.

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II. ELECTRIC VEHICLE CHARGING STATION

In Bangladesh, Electric vehicle charging stations are not sufficient. There are two types of charging stations exists- i.e. public and private charging stations. Government has established few charging stations in different cities of Bangladesh but maximum charging stations are private. These private charging stations have taken a higher charging rate. Fig. 1 shows a block diagram of an EVCS which comprises transformer, rectifier and converter. Basically, rectifier and converter make a charger which used for EV charging. The specifications of EVs available in Bangladesh are given in Table 1 below.

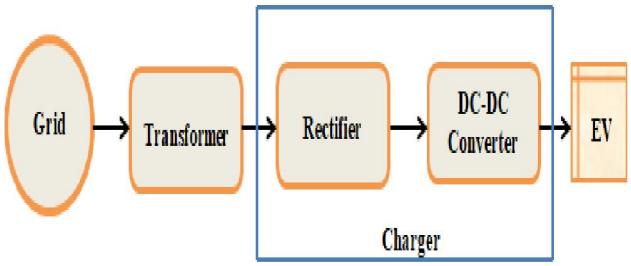

Fig.1: Block diagram of an Electric Vehicle Charging Station.

Table 1: Specifications of Electric Vehicles in Bangladesh

Easy Bike and Auto-rickshaw	**Electric motor cycle**
Power: 500 W-1000 W	Power: 1000 W
Voltage: 36/48/60 V	Voltage: 48/60 V
Battery: 120 Ah-130 Ah	Battery: 14-25 Ah
Charging time: 6-7 hours	Charging time: 6-8 hours
Max. speed: 30-40 km/h	Max. speed: 50-80 km/h
Driving distance: 60-100 km	Driving distance: 40-60 km

As the EV loads are increasing day by day in a rapid manner, thus the impacts of EVs should be analyzed. The impact of mass EV penetration on power system isexpressed in Fig. 2 below. Although EV penetration has cheapest transportation system, lower GHG emission facility, smart grid facilities. But negative impacts on power system network are very much significant.

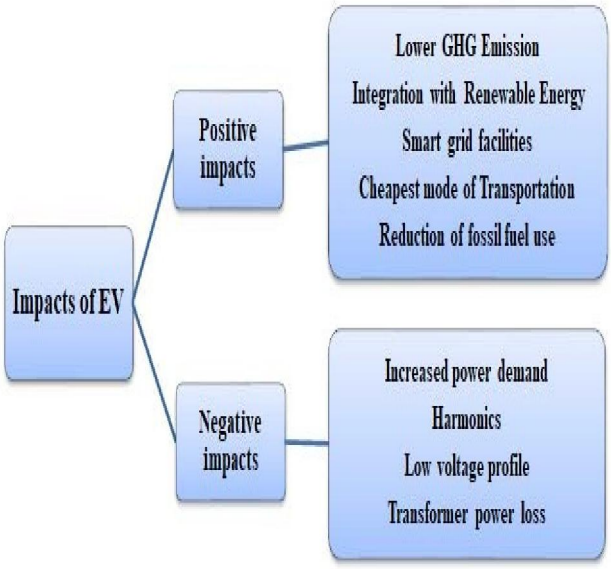

Fig. 2: Impacts of Electric Vehicle.

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III. MATHEMATICAL MODELING

As a non-linear load, EV charger produces harmonics, low voltage profile and power loss in distribution transformer. InBangladesh, for EV charging level 2 type AC charging scheme is used where maximum current rating is 16 A and maximum power rating is 3.3 kW. Most of the electric vehicles have power ranges from 0.5 kW to 1 kW and all of them use single phase 240 V, 50 Hz supply system. In this section, we have developed mathematical modeling for harmonics, voltage profile and transformer overloading due to EV charging.

3.1 Power Demand

Electric Vehicle battery takes charge from the power distribution system. The increased power demand affects the stability of the system due to non-linearity. The power demand by an EV can be expressed as in Equation (1).

$$P_{EV} = \frac{C_{Batt} * (SOC_{\max} - SOC_{\min})}{T_D}; \quad (1)$$

Where C_{Batt} is the battery capacity, T_D is the duration of charging. Battery SOC is a factor whether the EV takes high or small power. The gross power demand of the EVs is the summation of individual power demand of all EVs which likely signifies as in Equation (2).

$$P_{Gross} = \sum_{N=1}^{N} P_{EV}; \quad (2)$$

3.2 Harmonics

The rise in high frequency components of voltage and current with compared to fundamental frequency is defined as harmonics. Harmonics distorts the voltage & current waveforms and thereby affecting power quality. It can be measured by total harmonic distortion (THD) of current & voltage.

$$THD_i = \frac{\sqrt{\sum_{n=2}^{N} I_n^2}}{I_1} \times 100\%; \quad (3)$$

$$THD_v = \frac{\sqrt{\sum_{n=2}^{N} V_n^2}}{V_1} \times 100\%; \quad (4)$$

Equation (3) & (4) express the Total Harmonic Distortion (THD) for current and voltage respectively [6]. For slow charging THD_i, THD_v will be less than the fast charging. Thus, the EV with low SOC will have a great chance to produce harmonics.

3.3. Voltage Profile

The low voltage profile becomes a threatening issue inducedby EV charging. Voltage stability refers to the ability thatthe power network being stable after the sudden increase or decrease in the loads. EV loads take large amount of power at a very short duration. Thus, voltage profile will be degraded and grid will be unstable.

3.4 Transformer Performance

Mass deployment of EVs creates an additional stress on distribution transformers and their life cycles. Another problem is that, the EV charging rate should be limited per day and charging stations should keep far away from transformer for reducing power loss. Harmonic current is responsible for occurring load losses in transformer whereas harmonic voltage incurs no load loss. Due to these harmoniclosses, heating is increased relative to the pure sinusoidal wave. This harmonic withstand capability can be measured by a factor called k- factor.

$$K - factor = \sum_{n=1}^{N} n^2 \left[\frac{I_n}{I_R}\right]^2; \quad (5)$$

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I_n is the current related to nth harmonic and I_R is the rated load current. The presence of harmonics causes overheating in the transformer. Thus, the transformer should be selected according to the withstand capability at higher harmonic current for non-linear loading [7].

IV. MATLAB SIMULINK MODEL OF ELECTRIC VEHICLE CHARGING STATION

Electric Vehicle Charging Station (EVCS) when connected to the utility grid for recharging the batteries, it would hamper the power quality. In this paper, the impacts ofEVCS on utility grid are analyzed using MATLAB SIMULINK model shown in Fig. 3. In this modeling, the three phase source is used as utility grid and the battery ratings are taken as the EVs running in Bangladesh. Chargerconsist mainly a rectifier and a DC-DC converter circuit.

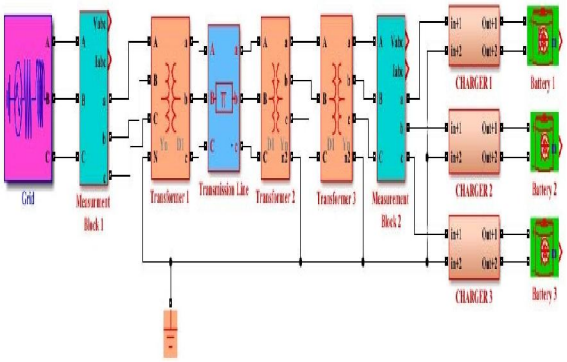

Fig. 3: Simulink model of Electric Vehicle Charging Station(EVCS)

In this simulation, 132 kV utility grid is assumed. Three stepdown transformers are used whose ratings are 132/33 kV, 33/11 kV and 11/0.4 kV. The π-section transmission line is used whose length is taken as 60 km. Switching Mode Power Supply (SMPS) charger is used whose input voltage varies from 180 V to 240 V AC and output voltage is 36/48/60 V. The Lead acid battery is assumed in this model which is used almost all the battery EVs.

V. IMPACT ANALYSIS

Power quality is the ability of a power grid network to supply a sustainable and clean power supply with sinusoidal wave shape, noise free within the standard limit of voltage& current harmonics. Harmonics, voltage sag/swelling are the common problems related to power quality. EV chargers are the components that causing these problems when connected with grid. The EV adoption in Bangladesh, is not only provides its negative impacts but also have some positive impacts. In this paper, we have discussed only the negative impacts.

5.1 Increased Power Demand

The increased electricity demand causes by electric vehicles add an extra pressure to the grid. Research showedthat, it needs 300-500 MW electric power daily. The daily load curve for Bangladesh power sector is given in Fig. 4.

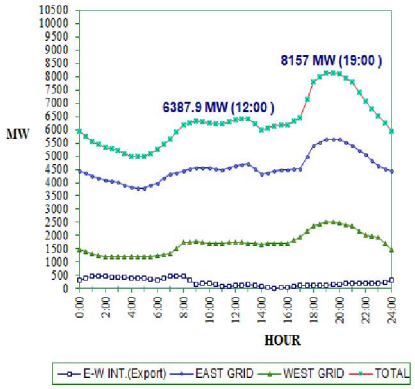

Fig.4: Load curve [8]

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The charging profile for EVs in a charging station is shown in Fig. 5. This graph indicates that, at the time of peak hour, the demand of EV charging increases. Thus, for mass penetration of EV leads to the huge demand during peak hour in all corners of Bangladesh.

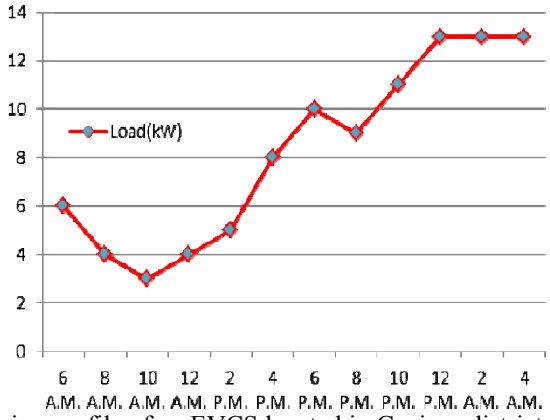

Fig. 5: Charging profile of an EVCS located in Gazipur district,Bangladesh

The increased power demand can be a cause of load- shedding and also hampers the power quality. If the EV charging is scheduled and maintain strictly at peak and off- peak period, then the problem arises with power demandwill be minimized.

5.2 Harmonics Disturbance

Harmonics are the disturbances of a power system. EVcharger is non-linear load and when it connected in thepower system then it generates harmonics. As the EV charger normally connected at the power distribution network for charging, the aggregated effects of harmonics can be threat for the whole power system. In the MATLAB Simulink modeling, the harmonics generated at the different ratio of EV charging is shown in below Fig. 6 (a), (b) & (c).

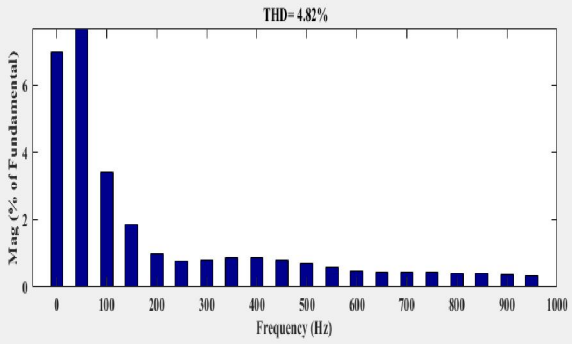

Fig. 6 a) Harmonics, when single EV is connected at a chargingstation

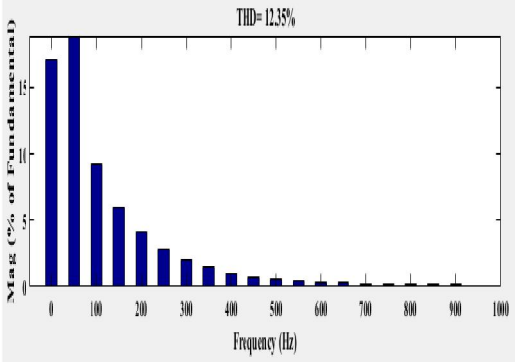

Fig. 6 b) Harmonics, when 3 EV chargers are connected at acharging station

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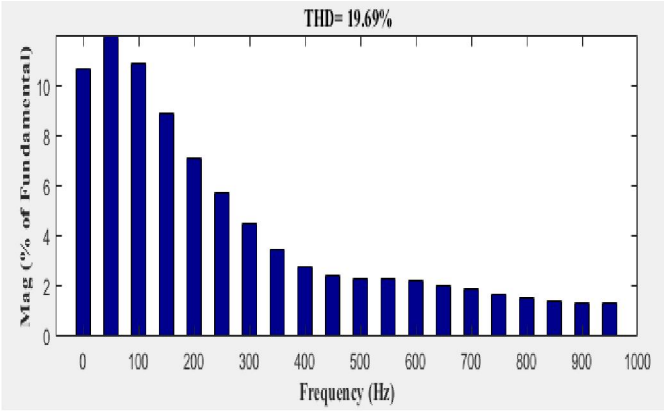

Fig. 6 c) Harmonics, when 5 EV chargers are connected at acharging station

According to the IEEE standard 519 stated that to maintain power quality, total harmonics distortion (THD) value should be below 5% for up to 69 kV power network. In this research, when the EV chargers are connected with the grid & distribution network, the harmonic disturbances will be higher. Thus, for single EVs connected with system produces THD about 4.82%, for three EVs about 12.35% and for five EVs with different specifications about 19.69%.

5.3 Voltage Disturbances

Voltage at the distribution end also reduces when multiple EV chargers are connected. The overloading due to large number of EVs causes this problem. The voltage profile variation before connecting EV charger and after connecting EV charger is shown in Fig. 7 (a) & (b). Fig. 7

(b) shows that, the voltage is affected by harmonics disturbanec compared to the voltage without connection of EV chargers in Fig. 7 (a). In the Fig. 7 (b), it is seen that voltage sag and swelling occurs with harmonic disturbances.

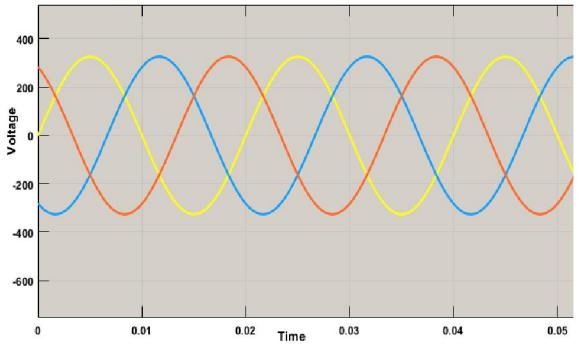

Fig. 7 a) Input Voltage, before connecting Charger.

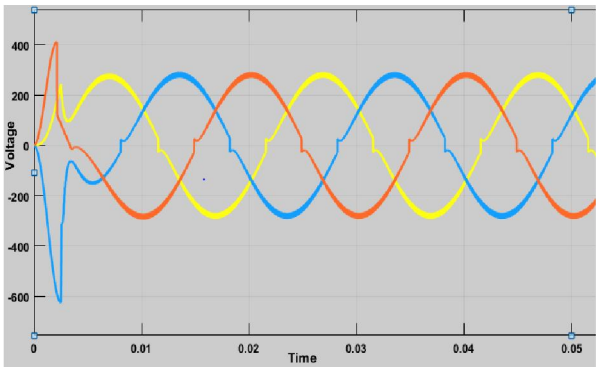

Fig. 7 b) Input Voltage, after connecting Charger.

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5.4 Transformer Power Loss

Clustered EV charging can be a cause of transformer overloading and thereby increasing the power loss. The overloading scenario of a distribution transformer with different EV load is shown in Table 2. The harmonic current produces heating losses in transformer core which further increases the overall power loss and decreases the kVArating of the transformer.

Table 2: Transformer output at different EV load

Output kVA underRated current	Output kVA under RatedHarmonic current
200	191.80(1 EV)
200	186.75(3 EV)
200	181.45(5 EV)

The transformer power loss due to harmonic effects can be minimized by selecting transformer with higher k-factor. More the EVs connected with the distribution transformer, the losses will be more and thereby the efficiency of the power system decreased.

VI. MITIGATION TECHNIQUE FOR POWER QUALITY PROBLEM

Several disturbances found in the MATLAB simulation acts as a threatening factor for the power system stability. Thus the power quality disturbances should be minimized in orderto obtain energy security & efficiency in power sector.

As it is known that, Bangladesh has a great potentiality on renewable resources like solar and biomass. Such kind of resources integration for EV charging can be a great solution to overcome these power quality barriers [9]. Fig. 8 shows solar irradiation profile for different cities of Bangladesh. It demonstrates that, Bangladesh is capable enough to ensure electricity generation using solar resources.

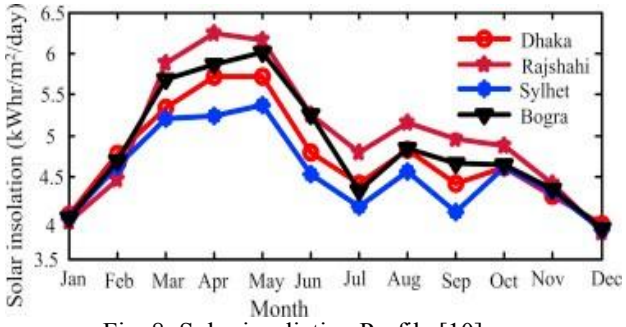

Fig. 8: Solar irradiation Profile [10].

Solar energy is available in Bangladesh only for few hoursin a day. But at cloudy, foggy environment and also at night time, this energy is absent. On the other hand, biomassresources like cow dung, poultry droppings and municipal solid waste (MSW) are available in Bangladesh [11]. Thus, the hybrid power generation scheme like solar and biomass can be an effective solution to overcome these challengesfor EV charging [12].If the EVs are charged from hybrid stand-alone renewable based charging station, then the utility grid will not suffer from the excess energy required for the EV charging especially at peak hour. In that case, utility grid relieves from the threats as like power quality problems. Another research performed on GHG emission said that, EV charges from non-renewable resources emits more GHGs than renewable resources [13]. So, renewable energy based EV charging scheme would be a greater one for improving power quality with lower GHG emission.

VII. CONCLUSION

Prominent features of less environmental pollution & cheapest mode of transportation makes EV market more attractive to the consumers. As maximum EVs are charged at residential connection due to the lack of charging stations in Bangladesh, the power sector has been failed to earn the profit from this sector. However, due to some reasons EVs penetration makes power system more vulnerable and hampers power quality. In this paper, the power qualityissues like harmonics, voltage fluctuation, transformerpower losses are analyzed using MATLAB Simulink in

the context of Bangladesh power sector. In addition to this, the mitigation technique using available renewable resources is also discussed in this paper. Although the EVs have several benefits as like stabilizing the grid at under loaded condition, lower GHG emission but the power quality issues should regulate properly for sustainable development in the power sector.

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