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Analysis for Evaluating the Impact of PEVs on New-Town Distribution System in Korea

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Abstract – This paper analyzes the impact of Plug-in Electric vehicles(PEVs) on power demand and voltage change when PEVs are connected to the domestic distribution system. Specifically, it assesses PEVs charging load by charging method in accordance with PEVs penetration scenarios, its percentage of total load, and voltage range under load conditions. Concretely, we develop EMTDC modelling to perform a voltage distribution analysis when the PEVs charging system by their charging scenario was connected to the distribution system under the load condition. Furthermore we present evaluation algorithm to determine whether it is possible to adjust it such that it is in the allowed range by applying ULTC when the voltage change rate by PEVs charging scenario exceed its allowed range. Also, detailed analysis of the impact of PEVs on power distribution system was carried out by calculating existing electric power load and additional PEVs charge load by each scenario on new-town in Korea to estimate total load increases, and also by interpreting the subsequent voltage range for system circuits and demonstrating conditions for countermeasures. It was concluded that total loads including PEVs charging load on new-town distribution system in Korea by PEVs penetration scenario increase significantly, and the voltage range when considering ULTC, is allowable in terms of voltage tolerance range up to a PEVs penetration of 20% by scenario. Finally, we propose the charging capacity of PEVs that can delay the reinforcement of power distribution system while satisfying the permitted voltage change rate conditions when PEVs charging load is connected to the power distribution system by their charging penetration scenario.

Keywords: PEVs, New-town, Impact, Distribution system, Voltage range, Power demand

1. Introduction

Electric power as an energy source for transportation is not a new idea. Many plants and distribution systems for electric railways and trams were built early on. But transport over long distances has primarily relied on the use of the internal combustion engine and petroleum fuels. But recently, since Electric Vehicles have begun to get positive responses from drivers, electric power has begun to take on a new role in automobile propulsion systems. As the potential for power plugs for recharging Plug-in Electric Vehicles (PEVs) batteries have been recognized as a power source, the development of hybrid electric vehicles have reached a turning point. The greatest advantage of PEVs is that they can use electric power instead of using gasoline, which is currently used to fuel conventional cars. This is especially true for countries like Korea which heavily rely on foreign supply sources for gasoline. [1]

Accordingly, the innovation of PEVs in the market can be anticipated in the near future, which will bring grid impact in the distribution system. [2-5] Based on these reasons, hyeok jin Son, kyung soo Kook [6] and L. zhao et al. [7] propose simulation methods based on a stochastic and comprehensive model to assess PEVs impact on distribution grids respectively.

PEVs are similar to existing HEVs (hybrid electric vehicles) but PEVs differ in that their power can additionally be supplied from distribution systems. An even greater benefit of PEVs is the much lower cost compared to gasoline for fueling cars. The current price of gasoline, while varying from country to country, is \$1.43/liter in Korea, with energy cost amounting to \$0.148/kWh (assuming a rate of 9.68kWh/liter). Such cost amounts to more than twice the expense compared to electricity costs in Korea(\$0.07/kWh).[8]

Moreover, the average of the efficiency of cars with internal combustion engines is 12.6% (energy efficiency the fuel actually delivers to the wheels). Also, relative efficiency of cars using electrical energy amounts to almost 70% (energy efficiency delivered to the wheels by electrical energy from the grid). Therefore, using electric energy to power cars can reduce driving costs by about 10.5% compared to internal combustion engines in cars. That is to say that the cost to drive cars using electric energy, if converted to gasoline price, would be \$1.28/liter. Also, considering that electric energy efficiency is 33%, The total efficiency for PEVs in a typical power system, which is 23.1% would be significantly high compared to the 12.6% rating for cars with internal combustion engines. [9]

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In addition, most of auto-vehicles are mainly dependent on gasoline or diesel for their energy sources while there are various fuel sources such as nuclear, coal, oil, wind, photovoltaic, etc. in the electric power system. So it is expected to replace a considerable part of fossil fuel consumption by eco-friendly energy if we use the electricity supplied by the power system for our transportation systems. By increasing the portion of renewable energy in the power system we could decrease the energy dependence on fossil fuel energy sources on the transportation sector.

And the energy consumption pattern of each vehicle is different, therefore the electric vehicle is used for distributing the peak load as mobile batteries. The electric vehicle almost charges its battery during off-peak time and provides the electricity to the power system by discharging the battery during peak time. It is called as V2G service which is a new type of service expected to appear in Smart Grid environments. In this kind of context, while HEV are now widely being used, PEVs will likely come to gain greater occupancy of the car market in the near future as PEVs technology develops.

On that basis, this paper analyses the impact of the power distribution system by calculating existing electric power load and additional PEVs charging load in accordance with each scenario on new-town in Korea. This is to estimate total load increases in that region by PEV penetration ratio. Further, the paper interprets the subsequent voltage range for distribution system and demonstrates conditions for countermeasures.

2. Simulation for PEVs Charging by Scenario

In this paper, a region is selected for the case study to analyze the impact of EVs to distribution power network. It is the 3rd construction area in Dongtan New-Town in which many commercial buildings, apartments, and houses are concentrated. The following sections explain regional and load characteristics of the assessment region composed of 7 district blocks.

2.1 Assessment for region characteristics

The assessment region, 3rd construction area in Dongtan New Town, consists of mainly commercial buildings, residential apartments, and detached houses as shown in the Fig. 1. The regional characteristics are as follows:

- Neighborhood Commercial facilities & Residential (apartments / detached houses)
- Assessment distribution line : 5 distribution lines from Byung-Jum substation
- Assessment area: 1.1km^2

2.2 Assessment for load characteristics

The characteristics of the assessment load are as follows:

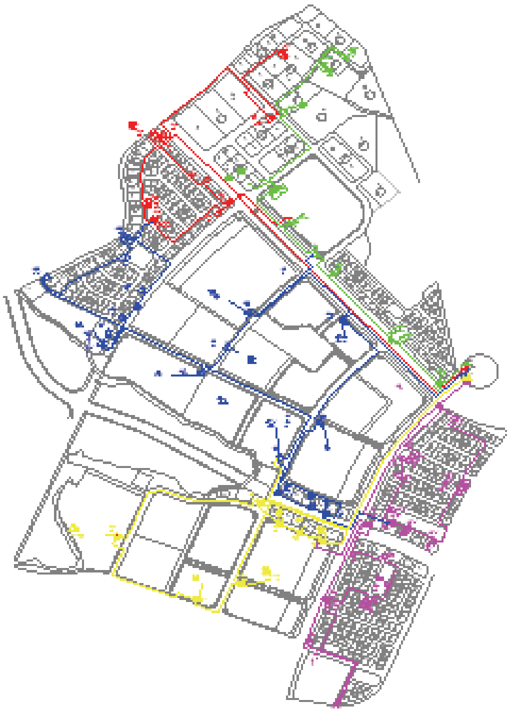

Fig. 1. Distribution system configuration (3rd construction site in dongtan new-town)

- Total houses: 5,446 households
  - Commercial buildings and others: 27 buildings
  - Residential apartments: 4,981 households
  - Detached houses: 465 households
- Entire average load: 37,480kW
  - Commercial buildings and others: 12,980kW
  - Residential Apartments: 15,500kW
  - Detached houses: 9,000kW

The above Fig. 1 illustrates the configuration of the distribution system which is supplied by 5 distribution lines from the Byung-Jum substation stated above. Table 1 shows the load characteristic and the number of households on each distribution line.

2.3 Distribution system simulation

3 scenarios are established about the distribution system in the 3rd construction site of Dong-tan new town. The first scenario is the base case with no additional load by PEVs on the current system load. The second and third scenarios are about 10% and 20% load increases by PEVs to the basic case.

For the case study, this study also assumes the additional conditions below for the case study as follows referring to documents of Better Place in Israel and ETEC (Energy Technology Engineering Center) in U.S.A:

-Slow charging capacity: 5kW
- Fast charging capacity: 50kW
- The number of slow charging vehicles: 2.5 times of

Table 1. Load Characteristics of Each Distribution Line in Sample Region

D/L & Districts		Customers	Average load [kW]	No.
Han-Kum D/L	Block #2	Bestech Corp.	300	1
	Block #2	Humansia Apt.	1,150	632
	Block #2	Korea Gas	500	1
	Block #2	The3rd Plastic	700	1
	Block #2	Bechtel Global	500	1
	Block #2	Forest Construction	750	1
	Block #2	detached houses	300kW×4	68
Neung-Dong D/L	Block #2	HON Corp.	400	1
	Block #2	Sung-Ji Industry	230	1
	Block #3	Nueng-Ri Underway	2,900	1
	Block #3	The2nd Pump Station	150	1
	Block #3	detached houses	300kW×12	169
Kwang-Nam D/L	Block #4	Nature&GyeongNam HonorsVill Apt(2-3)	2,750	455
	Block #4	ForestVillageNature & HonorsVill Apt(2~5)	3,250	621
	Block #4	KwangMyung Mayroute Apt	1,350	326
	Block #4	SamHan Public Management	500	1
	Block #4	Commercial	500	1
	Block #4	Deok-Cheon Plaza	500	1
SinByung D/L	Block #5	Fine Industry	600	1
	Block #5	KangNam Plaza	600	1
	Block #5	I-Land	600	1
	Block #6	Gold Plaza	750	1
	Block #6	detached house	300kW×14	228
YiJin D/L	Block #7	NeungDong Village Evergreen YeMa Apt	2,500	707
	Block #7	EasytheOne Apt	1,550	512
	Block #7	Song-Ri Elementary School	750	1
	Block #7	NeungDong Village Humansia Apt 7th division	2,950	1,728
	Block #7	Gisedo	650	1
	Block #7	Hansol Plaza	600	1
	Block #7	UmJungKwan	500	1

consumer households

- The number of fast charging vehicles: 1% of slow charging vehicles

Considering above conditions we simulated the load increases from the basic case by the market penetration of PEVs. Here, the mathematical formulation for calculating the slow and fast charging vehicle loads are as following formula (1) and (2):

No. of slow charging vehicle = No. of households x PEVs penetration rate x 2.5
Slow Charging Load = No. of slow charging vehicle x 5kW (1)
No. of fast charging vehicle = No. of slow charging vehicle x 0.01

Fast Charging Load = No. of fast charging vehicle x 50kW (2)

Here, the number of households was counted only on apartments and detached houses. The reason is that we assumed there is no additional PEVs load increase caused by commercial and other kinds of sectors. The following Table 2 & 3 show the numbers and load quantities of PEVs based on the scenario 1 and 2.

Table 2. No. of Charging PEVs and loads on both household types (Scenario 1)

Charging Method	No. of Charging PEVs	Charging Load (kW)
Slow Charging (Apt)	1,245	6,226
Slow Charging (detached house)	116	581
Fast Charging (Apt)	12	623
Fast Charging (detached house)	1	58
Total	1,374	7,488

Table 3. No. of Charging PEVs and loads on both household types (Scenario 2)

Charging Method	No. of Charging PEVs	Charging Load (kW)
Slow Charging (Apt)	2,491	12,453
Slow Charging (detached house)	233	1,163
Fast Charging (Apt)	25	1,245
Fast Charging (detached house)	2	116
Total	2,751	14,977

The next Table 4 shows the summed result of totally added loads to the base case by PEVs

Table 4. Result of totally added loads to the base case by PEVs

	Basic Load (kW)	PEVs Charging Load (kW)	Total load (kW)	Ratio (%)
Base Case	37,480	0	37,480	100
Scenario 1 (kW)	37,480	7,488	44,968	120
Scenario 2 (kW)	37,480	14,977	52,457	140

Table 4 shows the load increases in the PEVs sector and the entire system according to scenario 1 and 2. PEVs increase the system load up to 120% on scenario 1 and 40% on scenario 2. Considering this increasing trend, the basic load, 37,480kW is distributed to 5 distribution lines, which means each line should bear about 7,500kW. Therefore, it is required to ensure one more line for the PEVs load on scenario 1 and two more lines on scenario 2. Conclusively, the base case needs 5 lines to supply the load, the scenario 1 and 2 require 6 and 7 lines respectively.

3. Simulation of Distribution Voltage Range Based on Penetration of PEVs

When electric vehicle charging systems are linked to the distribution system, one must check to see if the connection criteria of the distribution power system grid are being met according to the electric vehicle system's form, capacity and location. In other words, because cases occur where the voltage cannot maintain the values of the regulations according to the electric vehicle system's form, capacity and location, so a simulation must be performed as a check.

In this study, a system analysis simulation program called EMTDC was used to perform a voltage distribution analysis when the electric vehicle charging system was connected to the distribution system. First, when the electric vehicle was at 10% and 20% penetration and the necessary charging system connected to the real distribution system, a voltage range analysis was performed during heavy load according to the charging system's location and capacity. The load on the charging system was calculated in accordance with formula (1) and (2) described previously.

3.1 Charging system modeling

Fig. 2 charts the system configurations simulating the D/L of Sinbyeong in Dongtan New Town (shown in Fig. 1) using EMTDC. D/L for Sinbyeong in the Dongtan New Town region was chosen in order to model the electric vehicle charging system under normal conditions. Loads for each line were put at "heavy load" when the simulation was performed.

On the other hand, when the domestic system connection criteria of distributed generator for Korea were observed by capacity, they were as follows:

- Distributed generation capacity
  - 3MW or less: connected to special high power distribution line
  - 3MW ~ 20MW: connected to exclusive distribution line
  - 20MW and over: connected to exclusive line with high-capacity distribution

Table 5. Synchronization requirements

Generating capacity (kVA)	Frequency (△f, Hz)	Voltage drop (△V, %)	Phase angle Difference (△∅, ○)
0～500	0.3	10	20
500～1,500	0.2	5	15
1,500～10,000	0.1	3	10

Table 6. Voltage change requirement

Voltage class		Voltage change rate (△V, %)
Special high voltage	Regular	2
	Moment	2
Low voltage	Regular	3
	Moment	4

In addition, synchronization and voltage regulation allowed when the distributed power grid was connected are as seen in Tables 5 and Table 6.

3.2 Case analysis of voltage range

To interpret the voltage range when the electric vehicle charging system was connected to the real distribution system, a case study was performed in accordance with the electric vehicle number, capacity and position while heavily loaded for interpreting voltage distribution for the system. Also, it was analyzed whether any changes in voltage distribution occurred in accordance with the application of ULTC when the electric vehicle charging system was connected.

Table 7 presents the end voltage regulations for the initial and end positions of Sinbyeong D/L for the cases with no EVs and a 10% EV penetration under heavy load. As shown, under heavy load and at 10% penetration the voltage regulation departed from the allowed scope of the distributed power system. Therefore as in Table 8, a case study was performed applying ULTC in order to solve the voltage problem. As a result, voltage criteria values stayed

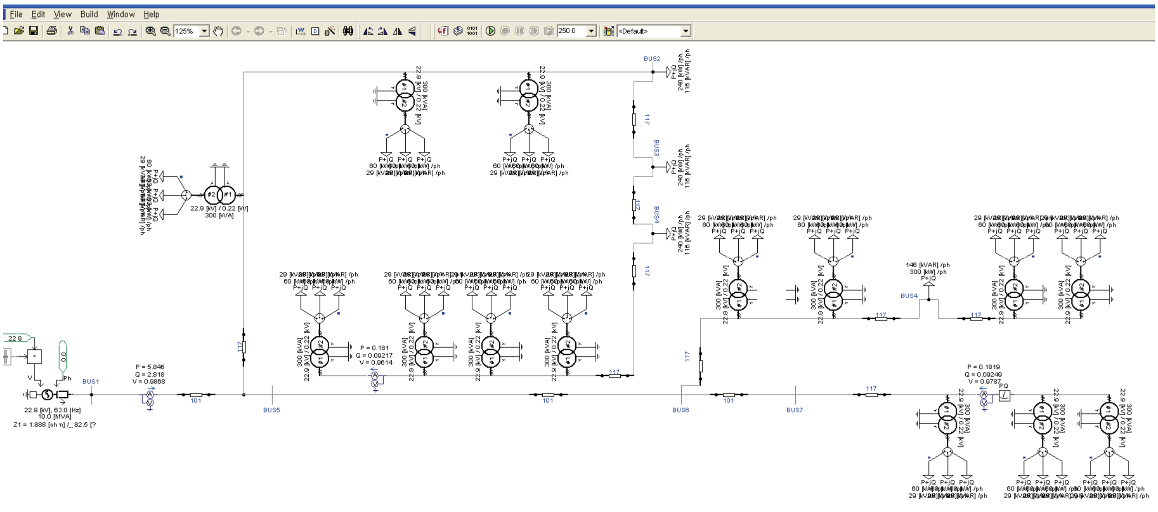

Fig. 2. Modeling electric vehicle charging system for Sinbyeong circuits (EMTDC)

Table 7. Sinbyeong D/L (PEVs 10% Penetration)

Load	PEVs	Voltage (P.U) in D/L		Voltage change rate (△V, %)
		Initial position	End position	
Heavy load	No	0.9872	0.9617	3.9825
	Yes	0.9861	0.9588	4.2970

Table 8. Sinbyeong D/L with ULTC applied (PEVs 10% Penetration)

Load	PEVs	Voltage (P.U) in D/L		Voltage change rate (△V, %)
		Initial position	End position	
Heavy load	No	1.0000	0.9749	2.5746
	Yes	1.0000	0.9731	2.7644

Table 9. Sinbyeong D/L (PEVs 20% Penetration)

Load	PEVs	Voltage (P.U) in D/L		Voltage change Rate (△V, %)
		Initial position	End position	
Heavy load	No	0.9872	0.9617	3.9825
	Yes	0.9849	0.9557	4.6353

Table 10. Sinbyeong D/L with ULTC applied (PEVs 20% Penetration)

Load	PEVs	Voltage (P.U) in D/L		Voltage change Rate (△V, %)
		Initial position	End position	
Heavy load	No	1.0000	0.9749	2.5746
	Yes	1.0000	0.9713	2.9548

within the allowed scope with 10% penetration by the electric vehicle charging system.

Table 9 charts the voltage regulation at the end in accordance with the presence or absence of 20% penetration by the electric vehicle number under heavy load for Sinbyeong D/L. As seen in Table 9, when the electric vehicle charging system penetrated at 20%, the voltage regulations departs from the allowed values. but if ULTC is applied in such a case, as in Table 10, the voltage regulation is significantly reduced and it is possible to adjust it to stay within the scope of allowed values.

Therefore, in this paper, we developed the EMTDC simulation modeling technique to enable us to analyze the impact on the grid voltage changes because of the charging of PEVs. The developed technique was applied to case studies involving new towns. More specifically, using the EMTDC simulation modeling technique, when a heavy load is applied to a power distribution system, the rate of change of voltage was calculated for the corresponding D/L using the PEVs charging penetration scenario, and we assessed the permitted range of voltages that could be connected to the electricity distribution system.

Furthermore, when the voltage change rate calculated for each PEVs charging scenario exceeded the allowed range connected to the electricity distribution system, we conducted an evaluation to determine whether it is possible to adjust it such that it is in the allowed range. This was done by applying ULTC. Based on our results, we proposed the charging capacity of PEVs that can be satisfied the allowed condition for the voltage change rate when connected to the power distribution system by each PEV charging penetration scenario without system reinforcement.

4. Conclusion

This paper analyzes the impact of PEVs charging using domestic power systems in Korea. Assessment focused on increases in PEVs demand power and distribution system total load, as well as voltage range according to PEVs penetration scenarios. In particular, in order to concretely analyze the impact of PEVs charging in the distribution system, PEVs charging loads were staged by scenario for Dongtan New Town in Korea and total charge load increase was calculated, while an analysis was performed on voltage distribution in accordance with PEVs penetration by scenario for Sinbyeong D/L. And to enhance PEVs charging simulation accuracy in comparison with the existing typical methodology, this paper presents mathematical formulation to calculate the slow and fast charging electric vehicle loads in considering with their number of households by PEVs penetration scenario.

Thus, this paper presents algorithm to analysis load increase and voltage range in accordance with load characteristic in the distribution system by calculating the number of apartments and detached houses, their fast and slow charging capacity in the New Town. Following is a summary of the results derived in this paper.

- According to the 10% increase of PEVs penetration in scenario 1, the system total load in New-town area increases by 20% compared to the base case.
- According to the 20% increase of PEVs penetration in scenario 2, the system total load in New-town area increases by 40% compared to the base case.
- The total distribution lines in New-town area increase up to 6 and 7 lines respectively according to scenario 1 and 2 from 5 lines in the base case. One more line is added for the 20% load increase on scenario 1, and two more lines are required for bearing the 40% increase of the system load on scenario 2.
- To analyze the impact of changes in the grid voltage caused by the charging of PEVs, we developed the EMTDC simulation modeling technique, which was applied to a case study involving new town areas in order to evaluate whether the voltage change to the power distribution system can be permitted for each PEV charging scenario
- The more PEVs charging capacity connected to the distribution system increased, voltage regulation increased. When connected to the distribution system, the PEVs charging capacity must be reviewed so as to allow the distribution system to run within the allowed voltage

scope.

- When ULTC was applied in order to reduce voltage regulation in accordance with the PEVs charging system's connection to the distribution system, significant reduction of voltage regulation was achieved in accordance with penetration conditions of the PEVs charging system.
- In addition, even though voltage regulation increased together with increase in PEVs charging capacity, applying ULTC made it possible to operate within the allowed scope for voltage regulation for up to PEVs 20% penetration.
- Furthermore, we proposed the charging capacity of PEVs that can delay the reinforcement of power distribution system in order to satisfy the permitted voltage change rate conditions when connected to the power distribution system for each PEV charging penetration scenario.

References

[1] John Voelcker, "Plugging Away in a Prius", IEEE Spectrum, vol. 45, issue 5. pp. 30-48, May 2008. IEEE Reference

[2] K. Schneider, C. Gerkensmeyer, M. Kintner-Meyer, and R. Fletcher, "Impact assessment of plug-in hybrid electric vehicles on pacific northwest distribution system" in IEEE Power and Energy Society 2008 General Meeting, pp. 1-6, Pittsburgh, Pennsylvania, USA, 2008.

[3] S.W. Hadley, "Evaluating the impact of plug-in hybrid electric vehicles on regional electricity supplies", in Bulk Power System Dynamics and Control, Charleston, S, USA, 2007

[4] Lian Liu, Xiang Lyu, Chuanwen Jiang and Da Xie, "Decision -Making of Determining the Start Time of Charging /Discharging of Electrical Vehicle Based on Prospect Theory" Journal of Electrical Engineering Technology, Vol. 9, No. 3: 803-811, 2014

[5] Soon-Jeong Lee et. al, "Evaluation of Voltage Sag and Unbalance due to the System Connection of Electric Vehicles on Distribution System", Journal of Electrical Engineering Technology, Vol. 9, No. 2: 452-460, 2014

[6] Hyeok Jin Son and Kyung Soo Kook, "Stochastic Modeling of Plug-in Electric Vehicle Distribution in Power Systems", Journal of Electrical Engineering Technology, Vol. 8, No. 6: 1276-1282, 2013

[7] L. Zhao, S. Prousch, M. Hubner and A. Moser, "Simulation Methods for Assessing Electric Vehicle Impact on Distribution Grids", 2010, IEEE.

[8] KEPCO Report, "Statistics of Electric Power in Korea", 2012.

[9] www.fueleconomy.gov, "Where does the Energy go?" http://www.fueleconomy.gov/feg/atv.shtml, July 2008. IEEE reference

[10] BERR Report, "Investigation into the Scope for the Transport sector to switch to Electric Vehicles and plug in Hybrid Vehicles", October, 2008.

[11] EPRI White Paper, "A Review of the Reliability of Electric Distribution System Components, Palo Alto, CA, 2001

[12] Power Systems Engineering Research Center, "Power System Level Impacts of Plug-in Hybrid Vehicles", Oct 2009.

[13] KEPRI Technical Report, "Underground Network Configuration and Equipment Management Strategy for Reliability Improvement", April 2009.

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