Medium Voltage Direct Current Distribution System for an Electric Vehicle Fast Charging Park

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Abstract: – There is an increasing shift towards the electrification of automobiles to meet zero-emission standards set by many nations. As electric vehicles become more common, their power demand on the power system becomes greater. A substantial modernization or upgrade of the current distribution power grid is required to meet such demand. Since most Level 3 fast chargers utilize DC power, medium voltage direct current (MVDC) provides a feasible alternative to the present AC distribution infrastructure. This study proposes an MVDC distribution model for powering a large EV park consisting of 40 EV charging stations with a 9.6-MW total power demand. Calculation and simulation are used to evaluate the model and compare it with an equivalent MVAC system. The outcomes show that implementing an MVDC distribution system is an efficient approach to meeting the increasing power demand for electric vehicles. The proposed 40-kV MVDC system power loss (13.1kW) is six times lower than that of the equivalent MVAC system (89.74kW). Further, since MVDC systems do not require AC step-down transformers and AC/DC converters at the equipment end, they can be a lower-cost option for powering large EV charging parks. The findings help enhance EV charging infrastructure, which expedites the adoption of EVs for reducing carbon emissions in the transportation sector.

Key-Words: - AC-DC conversion, charging park, distribution power system, electric vehicle, Level 3 charging, medium voltage direct current (MVDC).

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1 Introduction

Electric vehicles (EVs) are currently being promoted by many nations to reduce the reliance on fossil fuels for passenger vehicle travel and also to meet zero-emission standards and goals set by various governing bodies. In the upcoming years, as EV costs trend down and are more widely adopted by the populace, a convenient charging method will need to be provided. The Society of Automotive Engineers (SAE) has provided the international standard SAE1772 providing direction for three levels of charging that are available to be installed at residences and commercial locations. Forecasts considering the various government and environmental incentives for electric vehicles show a sharp increase in EV adoption in mid-2020's and by the start of the 2030s, roughly 50% of vehicle sales will be electric, as shown in Figure 1, [1].
The high rate of forecasted adoption of electric vehicles in the upcoming decades requires research and planning into new technologies to support the additional power demands of EV charging.

On a commercial scale where charging speed and consumer convenience are a priority, Level three EV charging set by the SAE 1772 standard is a suitable choice and will be used as the basis of our load in a medium voltage direct current (MVDC) microgrid that we aim to develop in this study. Level 3 charging is characterized by containing a DC voltage ranging from 200 to 600V, a maximum current less than or equal to 400A, and a power capability of up to 240kW, [2]. The differing characteristics of Level 3 charging in comparison to Level 1 and Level 2 charging, in the consumer perspective, is charging speed.

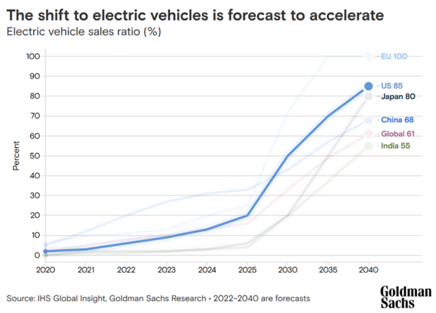

Fig. 1: Electric vehicle adoption rate in the upcoming decades, [1]

The DC Level 3power output of up to 240kW allows most current vehicles to charge from near depleted charge to 100% within one hour, [3].

EV charging time is critical when comparing refueling times for traditional internal combustion engine (ICE) vehicles as consumers prefer similar times when opting for EVs. With such a large power requirement for a single charger, it becomes apparent that having multiple EV chargers to support multiple customers simultaneously fed from a single power circuit will require a renewed look at the present power system infrastructure to supply the load, [4], [5].

Medium voltage DC distribution is a possible alternative to supply the DC nature of EV charging more efficiently and cost-effectively than the traditional AC power system, [6]. Medium voltage DC is of growing interest with the commercially successful construction and implementation of High-Voltage DC (HVDC) transmission lines throughout the globe. Large amounts of research have been done on the topic of HVDC concerning constructability, materials, and power electronics. MVDC theory is an extension of principles developed with HVDC at a much lower voltage and physical scale, [7], [8].

HVDC is a more efficient means of transmitting power along large distances. The most critical analysis when designing and selecting HVDC as a means of transmission is the equipment cost versus transmission line distance. This is due to the complexities involved in rectification and inverting the generated AC power, [9].

Based on the increasing interest in MVDC as a method to efficiently distribute power, the adoption of electric vehicles utilizing DC electricity as a method of charging, and large power requirements, this study will consider a hypothetical model of an EV Charging Park where consumers can conveniently charge in a short time and analyze the feasibility of an MVDC power system, its constructability, and efficiency over the existing AC power system. A DC distribution grid is more favorable over AC power systems when considering the continued implementation of DC technologies, [10], [11], [12].

MVDC can coincide with the existing MVAC distribution infrastructure providing additional services where required, [11]. Figure 2 shows possible implementations of MVDC in conjunction with the existing power system MVAC power grid.

A search of the literature did not find any study where an MVDC network is used for an EV charging park. This motivated us to design an MVDC EV charging park. The expected benefit of our study is improving understanding of MVDC network capability for EV charging, as well as determining the park core features and specifications. The findings will enable the implementation of MVDC networks for expanding EV charging infrastructure, which expedites the adoption of EVs for reducing carbon emissions in the transportation sector.

2 Basis of Design for EV Charging Park Utilizing MVDC

2.1 EV Charging Park Concept.

For our study, the EV charging park will serve a similar function as a traditional gas station. It will allow consumers to arrive and conveniently charge their EVs in a reasonable time. Due to the inherent relative charging times required for EVs it will have to be placed in a location where the consumer can be occupied for a minimum of thirty minutes such as a recreational park, commercial plaza, urban environments close to social amenities, etc. to allow for a sufficient charge. It will also require a substantial quantity of charging stations to prevent waiting times for incoming vehicles.

2.2 Charging Park Sizing

The hypothetical charging park can also function as a recreational park where consumers go to picnic, take their children to playgrounds, access public basketball courts, and tennis courts, have social gatherings, etc. A location such as this is ideal for an EV user to charge their vehicle and have local amenities while the vehicle charges. Local Los Angeles County ordinances provide minimum parking space requirements based on acreage for private and public parks. One space per half-acre of developed park for parks up to fifty acres.

Community parks are described as areas designed to serve residents of several surrounding neighborhoods with an ideal size of fifteen to twenty acres and a service radius of a minimum two miles. At a given park size of twenty acres, a proposed minimum of 40 charging stalls shall be proposed in the community park meeting parking space minimums and used in our model. Additional standard non-EV parking can be provided to accommodate regular ICE vehicles. The 40 EV stalls can be split between separate parking areas within the park to reduce congestion, [13], [14]. It is important to consider local and state ordinances as well as actual land size when planning for the quantity of EV charging parks.

2.3 EV Charging Standards

Level 3 DC charging will be utilized for our EV charging stations. Table 1 shows the standard set by SAE for each level of charging and requirements needed to be fulfilled by our MVDC power system, [2].

Our model and analysis only consider DC charging as part of our MVDC power system. This is to remove the necessary AC/DC conversion at the station end. Level 3 charging for each charging station can utilize a maximum power of 240 kW, [2].

With a total of 40 stations, it follows that our model utilizes a maximum of 9.6 MW of power. Our MVDC feeder circuit is required to sustain that quantity of power as part of the design and analysis.

It should be noted that there are multiple EV charging standards, such as the Society of Automotive Engineers (SAE) J1772, Japanese industry “Charge-de-Move” (CHAdeMO), CharIN organization combined charging system (CCS), Chinese and Indian EV manufacturers Guobiao standards (GB/T), and Tesla supercharger network, [15]. For our study, we utilize Level 3 DC charging specification which is part of SAE standard J1772. Other charging standards are not used so they are not discussed here for brevity.

2.4 MVDC System Specification

Medium voltage DC distribution power system is a topic of research that has not been widely implemented at a utility level. At the time this research was conducted, there were no standardized voltage levels and industrial practices widely adopted for MVDC as shown in [6]. Our implementation of an MVDC grid for our model utilizes previous research papers and reference HVDC implementations that can be appropriately applied to MVDC.

a) Line and cable design

There are different cable designs for MVDC currently proposed based on the station design and distribution method. The line design chosen for our system consists of two fully insulated conductors.

Other line designs proposed are a single-conductor with full insulation and 3-conductors with two fully insulated and one less insulated conductor, [16]. The 2-conductor line design is chosen as a compromise between power safety and cost.

Our two-conductor line design shall also be capable of supporting our maximum power load for the EV charging park and able to accommodate future growth within the system. Various cable sizes will be compared to analyze the appropriate cable sizes to utilize for a 9.6 MW electrical load.

Table 1. Charging mode characteristics, [2]

Type	Level	Input	Max Current (A)	Max Power Output (kW)
AC (On-Board Chargers)	Level 1	120 VAC (1-phase)	≤ 16 A	≤ 1.92 kW
	Level 2	208-240 VAC (1-phase)	≤ 80 A	≤ 19.2 kW
	Level 3	208-240 VAC (1 and 3-phase)	≤ 400 A	≤ 96 kW
DC (Off-Board Chargers)	Level 1	200-450 VDC	≤ 80 A	≤ 36 kW
	Level 2	200-450 VDC	≤ 200 A	≤ 90 kW
	Level 3	200-600 VDC	≤ 400 A	≤ 240 kW

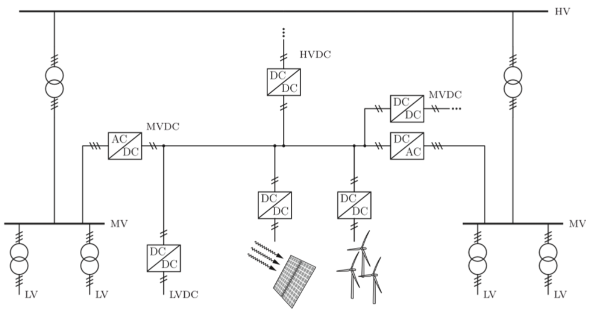

Fig. 2: Possible MVDC grid infrastructure

Consideration of conductor material is also required. The most widely used materials for cable design are copper or aluminum conductors. Both have their respective benefits and trade-offs. Copper conductors can support higher amperage than aluminum conductors at the same wire gauge, [17], while also having substantially less impedance. Aluminum conductors are less expensive than copper conductors and lighter than their respective counterparts allowing for ease of installation, [11]. The trade-off between performance and cost is one for engineers to consider when designing the cable plant for MVDC.

Our study primarily focuses on enhancing the efficiency of the power system. As such, copper cable conductors are selected for their reduced impedance providing for higher power efficiency transfer and reduced overall diameter at the chosen ampacity, [18], [19].

Selecting copper conductors for the cable plant considers higher initial capital expenditure while also providing a lifetime of the conductor power efficiency gains when compared to aluminum conductors. The proposed DC park considers a 1-mile distribution length from the substation. This length is relatively short when considering existing utility distribution systems where one distribution feeder can provide service for dozens of miles. As distance increases efficiency savings become more crucial, and copper conductors are recommended.

b) DC power station design selection

Three different versions of DC station designs have been researched for MVDC and implemented at the HVDC scale, [7]. The three versions (Figure 3) are:

- Asymmetric monopolar
- Symmetric monopolar
- Bipolar

Each station design is correlated to the line design selected. As part of our 2-conductors with full insulation design, our chosen station design is of a symmetric monopolar design. As shown in Figure 2, the neutral point for a symmetric monopolar is placed symmetrically between both lines. Therefore, the rated voltage of the system will be halved with respect to neutral. The voltage between the lines will be considered the nominal MVDC voltage.

Furthermore, the symmetrical monopolar design with the use of modern DC-DC converters, such as dual active bridge in [20], allows future considerations to be given to implement vehicle-to-grid bidirectional power flow operation, [20], and leveraged to assist in maintaining a more stable power system, [21], [22].

c) Distribution planning and operation design

The operation of our proposed MVDC power system does not differ from the commonly constructed traditional AC power system. AC power systems are commonly planned as a mesh system but operated radially at the distribution level. The different planning and operation design are shown in Figure 4. This allows for a less complex implementation at the utility-scale, [16]. Each feeder circuit serves a specific area where carefully placed interconnection points allow for redundancy when maintenance is required, or emergency rerouting of power is required in outages. Additionally, maintaining a similar planning and operation design allows power utilities to approach MVDC easily.

For the hypothetical model being proposed in this paper, only a single circuit will be analyzed. Further research will be required when considering mesh connections and planning interconnections between various MVDC feeder circuits.

d) Voltage level

Since MVDC is still in its infancy with respect to deployment within the power system by power utilities, no official or commonplace DC voltage levels have been standardized, [6]. IEEE 1709 standard guides MVDC with respect to DC power systems on ships, [23]. We use this as a guideline when selecting a voltage level for our system.

Various parameters must be considered when selecting a voltage level. First and foremost, the voltage level has to be sufficient to support our required power load of 9.6MW. Further, voltage loss has to be within a specific range, maintenance ease for workers has to be considered, power safety, and power electronic equipment capabilities have to be able to support the voltage level.

Commonly used feeder conductors for traditional AC distribution power systems range between 500-750 kcmil. Table 2 displays the maximum power capacity for various distribution levels for a 500kcmil conductor at 400 amperes, [23], [24]. The 500 kcmil copper conductor ampacity, as specified by Southwire manufacturer, is 455A, [19], allowing for future overhead or further power capacity. Resistive line loss and AC/DC conversion efficiency loss will be considered when analyzing a theoretical performance for MVDC distribution.

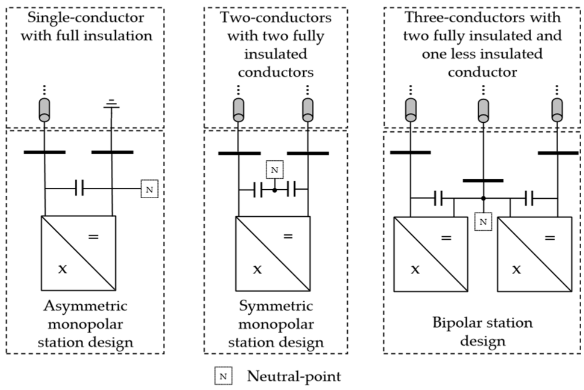

Fig. 3: Station and line concepts of DC grids, [16]

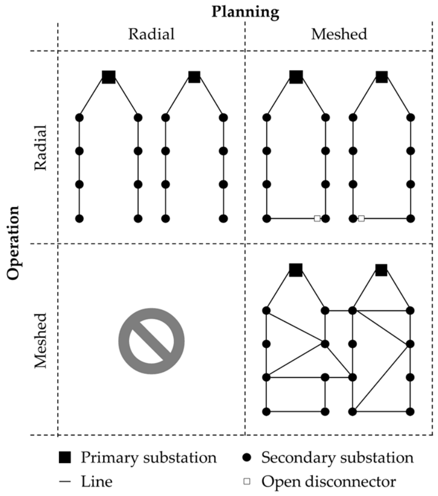

Fig. 4: Power line configurations, [16]

Table 2. Medium voltage level feeder capacity, [23], [24].

Type	Voltage Level	Nominal MVDC Class	Distribution Type	Max Power (MW)
AC	4.8 kV	-	3-phase Delta	3.32 MW
	13.8 kV	-	3-phase Delta	9.56 MW
	22.9 kV	-	3-phase Delta	15.86 MW
	34.5 kV	-	3-phase Delta	23.90 MW
DC	±3 kV	6kV	Symmetric Monopolar	2.4 MW
	±6 kV	12kV	Symmetric Monopolar	4.8 MW
	±12 kV	24kV	Symmetric Monopolar	9.6 MW
	±15 kV	30kV	Symmetric Monopolar	12 MW
	±20 kV	40 kV	Symmetric Monopolar	16 MW

Table 3. EV charging park electrical specification

Parameter	Value
EV Charging Park	
Charging Level	Level 3
Charging Level Output	240 kW
Charging Station Quantity	40
Max Park Power Load	9.6 MW
MVDC	
Line Design	Two-Conductor Insulated
Station Design	Symmetric Monopolar
Planning/Operation Design	Mesh Planned / Radial Operated
Voltage Level	±20 kV
Conductor Sizing	500 kcmil
Conductor Max Ampacity	465 Amps
Max Feeder Capacity	≈16 MW

Table 4. Electrical cable specifications and electrical data, [19]

Characteristic	Value
Conductor Size	500 Kcmil
Approx O.D.	1.819 inch
Approx Weight	3.64 lb/ft
DC Resistance @ 25°C	0.0216 Ω/1000ft
AC Resistance @ 90°C	0.028 Ω/1000ft
Capacitive Reactance @60Hz	0.027 MΩ/1000ft
Inductive Reactance @60Hz	0.040 Ω/1000ft
Allowable Ampacity @ 90°C	455
Dielectric Loss	153.971 W/1000ft

2.5 EV Charging Park Parameters

As shown in Table 2, the most commonly used voltage levels of distribution cannot accommodate the required power load for our proposed EV charging park. The minimum nominal voltage class capable of supporting the power demand is 24kV nominal DC. At 24-kV DC there is no additional headroom for expansion. At 40kV MVDC, the selected voltage can support our load and accommodate future growth for the system. Therefore, our charging park specification is chosen as shown in Table 3. Electrical cable specifications and electrical data are provided in Table 4.

3 EV Charging Park Performance and Efficiency Analysis

Our model considers a maximum load scenario for the charging park, as well as a one-mile cable feed from its respective substation. At the substation, the generated power will be converted to the chosen ±20 kV MVDC (Nominal 40kV).

Utilizing and selecting a 25kV rated copper EPR cable from Southwire, we acquire electrical data from the cable. Its electrical specifications are shown in Table 4.

$$V_L = IR \quad (1)$$

Equation (1) is the standard Ohm's law equation. Utilizing Ohm's law allows us to calculate the voltage loss in the MVDC line at the one-mile distance. DC resistance is utilized, and any reactance is ignored.

$$P = VI \rightarrow I = \frac{P}{V} = \frac{9{,}600\ kW}{40\ kV} = 240A \qquad (2)$$

$$V_L = IR = 240A * 0.114\ \frac{\Omega}{mi} = 27.37\ \text{volts} \qquad (3)$$

$$\Delta V = \frac{\pm 20\ kV - 27.37v}{\pm 20\ kV} = 99.862\% \qquad (4)$$

The amperage through the circuit at the given power load is calculated using equations (2), (3), and (4). We can calculate the given voltage loss at 27.37 volts after a one-mile length. The complete round-trip path for the MVDC circuit is two miles. Given this, the actual voltage loss to provide power to the EV chargers is twice the voltage loss of our calculated one-mile calculation at 54.74 volts. Voltage loss as distance increases is linear as shown in Figure 5. The total percentage drop for voltage is 0.272% and within the margins of a stable power system at typically less than 5%.

$$P_L = VI = \frac{V^2}{R} = I^2R = 240A^2 * 0.114\Omega = 6.55kW \qquad (5)$$

The resistive power loss for providing power to 40 EV charging stations at a 1-mile distance is 6.55kW. The round-trip power loss is 13.1kW and the efficiency of power transfer is 99.86%.

Further power loss calculations using equation (3) are completed as shown in Figure 5. The figure displays the linear relationship between the resistive power loss as cable length is increased. This analysis is useful in the planning of MVDC circuit origination.

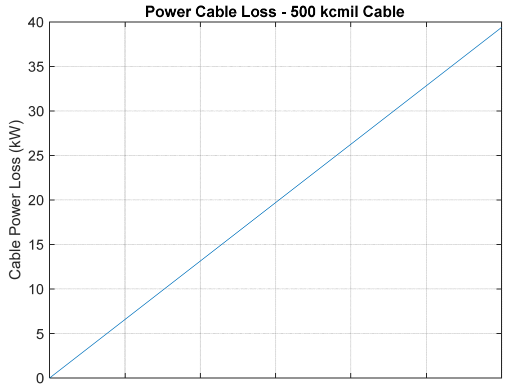

Fig. 5: Power loss is linear as the cable distance to the EV charging station is extended

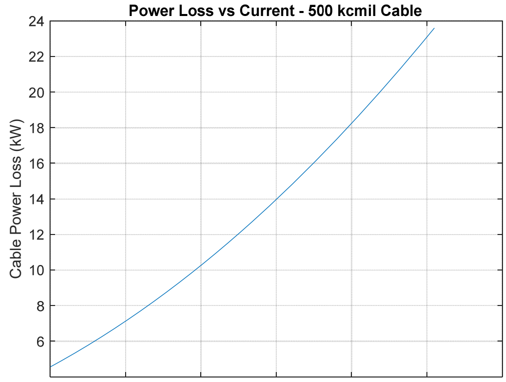

Fig. 6: Exponential power loss as the cable is loaded to its maximum allowed ampacity

Table 5. Efficiency of energy conversion equipment, [17].

Voltage rating (kV)	Energy conversions equipment efficiency (%)
±320	98.4
±150	98
±30	97.6
±10	97.2

Given the minimal power loss shown by the MVDC circuit, EV chargers can be provided at greater distances than one mile and up to 18 miles before a 5% voltage loss is reached.

Additional calculations are completed with equation (5) to gain further insight into power loss as cable power loading increases. Figure 6 displays the power loss for the 1-mile cable scenario. As power loading increases to its maximum allowed ampacity of 465 amperes, a substantial exponential power loss increase occurs in contrast to findings in Figure 5 where power loss is linear in nature.

As shown in Figure 6, a doubling in the current quadruples the cable power loss in our test scenario. Both Figure 5 and Figure 6 provide important information when planning MVDC distribution cable plants to support EV charging. It is important to consider the power loss caused by additional power load and cable distance and its implications for future load growth against the cost of installing a secondary MVDC cable to service additional loads.

Additional power losses shall be considered such as the dielectric loss, AC/DC conversion at the substation, and DC/DC conversion as shown in Table 5, [17]. Research on DC conversion has been conducted, [16] and shown in Table 5. It is important to consider advances in DC conversion at the utility-scale and improved efficiency to be gained for MVDC. Table 5 displays high efficiency in the upper 90% range for DC conversion using newer technologies, [17].

4 Comparison of MVDC and MVAC Power Distribution Systems

In this section, we compare our proposed MVDC design with a traditional MVAC system using MATLAB Simulink. Figure 7 shows a visual representation of both a traditional MVAC and required transformer and AC/DC converters at the local equipment level. The MVDC scenario would provide AC/DC conversion at the substation level and distribute at MVDC to equipment.

Our 40-kV MVDC model and the power line loss and efficiency will be compared to a 22.9kV MVAC power system like the study in [25].

4.1 MVDC Simulation and Analysis

Simulation setting

MATLAB Simulink is utilized to validate the design specification and parameters for our MVDC distribution, as shown in Figure 8.

The first section of our simulation for validating our design is to create a Thevenin power source matching our parameters of nominal 40kV DC (±20kV) in a symmetrical monopolar design. The voltage and current provided by the source are shown in Figure 9.

The second section is our DC distribution line as chosen from our design specification and cable parameters. Electrical specifications of our 500kcmil underground copper conductor are incorporated into the simulation.

The third section is our equivalent power load from our DC charging park. A total of 40 Level 3 charging stations has an equivalent load of 9.6MW and are modeled as a resistive load in the simulation.

MVDC power loss quantification: Power at the source and the DC EV park is calculated in the simulation by utilizing Equation (2) at each end. The power loss is then calculated by taking the difference between them (i.e., the difference between input and output), as shown in our simulation in Figure 8.

Results

Figure 9 shows the voltage source displaying ±20kV and 240 amperes for current. These are expected values proving that our MVDC network for simulation works accurately.

The simulated power loss of 13.1kW of the MVDC distribution matches power loss calculations completed in Section 3 of the paper and verified by values shown in Figure 10.

4.2 MVAC Simulation and Analysis

Simulation setting

An equivalent MVAC system in Figure 11 is simulated to provide a power efficiency comparison to our MVDC model. A 22.9kV 3-phase delta system is selected as our equivalent MVAC system. From Table 2, the selected MVAC cable feeder power capacity is 15.86MW. This is comparable to our Nominal 40kV MVDC system at 16MW.

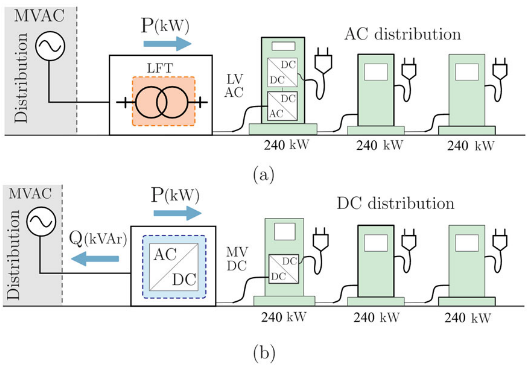

Fig. 7 (a): Existing fast charging infrastructure utilizing AC distribution grid. (b) proposed infrastructure utilizing MVDC to EV chargers, [11].

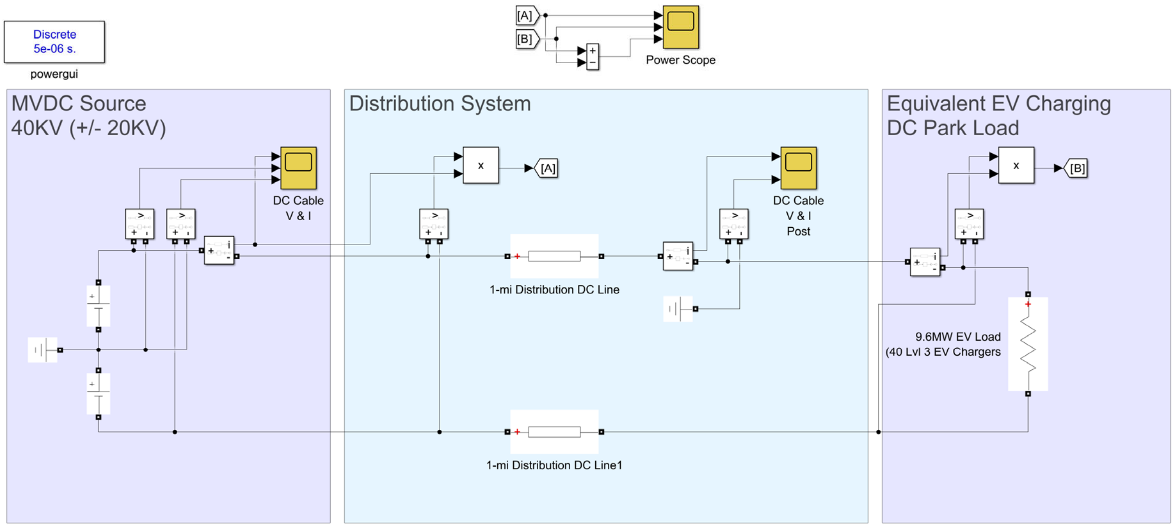

Fig. 8: MVDC Simulink simulation is composed of 3 separate sections: MVDC source, bipolar distribution line, and equivalent DC EV Park load

Fig. 9: Voltage source displays ±20kV and expected 240 amperes for current

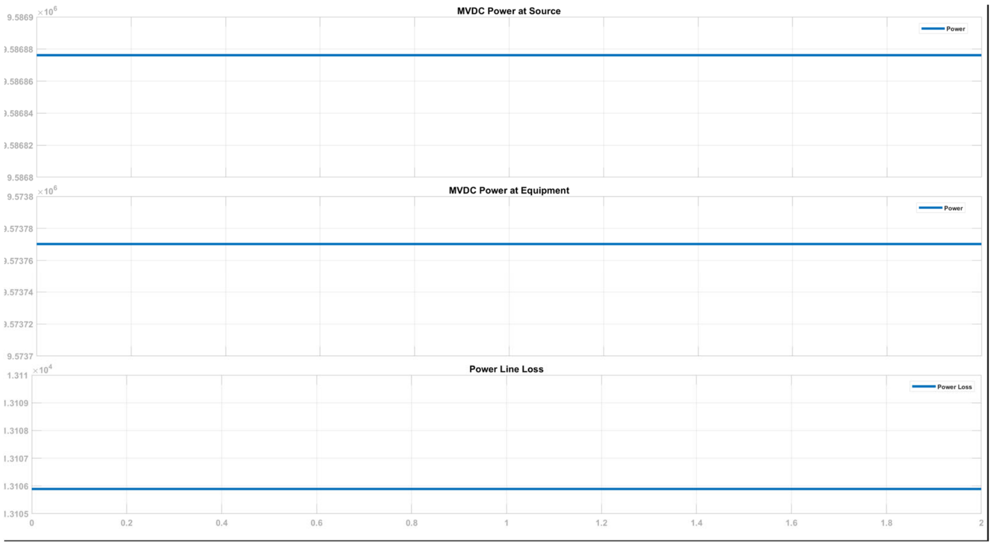

Fig. 10: The first and second plots display power before and after the modeled distribution line, respectively. Third row graph is our line power loss

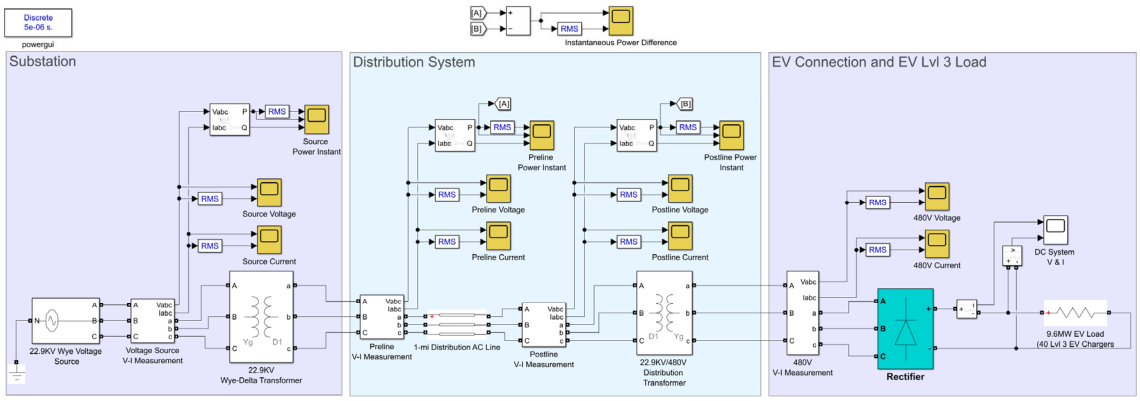

Fig. 11: The MVAC Simulink simulation consists of three sections similar to the MVDC simulation along with various scopes for analysis. The three sections are a MVAC Thevenin power source, 3-phase distribution power line, and an equivalent EV DC Park power load

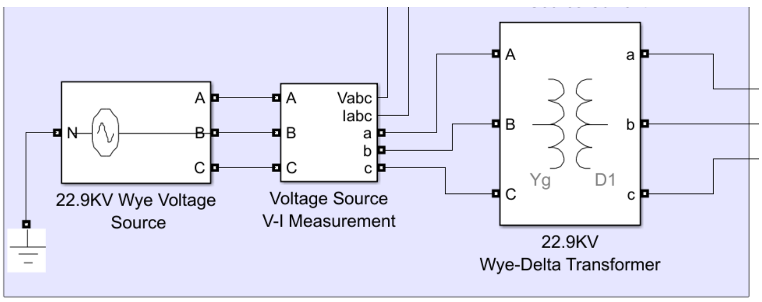

Fig. 12: 22.9kV MVAC voltage source Simulink components

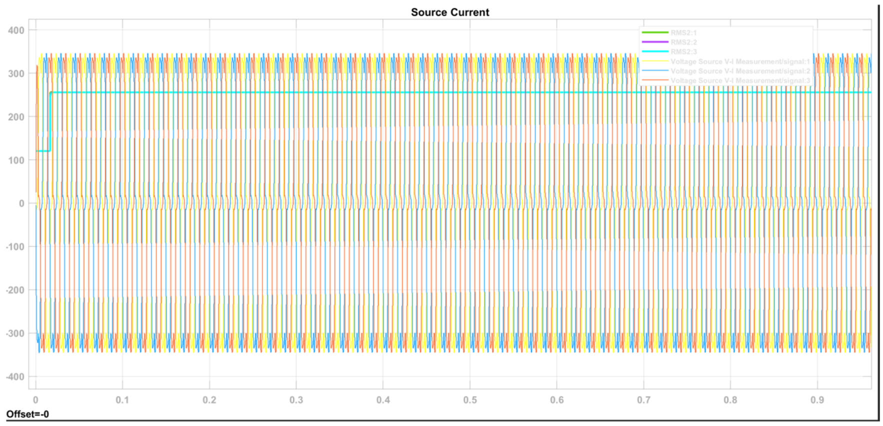

Fig. 13: 22.9kV source current. Plot displays individual balanced phase currents and respective RMS value

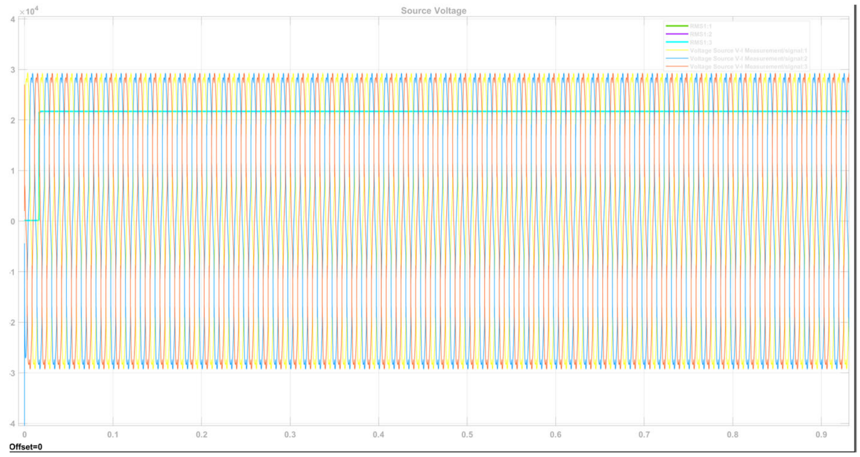

Fig. 14: 22.9kV source voltage. Plot displays individual balanced phase voltages and respective RMS value. Phase-phase voltage close to 22.9kV shows that our model is functioning normally

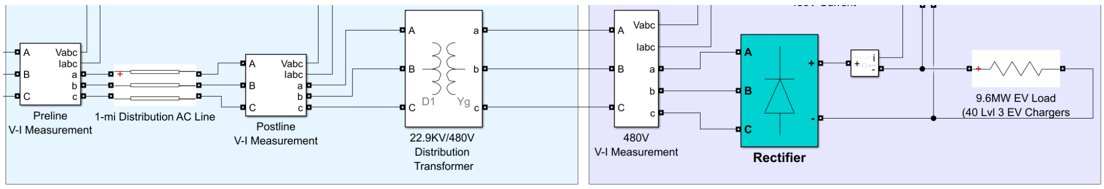

Fig. 15: Three-phase delta power line, interface to DC power load and power load in Simulink

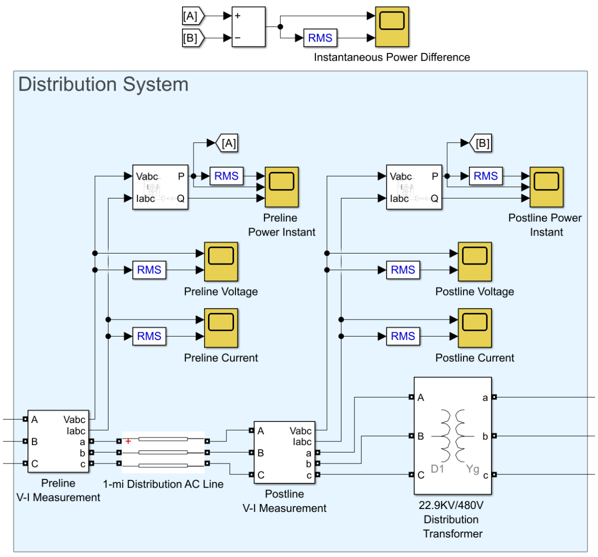

Fig. 16: Measurements blocks required to calculate power loss. Three-phase voltage and current measurement, instantaneous power, RMS, difference blocks are shown at both power line ends

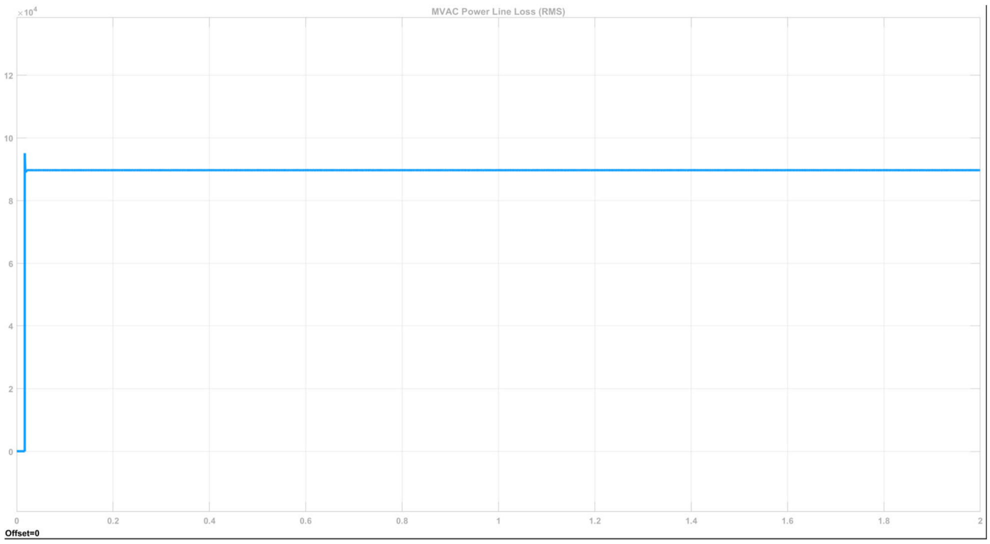

Fig. 17: MVAC power line loss

The Thevenin power source shown in Figure 12 is a combination of a three-phase 22.9kV voltage source in series with a transformer to convert the Wye voltage source to Delta configuration, which matches our Delta distribution power line.

Interfacing a 9.6-MW DC load as an equivalent to 40 Level 3 EV chargers requires additional simulation components when compared to our MVDC simulation. Voltage step-down transformation from medium voltage to low voltage is required. This is accomplished by transforming the voltage down to 3-phase wye 480VAC. The transformation is a real-world example as done by existing utilities and required by current Level-3 EV chargers. A simple rectifier is utilized for the AC/DC conversion and is included between the 3-phase low-voltage source and the equivalent power load by our charging park, as shown in Figure 15.

MVAC power loss quantification: The 3-phase 22.9-kV distribution power line parameters are based on the same selected 500kcmil underground copper conductors from our specifications in Section 3. Power values from our simulation are received from specific three-phase instantaneous power measurement blocks available in Simulink (as shown in Figure 16) before and after the power line. To capture the power line loss value, we take a difference in the RMS power value.

Results
Figure 13 displays source phase currents and respective RMS value. Figure 14 displays source phase voltages and respective RMS value where line voltage is close to 22.9kV. Both figures show that our MVAC model is functioning normally.

Figure 17 shows a power loss of 89.74kW for the MVAC distribution power line, more than 6 times the power loss of the proposed MVDC distribution system. The increased resistance from skin effect, capacitive and inductive reactance, and lower voltage when compared to our MVDC model are shown to cause a substantial power loss.

Key findings from MVDC and MVAC comparison
Both MVDC and MVAC function appropriately where there is no abnormality in terms of voltage and current.

The MVDC distribution system is superior as compared with the MVAC system in terms of power loss. Its loss is only 13.1kW, which is 6 times lower than that of the equivalent MVAC system (89.74kW).

5 Conclusion

In this study, we proposed an MVDC distribution system model for powering an EV park consisting of 40 EV charging stations. Calculation and simulation are used to evaluate the model and compare it with an equivalent MVAC system. The study outcomes are summarized as follows:

a) Implementing an MVDC distribution system is an efficient and cost-saving approach to meet the increasing power demand by electric vehicles. Our proposed 40-kV MVDC system power loss (13.1kW) is six times lower than that of the equivalent MVAC system (89.74kW).
b) MVDC systems have further advantages as they simplify the construction of EV charging parks by not requiring AC step-down transformers and AC/DC converters at the equipment end. This potentially lowers the cost for power utilities supplying such EV charging parks.

In terms of future study, additional analysis is required for power efficiency, cost, and power system protection where MVDC is considered. Cost and efficiency of AC/DC converters at the substation level should be considered when cost-benefit analysis is conducted to implement MVDC or upgrade of existing MVAC infrastructure. Increasing research is currently being done in AC/DC conversion for MVDC as well as transferring applicable breakthroughs in HVDC which have applicability at the lower voltage levels.

Overall, the benefits of our study include some insightful understanding of MVDC network capability for EV charging and power distribution in general, and key MVDC network features and specifications. These findings help enable the implementation of MVDC networks for expanding EV charging infrastructure, which expedites the adoption of EVs for reducing carbon emissions in the transportation sector.

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- Jesus Quintero-Arredondo: Identification of research issues, system data acquisition, design and implementation, simulation, writing an original draft, and revising.
- Ha Thu Le: Refining research issues and scope, methodology, technical advising, refining simulation scenarios, review of results, formatting and editing the final draft, revising the reviewed paper to meet review requirements.

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