

Date of publication xxxx 00, 0000, date of current version xxxx 00, 0000.

Digital Object Identifier 10.1109/ACCESS.2017.Doi Number

# Short Circuit Effects on HV Feeders of Optimally Located Electric Vehicle Fast Charging Stations

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**ABSTRACT** Today, there is a need to expand the network of fast charging stations to encourage the use of Electric Vehicles (EV). Fast charging stations are considered mobile loads, unlike conventional electric loads. This situation brings problems in electrical distribution systems. In addition, there will be problems caused by short circuits that occur for any reason in the networks to which EVs are connected. Considering the concerns about what these problems may be and how they may be reflected in the network, it is inevitable to examine the optimal positioning of the EV on the distribution network and its possible short-circuit effects. In this study, in the Istanbul/Vanikoy pilot region, HV/LV distribution feeders and substations in the region were selected using the distribution company infrastructure. An algorithm was created using multiple location data to determine the optimal locations of one-phase and three-phase Electric Vehicle Fast Charging Stations (EVFCS) on the distribution network. Simulation of short circuit types of the system was carried out using real-time technical data such as location data of distribution transformers, power data, load density, number and length of feeders, system protection, and control element data, based on optimal locations. The effects of short circuit types on the electricity distribution network, depending on the load density of residences, other structures, and optimally located urban EVFCS, connected to the distribution transformer feeders, were analyzed.

**INDEX TERMS** Distribution network, Optimal positioning, EV, EVFCS, Short circuit.

## I. INTRODUCTION

Due to global warming and the exhaustibility of fossil energy resources, many sectors are producing more environmentally friendly alternative solutions. From this point of view, the importance of EVs has increased and automotive manufacturers have started to shift their investments in this direction [1]. Regarding EV sales, the International Energy Agency (IEA) estimates that the global stock of EVs can reach 140 million by 2030 with stated policy scenarios [2]. EVs, which have longer charging times and shorter ranges than conventional vehicles, will reduce these negative situations with the establishment of a wide charging station network. However, charging stations that will be connected to the electricity grid at many points will accelerate the increase in electricity demand, which is increasing day by day in parallel with technology, especially regionally. However, to mitigate these impacts, load demand curves of

electricity grid systems should be extracted, and EV deployment and expected future demand growth and capacity should be estimated with technical infrastructure [3]. EVs can be charged in homes or garages, workplaces, charging stations or parking lots, depending on where they are used. From this point of view, it is foreseen that EVs will mostly be connected to the distribution grid [4]. With the addition of new generation electrical loads such as EV charging stations to the electricity grid, there are many different complexities in the operation of the power system today compared to the past [5]. Due to their high energy requirements, EVs are expected to have negative impacts on the distribution system. Especially in certain regions, if many EVs demand energy in the same period, the expected negative impact is expected to be much greater and measures need to be taken accordingly. Electricity distribution companies are obliged to provide quality electricity to their

customers. In this context, energy quality problems that may arise due to sudden and point loads may victimize both energy distribution operators and end users. In order to examine this situation and find solutions, charging infrastructure planning and operation should be done very well [6-8]. In EVFCS distribution network planning, short circuit calculation based on the electrical power of the network is vital to ensure the safe and healthy operation of electrical systems. Short circuits in electrical systems can have serious consequences and cause damage to both equipment and people. Short circuit calculation is an effective tool used to reduce these risks and implement appropriate safety measures. Short circuit calculations play an important role in the design phase of electrical systems. Calculations help to determine the maximum short circuit currents and analyze the distribution of these currents [9]. This information is used to make design decisions such as correct sizing, protection settings and selection of protective devices (switches, fuses, etc.) and relay coordination. Short circuit calculations help to determine the necessary protective measures for the safe and efficient operation of the system. When studies related to this topic are examined in the literature;

The transient fault currents on the AC side of the distribution system caused by short circuit faults occurring on the DC side of the EVs were investigated [10]. The effects of instruments such as renewable energy sources, EEs and heat pumps, which are increasingly entering the distribution system in low voltage installations, on the grid during a short circuit are observed [11]. They created simulation models to study the effects of voltage dips on EV charging and then analyzed the effects of voltage dips of different magnitudes and different types on chargers operating under different conditions. The simulation results showed that the effects of voltage dips on chargers are not only related to the strength and types of voltage dips but also to the operating condition of the chargers [12]. They examined the current state of the EV market, standards, charging infrastructure and the impacts of EV charging on the grid [13]. They examined the challenges and opportunities of Electric Vehicle Charging Stations (EVCSs). In the study, they emphasized that the importance of EV charging station location should not be ignored. They investigated the basic terminologies of charging stations such as charging station types and levels. They also analyzed various technologies along with lithium-ion battery charging strategies and battery management systems [14]. A constant voltage charging and discharging control system for EVs is proposed and fault models are simulated in the distribution network of non-fast DC charging stations. The obtained current and voltage numerical results provide references for the investigation of relay protection principles and performance evaluation of the network [15]. It focuses on the analysis of short circuit fault characteristics on the DC side in ungrounded fast charging stations. It does not analyze fault characteristics and does not

propose protection schemes for the AC side, whereas it proposes protection methods and configuration in the DC mode of operation [16]. After connecting the DC charging station to the distribution network, it analyzes asymmetric faults in the network. It analyzes the power affecting the charging and discharging station on the fault characteristics of the distribution network in the case of discharge, but does not take into account the protection plan for the fault situation in the charging state [17]. It proposes an energy management system that ensures the active operation of all units that will provide the service to meet the energy needs of the increasing EVCSs. Thanks to this system, it is clear how and by whom to intervene in case of a short circuit at any point [18]. It means that the grid voltage is affected due to any low-capacity short circuit that may occur during EV charging. Especially asymmetric faults that occur during single-phase EV charging have a greater impact on the three-phase grid [19]. It presents a new method for detecting a fault that may occur in charging stations connected to the distribution network. This method proposes a wavelet transform-based scheme and is shown to detect the fault efficiently [20]. A fault current limiting partial power converters (PPC) topology is proposed to solve the DC short circuit fault problem that occurs in the DC-DC converters in EVFCSs as their usage increases. The faulted circuit topology and fault current limiting feature are verified by numerical simulations [21]. All of the above studies are simulation studies modeled over unreal networks and data. In addition, in these studies, the effects of normal electric vehicle charging stations on the LV distribution system during a short circuit were modeled separately or partially by simple modeling over only a few feeders and busbars.

The original contributions of this study are as follows:

- ✓ The study modeled the electricity distribution network of a pilot region in Istanbul based on real dynamic load data,
- ✓ Modeling of substations located at certain distances on the HV distribution system side in the region,
- ✓ The locations of charging stations are found optimally by creating an algorithm based on the nearest transformer, shopping mall, main road, petrol station, parking lot, transportation station, official institution, normal charging station,
- ✓ Connected charging stations will be a new generation of fast charging stations and use one-phase and three-phase fast electric vehicle charging stations,
- ✓ Modeling of both system elements in the grid and new generation electric vehicles based on real data,
- ✓ Modeling of the distribution system with multiple feeders and EVCS,
- ✓ Application of all types of symmetric and asymmetric short circuit analysis on the modeled network,
- ✓ The data obtained will serve as a feasibility report for future charging station installations in the region.

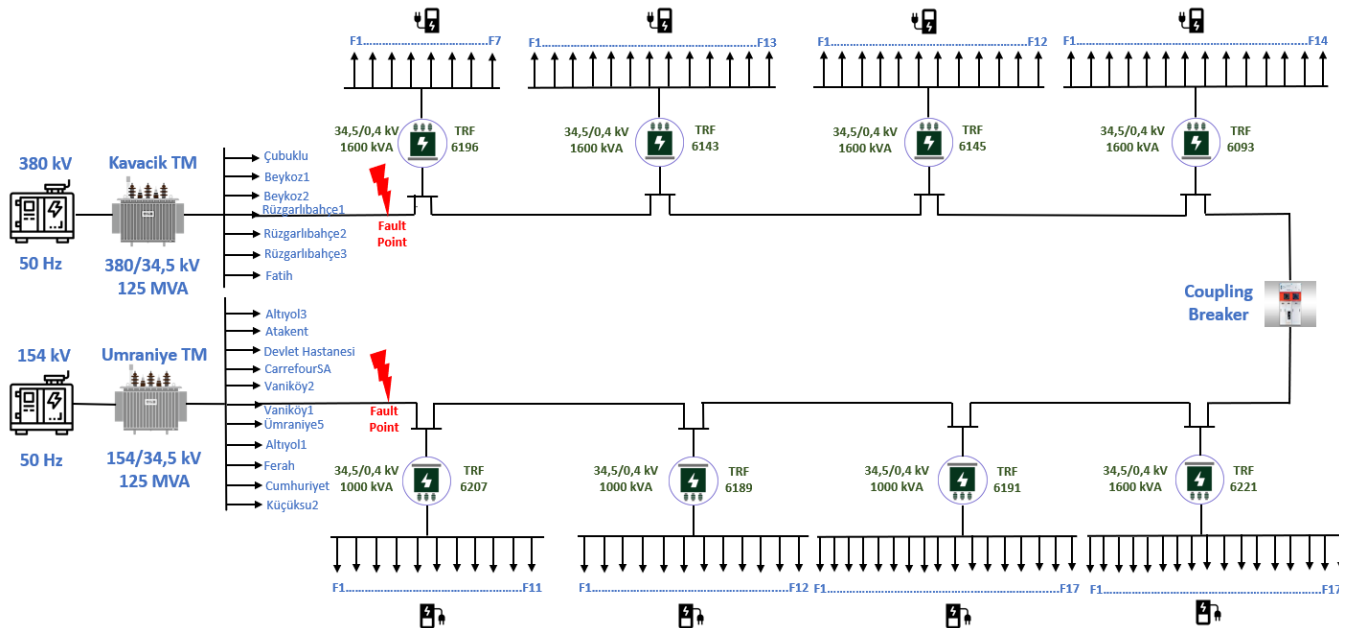


FIGURE 1. Single Line Diagram of the Selected Distribution Network.



FIGURE 2. Location of the selected Region on the Map.

## II. MATERIALS AND METHODS

Data such as transformer nameplate values, number of transformer sub-feeders, transformer locations, charging station locations, breaker information, line lengths, conductor cross-sections and peak hour loads were obtained from AYEDAS distribution company.

### A. NETWORK DATA

In this study, the sub-feeders of 380/34.5 kV and 125 MVA transformer feeding the distribution network of Umraniye district of Istanbul, located in AYEDAŞ responsibility area, were selected. Of these, 4 HV/LV transformers of 1600 kVA and 3 HV/LV transformer feeders of 1000 kVA and 1 HV/LV transformer of 1600 kVA from the sub-feeders of 154/34.5 kV and 125 MVA transformer feeding Beykoz district were used in a semi-ring network via a coupling breaker. In addition, the single-line diagram of the modeling of the one- and three-phase EVFCS to be connected to the sub-feeders of these transformers at the moment of the short circuit is shown in

Figure 1 and the region map-satellite location is shown in Figure 2 [22].

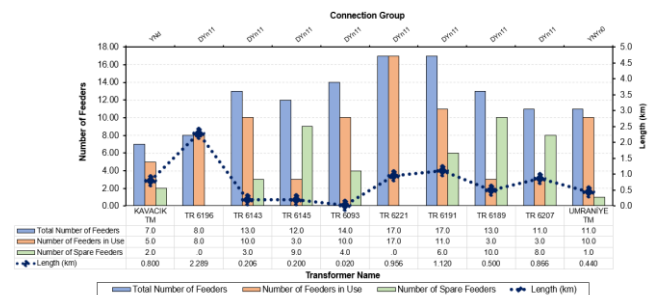


FIGURE 3. Feeder Status of Transformers.

Information about the total number of feeders, the number of used and spare feeders and the connection types of the transformers used in the distribution network before the charging stations were commissioned are given in the graph in Figure 3, whereas the power, peak transformer power, voltage and occupancy rate of the transformers are given in the graph in Figure 4 [22]

The locations of the transformers on the map are shown in Figure 5. Since the scope of the load model in this study is three-phase systems, the modeling is simplified by eliminating complex situations by using three-phase parallel RLC load. The cross-section, name, length and voltage level of the lines in the distribution network are given in the graph in Figure 6. The numbering of the lines was determined according to the modeling sequence [22].

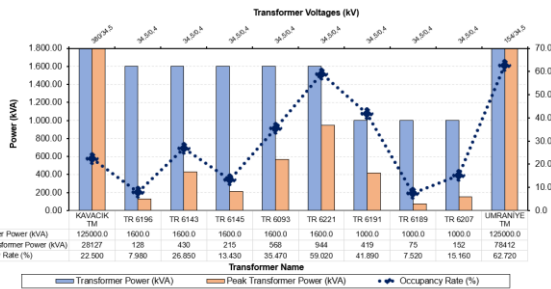


FIGURE 4. Electrical Characteristics of Transformers

### B. CHARGING STATION DATA AND LOCALIZATION

The lack of a sufficient number of charging stations is one of the most serious factors causing EVs to fail to expand sufficiently. Establishing a well-organized network of charging stations in cities is important for the traffic network and drivers. Multi-Criteria Decision Making (MCDM) systems are effectively used in the optimal location of charging stations. It is aimed to use GIS-based MCDM methods to select the optimum location for new charging stations. For this purpose, eight data collections were evaluated to determine the optimum locations. These criteria; proximity to main roads, proximity to shopping malls, proximity to official institutions, proximity to petrol stations, proximity to transportation stations, proximity to normal charging stations, proximity to substations and proximity to parking lots can be listed as latitude and longitude coordinates as in Table I [22].

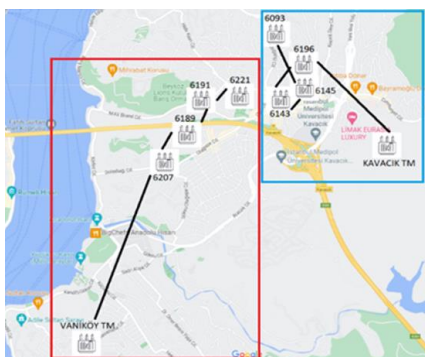


FIGURE 5. Location of transformers on the map

Charging station placement criteria and locations were calculated using equations (1)-(5) [23-25]. For the new charging station to be installed, the distance to the transformers in the selected region was determined as 230

meters from the distribution network using a minimum 95mm<sup>2</sup> NYA cable and not exceeding the permissible voltage drop limits according to the load density. Based on this value and the coordinates of other criteria, the haversine function was used in Python software language to determine the optimum location of the new charging station. For the location calculations, the optimal latitude and longitude coordinates of the EVFCS were calculated using the charging station placement algorithm flowchart shown in Figure 7.

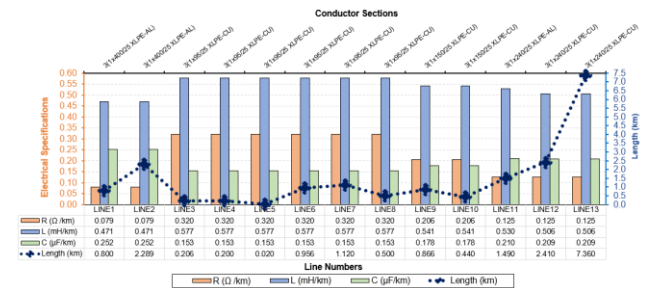


FIGURE 6. Line block parameter values of the modeled network

The equations (1)-(5) used in the algorithm are explained as follows.

In Equation (1), Let the central angle  $\theta$  between any two points on a sphere be:

$$\theta = \frac{d}{r} \quad (1)$$

Here:

- $d$  is the distance between the two points along a great circle of the sphere
- $r$  is the radius of the sphere

In Equation (2) is allows the haversine of  $\theta$  (that is,  $\text{hav}(\theta)$ ) to be computed directly from the latitude (represented by  $p$ ) and longitude (represented by  $m$ ) of the two points:

$$\text{hav}(\theta) = \text{hav}(p_2 - p_1) + \cos p_1 \cdot \cos p_2 \cdot \text{hav}(m_2 - m_1) \quad (2)$$

Here;

- $p_1, p_2$  are the latitude of point 1 and latitude of point 2,
- $m_1, m_2$  are the longitude of point1 and longitude of point2.

Finally, the haversine function  $\text{hav}(\theta)$ , applied above to both the central angle  $\theta$  and the differences in latitude and longitude, is

$$\text{hav}(\theta) = \sin^2\left(\frac{\theta}{2}\right) = \frac{1 - \cos \theta}{2} \quad (3)$$

The haversine function computes half a versine of the angle  $\theta$ . To solve for the distance  $d$ , apply the archaversine (inverse haversine) to  $h = \text{hav}(\theta)$  or use the arcsine (inverse sine) function:

$$d = r \cdot \text{archav}(h) = 2r \cdot \arcsin(\sqrt{h}) \quad (4)$$

or more clearly in equation (5)

$$d = 2r \cdot \arcsin\left(\sqrt{\sin^2\left(\frac{p_2 - p_1}{2}\right) + \cos p_1 \cdot \cos p_2 \cdot \sin^2\left(\frac{m_2 - m_1}{2}\right)}\right) \quad (5)$$

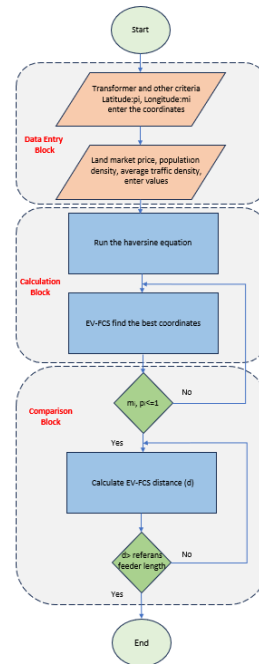


FIGURE 7. Charging stations placement algorithm diagram

TABLE I  
CHARGING STATION LAYOUT CRITERIA AND COORDINATES

EVFCS No	Phase Type	Connected Transformer No	Nearest Transformer (p, m)	Nearest Shopping Mall (p, m)	Nearest Main Road (p, m)	Nearest Petrol Station (p, m)	Nearest Parking Lot (p, m)	Nearest Transportation Station (p, m)	Nearest Official Institutions (p, m)	Nearest Normal EVCS (p, m)
1	1	6196	41.096871, 29.091761	41.100107, 29.092649	41.087264, 29.093720	41.094707, 29.091190	41.094448, 29.091959	41.095950, 29.091920	41.097126, 29.090889	41.095451, 29.086329
2	3	6143	41.096871, 29.091761	41.100107, 29.092649	41.087264, 29.093720	41.094707, 29.091190	41.094448, 29.091959	41.095950, 29.091920	41.097126, 29.090889	41.095451, 29.086329
3	3	6143	41.096871, 29.091761	41.100107, 29.092649	41.087264, 29.093720	41.094707, 29.091190	41.094448, 29.091959	41.095950, 29.091920	41.097126, 29.090889	41.095451, 29.086329
4	1	6143	41.095381, 29.091441	41.096110, 29.091826	41.089722, 29.092866	41.094707, 29.091190	41.094465, 29.092016	41.094751, 29.089318	41.094964, 29.091592	41.095451, 29.086329
5	1	6145	41.095382, 29.091456	41.095495, 29.088766	41.090328, 29.093477	41.094707, 29.091190	41.094465, 29.092016	41.095833, 29.091874	41.094900, 29.091787	41.095451, 29.086336
6	3	6093	41.100205, 29.088785	41.100094, 29.088810	41.090261, 29.093148	41.096613, 29.087185	41.094448, 29.091959	41.099265, 29.088321	41.099791, 29.090730	41.095451, 29.086329
7	3	6093	41.100205, 29.088785	41.100094, 29.088810	41.090261, 29.093148	41.096613, 29.087185	41.094448, 29.091959	41.099265, 29.088321	41.099791, 29.090730	41.095451, 29.086329
8	1	6093	41.100205, 29.088785	41.100094, 29.088810	41.090261, 29.093148	41.096613, 29.087185	41.094448, 29.091959	41.099265, 29.088321	41.099791, 29.090730	41.095451, 29.086329
9	1	6221	41.094042, 29.083742	41.094536, 29.085907	41.089461, 29.089987	41.094707, 29.091190	41.093637, 29.089722	41.092794, 29.083343	41.092688, 29.083276	41.095451, 29.086329
10	3	6221	41.094042, 29.083742	41.094536, 29.085907	41.089461, 29.089987	41.094707, 29.091190	41.093637, 29.089722	41.092794, 29.083343	41.092688, 29.083276	41.095451, 29.086329
11	3	6221	41.094042, 29.083742	41.094536, 29.085907	41.089461, 29.089987	41.094707, 29.091190	41.093637, 29.089722	41.092794, 29.083343	41.092688, 29.083276	41.095451, 29.086329
12	1	6191	41.093653, 29.079635	41.098745, 29.075859	41.092564, 29.084925	41.094707, 29.091190	41.092827, 29.083366	41.093941, 29.079458	41.092495, 29.076059	41.095451, 29.086329
13	1	6189	41.090284, 29.077828	41.086865, 29.082522	41.092166, 29.081385	41.081239, 29.076829	41.082896, 29.068689	41.088968, 29.078119	41.090728, 29.079886	41.080235, 29.078769
14	1	6207	41.088351, 29.075812	41.084618, 29.077625	41.091764, 29.072680	41.081239, 29.076829	41.082896, 29.068689	41.087720, 29.076065	41.087882, 29.075892	41.082627, 29.066668
15	3	6207	41.088351, 29.075812	41.084618, 29.077625	41.091764, 29.072680	41.081239, 29.076829	41.082896, 29.068689	41.087720, 29.076065	41.087882, 29.075892	41.082627, 29.066668
16	3	6207	41.088351, 29.075812	41.084618, 29.077625	41.091764, 29.072680	41.081239, 29.076829	41.082896, 29.068689	41.087720, 29.076065	41.087882, 29.075892	41.082627, 29.066668

### C. FAST CHARGING STATIONS

The fast-charging systems we use in our system are used in places where energy needs are urgent, in recreational facilities and in places with heavy traffic. In general, it can also be called places where parking times are less than half an hour. Fast charging stations are highly secure as they must be manufactured with special protection elements. There are signal and control pins on both sides of the connection cables. In addition, in the case of DC fast charging, which is called mode-4 according to the IEC 61851-1 standard, it is allowed to go up to a maximum level of 600 V, 400 A. However, the costs of DC fast charging stations are much higher than other charging modes. The average power values of fast charging stations vary between 50-150 kW. Figure 8 shows the classification of EVFCS charging units into levels [26].

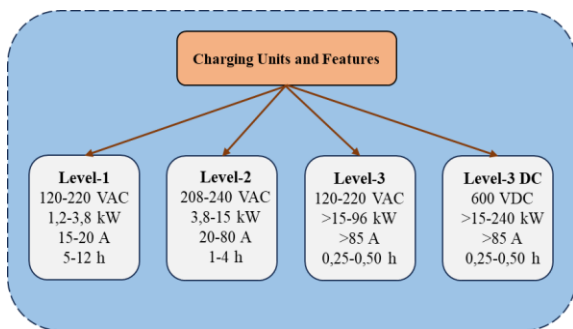


FIGURE 8. EVCS Charging units

### D. CHARGING STATION BATTERIES

The most popular battery type used in EVs is the Li-ion battery, which has higher energy density, longer lifetime and a high number of charge/discharge cycles. Li-ion batteries were chosen as the battery model for the system because they have many favorable characteristics such as the highest cell voltage per unit cell and the highest energy density per unit mass. The internal resistance is assumed to be constant during charge and discharge cycles and does not vary with the current amplitude. Also, the parameters of the model are derived from the discharge characteristics. The capacity of the battery does not vary with the amplitude of the current. The model does not represent battery self-discharge and the battery has no memory effect [27].

### E. SHORT CIRCUIT ANALYSIS

Short circuit event occurs as a result of an insulation fault, environmental effects or improper interventions that occur between phase-phase or between phase-earth in networks with a star point connected to the earth. All equipment belonging to the network up to the area where the short circuit occurs is protected from overcurrent by the protection elements within the shortest time frame. In this case, the network elements that will perform the cutting process must be selected resistant to short circuit current. Otherwise, the network elements may be

mechanically and thermally damaged and cause damage to the environment. Therefore, short circuit analysis results are important in the design and operation of the network. In electricity distribution networks, short circuits occur at a rate of 70% phase-to-ground, 15% phase-to-phase, 5% three-phase, and 10% two-phase-to-ground. It is necessary to consider short circuit analysis in many phases from energy production to consumption. In order to make these analyses, the following Figure 9 shows the connection types and the final equations of the short circuit types [28].

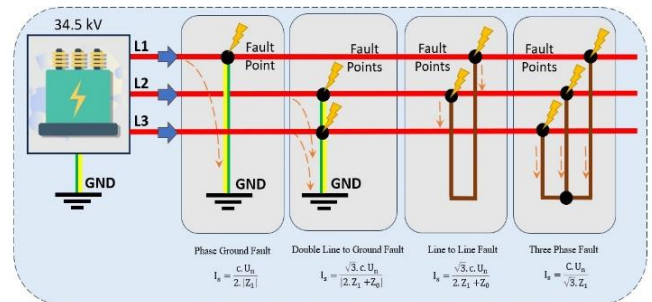


FIGURE 9. Connection diagrams of short circuit types

Here;

- C Voltage coefficient specified in IEC S.
- $I_k$  Short Circuit Current Value
- $U_n$  Voltage phasor at the desired phase
- $Z_0$  Zero component impedance phasor
- $Z_1$  Direct component impedance phasor
- $Z_2$  Reverse component impedance phasor

### F. SIMULINK MODELING

All parameters of the distribution system such as network, transmission lines, source values, transformer values, charging station values, line values, existing load data are modeled by MATLAB/Simulink program. Figure 10 shows the main schematic of the selected transmission and distribution network modeling between Kavacik-Umraniye substations. Here, short circuit current analysis will be performed depending on the amount of load and the type of fault that may occur in case of EV connection to the EVFCS. In the network modeling, the  $\pi$  (pi) equivalent circuit used in power transmission and distribution lines is selected. In the block diagram of the  $\pi$  (pi) equivalent circuit, parameters such as frequency, resistance, inductance and capacitance components and the length of the line are used. The parameter values are entered separately for each phase in the simulation study. The length of the transmission line, conductor cross-section, resistance, inductance and capacitance values per kilometer were obtained from the transmission and distribution company.

### III. FINDINGS

#### A. EVFCS LOCATIONS

In this study, for the positioning of the EVFCS on the map, the appropriate coordinates for the EVFCSs were optimally calculated using the graphical data in Table I and Figures 3-4-6 and the algorithm in Figure 7. The calculated latitude and longitude values for the EVFCS are given in Table II and shown on the map in Figure 11.

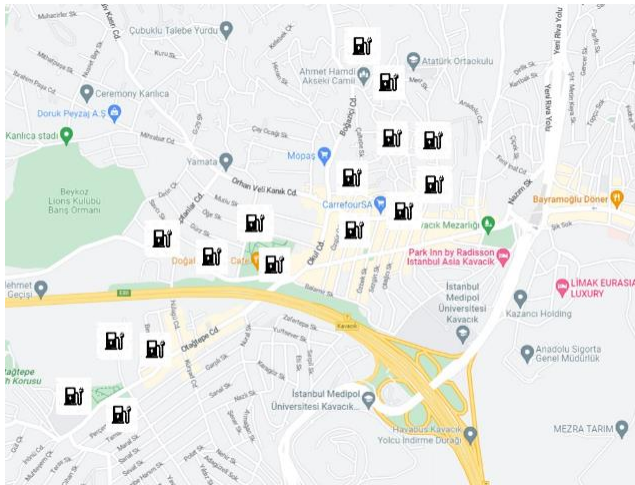


FIGURE 11. Location of Charging Stations on the map

Detailed analysis of the electrical parameter changes according to the types of short circuits that will occur in the distribution network, taking into account the location, number and power of the EVFCSs according to whether they are connected to the grid or not, are given below.

TABLE II  
OPTIMAL EVFCS LOCATION COORDINATES

EVFCS No	Phase Type	Connected Transformer No	Connected Feeder No	Location	
				p	m
1	1	6196	F7	41.097034	29.091026
2	3	6143	F1	41.097477	29.091949
3	3	6143	F2	41.097477	29.091949
4	1	6143	F13	41.094960	29.090716
5	1	6145	F12	41.097220	29.091988
6	3	6093	F1	41.099516	29.088542
7	3	6093	F4	41.099516	29.088542
8	1	6093	F14	41.101686	29.088644
9	1	6221	F2	41.094738	29.084808
10	3	6221	F16	41.093183	29.086152
11	3	6221	F17	41.093183	29.086153
12	1	6191	F17	41.093474	29.080351
13	1	6189	F12	41.090331	29.079285
14	1	6207	F1	41.089375	29.076388
15	3	6207	F2	41.087178	29.076605
16	3	6207	F11	41.087178	29.076605

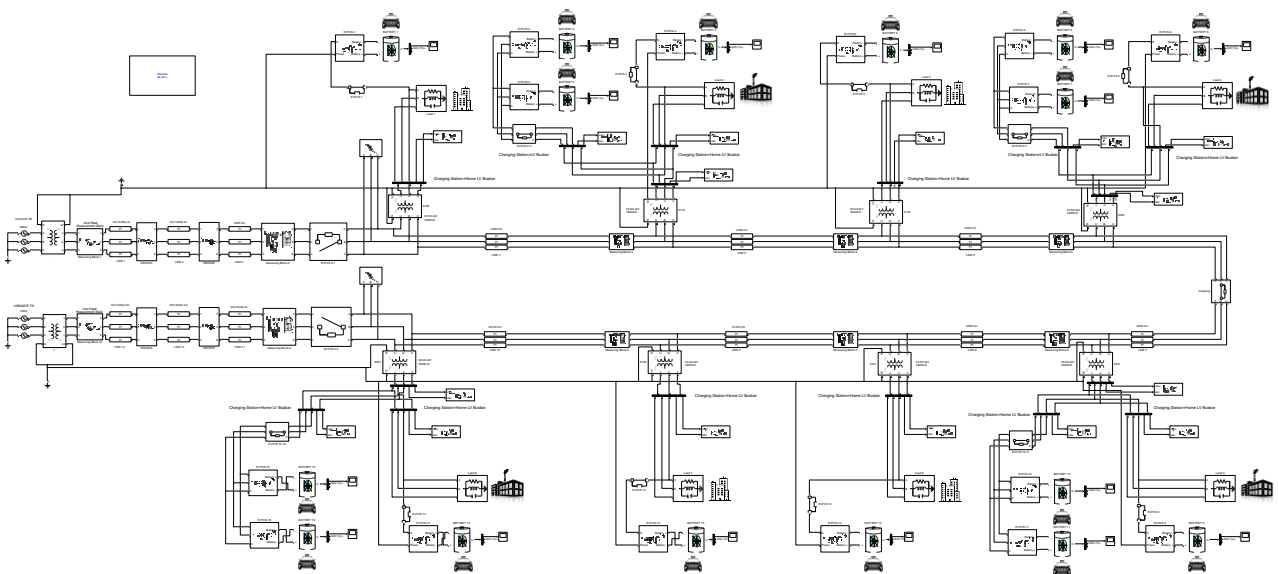


FIGURE 10. Schematic of the main MATLAB/Simulink model of the HV/LV distribution network

### B. SHORT CIRCUIT ANALYSIS ON KAVACIK LINE

In case of any short circuit that may occur at the beginning of the Kavacik line, the effects that may occur in our network due to the increase in the length of the semi-ring network HV feeder are examined in the graphs below. It is obvious that the protection and control elements of the entire network should be restructured in case of an increase in feeder length and supply depending on the number of EVFCSs and load density. Here, all types of short circuit conditions have been applied and the graphs obtained and their interpretations are given together.

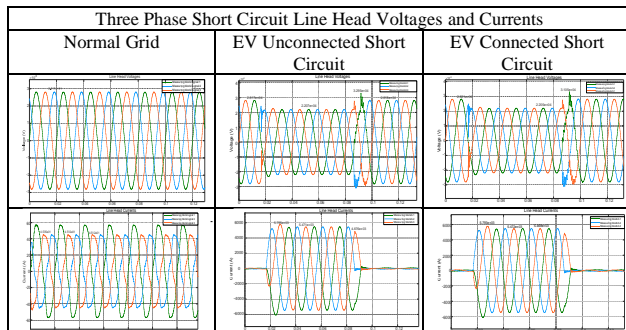


FIGURE 12. Kavacik three phase short circuit line head voltages and currents

In Figure 12, it is observed that while the phase voltage values are 28.21 kV at the line-head when the charging stations are operating, it decreases to 22.05 kV in the period when a three-phase short circuit occurs. During the transition from short circuit to normal operation, it can reach up to 31.6 kV. The current value, which was 57.26 A before the short circuit, increases up to 5790 A in the period when the short circuit occurs. This current value, which increases approximately 100 times, stresses all elements of the system thermally and dynamically.

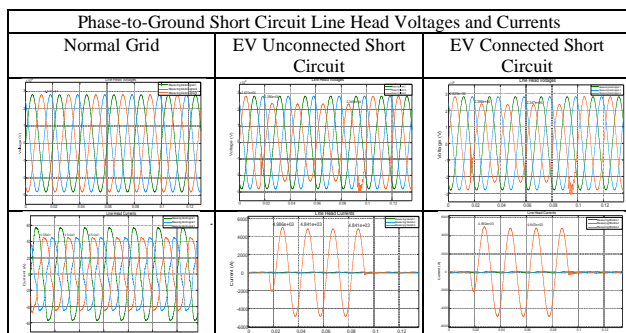


FIGURE 13. Kavacik phase to ground short circuit line head voltages and currents

In Figure 13, while the phase voltage values at line-head were 28.17 kV, it was observed that during the time when the phase-to-ground short circuit occurred, the two-phase voltage amplitudes and values remained the same, while the value of the phase short-circuited with the ground decreased to 23.86 kV. While the current amplitudes and values of the two phases continue in the same way, the current value of the phase short-

circuited with the earth increases from 45.12 A before the short circuit to 4990 A in the time period when the short circuit occurs. This current value, which increases approximately 110 times, puts thermal and dynamic stress on all elements of the system.

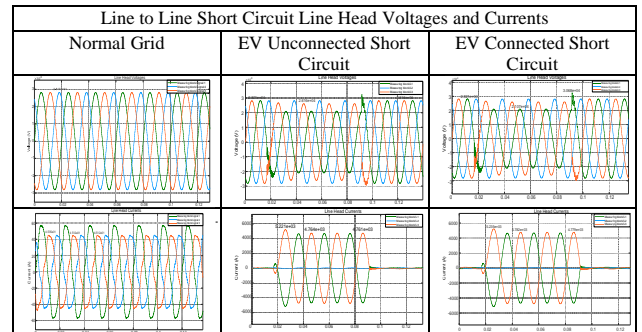


FIGURE 14. Kavacik Line to Line short circuit line head voltages and currents

In Figure 14, while the phase voltage values at the line-head were 28.17 kV, it was observed that the value of the short-circuited phases decreased to 21.07 kV while the amplitude and value of the non-fault phase voltage were the same in the period when a phase-to-phase short circuit occurred. While the current amplitude and value of the non-short-circuited phase continue in the same way, the current values of the short-circuited phases increase from 45.12 A before the short circuit to 5230 A in the time period when the short circuit occurs. This current value, which increases approximately 116 times, puts thermal and dynamic stress on all elements of the system.

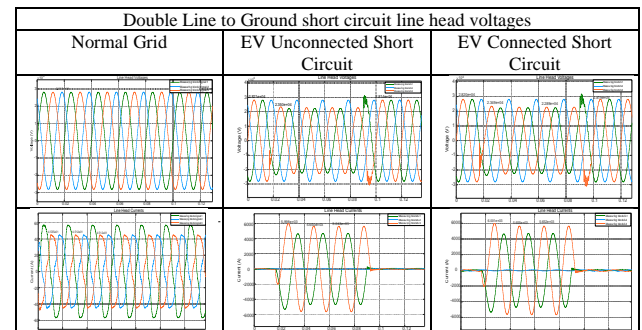


FIGURE 15. Kavacik Double Line to Ground short circuit line head voltages and currents

In Figure 15, while the line-head phase voltage values are 28.17 kV, when a two-phase ground short circuit occurs, the two-phase voltage amplitudes and values decrease to 22.89 kV, while no decrease in the value of the non-short-circuited phase is observed. While the current amplitude and value of the non-short-circuited phase continue in the same way, the current values of the phases short-circuited with the earth increase from 45.12 A before the short circuit to 6000 A in the time period when the short circuit occurs. This current value, which increases approximately 133 times, stresses all elements of the system thermally and dynamically.

When all these short circuit supply types are examined, distortions in the sine curve are clearly seen. These negativities will have effects on all elements of the system. When the line head currents are examined, significant increases are observed in the sine curves in the time period when short circuit occurs.

### C. SHORT CIRCUIT ANALYSIS ON UMRANIYE LINE

In case of any short circuit that may occur at the beginning of the Umraniye line, the effects of the network due to the increase in the length of the HV feeder due to the fact that our network is a semi-ring network are examined in the graphs below. It is obvious that the protection and control elements of the entire network should be reconfigured in the event of an increase in the feeder length and the supply depending on the number of EVFCSs and load density. All types of short circuit conditions have been applied and the graphs obtained and their interpretations are given together.

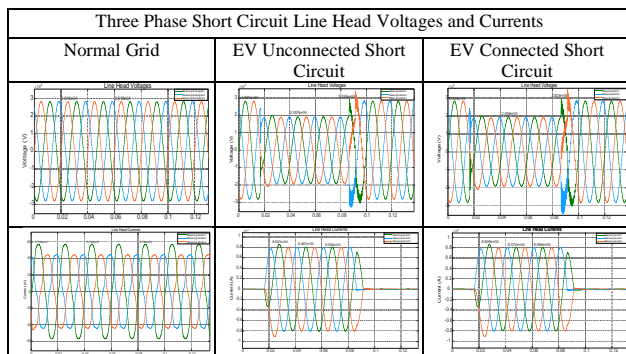


FIGURE 16. Umraniye Three Phase Short Circuit Line Head Voltages and Currents

In Figure 16, it is observed that while the phase voltage values are 28.11 kV at the line-head when the charging stations are operating, it decreases to 20.06 kV in the time period when a three-phase short circuit occurs. During the transition from short circuit to normal operation, it can instantaneously increase up to 29.79 kV. The current value, which was 57.36 A before the short circuit, increases up to 8600 kA in the time period when the short circuit occurs. This current value, which

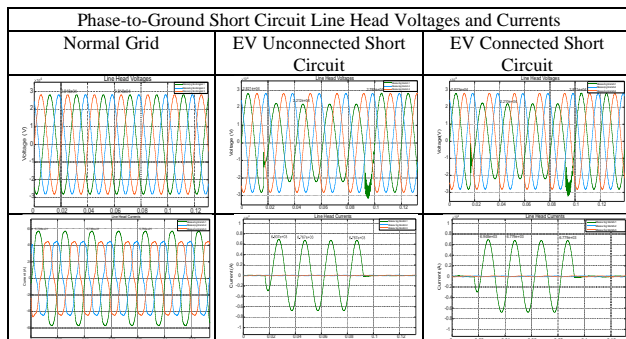


FIGURE 17. Umraniye Phase-To-Ground Short Circuit Line Head Voltages and Currents

increases approximately 150 times, stresses all elements of the system thermally and dynamically.

In Figure 17, it is observed that the line head phase voltage values are 28.11 kV and when a phase-ground short circuit occurs, the two phase voltage amplitudes and values are the same, while the value of the phase short-circuited with the ground drops to 22.1 kV. While the current amplitudes and values of the two phases continue in the same way, the current value of the phase short-circuited with the earth increases from 57.32 A before the short circuit to 6940 A in the time period when the short circuit occurs. This current value, which increases approximately 110 times, puts thermal and dynamic stress on all elements of the system.

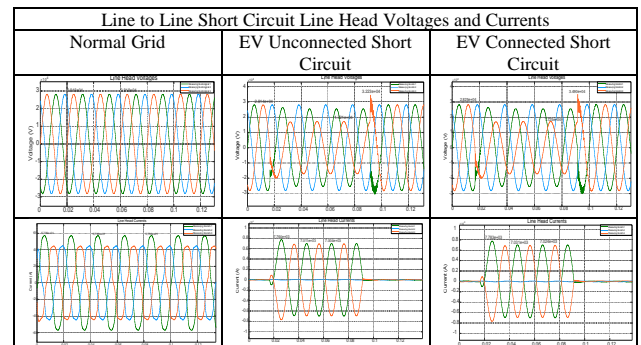


FIGURE 18. Umraniye Line to Line short circuit line head voltages and currents

In Figure 18, it is observed that while the linehead phase voltage values are 28.11 kV, when a phase-to-phase short circuit occurs, the non-fault phase voltage amplitude and value are the same, while the value of the short-circuited phases decreases to 17.25 kV. While the current amplitude and value of the non-short-circuited phase continue in the same way, the current values of the short-circuited phases increase from 57.36 A before the short circuit to 7780 A in the time period when the short circuit occurs. This current value, which increases approximately 136 times, puts thermal and dynamic stress on all elements of the system.

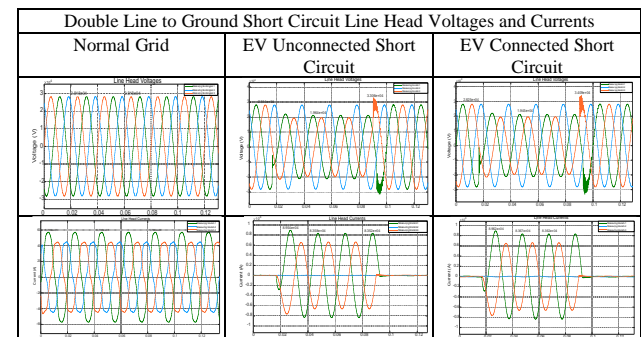


FIGURE 19. Umraniye Double Line to Ground short circuit line head voltages and currents

In Figure 19, while the phase voltage values are 28.18 kV at the beginning of the line when the charging stations are operating, the two-phase voltage amplitudes and values decrease to 19.45 kV in the time period when two phase earth short circuits occur, while no decrease is observed in the value of the non-short-circuited phase. While the current amplitude and value of the non-short-circuited phase continue in the same way, the current values of the phases short-circuited with the earth increase from 57.36 A before the short circuit to 8960 A in the time period when the short circuit occurs. This current value, which increases approximately 156 times, stresses all elements of the system thermally and dynamically.

When all these short circuit fault types are examined, distortions in the sine curve are clearly seen. These negativities will have effects on all elements of the system. When the line head currents are analyzed, significant increases in the sine curves are observed in the time period when a short circuit occurs.

In order to compare the findings of the study, Table III shows the numerical data of the current and voltage values of each phase of all fault models according to the short circuit types created in both regions, whether the EVs are connected or not, in normal and short circuit conditions.

TABLE III  
SHORT CIRCUIT CASE COMPARISON

Area	Measured Value	Working Status	Phases	Phase-Ground	Three Phase	Phase-Phase	Two Phase-Ground		
<b>Kavacik</b>	<b>Currents (kA)</b>	<b>Normal Grid</b>	L1	0.051	0.051	0.051	0.051		
			L2	0.051	0.051	0.051	0.051		
			L3	0.062	0.062	0.062	0.062		
		<b>EV Unconnected Short Circuit</b>		L1	0.067	5.42	4.671	4.724	
				L2	0.067	5.46	0.067	0.067	
				L3	4.847	5.46	4.763	5.65	
			<b>EV Connected Short Circuit</b>		L1	0.092	5.427	4.672	4.725
					L2	0.093	5.473	0.094	0.093
					L3	4.854	5.801	4.782	5.65
	<b>Voltages (kV)</b>	<b>Normal Grid</b>	L1	28.17	28.17	28.17	28.17		
			L2	28.17	28.17	28.17	28.17		
			L3	28.15	28.15	28.15	28.15		
		<b>EV Unconnected Short Circuit</b>		L1	28.1	8.48	12.99	10.57	
				L2	28.08	8.49	28.05	28.01	
				L3	12.3	8.48	18.24	10.51	
			<b>EV Connected Short Circuit</b>		L1	28.09	8.47	12.98	10.56
					L2	28.06	8.47	27.98	27.99
					L3	12.26	8.47	18.21	10.48
	<b>Umraniye</b>	<b>Currents (kA)</b>	<b>Normal Grid</b>	L1	0.057	0.057	0.057	0.057	
				L2	0.044	0.044	0.044	0.044	
				L3	0.044	0.044	0.044	0.044	
			<b>EV Unconnected Short Circuit</b>		L1	6.768	8.064	7.003	8.358
					L2	0.068	8.061	0.067	0.067
					L3	0.067	7.973	6.893	6.545
<b>EV Connected Short Circuit</b>					L1	6.781	8.074	7.031	8.369
					L2	0.094	8.066	0.095	0.091
					L3	0.092	8.072	6.952	6.646
<b>Voltages (kV)</b>		<b>Normal Grid</b>	L1	28.12	28.12	28.12	28.12		
			L2	28.14	28.14	28.14	28.14		
			L3	28.15	28.15	28.15	28.15		
		<b>EV Unconnected Short Circuit</b>		L1	16.72	12.49	21.11	14.96	
				L2	28.13	12.48	28.14	28.12	
				L3	28.13	12.47	13.62	14.17	
			<b>EV Connected Short Circuit</b>		L1	16.68	12.47	21.04	14.93
					L2	28.06	12.46	28.13	28.13
					L3	28.12	12.46	13.61	14.17

When the information in Table III is examined;

- ✓ During a three-phase short circuit, it is observed that the current values increase by 100 times at the Kavacik measurement point, while the current values increase approximately 200 times at the Umraniye measurement point. It was observed that the voltage values decreased by 3.32 times during the short circuit at both measurement points.
- ✓ During the phase-to-ground short circuit, it is observed that the current value of the short-circuited phase increases approximately 85 times at the Kavacik measurement point, while the current value of the short-circuited phase increases approximately 120 times at the Umraniye measurement point. In the voltage values, it is observed that the phase with short circuit decreases by approximately 2.3 times at Kavacik measurement point, while the phase with short circuit decreases by approximately 1.7 times at Umraniye measurement point.
- ✓ At the moment of phase-to-phase short circuit, it is observed that the current value of the short-circuited phases increases approximately 92 times at the Kavacik measurement point, while the current value of the short-circuited phase increases approximately 125 times at the Umraniye measurement point. In the voltage values, it is seen that the short-circuited phases decrease by approximately 2.17 times at the Kavacik measurement point, while the short-circuited phase decreases by approximately 2.07 times at the Umraniye measurement point.
- ✓ It is observed that the current value of the short-circuited phase increases approximately 91 times at the Kavacik measurement point, while the current value of the short-circuited phase increases approximately 147 times at the Umraniye measurement point. In the voltage values, it is seen that the phase with short circuit decreases by approximately 2.7 times at Kavacik measurement point, while the phase with short circuit decreases by approximately 2 times at Umraniye measurement point.

The fact that the transformer load density in both regions, HV feeder lengths, the number of EVFCSs and the number of one-phase and three-phase transformers are different according to the number of EVFCSs and the number of one-phase and three-phase transformers has led to variable results. In addition, it shows that these negative values will change logarithmically with the increase in load density due to the increase in the number of EVFCSs in the future and will negatively affect the distribution network.

## VII. CONCLUSION

With the advancement of charging station technologies and the increase in the number of charging stations, the frequency of EVs in traffic will increase in the near future. With this increase, it is important to know the effects that may occur on the high voltage side of the distribution system in case of any

short circuit in the networks to which the charging stations are connected. In this study, the optimal location algorithm has been used to locate 16 HV/LV distribution transformer feeders connected to 8 HV/LV distribution transformer feeders in the region between Kavacik-Umraniye using GIS based MCDM method. In this semi-ring network system together with the real data taken from the network; current and voltage changes during a short circuit were analyzed with scenarios created according to all short circuit types that may occur at the line heads in the system to which the EVFCS is connected. As a result of this modeling, it was observed that in all types of short circuits, the current values at the short circuit points on the HV side of the network increased between 100 and 150 times during the short circuit period, while the voltage values decreased between 2 and 3 times in the phases where the short circuit occurred. In addition to this, it is observed that the current and voltage values vary greatly at the start and end of the short circuit and there are significant distortions in the sinus curves. In the light of all these data, these rates are likely to increase as the number of charging stations increases. In this case, it will cause changes in the values of the control, control and protection elements of the distribution network, cable cross-sections, relay coordination calculations and the installation of new compensation facilities. As a result of all these changes, it is necessary to reorganize the distribution network and existing regulations and to cover the additional costs that will be incurred.

## ACKNOWLEDGMENT

We would like to thank Erhan CERİ, Electrical Engineer in charge of AYEDAS Vaniköy Operation Center, who helped us with technical information in this study.

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