ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

MSc THESIS

Ensari YILDIRIM

DISTRIBUTED SOLAR POWER GENERATION EFFECTS ON SHORT CIRCUIT PROTECTION OF DISTRIBUTION NETWORK - NEW TECHNIQUES FOR IMPROVEMENTS REGARDING ADVERSE EFFECTS

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

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We certify that the thesis titled above was reviewed and approved for the award of the degree of the Master of Science by the board of jury on 20/11/2018.

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ABSTRACT

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Distributed generation is a new application field regarding electricity generation and distribution. As this application grows, the network will face new challenges. One of the candidates for complications that may arise is the possibility of malfunction of the current relay coordination. Circuit breakers may be triggered, although there is no fault. Circuit breakers that must be triggered in the event of a fault might not interrupt the circuit unexpectedly. The network protection systems may lose their function. SAIDI (System Average Interruption Duration Index), SAIFI (System Average Interruption Frequency Index) and EENS (Expected Energy Not Served) values of the network may increase. In this thesis, the wide application of distributed generation (especially solar energy power plants) in the future is investigated and the possible effects on the existing relay coordination are predicted. In the network topology where the solar power plants are connected, the branches are systematically investigated in terms of safety. In order to conduct this investigation, the superposition analysis was applied for the first time in distributed generation short-circuit analysis. As a matter of fact that, the superposition analysis serve practical and easy ways to examine the effects of distributed generation on the distribution network. The literature survey shows that the IEEE 13-Node or IEEE 34-Node radial distribution test feeder topologies have been frequently used when the distribution network is examined. However, instead of using these topologies, an alternative topology which is sufficient and more useful for the required PSCAD simulation has been developed for the sake of simplicity, in this study. In order to obtain realistic results in PSCAD simulations, an Excel-based computing platform (Master Program) was developed that calculates the distribution network circuit parameters to be used in PSCAD. New applications are proposed that will help to reduce the adverse effects that are predicted/identified during all these simulations and investigation studies.

Keywords: Distributed generation; protection; spp (solar power plants); relay coordination

ÖZ

YÜKSEK LİSANS TEZİ

DAĞITIK GÜNEŞ ENERJİSİ ÜRETİMİNİN DAĞITIM SİSTEMİNİN KISA DEVRE KORUMASI ÜZERİNDEKİ ETKİLERİ – OLUMSUZ ETKİLERE İLİŞKİN GELİŞTİRMELER İÇİN YENİ TEKNİKLER

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Dağıtık üretim, elektrik üretimi ve dağıtımıyla ilgili yeni bir uygulama alanıdır. Uygulama yaygınlaştıkça yeni sorunlarla karşılaşılacaktır. Çıkabilecek sorunlara aday konulardan biri, mevcut röle koordinasyonunun bozulması ihtimalidir. Herhangi bir arıza olmasa dahi, devre kesiciler tetiklenebilir veya bir arıza durumunda tetiklenmesi gereken kesiciler devreyi kesmeyebilir. Şebeke koruma sistemleri etkisini kaybedebilir, dağıtım sisteminin kesinti süresi/kesinti sayısı/dağıtılamayan enerji endeksleri (SAIDI/SAIFI/EENS) artabilir. Bu tezde, mevcut röle koordinasyonunun gelecekte dağıtık üretimin yaygın olarak kullanılmasından, özelikle de güneş enerjisi santrallerinin yaygınlaşmasından nasıl etkileneceği tahmin edilmektedir. Güneş enerjisi santrallerinin bağlı olduğu şebeke topolojisinde, hangi noktaların daha çok etkileneceği ve hangi noktaların güvende kalacağı sistematik olarak incelenmektedir. Bu inceleme için, süperpozisyon analizi dağıtık üretim kısa devre analizinde ilk defa uygulanmıştır. Süperpozisyon analizi, dağıtım şebekesinde dağıtık üretim etkilerini incelemeyi pratikleştirmekte ve kolaylaştırmaktadır. Literatürde, dağıtım şebekesi incelenirken IEEE 13-Node veya IEEE 34-Node radyal dağıtım test fideri topolojilerinin sıklıkla kullanıldığı görülmektedir. Mevcut lisanssız santral uygulaması trendi doğrultusunda, varılacak dağıtım sisteminin pratik ve etkili bir şekilde incelenebilmesi için bu topolojilere alternatif ve ihtiyaç duyulan simülasyon için yeterli bir topoloji geliştirilmiş ve PSCAD ortamında test edilmiştir. PSCAD'de yapılacak simülasyonlarda gerçekçi sonuçlar alabilmek için, dağıtım şebekesi devre elemanlarının PSCAD'de kullanılacak parametrelerini hesaplayan Excel tabanlı bir hesaplama platformu (Master Program) geliştirilmiştir. Tüm bu simülasyon ve inceleme çalışmaları esnasında öngörülen/belirlenen olumsuz etkilerin azaltılmasını sağlayacak yeni uygulamalar önerilmektedir.

Anahtar Kelimeler: Dağıtık üretim; lisanssız üretim; koruma; ges (güneş enerjisi santrali); röle koordinasyonu

EXTENDED SUMMARY

Electric energy is an essential requirement for the development of human life and human civilization. Therefore, the demand of electricity of mankind tends to increase continuously. Most of the countries gather their electricity from the bulk and centralized electricity production facilities, such as production stations fired by fossil fuels, nuclear energy, and water or large solar panel stations.

Electricity produced from these facilities is usually transported over long distances since the end-users are hundreds of kilometers away from the existing production and distribution centers. In order to reduce the cost of transportation of coal basins, coal power plants are established in the coal mine. Yet another example, the hydroelectric power plants are established in large water basins which are limited areas away from human settlements. This situation requires a large investment in the transmission system. Energy losses occur due to conduction losses in transmission and also in order to reduce losses, the high voltage systems (transformers, large insulators, high masts) are used. All in all, the necessary huge investments in the transmission system, electricity transmission losses and high voltage electrical systems lead to inefficiency and excessive financial losses in the existing system. In addition, long transmission lines and high voltage systems cause security risks for people, buildings and the environment.

Furthermore, this type of generation of electricity causes some risks for mainland safety especially in times of war. Because the long transmission lines which carry huge power, as well as large central power plants, can be engaged sabotage interventions of possible enemy countries. In case of failure of the strategic electrical transmission lines or huge electricity generation plants, the breakdown occurs in the at least an important region of the country.

In addition, these large plants adversely affect nature. For example, coal power plants are established in the regions away from living areas and industrial centers, since those power plants cause to heavy air pollution to be avoided. Moreover, all of the fossil fuel power plants causes greenhouse gas emissions. The natural balance of the areas of extraction of fossil fuels is disrupted. Wastes from nuclear power plants are serious threats to the environment. Large-scale hydroelectric power plants which cover huge areas with water disrupt the natural balance of the regions.

Another major handicap for energy production centers is that in case of aging, deterioration or lack of capacity situations occurs, the renewing or replacing of these facilities is not always possible with the same type of electric power plants. Therefore, large and central production and transmission systems and the conventional electrical system are not sustainable.

With the distributed generation, electricity can be gathered from many different and small energy sources. The individual sources are mostly small and

they are mostly independent of the location. Therefore, they can be installed very close to end-users as distributed generation.

Although the size of individual plants of distributed generation is small, there can be huge mass production over all possible countless small generation units. With this mode of generation, the dependency on underground and aboveground resource locations will be decreased. Therefore, with the distributed energy production there is no need for long transmissions. In this way, large investments are not required for the transmission system. Losses due to transmission will be very small. In this way, there is no need for major investments in high-voltage systems. As a consequence; people, buildings, and environment will be at safer in the future electrical system in which high-voltage and transmission systems will occupy less space.

In the distributed generation electrical system, there will not be strategic spots subject to sabotage interventions. The collapse of a significant part of the system will not occur. Because there will be power plants mostly close to each electricity customer, ready to work in the island (off-grid) mode. Therefore, the system will be more stable.

In this system, renewable energy sources will be used more frequently. Renewable energy power plants are not convenient for conventional electricity systems since they produce small power individually and the production regimes of them are not controllable. However, there is no need for individual great powers in distributed generation electricity systems. Besides, uncontrollable regimes in power generation is not a great challenge by using bi-directional counters which allow selling electricity to the system in case of overproduction and buying electricity from the system in case of underproduction. In the case of the system allowing the production mostly from renewable energy sources, the natural balance will not be deteriorated by greenhouse gas emissions and nuclear wastes.

A further point that needs to be addressed, these power plants are more sustainable than conventional power plants by their size and fuels. The unsustainable properties arose from huge size plants and non-renewable energy resource is described before.

Distributed power generation facilities can be classified into two categories as one that can be used close to end-users (user mode) and the other that can be established in half-centralized regions (regional production). The user mode, ready to work as island (off-grid) mode will have the bi-directional counting of electricity generation facilities. Beside renewable energy there are the cogeneration plants, microturbines and modular internal combustion engine-electric generator couples will be used as user mode power generation. As a second class of such generation facilities; wind, geothermal, solar renewable energy sources might be used as regional production.

The missing aspects and losses of conventional electrical systems compared to distributed generation electrical systems are listed below in terms of commercial losses, safety weaknesses and adverse effects on nature.

Commercial losses:
• Large investments in the transmission system
• Investments in electrical isolation due to high voltage levels in the transmission system
• Electrical energy losses
• Unsustainable production systems

Safety weaknesses:
• The production and transmission systems vulnerable to sabotage
• Long transmission systems with high voltage that cause loss of life and property

Adverse effects on nature:
• Greenhouse gas emissions
• Nuclear wastes
• The natural imbalance of the mines and water basins

Distributed generation has many weak points that need improvement such as, control of DG systems, power quality improvements, multi-functional DG converters, power loss improvements, fault tolerance, protection issues etc. Protection has the greatest importance among these issues for implementing this new concept.

When DG systems are implemented, a ring designed and radial operated distribution feeders will lost its radial operation logic. In this case, unnecessary parts of the network may be isolated or necessary parts of the network may not be isolated. The current relay coordination logic will be inadequate to provide selectivity and back-up protection. Therefore, the current network operation and overcurrent coordination logic are going to prevent to safely grow of distributed generation. In order to fix these inconvenient relay coordination, distance relays and new relay settings, which only can be gathered by simulations, should be used. Then, selectivity and back-up protection will be gathered back.

As a literature survey; articles, conference materials and books obtained from IEEE and ScienceDirect databases, theses obtained from ProQuest and HEC databases, technical papers of some firms/laboratories and current corresponding regulations of Turkey have been investigated.

The use of solar energy seems to be dominant over other energy sources at the leading European countries. Although distributed generation system applications in Turkey is brand new compared to Europe, there is nevertheless the dominant status of solar energy in electricity production. Therefore, when studying the effects on the protection systems of distributed generation systems, solar energy should be selected as the distributed generation main resource to be modeled. Although the contribution to a fault current of the solar power plants supplying the grid through the inverters is low by comparison, it is possible that the existing relay coordination is negatively affected if a large number of solar energy plants are connected to the same feeder. Even though the relevant legislation in our country limits the electricity generation power per plant to 1 MW, there are no restrictions to get a large number of generation plants on the same feeder.

Distributed generation legislation in Turkey (unlicensed electricity production), promotes MV level electricity generation rather than LV level electricity generation. As a matter of fact, the overwhelming part of the installed power of distributed generation in our country belongs to the solar energy plants connected to the distribution network at MV level.

According to the relevant regulations in Turkey, the single-phase short-circuit current in the distribution feeder is limited 1000 A and the 3-phase short circuit current is limited to 16 kA. Therefore, the relay coordination for the single-phase short-circuit current will be affected by the short-circuit contribution of the distributed generation plants, earlier and more adversely.

Due to the reasons mentioned above, the thesis is concentrated on the effects of the MV level distribution network connected solar energy plants on single phase short circuit protection. In the literature, it is seen that the IEEE 13-Node or IEEE 34-Node radial distribution test feeder topologies are frequently used when the distribution grid is investigated. In order to investigate the current and future distribution system in a practical and effective way, an adequate and required topology (4-Node) which is alternative for these topologies was developed and tested in the PSCAD platform.

Realistic models have been used so that simulations in PSCAD yield results very close to reality. While these models are being developed, the grid limitations in current legislation, common line characteristics in the distribution grid and transformer and transmission grid parameters published for TEİAŞ substations are taken into consideration. In order to model the distribution grid in PSCAD, an Excel-based calculation platform was created in which the basic parameters of the circuit elements can be calculated.

As a result of the simulations made, it has been determined how much the distributed generation will affect the distribution system relay coordination. The techniques that can be used to avoid such unfavorable effects have been determined and such techniques have been tested by PSCAD simulations in order to find out how well these techniques will be successful. The cases in which the techniques should be used are also determined and indicated using graphs and flow diagrams.

GENİŞLETİLMİŞ ÖZET

Elektrik enerjisi insan yaşamı ve insan uygarlığının gelişimi için vazgeçilmez bir gereksinimdir. Bu sebeple, insanlığın elektrik enerjisi talebi sürekli artma eğilimindedir. Ülkemizde ve dünyanın genelinde, ihtiyaç duyulan elektrik enerjisi büyük ve merkezi tesislerden karşılanmaktadır. Bu tesisler arasında fosil yakıtla, nükleer enerjiyle, su gücüyle çalışan enerji santralleri ve büyük güneş paneli santralleri bulunmaktadır.

Bu tesislerden elde edilen elektrik genellikle uzak mesafelere taşınmakta, mevcut üretim ve dağıtım merkezleri son kullanıcılardan yüzlerce km uzakta bulunabilmektedir. Kömürün taşınma maliyetini azaltmak için kömür santralleri kömür madeni havzalarına kurulur. Yine bir başka örnek olarak hidroelektrik santralleri ancak geniş su havzalarının olduğu yine insan yerleşimlerine uzak kısıtlı alanlara kurulabilir. Bu durum büyük iletim sistemi yatırımları gerektirmektedir. İletimden dolayı enerji kayıpları meydana gelmekte ve yine iletim kayıplarının azaltılması için yüksek gerilim sistemleri (trafolar, büyük izolatörler, yüksek direkler) kullanılmaktadır. Tüm bunlar, büyük iletim sistemi yatırımları, elektrik iletim kayıpları ve yüksek gerilim sistemi yatırımları, mevcut elektrik sistemlerinde verimsizliğe ve büyük maddi kayıplara sebep olmaktadır. Ayrıca yüksek gerilim sistemleri ve uzun iletim hatları insanlar için güvenlik risklerine sebep olmaktadır.

Yine bu tarz elektrik üretimi özellikle savaş zamanlarında ülkeler için zayıf karın olmaktadır. Çünkü büyük güçler taşıyan uzun iletim hatları, büyük ve merkezi üretim yapan elektrik tesisleri başka ülkelerin sabotaj müdahalelerine açıktır. Yeterince stratejik olan elektrik iletim hatlarının kopması durumunda ya da yeterince büyük elektrik üretim santrallerinin devre dışı kalması durumunda tüm ülkenin ya da en azından ülkenin önemli bir bölümünün elektrik sistemi çökebilir.

Ayrıca doğa bu büyük santrallerden olumsuz etkilenmektedir. Örneğin kömür santralleri, ağır hava kirliliğine sebep olduğundan insanların yaşam alanlarından ve sanayi merkezlerinden uzaklara kurulur. Yine fosil yakıt santrallerinin tamamı sera gazı emisyonuna sebep olmaktadır. Fosil yakıtların çıkarıldığı geniş maden havzalarında bölgenin doğal dengesi bozulmaktadır. Nükleer santrallerin atıkları çevre için ciddi tehdit oluşturmaktadır. Hidroelektrik santralleriyle geniş ölçekli alanlar su altında bırakılır, kuruldukları bölgenin doğal dengesini bozar.

Bu büyük enerji üretim merkezleri için bir başka handikap ise zaman içinde yaşlanma, bozulma ve ya kapasite yetersizliği durumları oluştuğunda, bu tesislerin yerini aynı tipte elektrik santralleriyle doldurabilmek her zaman mümkün olmayacaktır. Dolayısıyla büyük ve merkezi iletim sistemleri ve klasik elektrik sistemi yeterince sürdürülebilir değildir.

Dağıtık üretim sayesinde, elektrik birçok farklı ve küçük enerji kaynaklarından üretilebilir. Bu kaynaklar tekil olarak küçük olmaları ve konuma çok bağlı olmamaları itibariyle dağıtık olarak, son kullanıcıların yanı başında kurulabilir.

Dağıtık üretimde tesislerin tekil büyüklükleri küçük olmakla birlikte, toplamda kitlesel üretim yapılabilir. Bu üretim tarzında yer altı ve yer üstü kaynaklarının konumlarına bağlılık çok azdır. Dolayısıyla dağıtık üretimle çok uzak mesafelere enerji taşımak gerekmemektedir. Bu sayede büyük iletim sistemi yatırımları gerekmemektedir. İletimden kaynaklanan elektrik kayıpları çok azdır. Bu sayede yüksek gerilim sistemleri için büyük yatırımlara gerek kalmamaktadır. Yüksek gerilim sistemlerinin ve iletimin daha az yer kaplayacağı bu sistemde insanlar ve yapılar daha güvende olacaktır.

Elektik üretim tesislerinin küçük ve dağıtık olacağı bu sistemde sabotaja açık stratejik noktalar oluşmayacaktır. Sistemin önemli bir bölümünün çökmesi meydana gelmeyecektir. Çünkü nerdeyse her kullanıcının yanı başında ada modunda çalışmaya hazır bir elektrik üretim tesisi olacaktır. Dolayısıyla sistem daha kararlı olacaktır.

Bu sistemde yenilenebilir enerji kaynakları daha çok yer bulabilecektir. Yenilenebilir enerji kaynaklarının elektriksel güç bakımından küçük olmaları ve elektrik üretim rejimlerinin kontrol altında olmaması sebepleriyle klasik elektrik sisteminde pek kullanılabilir değildir. Ancak dağıtık üretim sisteminde tesis başına büyük güçler gerekmemektedir. Yenilenebilir enerji kaynaklarının elektrik üretim rejimlerinin kontrol altında olmaması da dağıtık üretim sisteminde kullanılacak çift yönlü sayaçlarla kimi zaman sisteme elektrik satarak, kimi zaman da sistemden elektrik alarak bertaraf edilebilir. Yenilenebilir enerji kaynaklarının yaygın olarak kullanıldığı bir sistemde geniş havzaların doğal dengesi bozulmayacak, sera gazı salınımı meydana gelmeyecek ve nükleer atıklarla uğraşılmayacaktır.

Bir başka değinilmesi gereken nokta, bu sistemde kullanılan elektrik santrallerinin, boyutları ve kullandıkları enerji formları itibariyle klasik santrallere nazaran daha sürdürülebilir olduğudur. Büyük boyutlu tesislerden ve yenilenemeyen enerji kaynaklarından doğan sürdürülemez özellikler daha önce açıklanmıştır.

Dağıtık üretimde kullanılabilecek elektrik üretim tesisleri bölgesel kurulan ve son kullanıcının yanı başında kurulanlar olmak üzere iki çeşit olacaktır. Bölgesel üretimde rüzgar, jeotermal, solar gibi yenilenebilir enerji kaynaklarından yararlanılacaktır. Buna rağmen bu santraller kömür santralleri, hidroelektrik ya da nükleer santraller kadar büyük ve merkezi olmayacaktır. Bunların dışında kullanıcının hemen yanı başında ada modunda çalışmaya hazır çift yönlü sayaçlı elektrik üretim tesisleri olacaktır. Bunlar arasında da yenilenebilir enerji formlarıyla birlikte, kojenerasyon tesisleri, mikrotürbinler ve modüler içten yanmalı motor-elektrik jeneratörü çiftleri olacaktır.

Dağıtık üretime nazaran klasik elektrik sistemlerinin eksik kalan yönleri ve zararları maddi açıdan, güvenlik zafiyetleri açısından ve doğa üzerindeki etkiler açısından aşağıda sıralanmıştır.

Maddi zararlar:

- İletim sisteminde yapılması gereken büyük yatırımlar
- İletim sisteminde yüksek gerilim seviyelerinden kaynaklı elektriksel izolasyona yönelik yatırımlar
- Elektrik enerjisi kayıpları
- Üretim sistemlerinin sürdürülebilir olmayışı

Güvenlik zafiyetleri:

- Üretim ve iletim sistemlerinin sabotaja açık olması
- Yüksek gerilim taşıyan uzun iletim sistemlerinin can ve mal kayıplarına sebep olması

Doğaya verilen zararlar:

- Sera gazı salınımı
- Nükleer atıklar
- Maden ve su havzası bölgelerinin doğal dengesinin bozulması

Dağıtık üretimin, yeni ve geliştirilmeye açık bir konu olması itibariyle, üzerinde çalışılıp geliştirilmesi gereken birçok zayıf noktası bulunmaktadır. Bu konular arasında dağıtık üretim sistemlerinin kontrolü, güç kalitesi iyileştirmeleri, çok fonksiyonlu dağıtık üretim çevirgeçleri, güç kaybı iyileştirmeleri, hata toleransı ve koruma ile ilgili konular bulunmaktadır. Bu konular içinde koruma birinci derece öneme sahiptir. Dağıtık üretim sistemlerinin uygulanabilmesi için örneğin güç kaybı konularının aşılması kesin bir şart değilken, koruma ve güvenlik konuları mutlak surette gerekli bir şarttır.

Ring şeklinde tasarlanmış, radyal işletilen bir dağıtım sisteminde dağıtık üretim sistemleri kullanılmaya başlandığında fiderler radyal işletim mantığını kaybedecektir. Bu durumda arıza zamanlarında açmaması gereken kesiciler açabilecek, arızasız şebeke kısımları gereksiz yere izole edilebilecek ya da açması gereken kesiciler açmayıp arızalı şebeke kısımları sistemden izole edilemeyecektir. Seçicilik ve artçı koruma özelliklerini sağlayabilmek için mevcut röle koordinasyonu mantığı yetersiz kalacaktır. Dolayısıyla mevcut şebeke işletim ve aşırı akım role koordinasyonu mantığıyla, dağıtık üretimin güvenli büyümesi mümkün olmayacaktır. Bunun önüne geçebilmek ve dağıtık üretimin anılan faydalarından güvenli bir şekilde yararlanabilmek için dağıtım şebekesi koruma sistemlerinde önemli değişiklikler yapmak gerekecektir.

Literatür çalışması için IEEE ve ScienceDirect veri tabanlarından temin edilebilen makalelerden, konferans metinlerinden ve kitaplardan, ProQuest veri tabanından temin edilebilen tezlerden, YÖK veri tabanından temin edilebilen yerli tezlerden, bazı firma ve laboratuvarların teknik bildirilerinden ve Türkiye'de geçerli güncel mevzuattan yararlanılmıştır.

Yenilenebilir enerji ve dağıtık üretim sistemlerinin Avrupa'daki öncü ülkelerine baktığımızda, güneş enerjisi kullanımının diğer enerji kaynaklarına kıyasla daha baskın olduğu görülmektedir. Dağıtık üretim sistemleri konusunda henüz işin başında sayılabilecek Türkiye'de ise yine güneş enerjisinin aynı baskın durumu söz konusudur. Bu sebeple, dağıtık üretim sistemlerinin koruma sistemleri üzerindeki etkileri incelenirken, modellenecek dağıtık üretim kaynağı olarak güneş enerjisi seçilmelidir. Her ne kadar, invertörler üzerinden şebekeyi besleyen güneş enerjisi santrallerinin arıza akımına katkısı düşük olsa da, aynı fidere çok sayıda güneş enerjisi santrali bağlandığında, mevcut role koordinasyonunun olumsuz etkilenmesi söz konusu olabilecektir. Ülkemizdeki ilgili mevzuat santral başına elektrik üretim gücünü 1 MW ile sınırlandırsa da, aynı fider üzerinde çok sayıda üretim santrali bulunmasının önünde bir engel yoktur.

Türkiye'de dağıtık üretim (lisanssız elektrik üretimi) mevzuatı, AG seviyesinde elektrik üretiminden ziyade, OG seviyesinde elektrik üretimini teşvik etmektedir. Nitekim ülkemizdeki dağıtık üretim kurulu gücünün ezici orandaki kısmı OG seviyesinde dağıtım şebekesine bağlanan güneş enerjisi santrallerine aittir.

Türkiye'deki ilgili mevzuata göre dağıtım fiderlerinde tek faz kısa devre akımı 1000 A ile sınırlandırılırken, 3 faz kısa devre akımı ise 16 kA ile sınırlanmaktadır. Dolayısıyla tek faz kısa devre akımı için oluşturulan röle koordinasyonu, dağıtık üretim santrallerinin kısa devre katkısından daha erken ve daha çok etkilenecektir.

Yukarıda anılan sebeplerden dolayı, bu tez kapsamında dağıtım şebekesine OG seviyesinden bağlı güneş enerjisi santrallerinin, tek faz kısa devre koruması üzerindeki etkilerine yoğunlaşılmıştır. Literatürde, dağıtım şebekesi incelenirken IEEE 13-Node veya IEEE 34-Node radyal dağıtım test fideri topolojilerinin sıklıkla kullanıldığı görülmektedir. Mevcut lisanssız santral uygulaması trendi doğrultusunda, varılacak dağıtım sisteminin pratik ve etkili bir şekilde incelenebilmesi için bu topolojilere alternatif ve ihtiyaç duyulan simülasyon için yeterli bir topoloji geliştirilmiş ve PSCAD ortamında test edilmiştir.

PSCAD'de yapılacak simülasyonların gerçeğe yakın sonuç verebilmesi için gerçekçi modeller kullanılmıştır. Bu modeller oluşturulurken, güncel mevzuatlardaki şebeke kısıtlamaları, dağıtım şebekesinde yaygın kullanılan hat karakteristikleri ve TEİAŞ TM'ler için yayınlanan trafo ve iletim şebekesi parametreleri dikkate alınmıştır. Dağıtım şebekesinin PSCAD'de modellenebilmesi için devre elemanlarına ait temel parametrelerin hesaplanabildiği Excel tabanlı bir hesaplama platformu oluşturulmuştur.

Yapılan simülasyonlar sonucunda dağıtık üretimin dağıtım şebekesi role koordinasyonunu ne yönde ve ne ölçüde etkileyebileceği belirlenmiştir. Olumsuz etkilerin önüne geçebilmek için kullanılabilecek teknikler belirlenmiş ve yine PSCAD simülasyonlarıyla bu tekniklerin ne ölçüde başarılı olacağı test edilmiştir. Söz konusu tekniklerin hangi durumlarda kullanılacağı ise ayrıca tespit edilmiş ve grafikler ile akış diyagramları kullanılarak belirtilmiştir.

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LIST OF SYMBOLS

C	:	Total Capacitance for the Cable
C	:	the Lumped Capacitance
d	:	Diameter of the Conductor
D	:	Diameter over the Insulation
D_{ab}	:	the Distance Between Line-a and Line-b
D_{bc}	:	the Distance Between Line-b and Line-c
D_{ac}	:	the Distance Between Line-a and Line-c
$\varepsilon_{\circ}$	:	the Electric Constant Permittivity of Free Space
E	:	the Operator Implementing τ Operator to a Series of Impedance Values
F	:	Farad
F_0	:	the Main Feeder
F_1	:	the First Secondary Feeder
F_2	:	the Second Secondary Feeder
f	:	System Operating Frequency
H	:	Henry
I_{charge}	:	Charging Current
I_{sc}	:	the Short Circuit Current Reported by TEİAŞ for Each TS
I_T	:	the Calculated Total Current Value Supplied by All the Sources
$KVAR_{charge}$	:	Single Phase KVAR or Charging VARs per Cable
L	:	Length of the Cable

L	:	the Lumped Inductance
L_s	:	the Serial Equivalent Inductance of both TS and the Upstream Network of TEİAŞ
L_{eq}	:	the Thevenin Equivalent Inductance of the Circuit (Lines and SSs)
$\mu_{\circ}$	:	the Magnetic Constant Permeability of Free Space
φ_{sc}	:	the Short-Circuit Angle
φ_L	:	the Load Angle
q_a	:	the Charges of Line-a
r	:	Radius
R_{AC}	:	AC Resistance of the Conductor at Operating Temperature
R_{AC20C}	:	AC Resistance of the Conductor at 20 ˚C
R_s	:	the Serial Equivalent Resistance of both TS and the Upstream Network of TEİAŞ
R_l	:	the Serial Equivalent Resistance of the Line between Two Nodes (TS-SS or SS-SS)
R_c	:	the Thevenin Equivalent Contact Resistance
R_{eq}	:	the Thevenin Equivalent Resistance of the Circuit (Lines and SSs)
R_F	:	the Fault Resistance
SIC	:	the Dielectric Constant of the Cable Insulation
S_{tr}	:	The Rated Power of TS Transformer
S_{sc}	:	the Calculated Short Circuit Apparent Power
T	:	Operating Temperature of the Conductor
τ	:	the Operator Calculating the New Equivalent Impedance After Adding New Impedance to the Network

t_{inv}	:	Inverter Tripping Time
U_{sc}	:	the Relative Short Circuit Voltage (U_k)
U_k	:	the Relative Short Circuit Voltage (U_{sc})
U	:	3-Phase, Line to Line and RMS Voltage Value
U_n	:	the nth Thevenin Voltage Value in the Specified Topology
V_{ll}	:	System Operating Voltage – Line to Line
V_B^2	:	the Voltage of the Corresponding Side (Primary or Secondary) of the Calculated Transformer Impedance
V_{an}	:	the Line-Ground Voltage of Line-a
Z_{tr}	:	the Transformer Impedance
Z_{up}	:	the Calculated Thevenin Impedance of the Upstream Network
Z_0	:	the Impedance Connecting the Neutral Point of Y-Connected Transformer to Ground
Z_n	:	the Impedance Connecting the Neutral Point of Y-Connected TS Transformer to Ground
Z_{lim}	:	the Selected Tripping Value of the Impedance Relay
Z_n^s	:	the nth Source Serial Impedance Value in the Specified Topology
Z_n^{eq}	:	the Thevenin Equivalent Impedance Value Perceived by the nth Source in the Specified Topology
Z_F	:	the Fault Impedance
ω	:	the Angular Frequency
X_{tr}	:	the Transformer Reactance
X_{up}	:	the Calculated Thevenin Reactance of the Upstream Network

X_L	:	the Inductive Reactance
X_C	:	the Capacitive Reactance
X_l	:	the Serial Equivalent Reactance of the Line between Two Nodes (TS-SS or SS-SS)

LIST OF ABBREVIATIONS

AAC	:	All Aluminum Conductor
AAAC	:	All Aluminum Alloy Conductor
AC	:	Alternating Current
ACSR	:	Aluminum Conductor Steel Reinforced
AWG	:	American Wire Gauge
BRK	:	Circuit Breaker in PSCAD
CB	:	Circuit Breaker
CdTe	:	Cadmium Telluride
CoT	:	Cut Off Time
CT	:	Current Transformer
CVERF	:	Current Values Encountered by the Relay of the Feeder
DC	:	Direct Current
DG	:	Distributed Generation Systems
DN	:	Distribution Networks
DS	:	Distribution Station
EG	:	Embedded Generators
EMRA	:	Energy Market Regulatory Authority
EU	:	European Union
FRT	:	Fault Ride Through
GaAs	:	Gallium Arsenic
GMD	:	Geometric Mean Diameter
GMR	:	Geometric Mean Radius
HV	:	High Voltage
IEE	:	Institute of Electrical Engineers
IEEE	:	Institute of Electrical and Electronics Engineers
LoM	:	Loss of Mains Relay

LV	:	Low Voltage
MCM	:	Thousands of Circular Mils
MF	:	Main Feeder
MFCV	:	The Main Feeder Current Values
MP	:	Master Program
MPI	:	Master Program Inputs
MPO	:	Master Program Outputs
MPPT	:	Maximum Power Point Tracking
MV	:	Medium Voltage
PF	:	Primary Feeder
PI	:	PSCAD Inputs
PCC	:	Point of Common Connection
PLC	:	Power Line Communication
PSCAD	:	Power System Computer Aided Design
PV	:	Photovoltaic
RDS	:	Restored Default Settings
RMS	:	Root Mean Square
SC0	:	Short-Circuit 0 Analysis
SC1	:	Short-Circuit 1 Analysis
SC2	:	Short-Circuit 2 Analysis
SF	:	Secondary Feeder
SPP	:	Solar Power Plant
SS	:	Substation
STS	:	Solar Tracking System
TEDAŞ	:	Turkish Electricity Distribution Corporation
TEİAŞ	:	Turkish Electricity Transmission Corporation
TPV	:	Thermophotovoltaic
TS	:	Transformer Substation

US	:	United States
VBA	:	Visual BASIC for Applications
XLPE	:	Cross-Linked Polyethylene

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1. INTRODUCTION

1.1. Background and Research Motivation

There are multiple definitions in the literature for distributed generation. The definition used by IEEE for distributed generation is "the generation of electricity by facilities that are sufficiently smaller than central generating plants as to allow interconnection at nearly any point in a power system" (Esmaeilzadeh, Alizadeh-Sherayeh, Tohidifar, Mazaheri-kalahrodi, & others, 2015). Unlike the traditional centralized generation, distributed generation refers to a method in which a part of the electric power is generated and delivered to customers with small generation units placed close to the end users (Pesaran H.A, Huy, & Ramachandaramurthy, 2017). Distributed production is seen as a change in the energy production paradigm in the world (Quiroga, Almeida, Kagan, & Kagan, 2018).

Distribution networks have increased reliability and security with the penetration of distributed generations and the application of automation functions that imply in topological reconfigurations (da Silva et al., 2018). Since distributed generation supports renewable energy sources, it contributes to the reduction of greenhouse gas emissions that cause climate change (Saeedi, 2016). The possibility of widespread production in small powers by distributed generation, promises a more reliable supply of energy compared to the centralized production of conventional systems (Turan, 2014). Distributed generation will be a significant economic factor for distributed generation developers/owners, as well as reducing energy losses, increasing energy supply continuity and other noted technical benefits (Anaya & Pollitt, 2017). However, besides all these technical/economic advantages, distributed generation power plants may contribute to short-circuit current in the junction which they are connected. This may prevent the existing protection systems from functioning properly (Çetinkaya & Dumlu, 2013). The insertion of other sources in the distribution system may cause impacts on the quality of the energy generated as well as it can alter the power flow and modify voltage values and short circuit currents (Mendes, Vargas, Batista, & Simonetti, 2018). In order to integrate this kind of energy generation, technical challenges in protection schemes must be overcome (Santos, Lopes, & Reis, 2018).

DG may have detrimental effects on the protection coordination of overcurrent relays regarding varying short circuit levels. Overcurrent relays are necessary to ensure the reliability of the power system by avoiding malfunction and the unnecessary outage of the healthy part of the system (Sookrod & Wirasanti, 2018). The potential problems to protection are mainly protection under-reach and false-tripping. When a large production unit or several small ones are connected to medium voltage network, the fault current seen by the feeder protection relay may be reduced, which can lead to prevention of the operation of overcurrent relays. This is called protection under-reach or blinding of protection. In addition, the healthy state current seen by the feeder protection relay may be increased in some points of the topology, which can lead to false-tripping of overcurrent relays (Kauhaniemi, 2004).

The extent to which distributed generation can be implemented in a distribution system is determined both by the technical capacity of the network and by the current legislation. For example, the current regulations in Turkey limit the distributed generation (including PV) connection power per plant by 1 MW (EMRA, 2013). However, since there can be many independent power plants on the same feeder, the limit of the distributed generation power is determined by the network. Even if the capacity of the network is not strained, the distributed generation can disrupt the relay coordination. In other words, distributed generation limited by network capacity may not be sufficient for a secure protection system and lead to degradation of relay coordination. With the widespread use of distributed generations, protection systems of electrical networks will face new challenges. This is due to the additional fault current injected by distributed generators to network faults (Mohammadi Chabanloo, Ghotbi Maleki, Mousavi

Agah, & Mokhtarpour Habashi, 2018). Testing the possibility of relay coordination to malfunction by simulations will provide a good insight into the future of distributed generation; since distributed generation has not yet become widespread. The predictions provided by this study are important, since solar power plants which are Turkey's leading energy source for electricity generation among the distributed generation plants correspond to 0,38 % of the total generation yet (TEDAŞ, 2017b). The challenges such as increasing fault current levels and bi-directional power flow must be assessed in advance so that distributed generation can grow safely and continuously in the future (Van der Walt, Bansal, & Naidoo, 2018).

In order to test the relay coordination in the network, realistic models should be used. Radial-operated distribution systems can have many different forms. However, a few models to summarize all the forms can be identified. In these models, how the short-circuit protection behaves for the contribution of the various levels of distributed generation has been determined using simulations via PSCAD.

Distribution feeders single-phase short-circuit current is limited by 1 kA, while distribution feeders three-phase short-circuit current is limited by 16 kA in Turkey (EMRA, 2014). Therefore, the relay coordination for the single-phase short-circuit current will be affected by the short-circuit contribution of the distributed generation plants, earlier and more adversely. For this reason, single-phase short-circuit current is modeled and simulated in the study.

Distributed generation legislation in Turkey (unlicensed electricity production), promotes MV level electricity generation rather than LV level electricity generation (EMRA, 2013). Thus, in modeling and simulations, distributed generation at the MV level is modeled, or distributed generation at the AG level is modeled at the equivalent power in the MV level. That is, the protection issue has been examined at the MV level.

According to the IEEE's forecasting survey in Germany, Denmark, and Sweden, three leading countries of distributed generation, the expectations about various energy sources is as follows (Anaya & Pollitt, 2014).

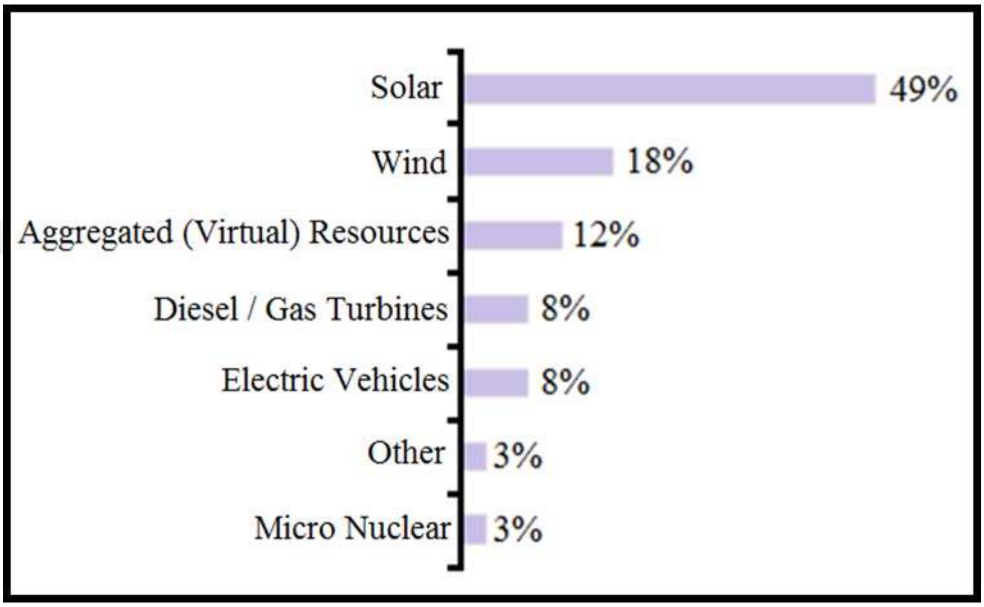

Figure 1.1. Distributed generation sources with the expected demand in Germany, Denmark, and Sweden (IEEE Comission, 2012)

On the other hand, installed power statistics as per source type in Turkey, published by TEIAS as of April 30, 2017, is as follows (TEİAŞ, 2017b). Instead of the entire table, only the relevant part is presented.

Table 1.1. Installed powers of resources in Turkey

Source Type	Installed Power (MW)	Number of Power Plants
Wind (Unlicensed)	16,5	27
Solar (Unlicensed)	1.090,8	1.355

Moreover, installed power statistics by source type published by TEIAS in 2018 is in the table below (TEİAŞ, 2018). The installed power ratio of unlicensed solar power plants among other unlicensed resource types is specified as 93,9%, in the EMRA's market development report published in 2018, as to support the following table (EMRA, 2018).

Table 1.2. Installed powers of resources in Turkey-detailed

SOURCE TYPE	THE END OF YEAR 2017			FEBRUARY 2018		
	INSTALLED POWER MW	CONTRIBUTION %	NUMBER OF POWER PLANTS	INSTALLED POWER MW	CONTRIBUTION %	NUMBER OF POWER PLANTS
SOLAR (UNLICENSED)	3.402,8	93,3%	3.613	3.919,2	93,2%	4.704
THERMAL (UNLICENSED)	201,1	5,5%	67	231,2	5,5%	79
WIND (UNLIENSED)	34,0	0,9%	46	46,9	1,1%	62
HYDRAULIC (UNLICENSED)	7,4	0,2%	10	7,4	0,2%	10
TOTAL	**3.645,3**	**100,0%**	**3.736**	**4.204,7**	**100,0%**	**4.855**

Distribution of unlicensed power generation projects delivered over the years is in the figure below (Şimşek & Bizkevelci, 2018).

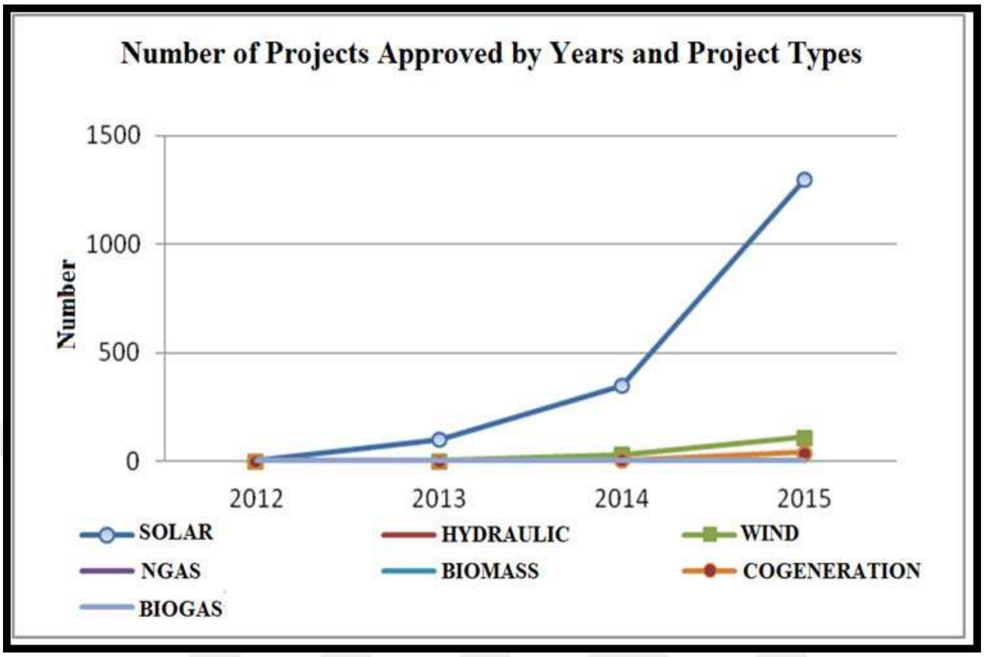

Figure 1.2. Proposed projects respect to energy sources and years

In addition, project approval application and approval status statistics according to the types of resources included in the annual report published by TEDAS in 2017 are in the table below (TEDAŞ, 2017a).

Table 1.3. Projects by source type

SOURCE TYPE	APPLIED PROJECTS NUMBER	APPLIED TOTAL kW	APPROVED TOTAL PROJECTS NUMBER	APPROVED PROJECTS INSTALLED POWER kWe
BIOMASS	77	97.201	44	62.879
SOLAR	8.713	7.133.784	7.956	6.655.183
HYDRAULIC	10	6.604	3	3.030
EMG	31		19	
WIND	338	272.205	240	208.021
TRI/COGENERATION	91	244.716	69	189.877
TOTAL	**9.260**	**7.754.510**	**8.331**	**7.118.990**

Figure 1.1 shows that solar power plants have a high application potential in the leading countries of distributed generation. As supported from Table 1.1, Table 1.2, Table 1.3 and Figure 1.2; PV plants dominate the network in distributed generation due to market conditions, legislation and technological advancement levels in Turkey. Therefore, it is envisaged that the most widespread of distributed generation will be provided by PV power plants. For these reasons, the single-phase short-circuit contribution of PV power plants at MV level is one of the most important specific issues for distributed generation.

1.2. Designated topology for modeling

In the radial-operated distribution network, the main busbar in a distribution center is energized by the main feeder. The power reaching this busbar is distributed by other feeders. The distribution feeders can be numerous; some distribution feeders may include distributed generations as well as loads, while other distribution feeders may only have loads. In short, there are three types of feeders in terms of short circuit analysis in distributed generation:

i. The main feeder that energizes the distribution busbar
ii. The downstream feeder which is fed from the main distribution busbar and including the solar power plants
iii. The downstream feeder which is fed from the main distribution busbar and including no solar power plants

According to this classification and in the direction of the current unlicensed power plant application trend, in order to efficiently investigate the distribution system of the future, a sufficient and compact topology model has been created.

1.3. Distribution Systems Network Parameters

In the basic topology covering distribution network topologies, commonly used line characteristics of the distribution network are used to provide a realistic model of the distribution network and to obtain near-realistic results in simulations. Hawk conductor, 1X150 / 25 cross-sectioned-XLPE insulated-aluminum core cable and 1X95 / 16 cross-sectioned-XLPE insulated-copper core cable are used for modeling respectively the main feeder and distribution feeders. The feeder characteristics in the modeled network are given in the table below.

Table 1.4. Feeder parameters – commonly used

Feeders	**F0**	**F1**	**F2**
Line Characteristics	3xHawk	3x1x150/25 XLPE AL	3x1x95/16 XLPE CU
Length (km)	8	4	4
Load ∑ MW	0	16	13
Load ∑ MWAR	0	1	1
Solar ∑ MW	0	5	0

The TS parameters used in the modeled network are given in the table below.

Table 1.5. TS parameters – commonly used

Parameter	**Substation Values**
Short Circuit Current in Primary (kA)	5,85
Voltage Level in Primary (kV)	154
Short Circuit Power in Primary (MVA)	1.561
Thevenin Equivalent Impedance of Primer Network (Ω)	15,19
Thevenin Equivalent Inductance of Primer Network (mH)	48,40
Voltage Level in Secondary (kV)	34,5
Secondary Wound Neutral Resistance (Ω)	20,00
Short Circuit Impedance Voltage of the Transformer (%)	12,60
Rated Power of the Transformer (MVA)	50
Serial Impedance of the Transformer (Ω)	2,91
Serial Inductance of the Transformer (H)	0,0093

In the later sections of the thesis, the topology developed in PSCAD is modeled using the parameters specified in Table 1.4 and Table 1.5.

1.4. Possible New Techniques to Mitigate Adverse Effects of Distributed Generation Applications

It is foreseen that the common features of all possible ways of limiting the adverse effects of distributed generation on the existing relay coordination in the distribution network are as follows.

i. Limiting the solar power plant short-circuit contribution current somehow
ii. Increasing the tolerance of circuit breaker relays to generation variations and load changes

Some of the methods that have or are likely to have these common characteristics are listed below.

i. Keeping the trip time so small for inverter protection
ii. Keeping the instantaneous trip current setting in the circuit breaker relays at the lowest level that does not disturb the selectivity
iii. Using distance relays in the distributed networks where distributed generation are included or may likely be connected
iv. Limiting the power of solar power plants to be connected to the network
v. Connecting the solar power plant to the network via a serial reactance and limiting short-circuit contribution by the serial reactance etc.

It will be ensured that the benefits of distributed generation which reduce losses, increase network stability, and increase renewable energy use is safely obtained with the implementation of these methods.

1.5. Scope of the Thesis

The subject of the thesis is the development of a simulation platform in which distributed generation systems can be modeled for protection analysis. As a result of the researches and examinations made within this scope; the thesis is concentrated on the effects of the MV level distribution network connected solar energy plants on single phase short circuit protection due to the current legislation in our country, the design of the distribution network in our country and the trends of distributed generation systems around the world. In the literature, it is seen that the IEEE 13-Node or IEEE 34-Node radial distribution test feeder topologies are frequently used when the distribution grid is investigated. In order to investigate the current and future distribution system in a practical and effective way, an adequate and required topology which is alternative for these topologies was developed and tested in the PSCAD platform.

In addition, an Excel-based calculation/simulation platform was created in the direction of the thesis. The main reason for creating this platform is the absence of a simulation program that can model the distribution network of Turkey in a realistic way. Although PSCAD was chosen for the simulation work to be done in this thesis study, an Excel-based computing platform was additionally needed to model the distribution system in the most realistic way.

On the main page of the computing platform, there is a circuit structure ready to be simulated in PSCAD as seen below. This circuit can be a radial designed feeder fed from a single transformer station or it can be designed as a tie designed circuit which can be fed from two different transformer centers and can feed up to 7 distribution centers. Several macros are running on the backplane for the necessary calculations can be made and in order to switch between the pages where parameters are entered and the pages where subdirectories are located.

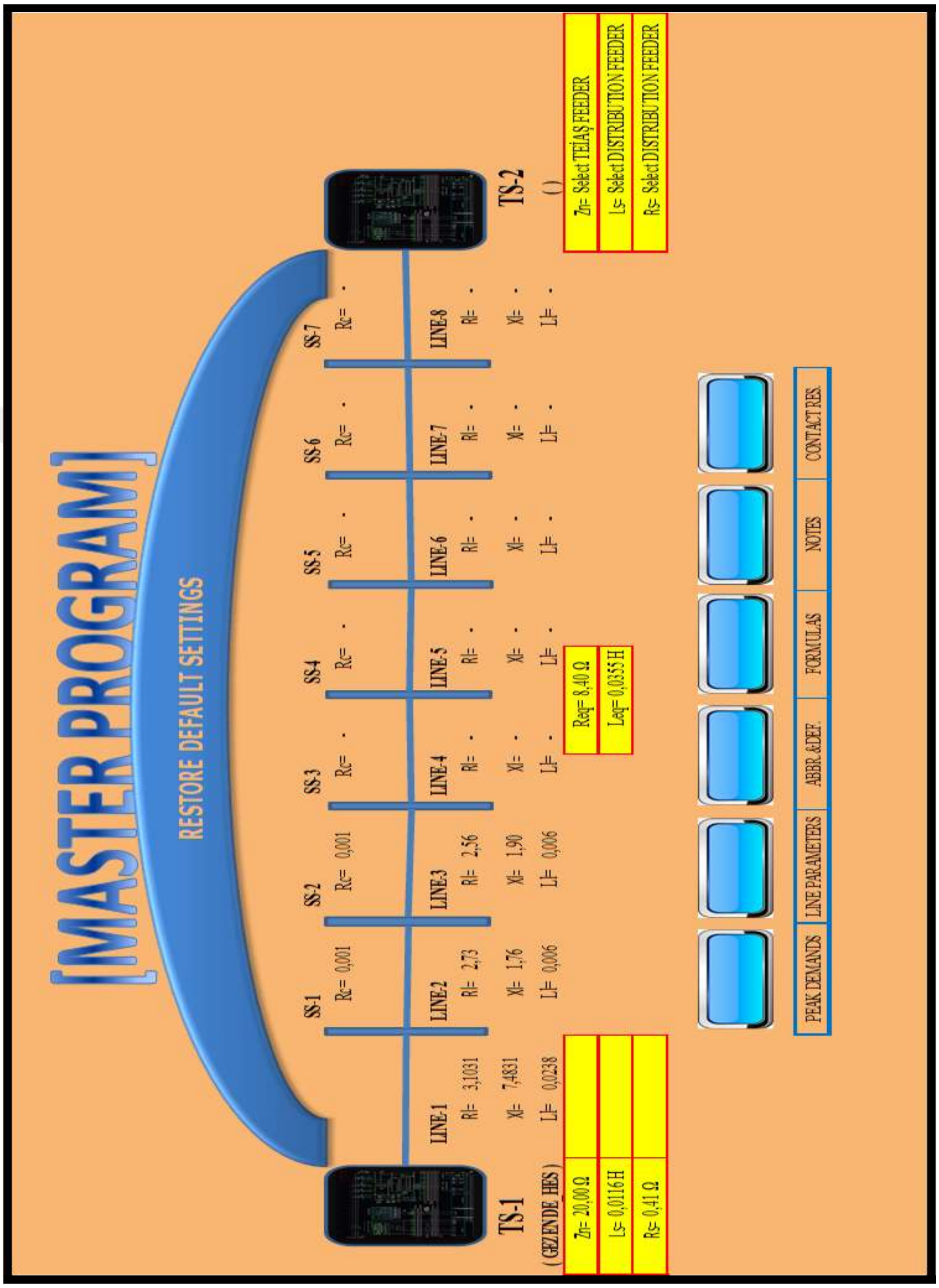

Figure 1.3. Master Program

There are two separate TEİAŞ transformer substations, 8 separate main feeders and 7 distribution centers that can be selected in the circuit shown in this page. When TS-1 is clicked, the following page is displayed where TS-1's parameters can be selected.

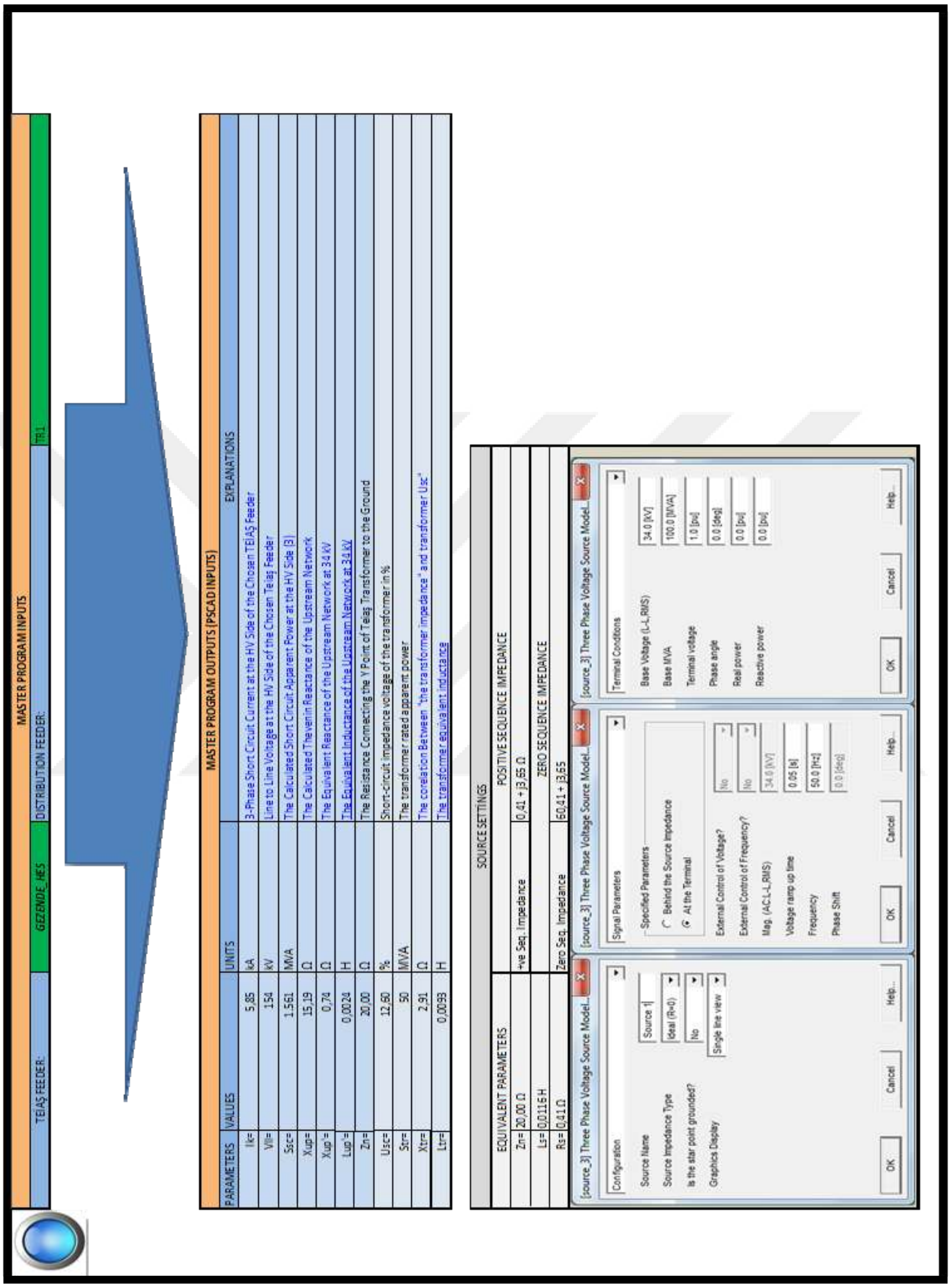

Figure 1.4. The configuration page of TS-1

In this page, it is seen that the relevant transformer substation belonging to TEİAŞ and the corresponding distribution feeder in this transformer center can be selected. After making these selections, it seems that the page has created the parameters that can be used by the PSCAD by making calculations related to the transformer center and the feeder. In order to be able to make these calculations, the program uses the data specified by TEİAŞ in the load distribution reports. These data can be accessed via the "PEAK DEMANDS" button on the main page of the program. A part of the program page where the data is available is shown below. Since there is a lot of data on the page, only a part of it is shown below.

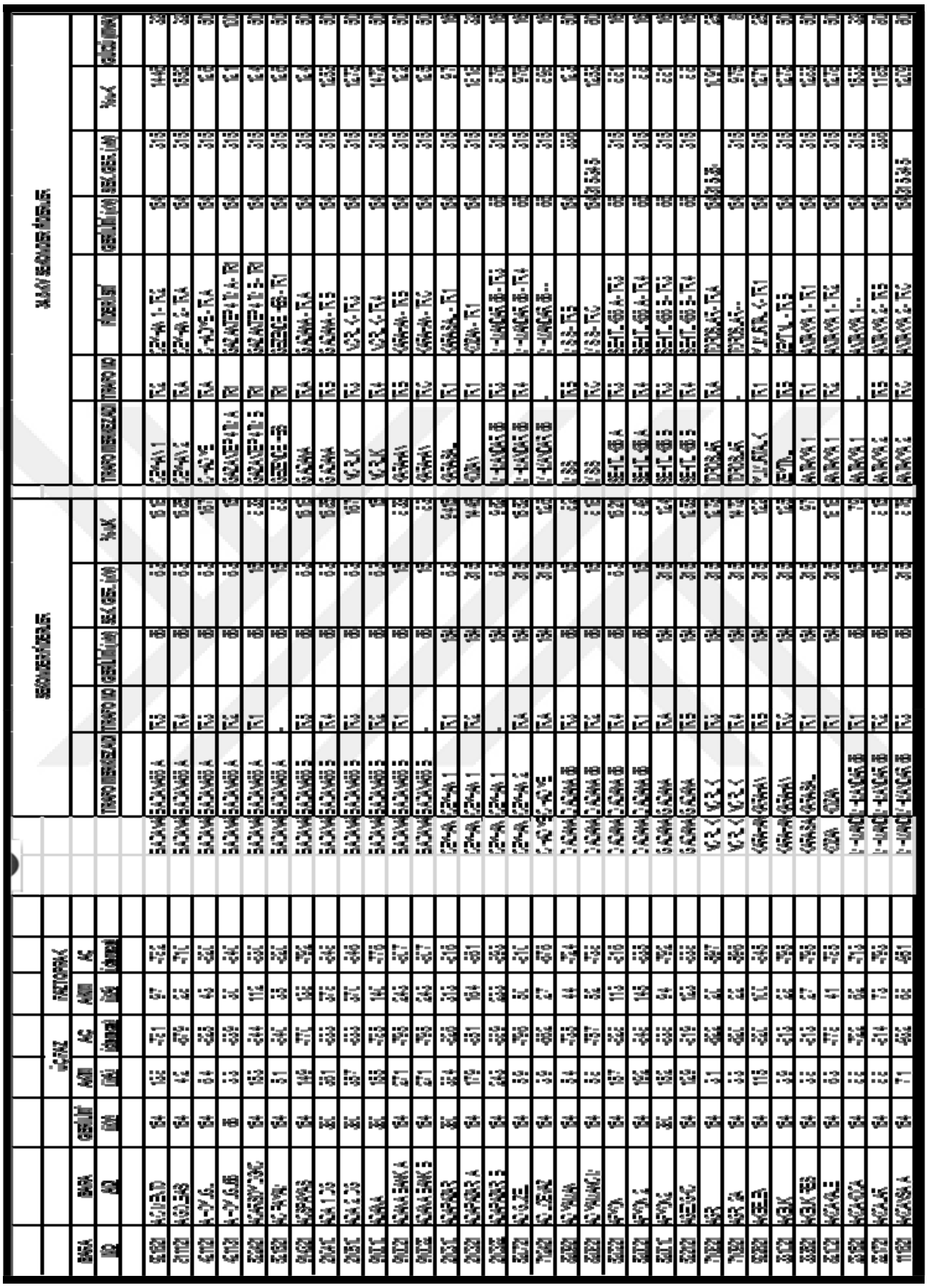

Figure 1.5. Peak Demands Page

In addition, it is also specified to which screens the parameters (the source parameters calculated on TS-1 page) will be entered. On the main page of the program after the selection of transformer substations, the pages where the characteristics of the lines, the circuit length and the number of circuits can be selected can be entered. The following example page shows the page of Line-1.

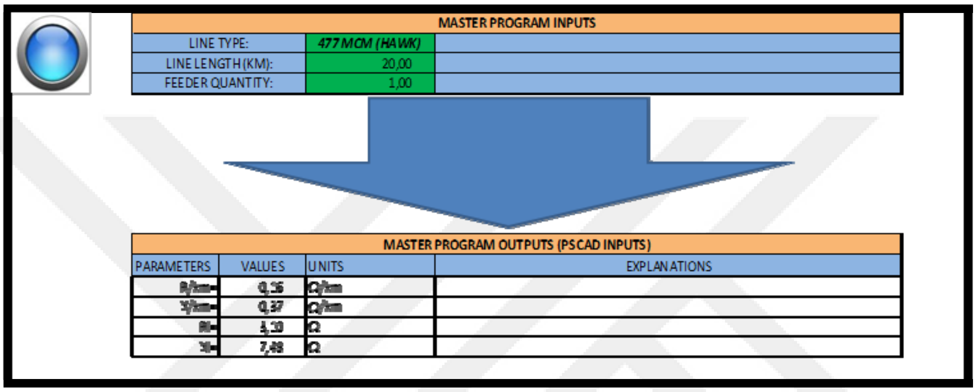

Figure 1.6. The configuration page of Line-1

In this page, the feeder characteristics, the circuit length and the number of circuits are entered in the green color specified area. Then the program calculates the feeder parameters in a way that PSCAD can use. The background page which allows calculation of feeder parameters can also be accessed with the "LINE PARAMETERS" button on the main screen. Such data page can be seen below.

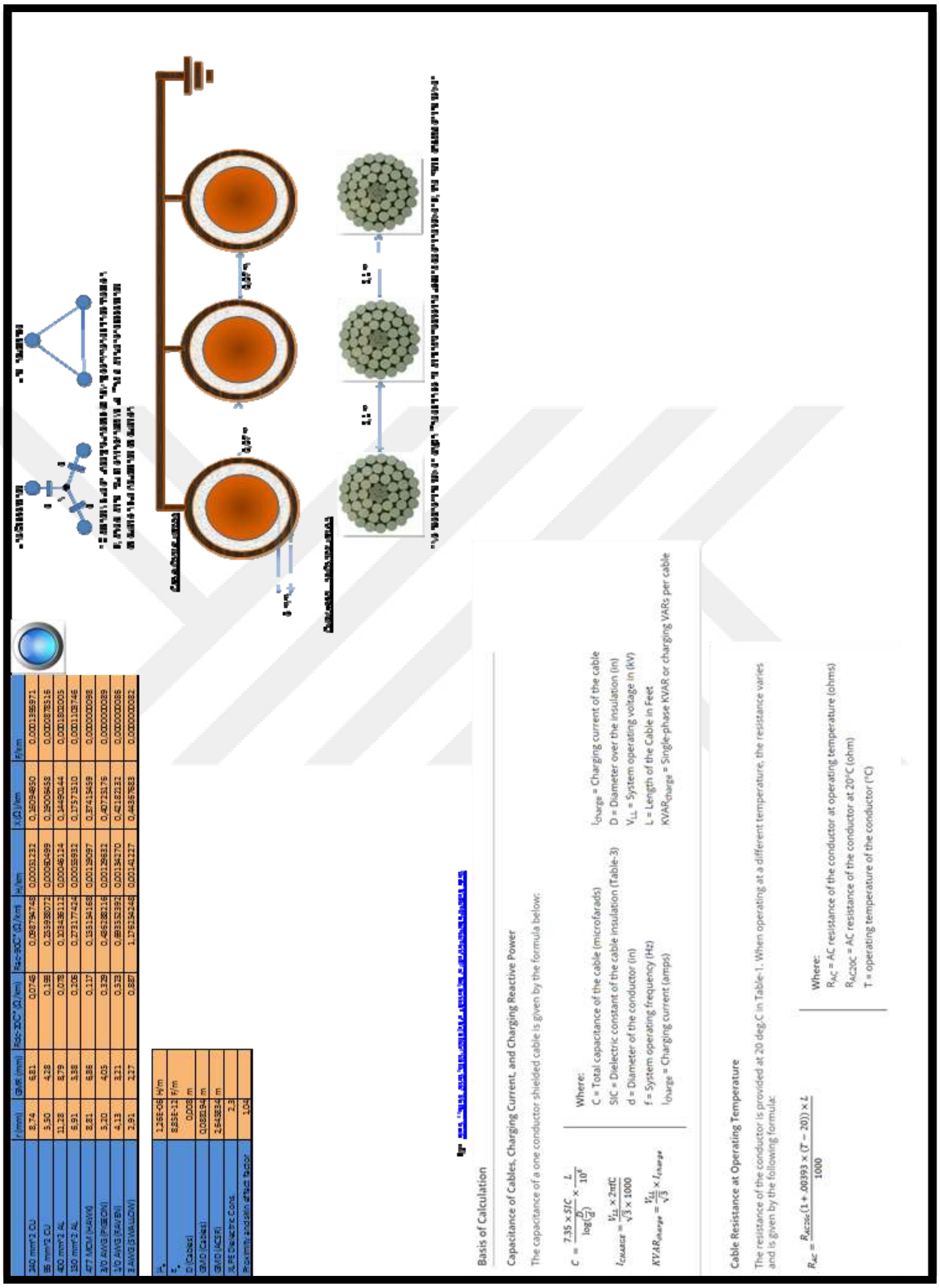

Figure 1.7. Line parameters page

One of the distribution substations on the main page of the program can be clicked so that the distribution substations can be modeled after the TS and the lines.

The following example shows SS-1 page.

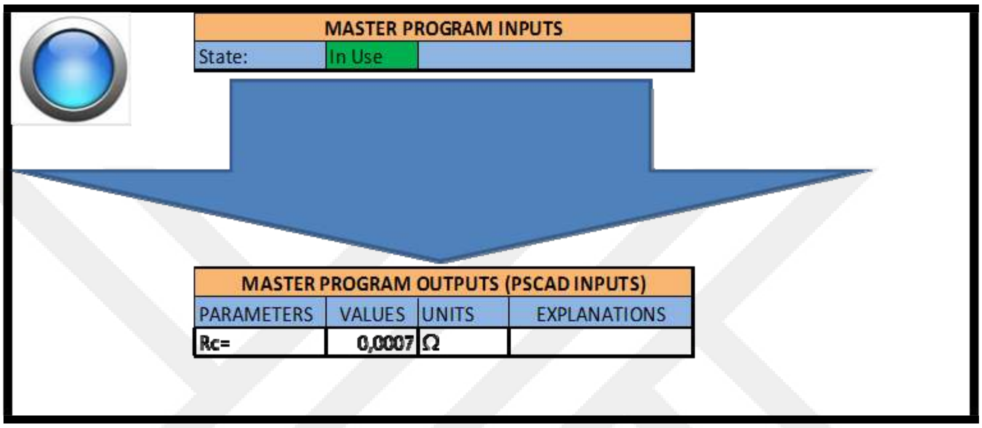

Figure 1.8. The configuration page of SS-1

When the distribution center is selected as included in the circuit in this page, the program calculates the contact resistances in the distribution substations so that the contact resistances of the circuit breakers can be included in the simulation. On the main page of the program, TS parameters, line parameters, contact resistance parameters, formulas used by the program, abbreviations used by the program, and notes about the program can be accessed by separate buttons. Some of the pages which contain formulas can be seen below. A part of the page which contains formulas can be seen below.

#	FORMULA	EXPLANATION
1	$Z_{tr} = \frac{U_k \times V_B^2}{S_{tr}} \approx X_{tr}$	The corelation Between "the transformer impedance" and transformer Usc"
2	$Z_{up} = \frac{U^2}{S_{sc}} \approx X_{up}$	The Calculated Thevenin Reactance of the Upstream Network
3	$S_{sc} = \sqrt{3} \times I_{sc} \times V_{ll}$	The Calculated Short Circuit Apparent Power. It is the absolute value of the complex power. It is a scalar value.
4	$\frac{R_1}{R_2} = \frac{V_{1tr}^2}{V_{2tr}^2}$	The Equivalent Resistance at Both Side of Transformer
5	$X_L = \omega \times L$ $X_L = 2 \times Pi \times f \times L$ $L = \frac{X_L}{2 \times Pi \times f}$	The Corelation Between Inductance and Reactance
6	$X_C = -\frac{1}{\omega C} = -\frac{1}{2\pi f C}$	The Corelation Between Capacitance and Reactance
7	$GMD = \sqrt[3]{D_{ab} D_{bc} D_{ca}}$ $L = 2 \times 10^{-7} \ln \frac{GMD}{r'}$ H/m	3 phase inductance GMD: Geometric Mean Distance REF: http://nptel.ac.in/courses/Webcourse-contents/IIT-KANPUR/power-system/chapter_1/1_8.html
8	$C = \frac{q_a}{V_{an}} = \frac{2\pi \varepsilon_0}{\ln(GMD/r)}$ F/m	3 phase capacitance ε: permittivity $\varepsilon_0 \approx 8.854\,187\,817\,620... \times 10^{-12}$ F·m^{-1}

Figure 1.9. Formulas page

As a result, the excel-based calculation and simulation platform makes it very easy to simulate the distribution network in the PSCAD, and the data used for the calculation is easily accessible. In addition, the program design provides ease of use, clarity, comprehensibility and reliability in calculation.

1.6. Objectives and Disposition of the Thesis

The objectives of this thesis are as follows:

- To determine the benefits of distributed production
- To understand the evolution of distributed production worldwide
- To predict the future of distributed generation in Turkey
- To identify the distribution network problems in the world's leading countries originating from distributed generation
- To anticipate difficulties that may arise in Turkey's distribution network due to distributed generation
- To anticipate in which parts of the network and under what conditions the distributed production can cause distress
- To identify the parts of distributed generation that need to be focused in the reality of Turkey
- To create a calculation and simulation platform for easy and efficiently modeling of distributed generation and distribution network
- To develop an alternative and more efficient topology than the existing frequently used topologies for easy analysis and modeling of distributed generation and distribution network
- To identify possible problems of the network to be faced with the aid of the computation platform on the developed topology
- Foreseeing new methods for reducing / eliminating possible adverse effects of distributed generation on network protection systems

- To test new methods on the developed topology with the help of the calculation platform,
- To develop an algorithm that explains in which parts of the network and under what conditions the new methods can be used ,
- Beyond this work, to identify the common features of the methods that can be used in future work, to provide light for future work.

1.7. Contributions of the Thesis

This thesis project provides the following original contributions to the research and application area of smart systems;

- Wide application of distributed generation, especially solar energy power plants, in the future is investigated and the possible effects on the existing relay coordination are predicted. In the network topology where the solar power plants are connected, the branches are systematically investigated in terms of safety. In order to conduct this investigation, the superposition analysis was applied for the first time in distributed generation short-circuit analysis. The superposition analysis serves practical and easy ways to examine the effects of distributed generation on the distribution network.
- As a result of the researches and examinations made within this scope; it is determined that the corresponding works in the field should be concentrated on the effects of the MV level distribution network connected solar energy plants on single phase short circuit protection due to the current legislation in our country, the design of the distribution network in our country and the trends of distributed generation systems around the world.
- A calculation and simulation platform has been created for easy and effective modeling of distributed generation and distribution network. To

obtain realistic results in PSCAD simulations, an Excel-based computing platform was developed that calculates the distribution network parameters to be used in the PSCAD. In addition, the Excel-based calculation and simulation platform makes it very easy to simulate the distribution network in the PSCAD, and the data used for the calculation is easily accessible. Also, the program design provides ease of use, clarity, comprehensibility, and reliability in calculation.

- The literature survey shows that the IEEE 13-Node or IEEE 34-Node radial distribution test feeder topologies have been frequently used when the distribution network is examined. However, instead of using these topologies, an alternative topology which is sufficient and more useful for the required PSCAD simulations has been developed and tested in PSCAD with the help of the Excel-based calculation platform.

1.8. Outline of the Thesis

The content of the thesis is arranged as follows:

After an introductory section where the research motivation, the designated topology for modeling, the design parameters, distribution system network parameters, possible new techniques to mitigate adverse effects of DG systems are given, the scope, objectives and disposition, and contributions of the thesis are introduced.

In Chapter 2, the literature survey studies on the comparison of distributed generation systems and conventional distribution systems, benefits and challenges of distributed generation systems, corresponding legislation-regulations and statistics of Turkey and useful analysis methods and likely beneficial applications for distributed generation systems is given.

In Chapter 3, the designated topology for modeling is explained. The basic parts of the topology are classified.

In Chapter 4, the network parameters (Line characteristics of the feeders, TS parameters etc.) of the simulated model is given. 11 cases under the topics “Healthy Network (Steady State) Analysis”, “Short-Circuit 0 (SC0) Analysis”, “Short-Circuit 1 (SC1) Analysis”, “Short-Circuit 2 (SC2) Analysis and Limiting Overcurrent Time Value of the Inverter” are simulated. The simulation results of all 11 cases are given and interpreted.

In Chapter 5, the definition, characteristics, and benefits of distance relays are given. The convenient properties of distance relays for DG protection are explained.

In Chapter 6, all the study is summarized and likely future works are stated.

Finally, all the references used in the thesis, biographical information of the author and sections of the Appendices are presented.

2. REVIEW OF RELATED LITERATURE

In the literature review section, especially studies published in the last few years and related works published in the wider time interval have been reviewed. Such studies are related with distributed generation systems, new concepts about relay coordination, unlicensed power generation, solar power plants, renewable energy power plants, protection issues of distributed generation systems, other issues of distributed generation systems and distance relays. Especially, theses, journal articles and conference publications published in IEEE, IEE, SCIENCE DIRECT digital libraries, and PROQUEST Dissertation and thesis database have been investigated. In addition, the current legislation in Turkey and relevant books on the subject was examined extensively and thoroughly. In all studies, protection issues are the most prominent subject among others. The most important problem that can be encountered in the future of distributed generation, and the circumstances under which this problem may arise have been determined by the help of results reached in the direction of literature studies, examination of the problems encountered in the leading countries of distributed generation and investigation of the structure of current legislation and the existing network in Turkey. Accordingly, it is recommended that the corresponding works in the field should be concentrated on the effects of the MV level distribution network connected solar energy plants on single phase short circuit protection due to the current legislation in our country, the design of the distribution network in our country and the trends of distributed generation systems around the world.

Under the following sections, the latest literature including research articles, conferences, e-books, company reports, web pages, MSc and PhD theses related to the topic of this thesis are summarized in detail.

2.1. Comparison of Distributed Generation Systems (DG) and Conventional Distribution Systems

Distributed generation systems are implemented in both low voltage systems and medium voltage systems. That is to say, Distributed generation systems are implemented in distribution system. The distribution system structure is explained in short as follows.

There are two fundamental types of the structure; radial and ring (loop). Simply defined, a radial system has only a single direction current flow. A ring (loop)-tie feeder has bidirectional current flow (Short, 2004).

The radial-tie and ring structures of distribution system are shown in the following figure.

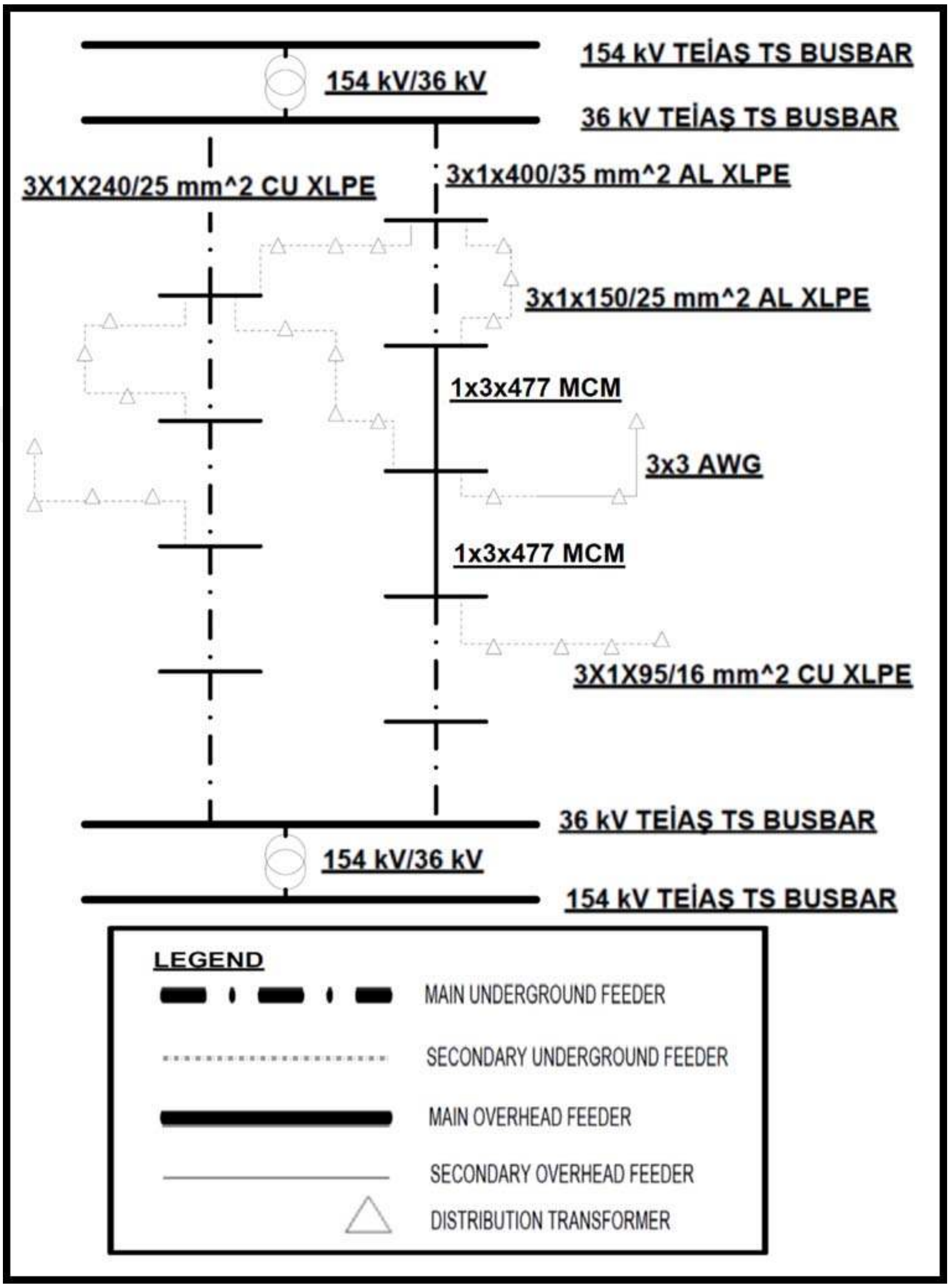

Figure 2.1. Distribution system structures

The concept of DG contrasts with the traditional centralized power generation concept, where the electricity is generated in large power stations and is transmitted to the end users through transmission and distributions lines. While central power systems remain critical to the global energy supply, their flexibility to adjust to changing energy needs is limited. Central power is composed of large capital-intensive plants and a transmission and distribution grid to disperse electricity (Dede, 2013).

On the other hand, increasing interest to alternative energies provides small-scale power plants to be installed where the demands or sources are located; in case of renewable energy for example power plants are installed in areas where the sources are free, like in wind energy, tidal energy, geothermic energy and so on. It is much cheaper and easier to meet a growing local demand for electricity by adding new generators close to the load than by adding transmission capacity. This is partly because of the lengthy permitting process required for new transmission lines. Modular power plants can be approved and sited close to a new load in a matter of months, versus several years for transmission line upgrades. Transmission networks are also inherently expensive to build and maintain (Herig, 1999).

There are multiple definitions in the literature for distributed production. The definition used by the IEEE for distributed manufacturing is "the generation of electricity by facilities that are sufficiently smaller than central generating plants as to allow interconnection at nearly any point in a power system " (Esmaeilzadeh et al., 2015). In addition, one of the most common prospects of all these definitions is that DG is commonly perceived as small-scale electricity generation nearby the consumer. A simple definition has been provided by the European Commission as "*a source of electric power connected to the distribution network or the customer side*" (Coster, Myrzik, & Kling, 2009).

Unlike the traditional centralized generation, distributed generation refers to a method in which a part of the electric power is generated and delivered to customers with small generation units placed close to the end users (Pesaran H.A et al., 2017). Distributed production is seen as a change in the energy production paradigm in the world (Quiroga et al., 2018).

2.2. Benefits and Challenges of Distributed Generation Systems (DG)

There are many studies regarding the benefits of distributed systems. Since distributed generation supports renewable energy sources, it contributes to the reduction of greenhouse gas emissions that cause climate change (Saeedi, 2016). The possibility of widespread production in small powers by distributed generation promises a more reliable supply of energy compared to centralized production of conventional systems (Turan, 2014). Distributed generation will be a significant economic factor for distributed generation developers/owners, as well as reducing energy losses, increasing energy supply continuity and other noted technical benefits (Anaya & Pollitt, 2017). Distribution networks have increased reliability and security with the penetration of distributed generations and the application of automation functions that imply in topological reconfigurations(da Silva et al., 2018).

However, besides all these technical/economic advantages, there will be many issues arising from the widespread implementation of distributed generation systems. The insertion of other sources in the distribution system may cause impacts on the quality of the energy generated as well as it can alter the power flow and modify voltage values and short circuit currents(Mendes et al., 2018). In order to integrate this kind of energy generation, technical challenges in protection schemes must be overcome(Santos et al., 2018).

There are studies on the following issues throughout the literature:

- Communication and Control of Distributed Generation Systems
- Power Quality Improvements – Storage Systems
- Distributed Generation Inverters (Multifunctional: Interface, Active Filtering, Power Factor Improvement)
- Power Loss Improvements
- Voltage Profile Improvements
- Fault Tolerance
- Protection Issues

Distributed generation has many weak or problematic points that need improvement as listed above. Protection has the greatest importance among these issues for implementing this new concept.

DG may have detrimental effects on the protection coordination of overcurrent relays regarding varying short circuit levels. Overcurrent relays are necessary to ensure the reliability of the power system by avoiding malfunction and the unnecessary outage of the healthy part of the system(Sookrod & Wirasanti, 2018). The potential problems to protection are mainly protection under-reach and false-tripping. When a large production unit or several small ones are connected to medium voltage network, the fault current seen by the feeder protection relay may be reduced, which can lead to prevention of the operation of overcurrent relays. This is called protection under-reach or blinding of protection. In addition, the healthy state current seen by the feeder protection relay may be increased in some points of the topology, which can lead to false-tripping of overcurrent relays (Kauhaniemi, 2004).

Distributed generation power plants may contribute to short-circuit current in the junction which they are connected. This may prevent the existing protection systems from functioning properly (Çetinkaya & Dumlu, 2013).

2.3. Review of Corresponding Legislation, Regulations and Statistics of Turkey

The extent to which distributed generation can be implemented in a distribution system is determined both by the technical capacity of the network and by current legislation. For example, current regulations in Turkey limit the distributed generation (including PV) connection power per plant by 1 MW (EMRA, 2013). However, since there can be many independent power plants on the same feeder, the network determines the limit of the distributed generation power. Even if the capacity of the network is not strained, the distributed generation can disrupt the relay coordination. In other words, distributed generation limited by network capacity may not be sufficient for a secure protection system and lead to degradation of relay coordination. With the widespread use of distributed generations, protection systems of electrical networks face new challenges. This is due to the additional fault current injected by distributed generators to network faults (Mohammadi Chabanloo et al., 2018). Testing the possibility of relay coordination to malfunction by simulations will provide a good insight into the future of distributed generation; since distributed generation has not yet become widespread. The predictions provided by this study are important since, solar power plants which are Turkey's leading energy source for electricity generation among the distributed generation plants, correspond to 0,38 % of the total generation yet (TEDAŞ, 2017b). The challenges such as increasing fault current levels and bi-directional power flow must be assessed in advance so that distributed generation can grow safely and continuously in the future (Van der Walt et al., 2018).

Distribution feeders single-phase short-circuit current is limited by 1 kA, while distribution feeders three-phase short-circuit current is limited by 16 kA in Turkey. (EMRA, 2014). Therefore, the relay coordination for the single-phase short-circuit current will be affected by the short-circuit contribution of the

distributed generation plants, earlier and more adversely. For this reason, single-phase short-circuit current is modeled and simulated in the study.
Distributed generation legislation in Turkey (unlicensed electricity production), promotes MV level electricity generation rather than LV level electricity generation (EMRA, 2013). Thus, in modeling and simulations, distributed generation at the MV level is modeled, or distributed generation at the AG level is modeled at the equivalent power MV level. That is, the protection issue has been examined at the MV level.

The studies throughout the literature and the statistics about Turkey denote that PV plants dominate the network in distributed generation due to market conditions, legislation and technological advancement levels in Turkey (Anaya & Pollitt, 2014) (IEEE Comission, 2012) (TEİAŞ, 2017b) (TEİAŞ, 2018) (EMRA, 2018) (Şimşek & Bizkevelci, 2018) (TEDAŞ, 2017a). Therefore, it is envisaged that the most widespread of distributed generation will be provided by PV power plants. For these reasons, the single-phase short-circuit contribution of PV power plants at MV level is one of the most important specific issues for distributed generation.

2.4. Useful Analysis Methods and Likely Beneficial Applications for Distributed Generation Systems (DG)

The superposition analysis is used in this study in order to efficiently examine how the rated and short-circuit currents of DG will affect the relay coordination. The main idea of using theorem of superposition in the distribution system with EGs is to decompose the original distribution system with an EG in two systems: a passive distribution system without EGs where the system state is actually known, and a fictive, “no main generator units” system, where only the considered EG operates. According to the theorem of the superposition, the state in the fictive, “no main generator units” system actually represents the impact of EG on the overall system(Ciric, Nouri, & Feltrin, 2005). That is to say, according to the superposition theory which can be applied to the linear electric circuits, the network reaction to SPP and the network reaction to TS can be examined separately. The system power is equivalent to a voltage source with short circuit, and the DG power equivalent to that of the current source with open circuit (Yang & Li, 2011). According to the superposition theory which can be applied to the linear electric circuits, the response of the network to the TS and the response to the DG can be examined separately. The sum of the two responses will be equal to the response of the network when both TS and DG are engaged (Riedel & Nilsson, 2010). The results of the superposition analysis will deviate slightly, even if it is close to reality. Because in superposition analysis, the equivalent impedance of the current or voltage sources should not be deactivated, the voltage source should be short-circuited and the current source should be open-circuited (Riedel & Nilsson, 2010).

One of the main reasons for the deterioration of the relay coordination is that the existing relays cannot tolerate varying power and load conditions. The relays which might be the solution to such problem should be able to adapt to changing network conditions. The currents in the network can change quite a lot, due to the loads and production resources added to the distribution system as time goes on and the changes in the production powers in the system during the day. The equivalent impedance of the mains is less affected than the currents in the mains. When the literature is examined, it can be seen that the distance relays that generate the trip signal over the impedance value instead of the current or voltage values in the network, can be used. At this point, the distance relays can be used in distribution systems where distributed generation is made. These relays, which are based on the principle that the impedance is obtained by the ratio of the voltage phasor to the current phasor, determine the fault and fault location according to the value of the calculated impedance. (Bayrak & Usta, 2018). Therefore, the distance relays that generate the trip signal according to the measured impedance value detect faults more accurately than the overcurrent relays that generate the trip signal relative to the measured current values.

Besides, this type of relay is considered as a reasonable alternative to overcurrent devices susceptible to presence of upstream power flows and replacement for voltage protection of distributed generation (DG) units restricting their fault ride through (FRT) capability (Pandakov, Høidalen, & Marvik, 2016).

In addition, distance relaying in DG interconnections provide shorter fault-clearing times and allowing larger amounts of DGs to be connected to distribution system circuits (El-Arroudi & Joos, 2018).

From Gençaydın's standpoint, the distance protection is faster and more selective than the overcurrent protection. Moreover, the distance protection is more susceptible to changes in relative source impedances and system conditions. The tripping time is approximately 1 or 2 periods in the first zone, corresponding to respectively 20 or 40 ms. (Gençaydın, 2006).

Accordingly, the distance relays have a quick protection action by measuring the equivalent impedance value of the network. The equivalent impedance of the network is determined by the impedance value of the line instead of branch loads and branch production resources (Campos, 2018). Therefore, the network protection with distance relays will not be affected by the addition of new distributed generation plants to the grid, the change of distributed generation power in day-season-year or the change in consumption loads in the network.

2.5. Summary

In this section, a comprehensive review on new concepts about relay coordination, unlicensed power generation, solar power plants, renewable energy power plants, protection issues of distributed generation systems, other issues of distributed generation systems and distance relays are presented.

To summarize, while the definitions and related literatures are investigated, the following points have been drawn the attention.

In the first part of this section, the distributed generation systems are compared to the conventional distribution systems. While the definitions and related literature are investigated, the following points have been drawn the attention.

- There are two fundamental types of the structure; radial and ring (loop). Simply defined, a radial system has only a single direction current flow. A ring (loop)-tie feeder has bidirectional current flow(Short, 2004).
- The concept of DG contrasts with the traditional centralized power generation concept, where the electricity is generated in large power stations and is transmitted to the end users through transmission and distributions lines. While central power systems remain critical to the global energy supply, their flexibility to adjust to changing energy needs is limited. Central power is composed of large capital-intensive plants and a transmission and distribution grid to disperse electricity(Dede, 2013).
- Increasing interest to alternative energies provides small-scale power plants to be installed where the demands or sources are located; in case of renewable energy for example power plants are installed in areas where the sources are free, like in wind energy, tidal energy, geothermic energy and so on. It is much cheaper and easier to meet a growing local demand for electricity by adding new generators close to the load than by adding transmission capacity. This is partly because of the lengthy permitting process required for new transmission lines. Modular power plants can be approved and sited close to a new load in a matter of months, versus several years for transmission line upgrades. Transmission networks are also inherently expensive to build and maintain (Herig, 1999).
- There are multiple definitions in the literature for distributed production. The definition used by the IEEE for distributed manufacturing is "the generation of electricity by facilities that are sufficiently smaller than

central generating plants as to allow interconnection at nearly any point in a power system " (Esmaeilzadeh et al., 2015).

- One of the most common prospects of all these definitions is that DG is commonly perceived as small-scale electricity generation nearby the consumer. A simple definition has been provided by the European Commission as "*a source of electric power connected to the distribution network or the customer side*" (Coster et al., 2009).
- Unlike the traditional centralized generation, distributed generation refers to a method in which a part of the electric power is generated and delivered to customers with small generation units placed close to the end users (Pesaran H.A et al., 2017).
- Distributed production is seen as a change in the energy production paradigm in the world (Quiroga et al., 2018).

The second part of this section covers the benefits and challenges of distributed generation systems. The most prominent conclusions of this second section are as follows:

- Since distributed generation supports renewable energy sources, it contributes to the reduction of greenhouse gas emissions that cause climate change (Saeedi, 2016).
- The possibility of widespread production in small powers by distributed generation promises a more reliable supply of energy compared to centralized production of conventional systems (Turan, 2014).
- Distributed generation will be a significant economic factor for distributed generation developers/owners, as well as reducing energy losses, increasing energy supply continuity and other noted technical benefits (Anaya & Pollitt, 2017).

- Distribution networks have increased reliability and security with the penetration of distributed generations and the application of automation functions that imply in topological reconfigurations(da Silva et al., 2018).
- The insertion of other sources in the distribution system may cause impacts on the quality of the energy generated as well as it can alter the power flow and modify voltage values and short circuit currents(Mendes et al., 2018).
- In order to integrate this kind of energy generation, technical challenges in protection schemes must be overcome(Santos et al., 2018).
- DG may have detrimental effects on the protection coordination of overcurrent relays regarding varying short circuit levels. Overcurrent relays are necessary to ensure the reliability of the power system by avoiding malfunction and the unnecessary outage of the healthy part of the system (Sookrod & Wirasanti, 2018).
- The potential problems to protection are mainly protection under-reach and false-tripping. When a large production unit or several small ones are connected to medium voltage network, the fault current seen by the feeder protection relay may be reduced, which can lead to prevention of the operation of overcurrent relays. This is called protection under-reach or blinding of protection. In addition, the healthy state current seen by the feeder protection relay may be increased in some points of the topology, which can lead to false-tripping of overcurrent relays (Kauhaniemi, 2004).
- Distributed generation power plants may contribute to short-circuit current in the junction which they are connected. This may prevent the existing protection systems from functioning properly (Çetinkaya & Dumlu, 2013).

The third part of this section covers the current legislation, regulations and statistics of Turkey. The most striking conclusions of this third section are as follows.

- The current regulations in Turkey limit the distributed generation (including PV) connection power per plant by 1 MW (EMRA, 2013).
- With the widespread use of distributed generations, protection systems of electrical networks face new challenges. This is due to the additional fault current injected by distributed generators to network faults (Mohammadi Chabanloo et al., 2018).
- Solar power plants which are Turkey's leading energy source for electricity generation among the distributed generation plants correspond to 0,38 % of the total generation yet (TEDAŞ, 2017b).
- The challenges such as increasing fault current levels and bi-directional power flow must be assessed in advance so that distributed generation can grow safely and continuously in the future (Van der Walt et al., 2018).
- Distribution feeders single-phase short-circuit current is limited by 1 kA, while distribution feeders three-phase short-circuit current is limited by 16 kA in Turkey. (EMRA, 2014).
- Distributed generation legislation in Turkey (unlicensed electricity production), promotes MV level electricity generation rather than LV level electricity generation (EMRA, 2013).
- The studies throughout the literature and the statistics about Turkey denote that PV plants dominate the network in distributed generation due to market conditions, legislation and technological advancement levels in Turkey (Anaya & Pollitt, 2014) (IEEE Comission, 2012) (TEİAŞ, 2017b) (TEİAŞ, 2018) (EMRA, 2018) (Şimşek & Bizkevelci, 2018) (TEDAŞ, 2017a).

Finally, in fourth part of the literature review, a useful analysis method and likely beneficial applications for distributed generation systems are presented in detail. The most outstanding conclusions of this last section are as follows.

- The main idea of using theorem of superposition in the distribution system with EGs is to decompose the original distribution system with an EG in two systems: a passive distribution system without EGs where the system state is actually known, and a fictive, “no main generator units” system, where only the considered EG operates. According to the theorem of the superposition, the state in the fictive, “no main generator units” system actually represents the impact of EG on the overall system (Ciric et al., 2005).
- The system power is equivalent to a voltage source with short circuit, and the DG power equivalent to that of the current source with open circuit (Yang & Li, 2011).
- According to the superposition theory which can be applied to the linear electric circuits, the response of the network to the TS and the response to the DG can be examined separately. The sum of the two responses will be equal to the response of the network when both TS and DG are engaged (Riedel & Nilsson, 2010).
- The results of the superposition analysis will deviate slightly, even if it is close to reality. Because in superposition analysis, the equivalent impedance of the current or voltage sources should not be deactivated, the voltage source should be short-circuited and the current source should be open-circuited (Riedel & Nilsson, 2010).
- The distance relays, which are based on the principle that the impedance is obtained by the ratio of the voltage phasor to the current phasor, determine the fault and fault location according to the value of the calculated impedance (Bayrak & Usta, 2018).
- Besides, this type of relay is considered as a reasonable alternative to overcurrent devices susceptible to the presence of upstream power flows and replacement for voltage protection of distributed generation (DG) units restricting their fault ride through (FRT) capability (Pandakov et al., 2016).

- In addition, distance relaying in DG interconnections provide shorter fault-clearing times and allowing larger amounts of DGs to be connected to distribution system circuits (El-Arroudi & Joos, 2018).
- Accordingly, the distance relays have a quick protection action by measuring the equivalent impedance value of the network. The equivalent impedance of the network is determined by the impedance value of the line instead of branch loads and branch production resources (Campos, 2018).

3. THE DESIGNATED TOPOLOGY FOR MODELING

In the radial-operated distribution network, the main busbar in a distribution center is energized by the main feeder. The power reaching this bar is distributed by distribution feeders. The distribution feeders can be numerous and some of them may include distributed generation while the rest may not include any generation. In short, there are three types of feeders in terms of short circuit analysis in distributed production.

i. The main feeder that feeds the distribution busbar
ii. The secondary feeder, which is fed from the distribution busbar and has SPP connection
iii. The secondary feeder, which is fed from the distribution busbar and has no generation connection

The transmission network will be represented as a black box in the following figures. The black box representation of the transmission network and its equivalent schematics are displayed below.

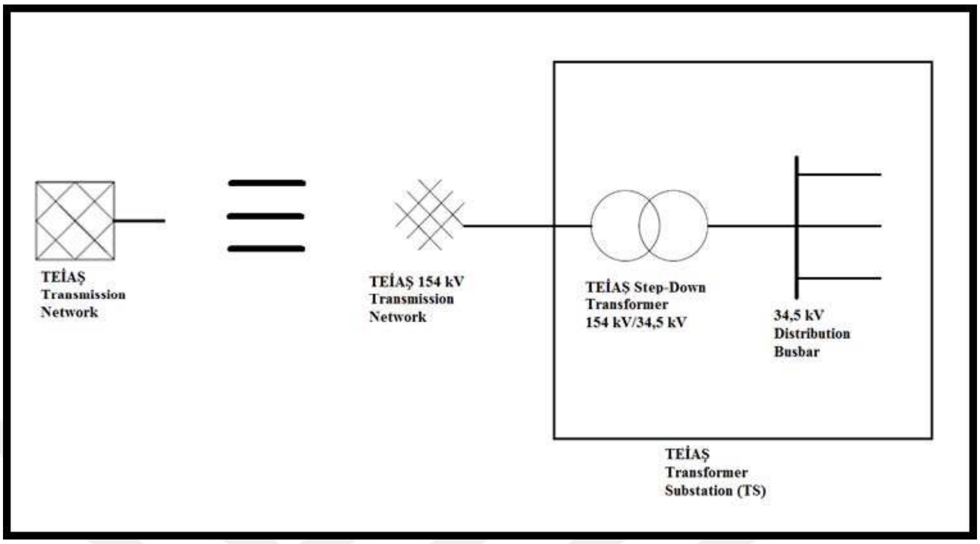

Figure 3.1. TEİAŞ transmission network and its equivalent schematics

Distribution feeders with distributed generation can be modeled with an equivalent feeder. Similarly, distribution feeders where there is no production but only consumption can be modeled with an equivalent feeder. In this case, the following Figure 3.2 can be used as the simplest but comprehensive model covering the distribution network.

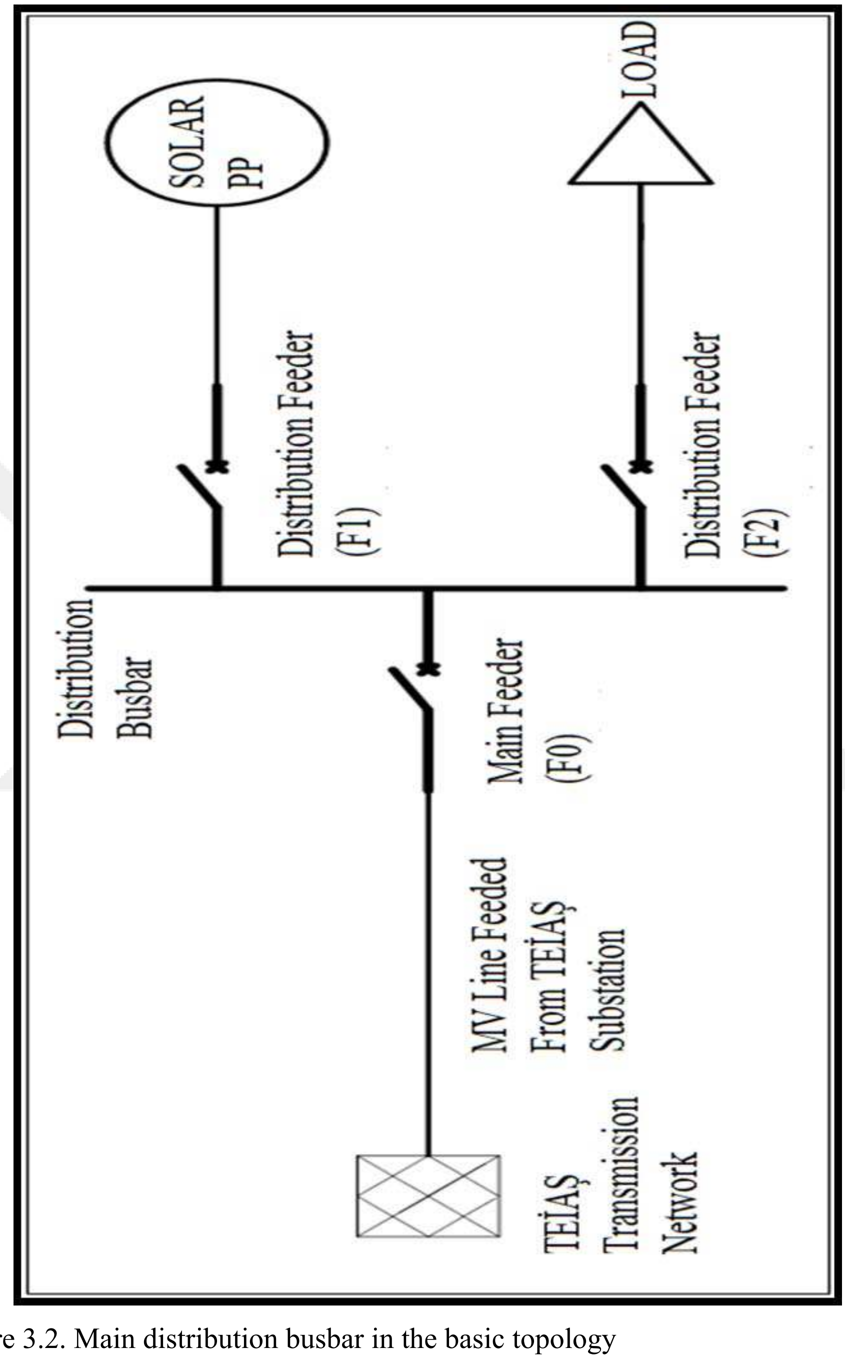

Figure 3.2. Main distribution busbar in the basic topology

It is also necessary to include the load on the equivalent feeders as well. The branch loads present along the feeder can be taken into account as equivalent branch load. The consumption which is right beside distributed generation should be shown separately. Since there are 4 nodes and 3 protection zones in the basic topology, short circuit simulations should be performed at the 3 points shown in Figure 3.3.

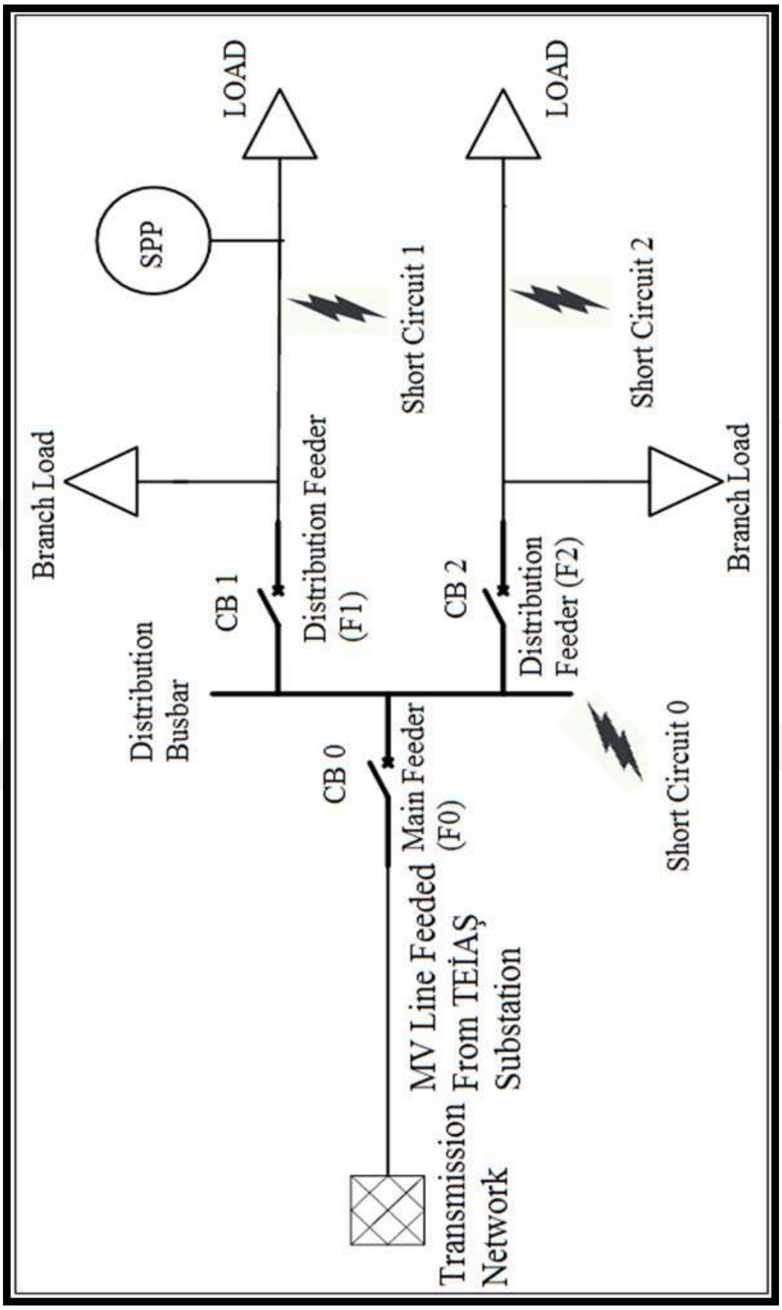

Figure 3.3. The basic topology used in protection analysis

4. MODELING AND SIMULATIONS

Figure 3.3 is modeled in the basic topology covering distribution network topologies. Common line characteristics of the distribution network are used to provide a realistic model of the distribution network and to obtain near-realistic results in simulations. Hawk conductor, 1X150 / 25 cross-sectioned-XLPE insulated-aluminum core cable and 1X95 / 16 cross-sectioned-XLPE insulated-copper core cable are used for modeling respectively the main feeder and distribution feeders. The distribution feeders in these characteristics can carry up to about 17 MW in medium voltage (34.5 kV). Therefore, the distribution feeders are modeled to carry a total of 12 MW and 16 MW. Similarly, the main feeder length has been selected as 8 km, especially considering the main feeder topologies of the rural distribution networks suitable for distributed generation connection. In addition, the distribution feeders in the modeled topology have been selected as 4 km, based on the long distribution feeders in the city. Besides considering the current applications in the distribution network, voltage drop/current carrying capacity calculations have been made by taking into account the specified line characteristics, then load conditions-line lengths have been selected in such a way that the legislative electricity quality standards will be obeyed. Briefly, the parameters such as the selected line lengths, the characteristics of the feeders, the distributed loads of the feeders and the distributed generations of the feeders have been determined by taking voltage drop-current carrying capacity calculations, common applications of distribution networks, the statistics related to distribution systems and the legislation specifying the design parameters into consideration (TEDAŞ, 2017b) (EMRA, 2014) (ETKB, 2000). The feeder characteristics in the modeled network are given in the table below.

Table 4.1. Modeled feeder parameters

Feeders	F0	F1	F2
Line Characteristics	3xHawk	3x1x150/25 XLPE AL	3x1x95/16 XLPE CU
Length (km)	8	4	4
Load ∑ MW	0	16	13
Load ∑ MWAR	0	1	1
Solar ∑ MW	0	5	0

In order to obtain a realistic model for a step-down substation (TS) connecting the transmission and distribution networks, the average of the values in the load distribution reports issued by TEİAŞ has been taken into consideration (TEİAŞ, 2017a). The TS parameters used in the modeled network are given in the table below.

Table 4.2. TS parameters

Parameters	Substation Values
Short Circuit Current in Primary (kA)	5,85
Voltage Level in Primary (kV)	154
Short Circuit Power in Primary (MVA)	1.561
Thevenin Equivalent Impedance of Primer Network (Ω)	15,19
Thevenin Equivalent Inductance of Primer Network (mH)	48,40
Voltage Level in Secondary (kV)	34,5
Secondary Wound Neutral Resistance (Ω)	20,00
Short Circuit Impedance Voltage of the Transformer (%)	12,60
Rated Power of the Transformer (MVA)	50
Serial Impedance of the Transformer (Ω)	2,91
Serial Inductance of the Transformer (H)	0,0093

The following network is modeled in PSCAD using the basic topology and the parameters specified in Table 4.1 and Table 4.2.

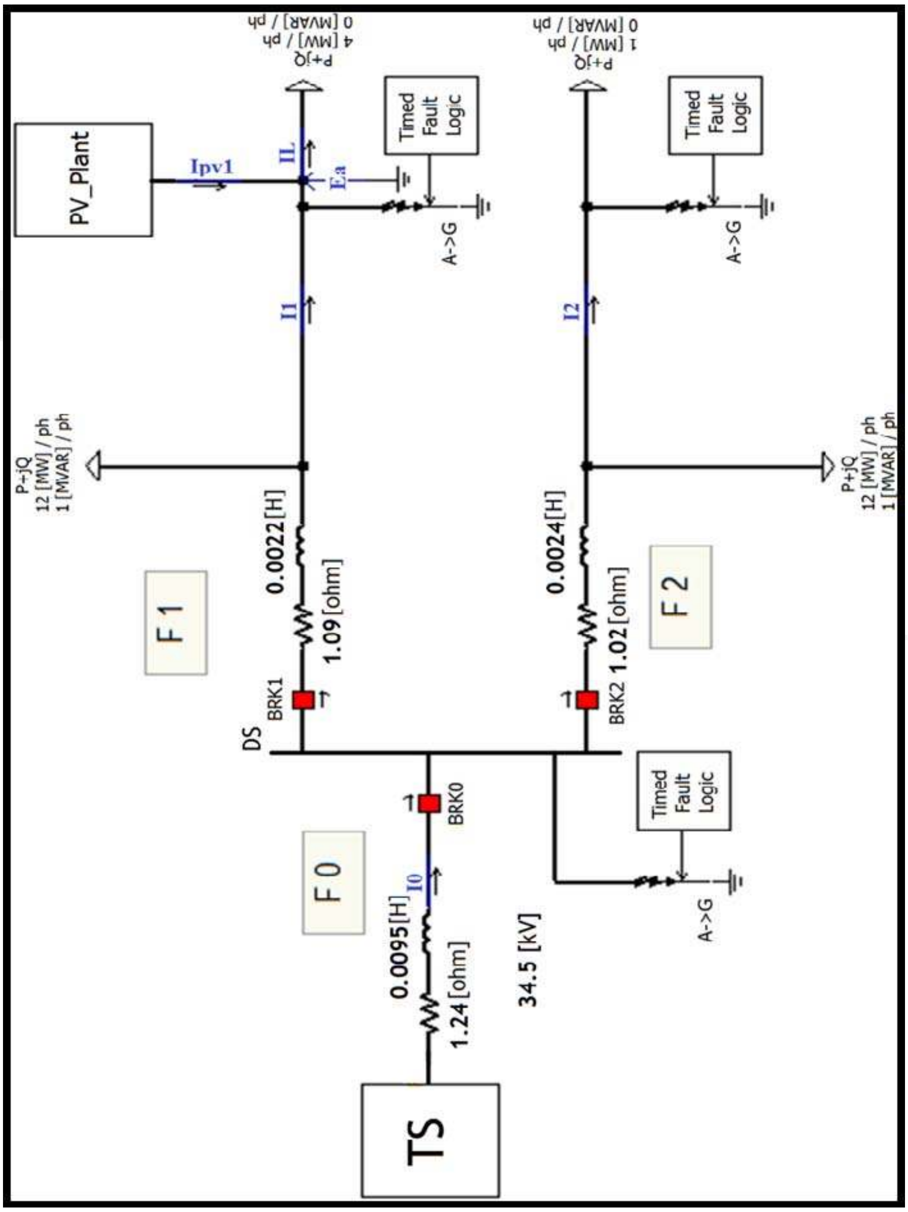

Figure 4.1. The Modeled network

4.1. Healthy Network (Steady State) Analysis

In this analysis, how the nominal current of the SPP will affect the relay coordination has been examined with the help of superposition theory. The main idea of using theorem of superposition in the distribution system with EGs is to decompose the original distribution system with an EG in two systems: a passive distribution system without EGs where the system state is actually known, and a fictive, "no main generator units" system, where only the considered EG operates. According to the theorem of the superposition, the state in the fictive, "no main generator units" system actually represents the impact of EG on the overall system (Ciric et al., 2005). That is to say, according to the superposition theory which can be applied to the linear electric circuits, the network reaction to SPP and the network reaction to TS can be examined separately. The system power is equivalent to a voltage source with short circuit, and the DG power equivalent to that of the current source with open circuit (Yang & Li, 2011). In the ideal case, the sum of the two responses will be equal to the response of the network when both TS and SPP are engaged (Riedel & Nilsson, 2010). However, the results of the superposition analysis will deviate slightly, even if it is close to reality. Because in superposition analysis, the equivalent impedance of the current or voltage sources should not be deactivated, the voltage source should be short-circuited and the current source should be open-circuited (Riedel & Nilsson, 2010). Unlike the ideal case, TS has been short-circuited by the disconnection of both TS and its equivalent impedance from the network, in the analysis executed in PSCAD. Since SPP behaves like a source of current, it has been open-circuited by the disconnection of both SPP and its equivalent impedance from the network. In the table below, there are the values of the following cases of the simulation respectively:

a) The current values in the case of both the enabled TS and the disabled SPP (open circuit)
b) The current values in the case of both the disabled TS (short circuit) and the enabled SPP
c) The current values in the case both the enabled TS and enabled SPP

Table 4.3. Superposition analysis

Case, (A)	I0	I1	I2
a) Simulation 1: The Substation Enabled, PV Disabled (Open Circuit)	417	57	15
b) Simulation 2: The Substation Disabled (Short Circuit), PV Enabled	-74	-83	1
Expected Total Network Response	**343**	**-26**	**16**
c) Simulation 3: The Substation Enabled, PV Enabled	347	-26	15

Regarding the simulation results shown in Table 4.3; current values obtained when both TM and PV are in operation are close to the expected total network response values, but small deviations have been recorded. Let us define two operators τ (tau) and E in order to express mathematically the small deviations observed in the simulation. Similar to the arithmetic + (plus) operator, the τ operator creates a new equivalent impedance according to the topology, indicating that a new impedance is involved in the current equivalent impedance. Let us use the τ operator defined in this way to define and derive the operator E. Similar to the arithmetic Σ (sum, sigma) operator; E means implementing τ Operator to a series of impedance values. Let's define the remaining symbols as follows:

- U_n stands for the n[th] Thevenin Voltage Value in the Specified Topology.
- Z_n^s represents the n[th] Source Serial Impedance Value in the Specified Topology.
- Z_n^{eq} represents the Thevenin Equivalent Impedance Value Perceived by the n[th] Source in the Specified Topology.

In the direction of these definitions, when we sum up the current values that occur at a certain point of the determined topology separately by activating each production source separately; the obtained total current value will be as follows regarding the superposition theory.

Equation 1:

$$I_T = \sum_{n=1}^{k} I_n = \sum_{n=1}^{k} \frac{U_n}{Z_n^{eq} + Z_n}. \tag{4.1}$$

Similar to the Equation-1; when all production resources on the specified topology are in operation, the value of the current at a certain point in the topology will be as follows;

Equation 2:

$$I = \sum_{n=1}^{k} \frac{U_n}{Z_n^{eq} + \sum_{n=1}^{k} Z_n}. \tag{4.2}$$

Equation 1 and Equation 2 tells us that the impedance Z_n^{eq} will have to be very large compared to the other impedances in the denominator, in order to obtain $I \approx I_T$ approximate equality. This requirement is easily provided in the distribution network. As an indicator of this statement, on the topology which is identified with realistic values in the distribution network, the approximate equation $\mathrm{I} \approx I_T$ was achieved. This approximate equivalence can be clearly observed in the simulations in which we obtain the values in Table 4.3. The small differences between the expected total network response and the results obtained in Simulation 3 is caused by disabling the power supplies together with equivalent impedances. The network responses to TM, SPP, and the TM + SPP are illustrated separately in Figure 4.2 below.

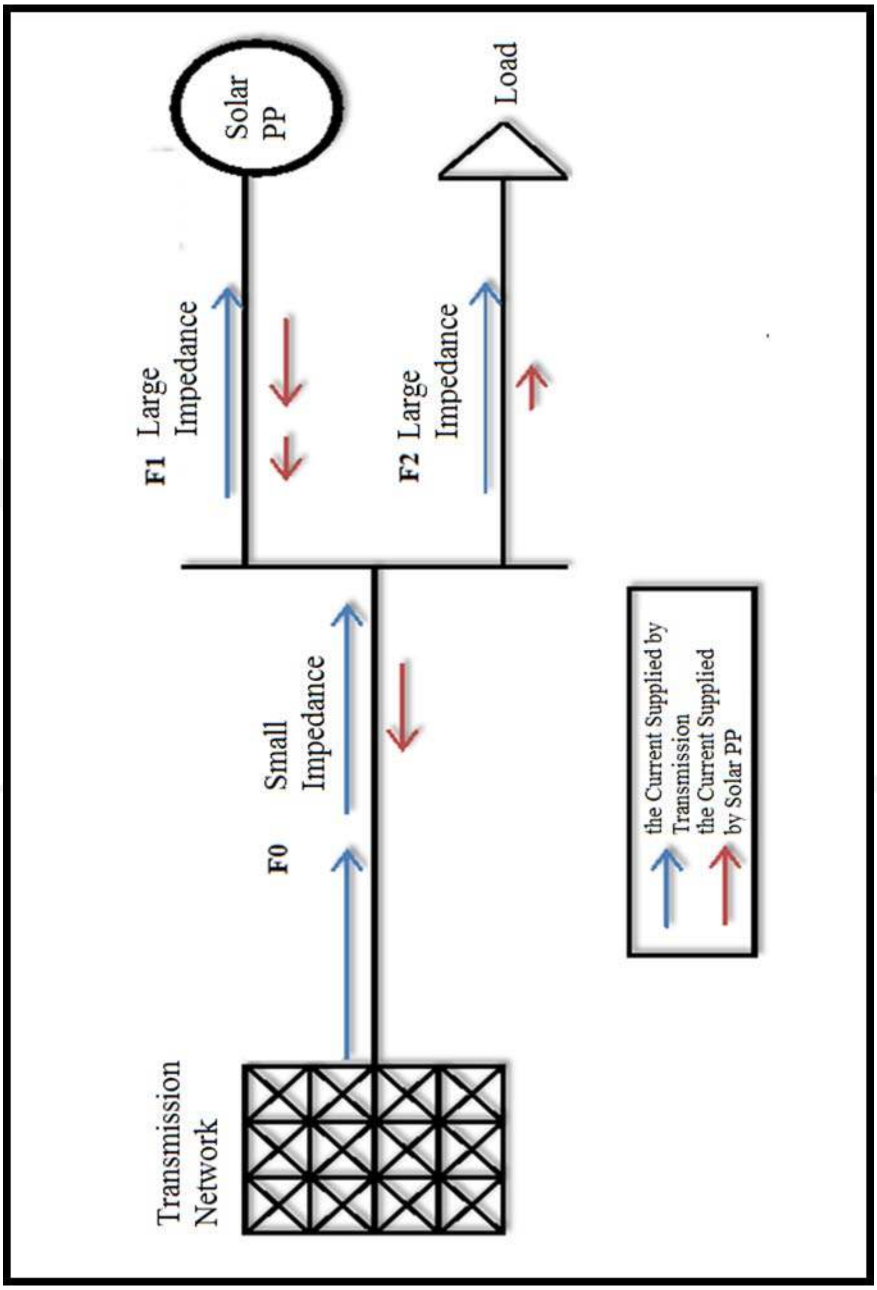

Figure 4.2. The superposition analysis

It is seen that the entire SPP current flows from F1. Then, a large part of the SPP current which is reached the main busbar flows to F0 and a very small part of the SPP current flows to F2. Because the equivalent impedance of F0 is quite low compared to the equivalent impedance of F2. In the modeled network shown in Figure 3.3, the equivalent positive sequence impedance of TS contributing to the impedance of F0 is around 4 Ω, and the positive sequence impedance of 12 MW load contributing to the impedance of F1 is around 100 Ω. Therefore, the nominal current of the SPP decreases I0 and I1, while I2 slightly increases.

Due to the current contribution of the SPP, the network currents change as described above. This information provides a preliminary estimate of the short-circuit analysis before simulations. In the event of a short circuit, due to the short circuit current contribution of the SPP, I0, and I1 may be below the tripping level current by moving away from the correct operating levels of the tripping current of the circuit breaker. On the other hand, I2 will rise slightly and remain at the correct working levels. Therefore, I2 will remain above the tripping level in case of a fault, which will allow the circuit breaker to operate safely. In other words, there are potential risks in the correct operation of the circuit breakers in F0 and F1 feeders; but the rated or short-circuit current of any SPP will not have a negative effect on the current relay coordination in F2.

4.2. Short-Circuit 0 (SC0) Analysis

SC0 has been applied to the main busbar at the point indicated in Figure 3.3. In the first implementation, SPP was not included in the simulation. In this way, the work of the existing relay coordination in the conventional distribution network has been tested. The graphic forms obtained in the simulation are shown below.

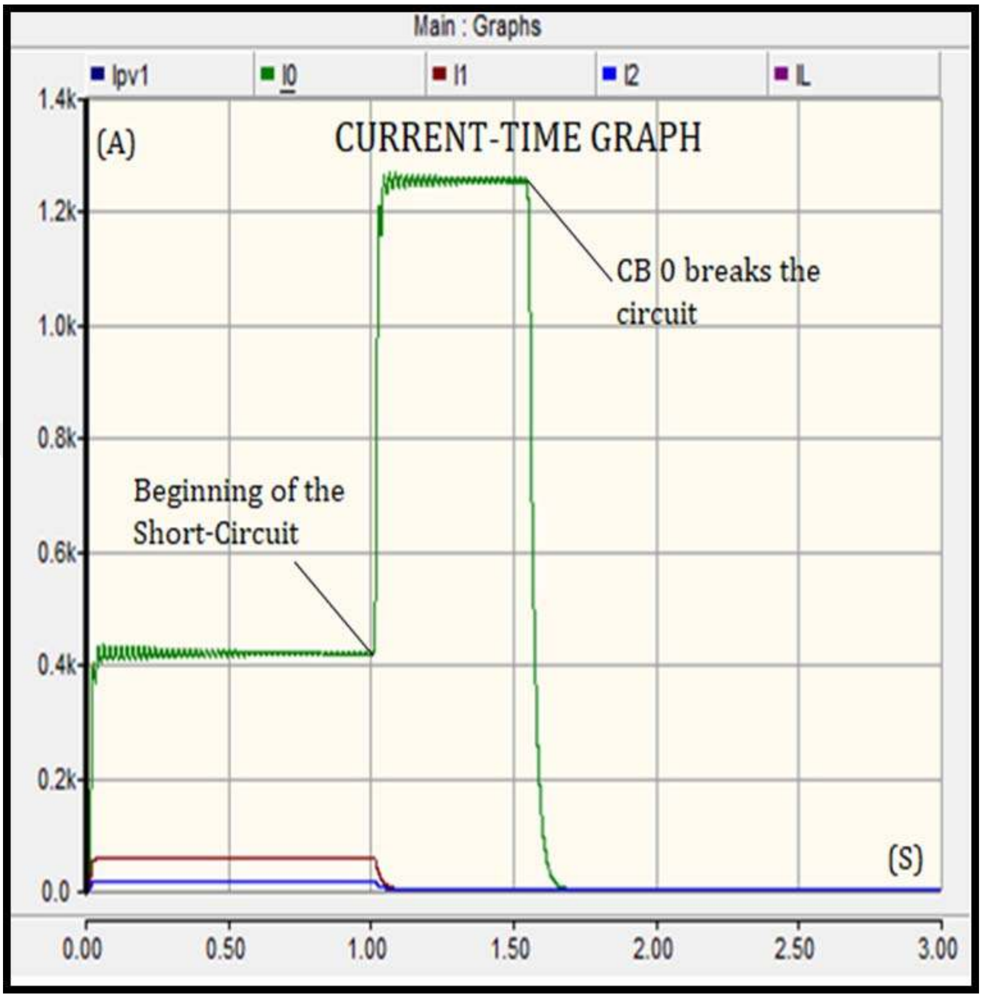

Figure 4.3. SC 0 analysis in conventional network

The values appearing in Figure 4.3 are the effective (RMS) values of the feeder currents. At T = 1 s it appears that the fault has started. At T = 1.5 s CB 0 clears the fault by breaking the circuit. In this phase, the reaction of the circuit breakers has been measured by using the SPP's at the various powers. Up to 5 MW, no disruptive effect on relay coordination was observed. However, it is seen in the graphs in Figure 4.4 that CB 0 cannot clear the fault after connecting the SPP at 5 MW power.

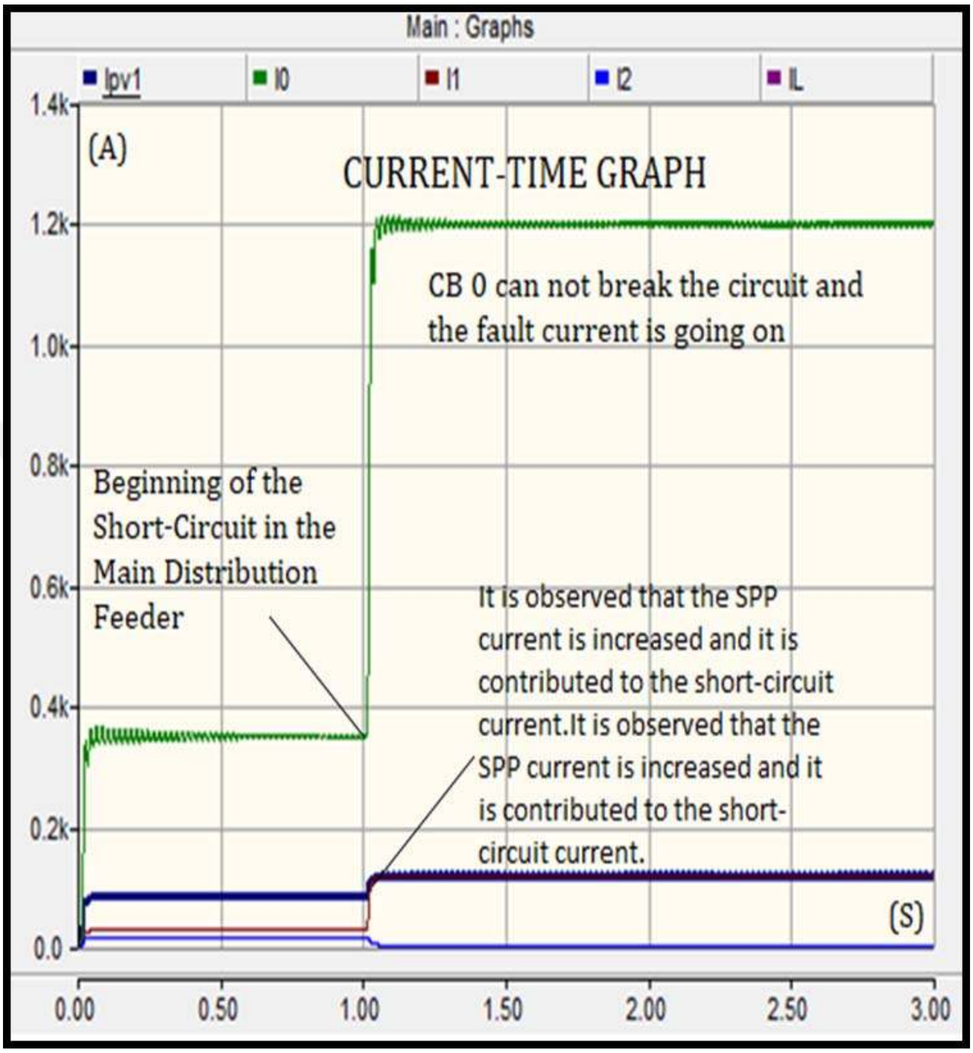

Figure 4.4. SC 0 analysis in the network where 5 MW DG contributed

In the above graphs, it can be seen that the fault starting at T = 1 s cannot be cleared. That is to say, CB 0 could not isolate the faulty circuit. In the blue color graphic, it is seen that SPP has partly short circuit contribution. The short circuit current (I0) (green graphic) fed from F0 is reduced compared to the previous case. Therefore CB 0 could not isolate the faulty network.

4.3. Short-Circuit 1 (SC1) Analysis

SC1 has been applied to the main busbar at the point indicated in Figure 3.3. In the first implementation, SPP was not included in the simulation. In this way, the work of the existing relay coordination in the conventional distribution network has been tested. The graphic forms obtained in the simulation are shown below.

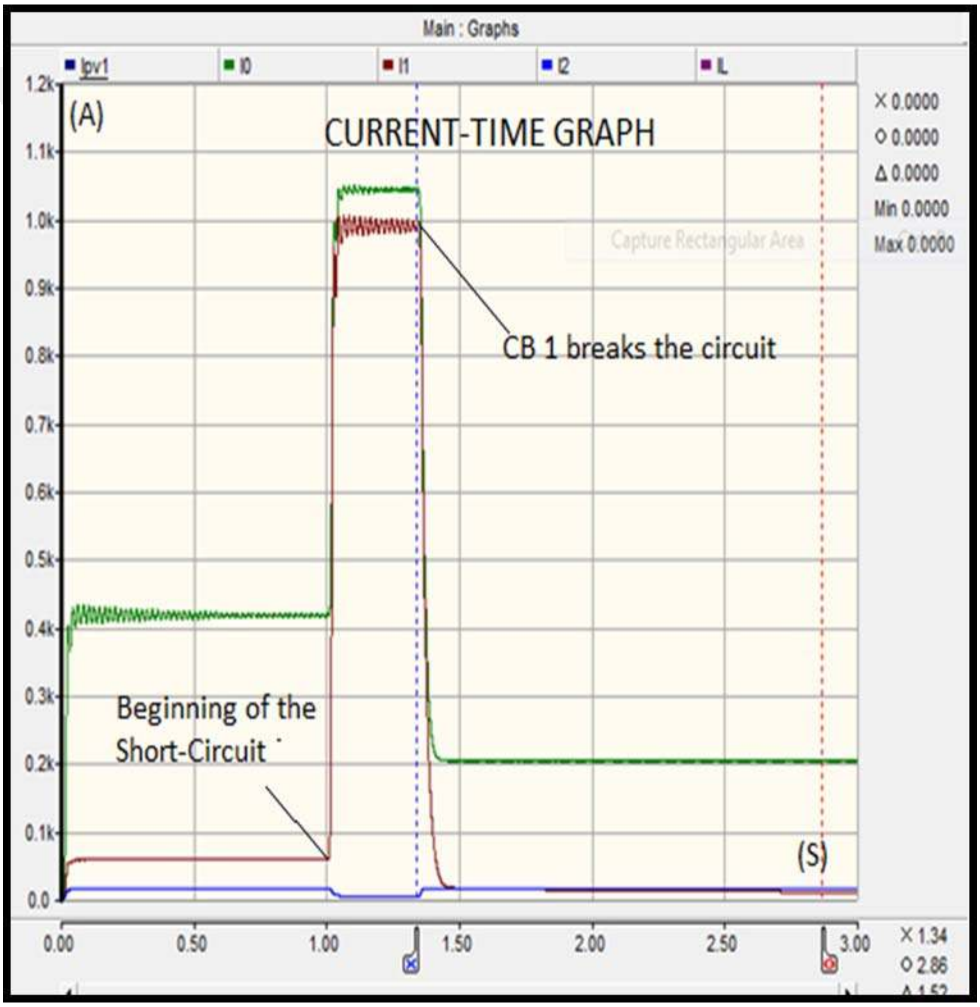

Figure 4.5. SC 1 analysis in conventional network

The values appearing in Figure 4.5 are the effective (RMS) values of the feeder currents. At T = 1 s it appears that the fault has started. At T = 1.3 s CB 1 clears the fault by breaking the circuit. In this phase, the reaction of the circuit breakers has been measured by using the SPP's at the various powers. Up to 4 MW, no disruptive effect on relay coordination was observed. However, it is seen in the graphs in Figure 4.6 that CB 1 cannot clear the fault after connecting the SPP at 4 MW power.

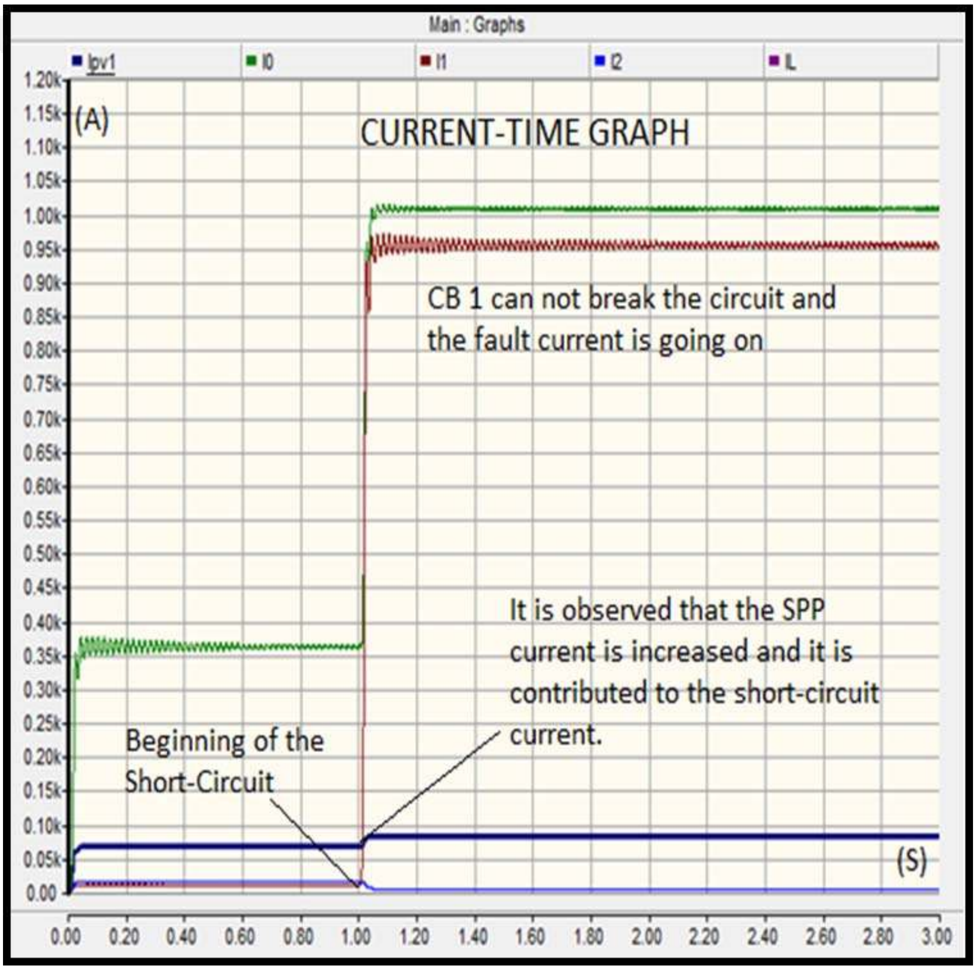

Figure 4.6. SC 1 analysis in the network where 4 MW DG contributed

In the above graphs, it can be seen that the fault starting at T = 1 s cannot be cleared. That is to say, CB 1 could not isolate the faulty circuit. In the blue color graphic, it is seen that SPP has partly short circuit contribution. The short circuit current (I1) (claret red graphic) fed from F1 is reduced compared to the previous case. Therefore CB 1 could not isolate the faulty network.

4.4. Short-Circuit 2 (SC2) Analysis

SC2 has been applied to the main busbar at the point indicated in Figure 3.3. In the first implementation, SPP was not included in the simulation. In this way, the work of the existing relay coordination in the conventional distribution network has been tested. The graphic forms obtained in the simulation are shown below.

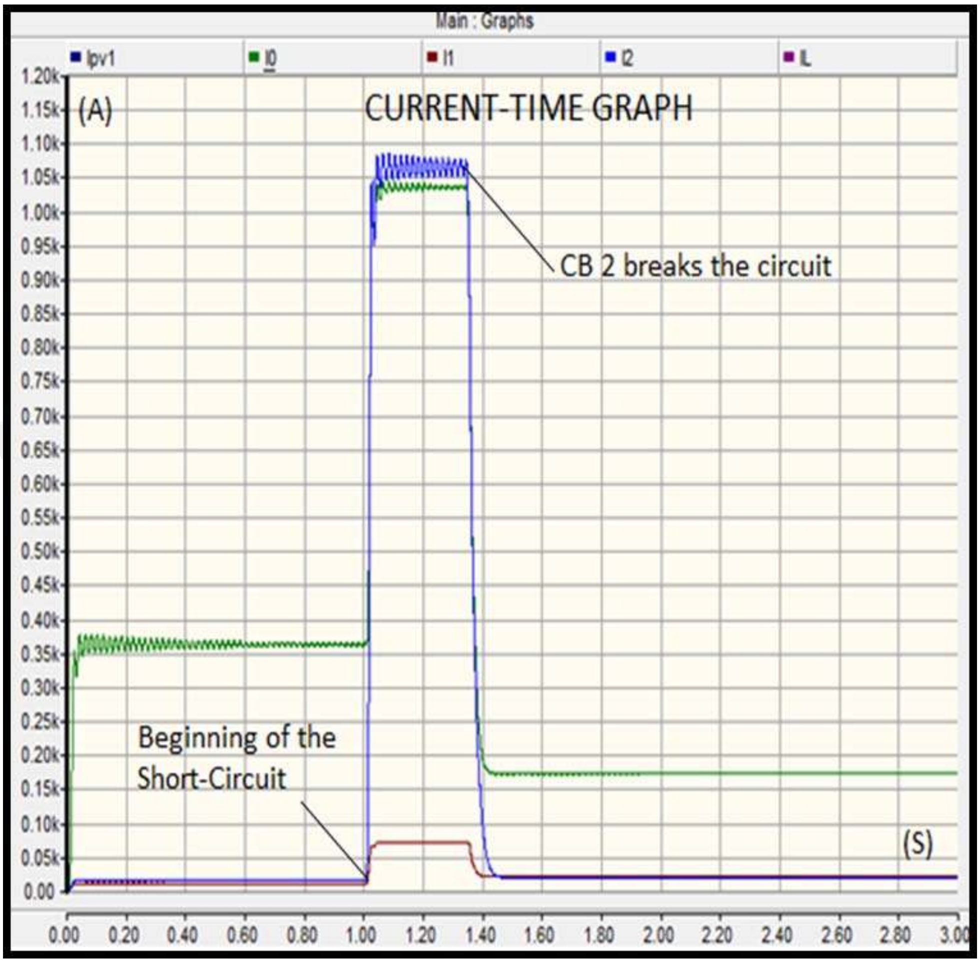

Figure 4.7. SC 2 analysis in conventional network

The values appearing in Figure 4.7 are the effective (RMS) values of the feeder currents. At T = 1 s it appears that the fault has started. At T = 1.3 s CB 2 clears the fault by breaking the circuit. In this phase, the reaction of the circuit breakers has been measured by using the SPP's at the various powers. No significant change in I2 was observed at powers lower than 10 MW. The graphs in Figure 4.8 show how the circuit breakers behave after the connection of SPP of 10 MW power. No disruptive effect on relay coordination was observed at any power of SPP in this case.

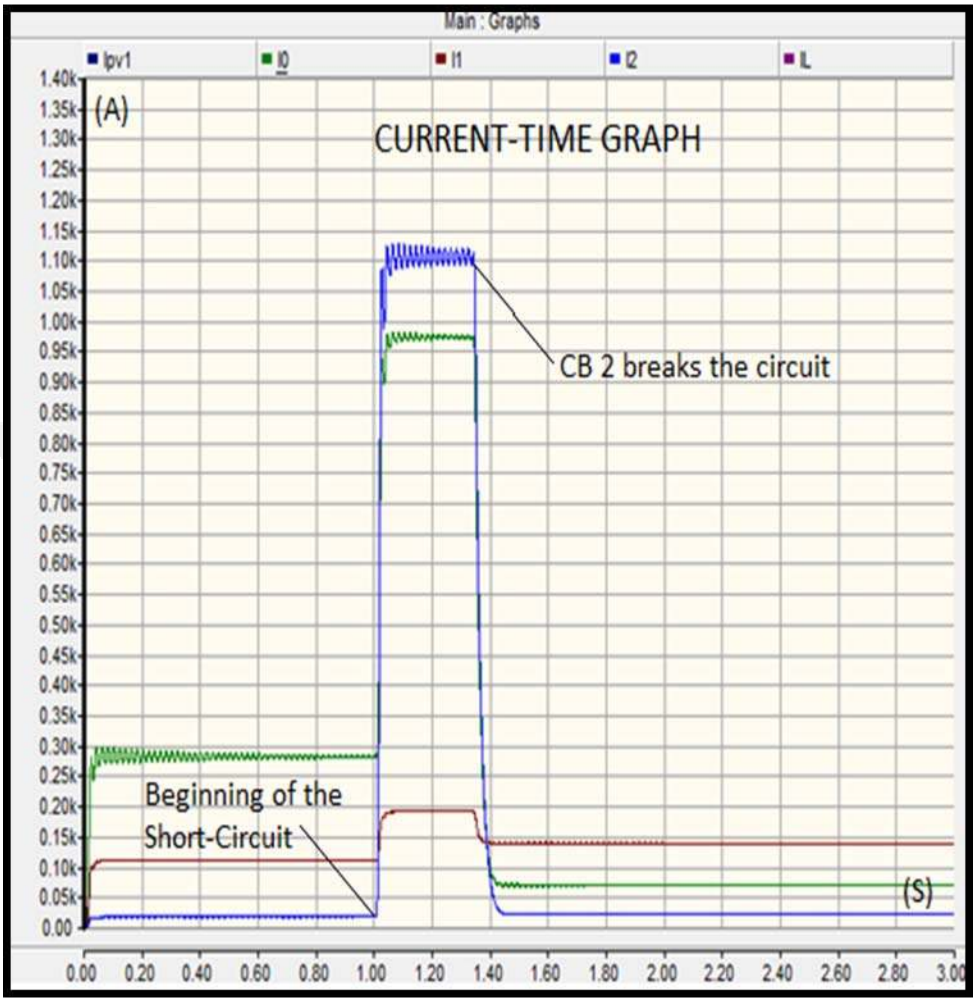

Figure 4.8. SC 2 analysis in the network where 10 MW DG contributed

It appears that the fault starting at T = 1 s has been cleared. Because the SPP on the 10 MW power has slightly increased the I2 current. I2 has shifted slightly towards the safe direction, in terms of relay coordination. As mentioned in the superposition analysis, the effect of the SPP current on I2 is very low. Moreover, the limited influence of the GES current on I2 magnifies it very slightly and supports the operation of the corresponding circuit breaker in case of failure. So, neither at stable nor at short-circuited cases, any value of SPP current has no significant effect on I2. Therefore, the relay coordination of circuit breaker 2 is not adversely affected.

4.5. Limiting Overcurrent Time Value of the Inverter

In the simulation studies on the main topology, 4 analyzes were performed in total, including steady-state analysis and short-circuit analysis at 3 points. In these simulations, the disrupted effects of SPP on the relay coordination were determined in SC 0 and SC 1 analyzes. These effects are due to the short circuit contribution of the SPP.

The tripping time of the circuit breaker relays in the modeled network is minimum 0.3 s. If the trip time of the inverter (LoM function of the inverter) that connects the SPP to the network is less than 0.3 s, the short circuit contribution of the SPP would be prevented relatively. In the following analyzes, the inverter tripping time is set to 0.2 s. In Figure 4.9, the SC 0 analysis with a distributed SPP at 5 MW power was retried.

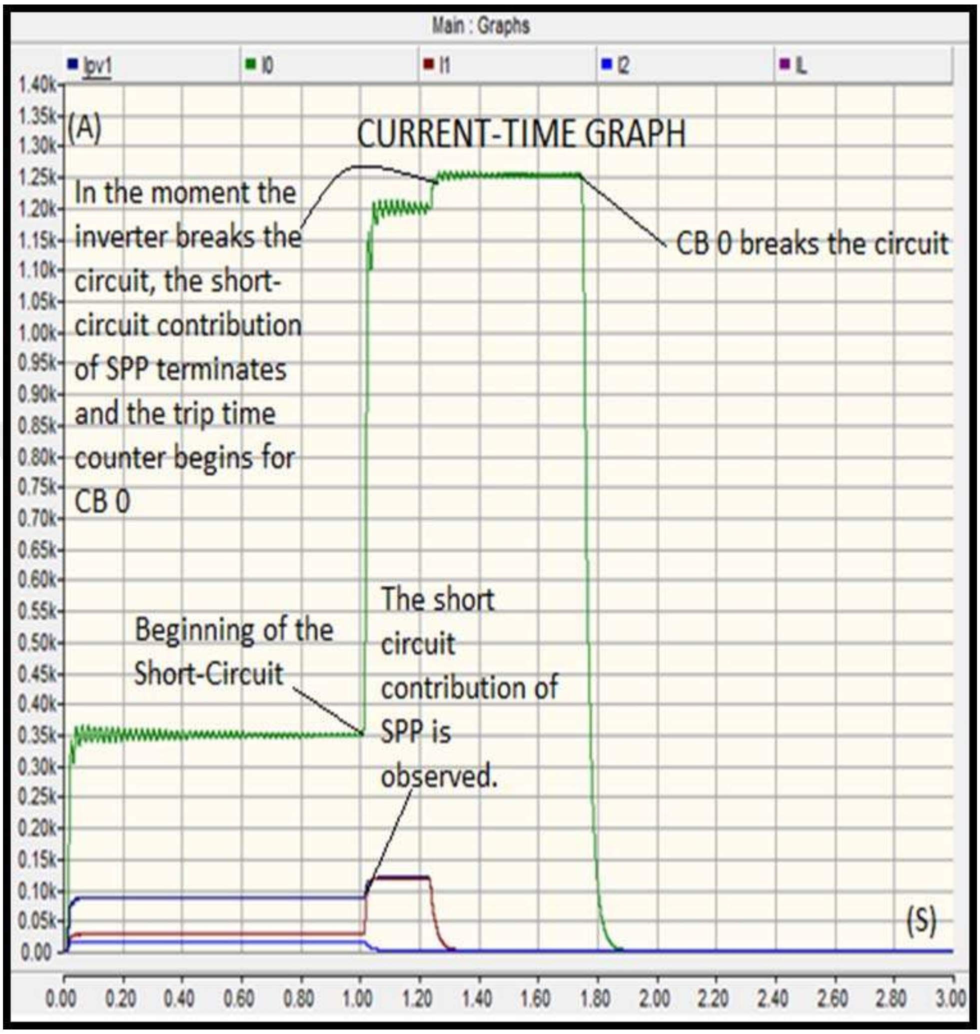

Figure 4.9. SC 0 analysis (t_{inv}=0,2 s)

At T = 1 s it appears that the fault has started. Due to the short circuit contribution of the SPP, the fault current remains lower than the trigger current of CB 0. The inverter deactivates the SPP at T = 1.2 s. After deactivation by the inverter, the short circuit contribution of the SPP has finished and the fault current has exceeded the trigger current. By the means of this, at T = 1.8 s the CB 0 could operate and the fault could be cleared. In this case, although the fault could be cleared, the fault remains nonisolated over a delay period.

In Figure 4.10, SC 1 analysis with a distributed generation SPP connected at 4 MW power was retried.

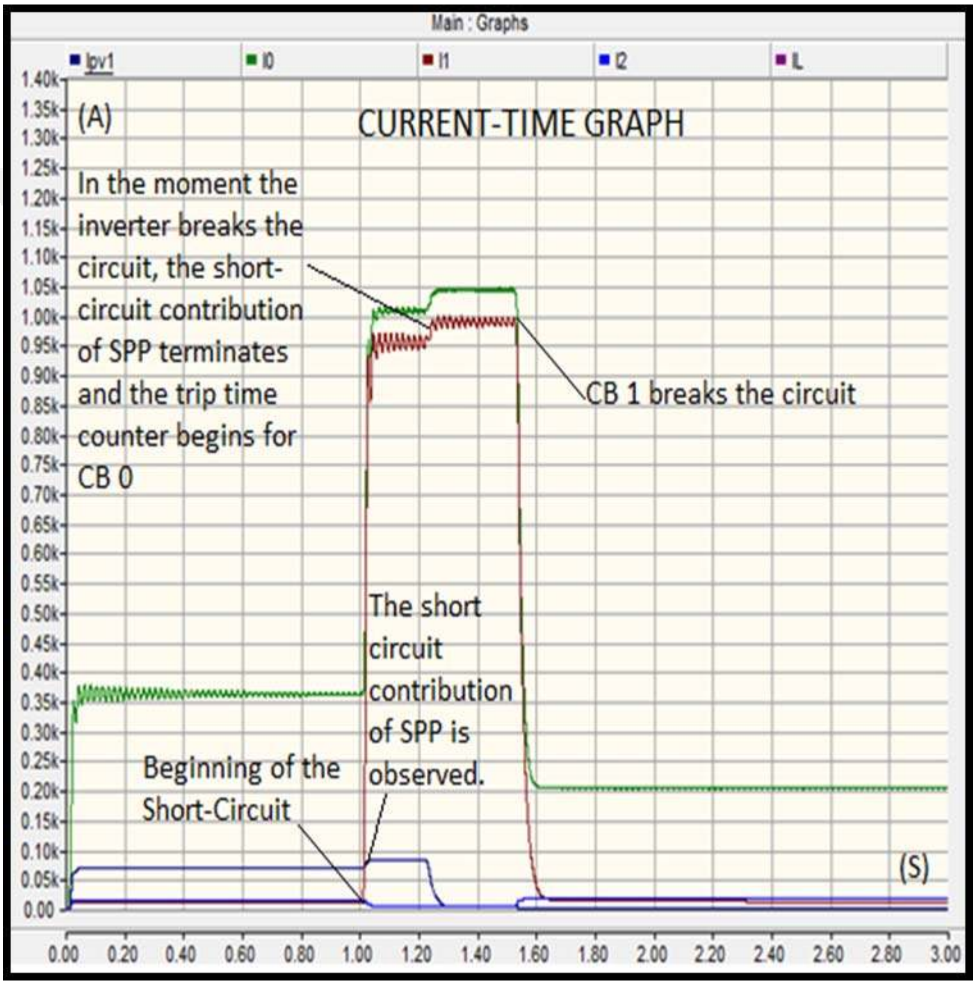

Figure 4.10. SC 1 analysis (t_{inv}=0,2 s)

At T = 1 s it appears that the fault has started. Due to the short circuit contribution of the SPP, the fault current remains lower than the trigger current of CB 1. The inverter deactivates the SPP at T = 1.2 s. After deactivation by the inverter, the short circuit contribution of the GES has finished and the fault current has exceeded the trigger current. By the means of this, at T = 1.6 s the CB 1 could operate and the fault could be cleared. In this case, although the fault could be cleared, the fault remains non-isolated over a delay period.

It is clear that the over-current trip time of the inverter reduces the adverse effect of the SPP on the relay coordination. Keeping the inverter's tripping time at small values improves the performance the relay coordination in distributed generation. For inverters to be used in distributed generation applications (unlicensed generation plants), limiting the overcurrent trip time by the legislation will reduce the short circuit contribution time of the distributed generation power plants.

4.6. Summary

The superposition analysis is used in this study in order to efficiently examine how the rated and short-circuit currents of DG will affect the relay coordination. Before the simulations stage, it was evaluated whether the superposition analysis, which gives accurate results for linear systems, can be used in this study or not. It is observed that superposition analysis results are very close to the correct values, although it is not accurate. The deviations in the results of superposition analysis were analyzed mathematically. Although this method does not yield sensitive and accurate results, it can practically indicate how the currents in the feeders and relay coordination will change, before simulations. In other words, the method can supply strong predictions without simulations too. The cases predicted by the superposition analysis have been tested by simulations on the basic topology.

It is observed that the over-current trip time of the inverter reduces the adverse effect of the SPP on the relay coordination. Keeping the inverter's tripping time at small values improves the performance of the relay coordination in distributed generation. For inverters to be used in distributed generation applications (unlicensed generation plants), limiting the overcurrent trip time by the legislation will reduce the short circuit contribution time of the distributed generation power plants.

5. UTILIZING THE DISTANCE RELAY

One of the main reasons for the deterioration of relay coordination is that existing relays cannot tolerate new power and load conditions. Relays that may be a solution to this problem should be able to adapt to changing network conditions. At this point, it can be seen that distance relays can be used in distribution systems where distributed generation exists. These relays, which are based on the principle that the impedance is obtained by the ratio of the voltage phasor to the current phasor, determine the fault and fault location according to the value of the calculated impedance (Bayrak & Usta, 2018). The currents in the network can change quite a lot, due to the loads and production resources added to the distribution system as time goes on and the changes in the production powers in the system during the day. The equivalent impedance of the mains is less affected than the currents in the mains. Therefore, the distance relays that generate the trip signal according to the measured impedance value detect faults more accurately than the overcurrent relays that generate the trip signal relative to the measured current values.

Besides, this type of relay is considered as a reasonable alternative to overcurrent devices susceptible to the presence of upstream power flows and replacement for voltage protection of distributed generation (DG) units restricting their fault ride through (FRT) capability (Pandakov et al., 2016).

In addition, distance relaying in DG interconnections provide shorter fault-clearing times and allowing larger amounts of DGs to be connected to distribution system circuits (El-Arroudi & Joos, 2018).

From Gençaydın's standpoint, the distance protection is faster and more selective than the overcurrent protection. Moreover, the distance protection is more susceptible to changes in relative source impedances and system conditions. The tripping time is approximately 1 or 2 periods in the first zone, corresponding to respectively 20 or 40 ms (Gençaydın, 2006).

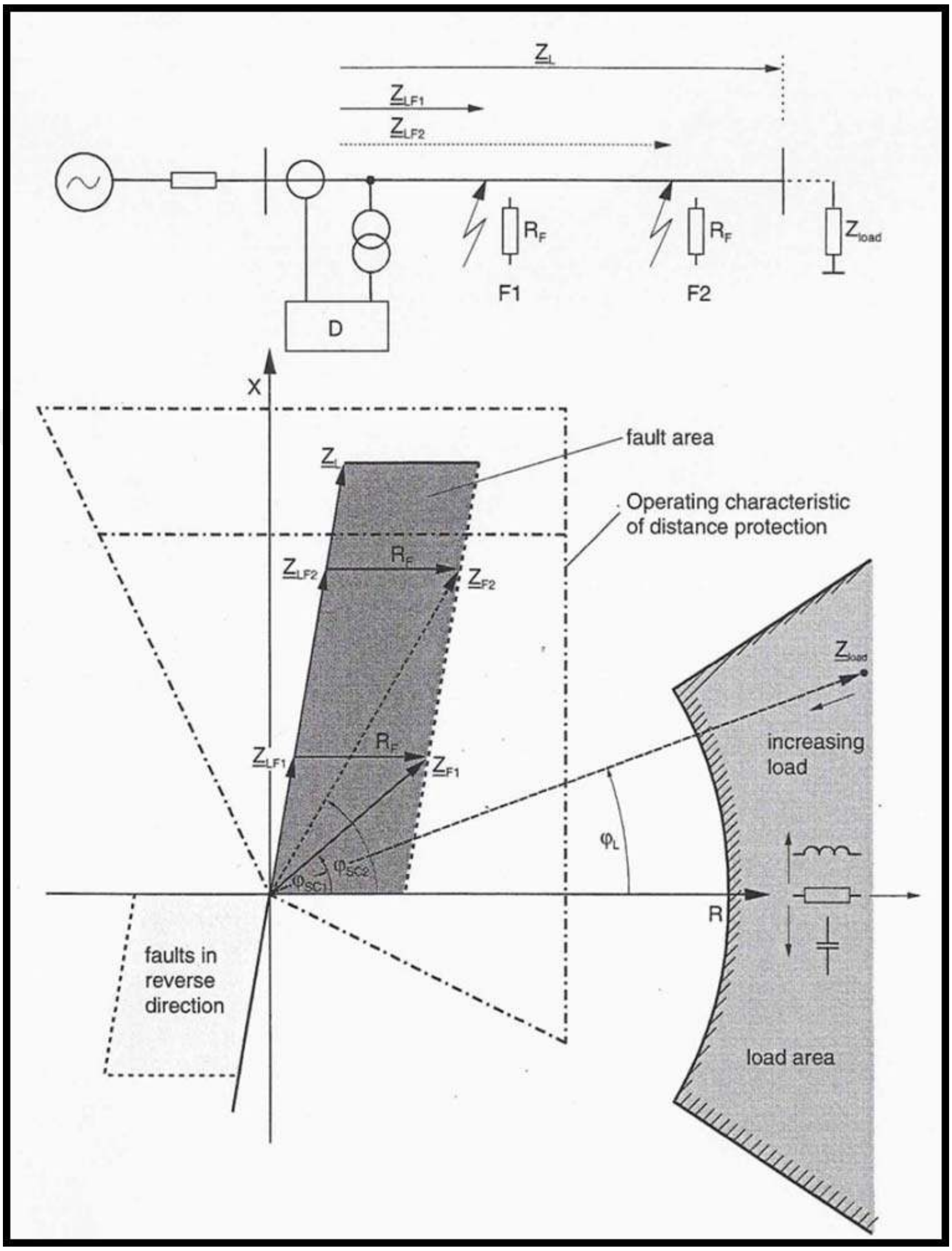

Figure 5.1. Load and short-circuit impedances of distance relay (Ziegler, 1999) (Gençaydın, 2006))

In Figure 5.1 above in which both the radial topology and the impedance characteristics of the distance relay (symbolized by D) are shown, there are the areas corresponding to the steady-state and fault impedances.

Assume that this distance relay, the impedance characteristics of which is known, is connected to the R point in the topology shown in Figure 5.2.

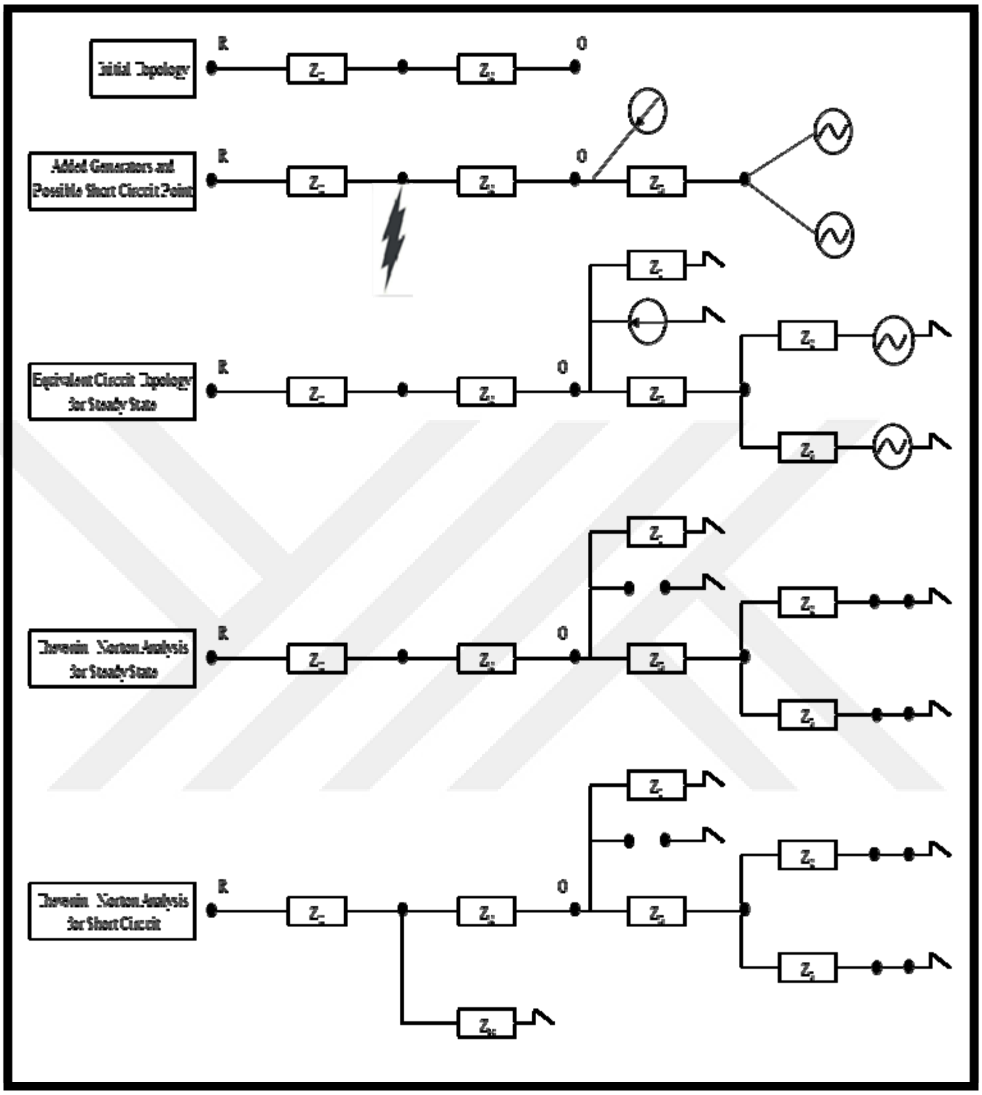

Figure 5.2. Equivalent impedances in the basic topology which include distance relay

Let Z_{lim} denote the equivalent impedance of the network up to the O point of the initial topology. After point O, let the distributed generation plants to connect. Then, assume the trip impedance of the distance relay is set to Z_{lim}. In this case, the appearance of Z_{lim} over the impedance characteristics of the distance relay will be as shown in Figure 5.3 below.

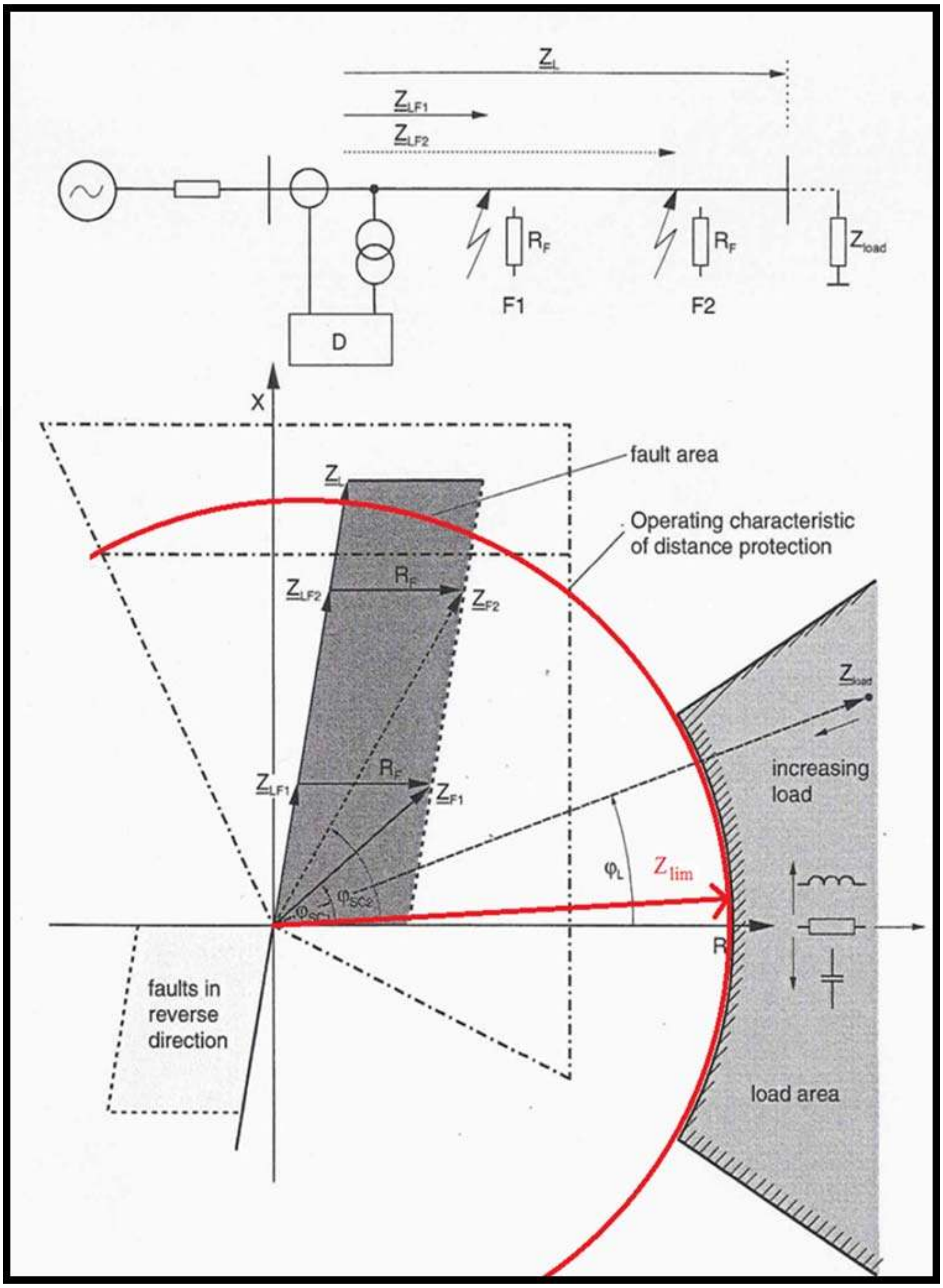

Figure 5.3. The limit impedance of the distance relay

Let's examine how the relay impedance at the topology of the distributed generation plants will change when there is a short circuit at the point indicated by the pointer in the topology shown in Figure 5.2. When the superposition analysis is performed for the final circuit (Thevenin / Norton Analysis for Short Circuit), the impedance sensed by the distance relay will be as given in the following equation.

Equation 3:

$$Z_{eq} = Z_{l1} + \frac{Z_{sc} \times \left(Z_{l2} + \dfrac{Z_1 \times \left(Z_{l3} + \dfrac{Z_2 \times Z_3}{Z_2 + Z_3} \right)}{Z_1 + \left(Z_{l3} + \dfrac{Z_2 \times Z_3}{Z_2 + Z_3} \right)} \right)}{Z_{sc} + \left(Z_{l2} + \dfrac{Z_1 \times \left(Z_{l3} + \dfrac{Z_2 \times Z_3}{Z_2 + Z_3} \right)}{Z_1 + \left(Z_{l3} + \dfrac{Z_2 \times Z_3}{Z_2 + Z_3} \right)} \right)} \tag{5.3}$$

According to Equation 3, how the relay impedance (equivalent impedance, Z_{eq}) will change by short circuit impedance variations in case of short circuit is shown in the graphic below. According to this graph, almost independent of the distributed generation connected to the network and the value of the short-circuit impedance; the impedance sensed by the relay falls below the trip impedance value at the time of failure and generates the trip signal.

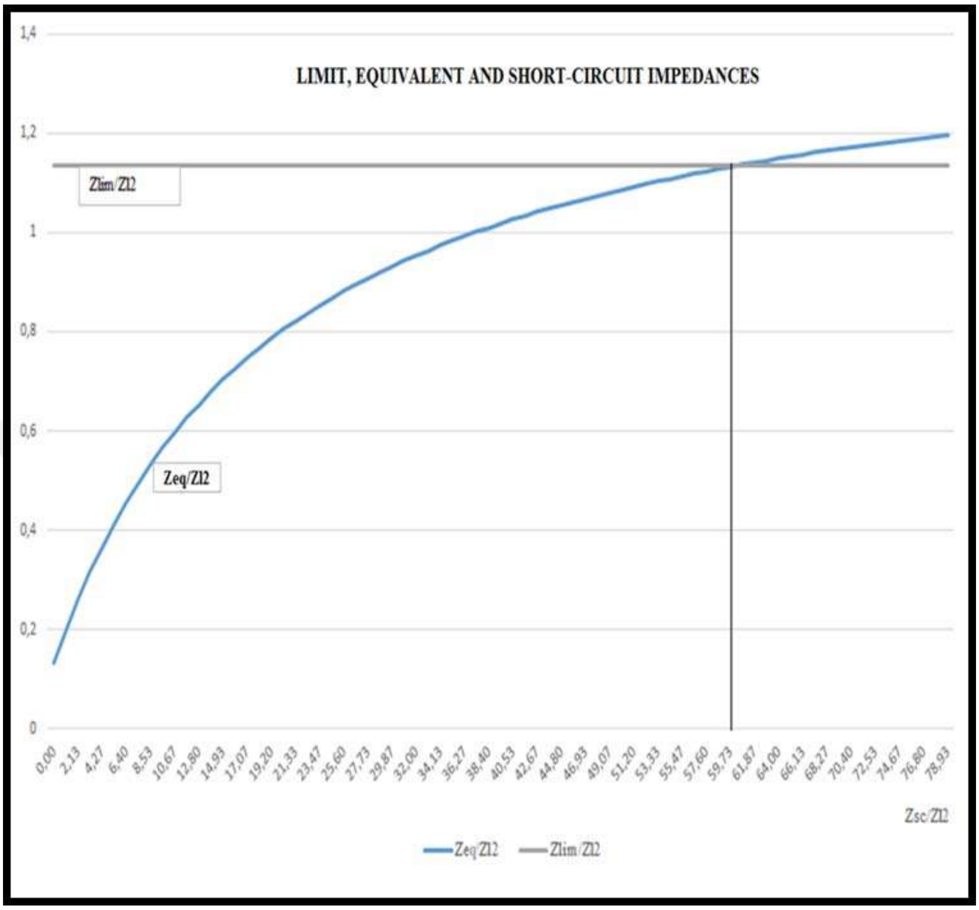

Figure 5.4. The chart of the change in equivalent impedance sensed by the distance relay

Accordingly, the distance relays have a quick protection action by measuring the equivalent impedance value of the network. The protection by distance relays depends not only on the network current value and the network voltage value alone but on the equivalent impedance value of the network in which these two values affect together. The equivalent impedance of the network is determined by the impedance value of the line instead of branch loads and branch production resources (Campos, 2018). Therefore, the network protection with distance relays will not be affected by the addition of new distributed generation plants to the grid, the change of distributed generation power in day-season-year or the change in consumption loads in the network.

Utilizing distance relays that are used in the interconnected transmission network but are not used in radially operated distribution networks will significantly solve the protection problems in the case of SC 0 and SC 1 in distributed generation systems.

6. CONCLUSIONS AND FUTURE WORKS

In this study, the effects of distributed generation on the protection of the distribution systems have been examined. For the sake of simplicity, solar power plants have been used as a distributed generation source. Because it has been predicted that solar energy would dominate distributed generation. As a matter of fact that, in the protection systems of the distribution systems, the single-phase short-circuit overcurrent protection at the MV level will be adversely affected in the first instance. For these reasons, the single-phase short-circuit contribution of PV power plants at MV level is one of the most important specific issues for distributed generation. Therefore, the thesis focuses on the single-phase short-circuit contribution of PV power plants at MV level.

In order to investigate the adverse effects, a calculation and simulation platform has been created for easy and effective modeling of distributed generation and distribution network. To obtain realistic results in PSCAD simulations, an Excel-based computing platform was developed that calculates the distribution network parameters to be used in the PSCAD. In addition, the Excel-based calculation and simulation platform makes it very easy to simulate the distribution network in the PSCAD, and the data used for the calculation is easily accessible. Also, the program design provides ease of use, clarity, comprehensibility, and reliability in the calculation.

In the literature, it is sighted that the IEEE 13-Node or IEEE 34-Node radial distribution test feeder topologies are frequently used when the distribution grid is investigated. In order to investigate the current and future distribution systems in a practical and effective way, an adequate and required topology (4-Node) which is alternative for these topologies was developed and tested in the PSCAD platform.

The superposition analysis is used in this study in order to efficiently examine how the rated and short-circuit currents of DG will affect the relay coordination. Before the simulations stage, it was evaluated whether the superposition analysis, which gives accurate results for linear systems, can be used in this study or not. It is observed that superposition analysis results are very close to the correct values, although it is not accurate. The deviations in the results of superposition analysis were analyzed mathematically. Although this method does not yield sensitive and accurate results, it can practically indicate how the currents in the feeders and relay coordination will change, before simulations. In other words, the method can supply strong predictions without simulations too. The cases predicted by the superposition analysis have been tested by simulations on the basic topology.

After identifying the problematic points in the topology, the likely solutions have been tested. It is observed that the over-current trip time of the inverter reduces the adverse effect of the SPP on the relay coordination. Keeping the inverter's tripping time at small values improves the performance of the relay coordination in distributed generation. For inverters to be used in distributed generation applications (unlicensed generation plants), limiting the overcurrent trip time by the legislation will reduce the short circuit contribution time of the distributed generation power plants.

Distance relays have been tested as another method for mitigating the adverse effects of DG systems. It is observed that utilizing distance relays that are used in the interconnected transmission network but are not used in radially operated distribution networks will significantly solve the protection problems.

Various negative effects of SPP as a distributed generation system on relay coordination have been observed in the simulations of the determined topology during the study. These adverse effects have been found to occur at specific points on the topology. The results of the simulations are shown in the table below.

Table 6.1. Simulations for different cases

* The current values determined during the simulation period are given in time sequence.							
CoT: Cut Off Time, MFCV: the Main Feeder Current Values, CVERF: Current Values Encountered by the Relay of the Feeder							
No	Simulation Definitions	CoT of the Interface Inverter (s)	the Fault Moment (s)	the Damping Moment of Fault (s)	MFCV Provided by the Substation* (kA)	CVERF Where the Fault Occurs - the Fault Moment Current* (kA)	SPP Contribution of the Fault Current
1	Steady State Analysis, SPP is not Connected	-	-	-	0,42	0,42	-
2	Steady State Analysis, 5 MW SPP is Connected	-	-	-	0,35	0,35	-
3	SC 0 (Main Busbar Fault) Analysis, SPP is not Connected	-	1,0	1,6	0,42 / 1,25 / 0,00	0,42 / 1,25 / 0,00	0%
4	SC 0 (Main Busbar Fault) Analysis, 5 MW SPP is Connected	-	1,0	-	0,35 / 1,20	0,35 / 1,20	8%
5	SC 0 (Main Busbar Fault) Analysis, 5 MW SPP is Connected	0,2	1,0	1,8	0,35 / 1,20 / 1,25 / 0,00	0,35 / 1,20 / 1,25 / 0,00	8%
6	SC 1 (Generation Feeder Fault) Analysis, SPP is not Connected	-	1,0	1,4	0,42 / 1,05 / 0,20	0,05 / 0,99 / 0,00	0%
7	SC 1 (Generation Feeder Fault) Analysis, 4 MW SPP is Connected	-	1,0	-	0,35 / 1,01	0,01 / 0,95	9%
8	SC 1 (Generation Feeder Fault) Analysis, 4 MW SPP is Connected	0,2	1,0	1,6	0,35 / 1,01 / 1,05 / 0,21	0,01 / 0,95 / 1,00 / 0,00	9%
9	SC 2 (Load Feeder Fault) Analysis, SPP is not Connected	-	1,0	1,4	0,36 / 1,05 / 0,18	0,01 / 1,06 / 0,00	0%
10	SC 2 (Load Feeder Fault) Analysis, 10 MW SPP is Connected	-	1,0	1,4	0,29 / 0,98 / 0,08	0,01 / 1,11 / 0,00	1%
11	SC 2 (Load Feeder Fault) Analysis, 10 MW SPP is Connected	0,2	1,0	1,4	0,29 / 0,98 / 0,08	0,01 / 1,11 / 0,00	1%

This table shows that there are %9 short-circuit current contribution in the cases of the main busbar fault and the generation feeder fault and a short-circuit contribution at this level is sufficient to disturb the existing overcurrent relay coordination. However, there is only %1 short-circuit current contribution in the case of load feeder fault and a short-circuit contribution at this level does not disturb relay coordination of the corresponding feeder. Faults cannot be cleared when a short-circuit fault occurs in the main distribution busbar and in F 1. In case of a short circuit in F 2, there is no negative effect on the existing relay coordination. In other words, the SPP adversely affects its own feeder and the main distribution busbar, and the rest of secondary feeders does not adversely affected in any way. In addition, It is observed that faults that cannot be cleared by the existing relay coordination can be cleared by limiting the trip time of the interface inverter of SPP, even if the clearing time is delayed as much as the inverter tripping time. On the other hand, the adaptive nature of a relay coordination by distance relays is stronger than over-current relays. In other words, the correct working tolerance (of distance relays) to changing load and production conditions in the distribution network is higher than the tolerance of over-current relays. In the flow diagram below, the specific circuit points at which the relay coordination may be disturbed and the actions to be taken accordingly are indicated.

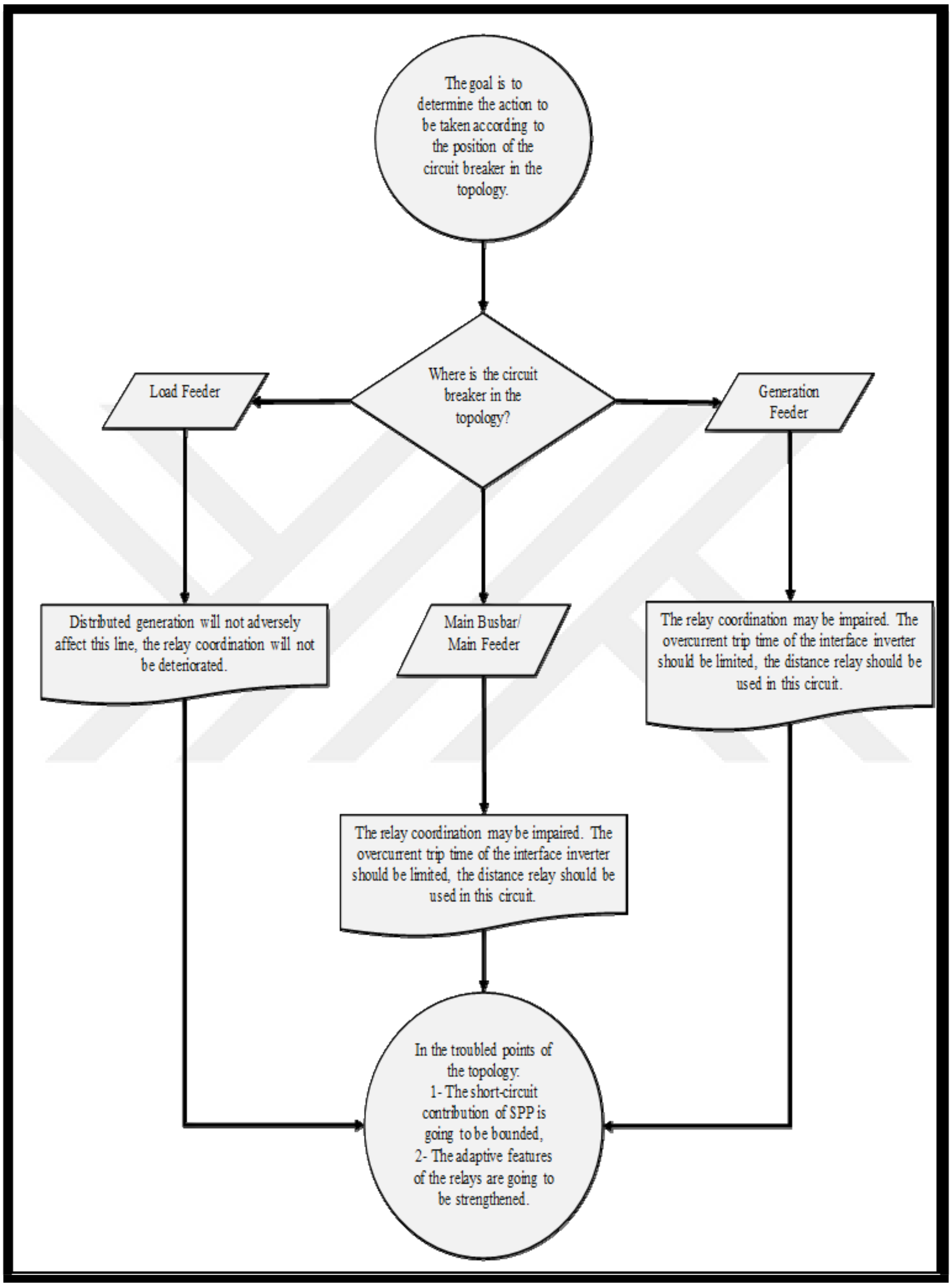

Figure 6.1. Actions to be taken according to the position on the topology

It is seen that an effective way of limiting the adverse effects that occur in the SC 0 and the SC 1 is to keep the tripping time of the inverter of the SPP small. In addition, it is observed that establishing a relay coordination by distance relays will be effective in order relay coordination to be less affected by changing distributed production power levels. The common features of these methods and all other methods that will limit adverse effects are listed below:

i. To limit the SPP short-circuit contribution current
ii. To increase the tolerance of circuit breaker relays to load and production variations

Some of the methods that have or are likely to have these common characteristics are listed below.

i. Keeping the trip time so small for inverter protection (Loss of Main Function)
ii. Keeping the instantaneous trip current setting in the circuit breaker relays at the lowest level that does not disturb the selectivity
iii. Using distance relays in the distributed networks where distributed generation are included or may likely be connected
iv. Limiting the power of solar power plants to be connected to the network
v. Connecting the solar power plant to the network via a serial reactance and limiting short-circuit contribution by the serial reactance etc.

It will be ensured that the benefits of distributed generation which reduce losses, increase network stability, and increase renewable energy use is safely obtained with the implementation of these methods.

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CURRICULUM VITAE

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He has been working as process leader in Distribution Assets and Investment Planning Management Department of Enerjisa-Toroslar Electricity Distribution Company since 2012. His research areas are distribution systems, renewable energy resources, energy efficiency, distributed generations, electric machinery, and investment planning.

APPENDIX

APPENDIX A: SUPERPOSITION THEORY

Superposition theorem is applied to the electric circuits where two or more sources are contained. In this method, other sources are deactivated while examining the effect of any independent source. The terminals of voltage sources are short-circuited and the terminals of current sources are open circuited in this method. Dependent resources are not disabled because they are controlled by circuit variables.

In order to apply superposition theory, all elements in the circuit must be linear and bi-directional. This theorem can be applied in every frequency and waveform as long as the circuit elements are linear. Linearity is the proportionality of input and output. Linearity includes the additivity and scalability features.

Additivity:

Let's assume that when the signal x_1 is given to the system as an input, the system give the signal y_1 as an output. Besides, when the signal x_2 is given to the system as an input, the system give the signal y_2 as an output. Hereafter, if the signal $x_1 + x_2$ is given to the system as an input and the system give the signal $y_1 + y_2$ as an output, then the system has passed the first phase of linearity.

In an additive circuit;

If,

$x_1 \rightarrow y_1$ and

$x_2 \rightarrow y_2$

Then,

$x_1 + x_2 \rightarrow y_1 + y_2$

Scalability:

Let's assume that when the signal x_1 is given to the system as an input, the system give the signal y_1 as an output. Hereafter, if the signal ay_1 (a is any constant) is obtained when the signal ax_1 is given to the system as an output, then the system has passed the second phase of linearity. That is to say, when the input is multiplied with a constant, the linear system multiply the output with the same constant.

In a scalable circuit;

If,

$$x_1 \rightarrow y_1$$

Then,

$$ax_1 \rightarrow ay_1$$

Linearity:

In this case, if both properties are taken into account, it can be stated that the systems provide the superposition feature is the linear systems. The linear (additive and scalable) system behavior is modeled below.

$$ax_1 + bx_2 \longrightarrow \boxed{\text{The Linear System}} \longrightarrow ay_1 + by_2$$

Figure 1. The linear system

Bi-Directionality:

Superposition method requires bi-directionality as well as linearity. The amount of the current passing through bi-directional element does not change even though the direction of the voltage applied to the element's terminals has been changed. In electrical circuits, coils, capacitors, resistors are usually linear and bi-directional. Semiconductor elements such as transistors and diodes are not bidirectional and linear. Therefore, the superposition method cannot be applied to the networks that include such semiconductor elements. The disadvantage of this method is that it requires circuit analysis as many as the number of independent sources.

Application Steps

- All other sources are disabled except for one source in the circuit.
- The desired output is calculated by using the mesh analysis or the node analysis methods.
- The above procedures are repeated for each source.
- As a result, the summation is done with considering each source's direction and effects.

In multiple-source circuits, the voltage or current of any circuit equals the algebraic sum of the voltages or currents produced by each source separately.

To explain with a sample, the circuit diagram shown below consists of two voltage sources.

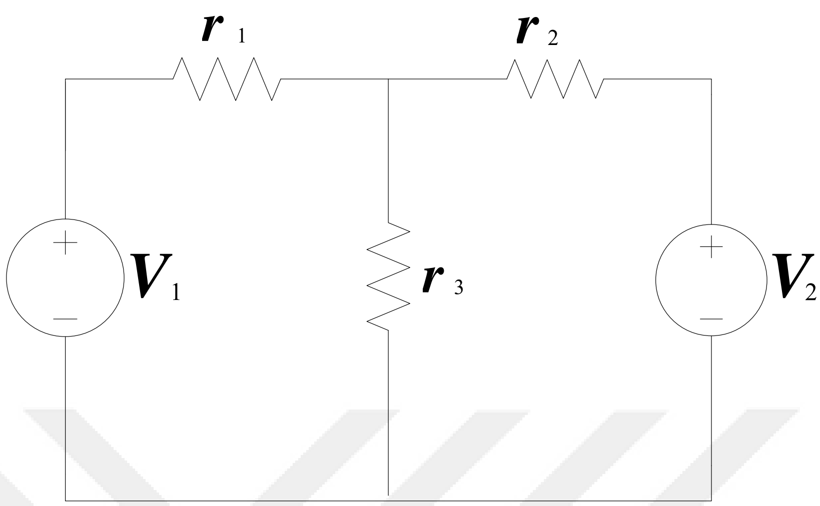

Figure 2. The circuit with two sources

First, the voltage source V_1 is enabled, the voltage source V_2 is short-circuited.

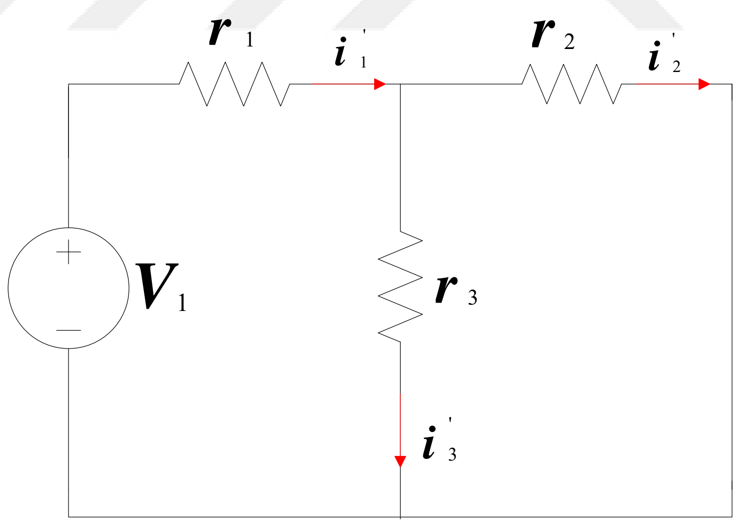

Figure 3. The circuit in which V_2 is disabled

The current values flowing through each branch (i'_1, i'_2, i'_3) is calculated by the following equations.

Equation 4:

$$i'_1 = \frac{V_1}{\frac{r_2 r_3}{r_2+r_3}+r_1} \tag{1}$$

Equation 5:

$$i'_2 = i'_1 \frac{r_3}{r_2+r_3} \tag{2}$$

Equation 6:

$$i'_3 = i'_1 - i'_2 \tag{3}$$

Now, the voltage source V_2 has been enabled, and the voltage source V_1 has been shorted (i.e. disabled) in the following circuit.

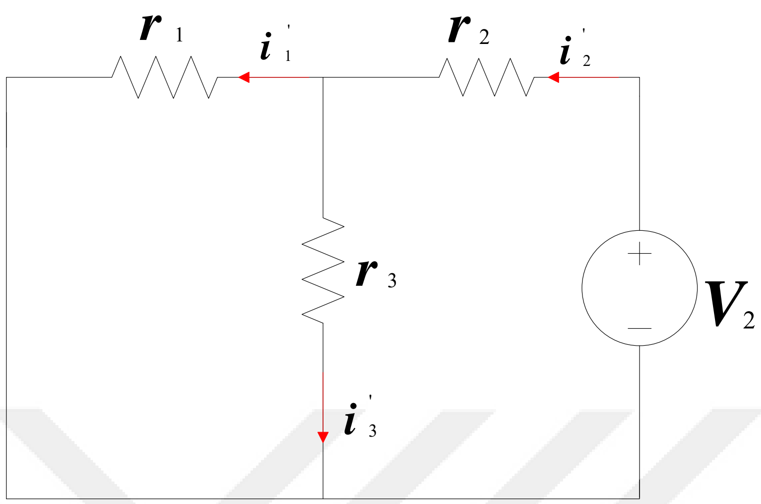

Figure 4. The circuit in which V_1 is disabled

In this circuit, the currents i_1'', i_2'' *and* i_3'' can be calculated by the following equations.

Equation 7:

$$i_2'' = \frac{V_2}{\frac{r_1 r_3}{r_1+r_3}+r_2} \tag{4}$$

Equation 8:

$$i_1'' = i_2'' \frac{r_3}{r_1+r_3} \tag{5}$$

Equation 9:

$$i_3'' = i_2'' - i_1'' \tag{6}$$

According to the superposition theory, the actual current flows i_1, i_2 ve i_3 will be obtained by the following equations.

Equation 10:

$$i_1 = i_1' - i_1'' \tag{7}$$

Equation 11:

$$i_2 = i_2' - i_2'' \tag{8}$$

Equation 12:

$$i_3 = i_3' - i_3'' \tag{9}$$

APPENDIX B: DISTANCE RELAYS

In the short-circuit faults that occur in the energy transmission lines that form the interconnected network, the protection relay which detects and disables the faulty part is named the distance relay.

It is essentially a resistance relay, they are named distance relays, because of resistances of the lines and the networks depend on the length.

Although the old models are the electromechanical type, microprocessor-based types which are capable of electronic and more sensitive protection are preferred today.

The relay consists of three main units that undertake different tasks:

• Starting unit
• Direction unit
• Measuring unit

The distance relay is a secondary type of relay that provides selective protection. Proper protection function of the distance relay depends on the initiation, direction and measurement units to operate respectively.

The most important feature of these relays is that the tripping time in the event of failure is directly proportional to the distance of the fault location from the supply point. Overcurrent relays are also used in combination with distance relays in relay coordination.

The Basic Working Principle

Generally, the distance protection relays are based on a comparison of current and voltage values at a point of the line regardless of the structure. In other words, the relay measures according to $Z = U / I$ the line impedance. In the fault of a short circuit, the voltage value of line decreases and the current value increases.

Accordingly, the short-circuit impedance is smaller than in normal operating conditions.

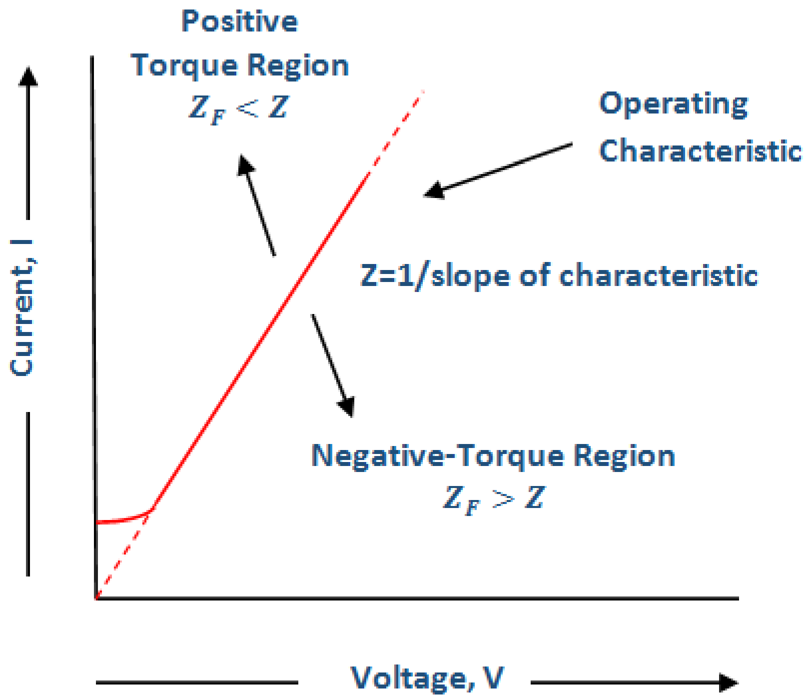

Figure 5. The basic tripping characteristics of a distance relay

If the measured impedance is in the negative-torque region of the graph, there may be an open circuit fault in the system. Since the measured impedance is greater than the threshold impedance. On the other hand, if the measured impedance is in the positive-torque region of the graph, there is a short circuit fault in the system. Since, the measured impedance is smaller than the threshold impedance. The measured impedance value of the relay depends on the distance between the relay with the fault point in the case of a short-circuit. The impedance value is directly proportional to the length of the line.

Then, if the measured impedance of the distance protection relay is lower than the value set by the relay, it activates the initialization chain.

The short-circuit fault current in the energy transmission lines forming an interconnected network is quite great value because the network is fed from several sources. For this reason, it is necessary to determine the location of the short circuit of the line and leave it out of service immediately. Otherwise, elements such as alternator and transformer may be damaged in a very short time and the power of the interconnection system may be completely cut off.

Loads of the networks are considerably reduced during night hours. In this case, the alternator excitation is also too small. In the event of a short circuit that occurs at times when the network load is low, the currents flowing through the lines are small. This current cannot be sufficient for the operation of overcurrent relays used for protection purposes.

The distance relay is a protection element that detects and deactivates the faulty part in such type short circuit fault conditions and ensures continuity of the energy in the solid parts of the line without interrupting energy the other parts of the network. The distance relay detects and deactivates the faulty part in the event of a short-circuit fault. It does not cut off the energy of the other parts of the network and ensures the continuity of the energy in the healthy parts of the line.

Distance Relay Types

Distance relays can be classified with respect to its characteristics as follows.

1) Impedance Relay
2) Reactance Relay
3) Admittance (MHO) Relay
4) Offset Mho (Modified impedance) Relay
5) Ohm Relay

The characteristics diagram of these relays are given in the following titles.

1) Impedance Relay Characteristics

The impedance relays do not consider the phase angle between current and voltage applied. For this reason, as shown in the figure, the characteristic of impedance relay on R-X plane is a circle, the center of which is the origin of the coordinates. That is, for the relay to operate, the impedance of the line must be in the region inside the circle.

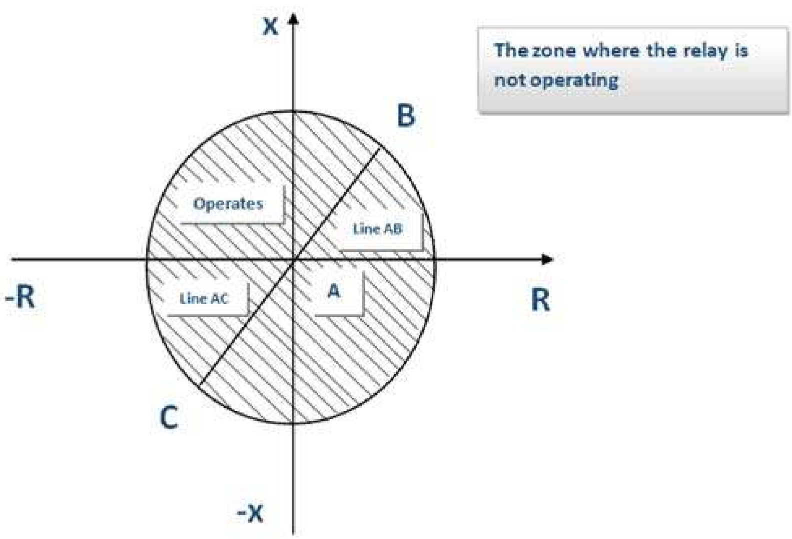

Figure 6. The tripping characteristics of an impedance relay

2) Reactance Relay Characteristics

The characteristic of the reactance relay is indicated by a line parallel to the horizontal axis R on the plane R-X, as shown in the figure. The characteristic of the reactance relay is independent of resistance. The relay only reacts to the reactance component of the impedance.

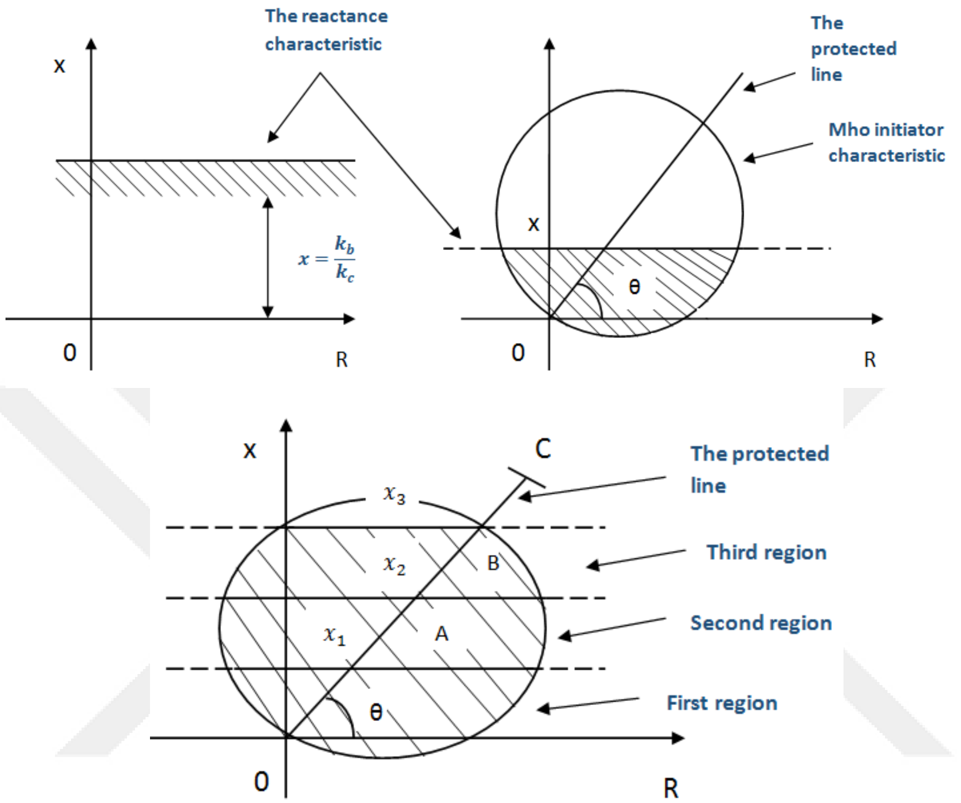

Figure 7. The tripping characteristics of a reactance relay

Since the reactance relay responds only to the reactive component of the system impedance, it is not affected by arc resistance formed in a fault.

3) Admittance (Mho) Relay Characteristics

If the characteristic of the mho relay is drawn in plane R-X as shown in the figure (a), a circle passing through the origin (0,0) is obtained. The characteristic of the mho relay in the figure (b) is seen in the form of a straight line in the admittance plane G-B.

The fact that the characteristic circle of the Mho relay in the figüre (c), passes through its origin naturally ensures that the relay has a direction property.

For this reason, a mho characteristic relay only makes distance protection in one direction. In this way, the relay also does not require a directional unit. The setting of the protection limits of the Mho relay varies with the fault angle due to the fact that there is no impedance measurement for all angles. Therefore, the fault angle depends on the relative values of R and X.

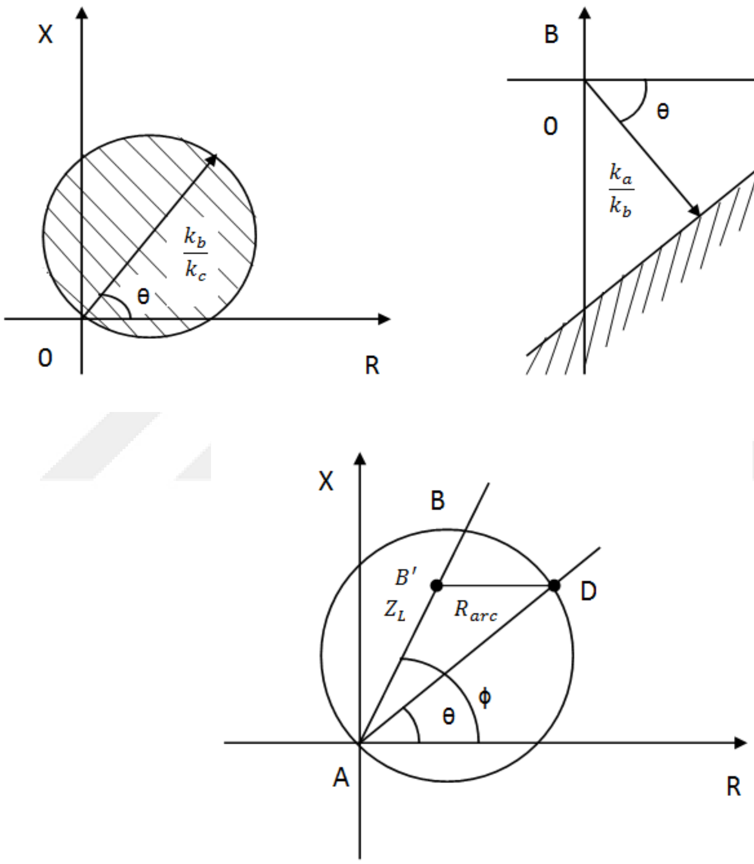

Figure 8. The tripping characteristics of an admittance relay

4) Offset Mho (Modified impedance) Relay Characteristics

The operation characteristic of the Offset mho relay is shown in the figure.

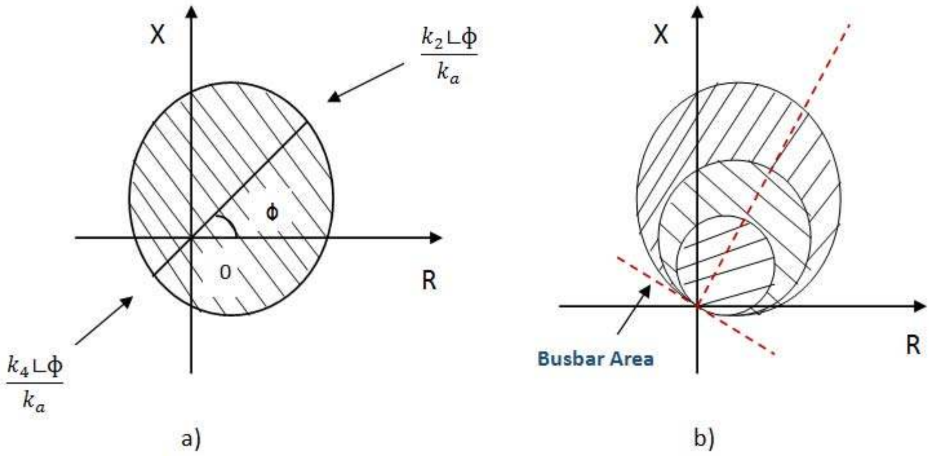

Figure 9. The tripping characteristics of a modified impedance relay

5) Ohm Relay Characteristics

The Ohm relay characteristic is a straight form on the R-X plane.

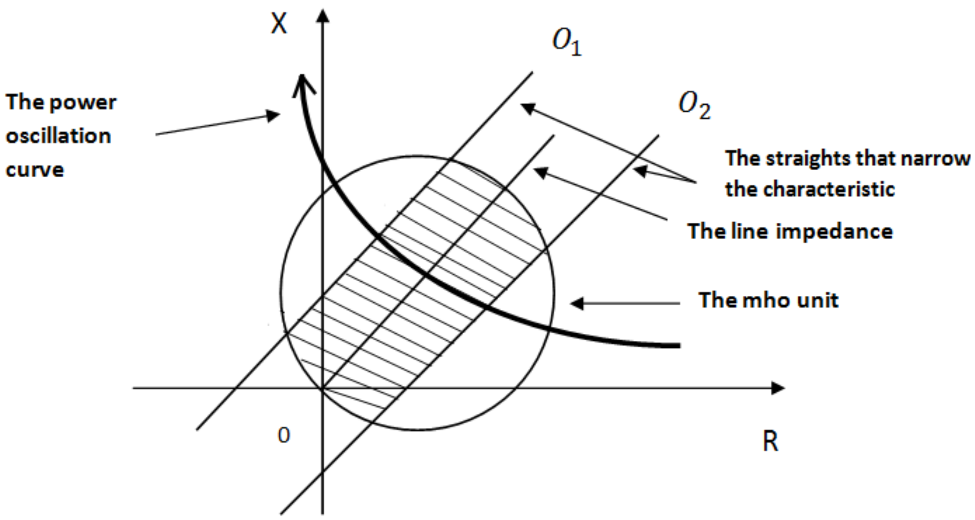

Figure 10. The tripping characteristics of an ohm relay

APPENDIX C: THE MASTER DATA OF THE MASTER PROGRAM

C.1. VBA Macros Codes

```
Sub NETWORK()
' NETWORK Makro
    Sheets("NETWORK").Select
    Range("A1").Select
End Sub

Sub LINE1()
' LINE1 Makro
    Sheets("LINE-1").Select
    Range("A1").Select
End Sub

Sub SUBSTATION1()
' SUBSTATION1 Makro
    Sheets("SS-1").Select
    Range("A1").Select
End Sub

Sub LINE2()
' LINE2 Makro
    Sheets("LINE-2").Select
    Range("A1").Select
End Sub
```

```
Sub SUBSTATION2()
' SUBSTATION2 Makro
   Sheets("SS-2").Select
   Range("A1").Select
End Sub

Sub LINE3()
' LINE3 Makro
   Sheets("LINE-3").Select
   Range("A1").Select
End Sub

Sub SUBSTATION3()
' SUBSTATION3 Makro
   Sheets("SS-3").Select
   Range("A1").Select
End Sub

Sub LINE4()
' LINE4 Makro
   Sheets("LINE-4").Select
   Range("A1").Select
End Sub

Sub SUBSTATION4()
' SUBSTATION4 Makro
   Sheets("SS-4").Select
   Range("A1").Select
End Sub
```

```
Sub LINE5()
' LINE5 Makro
    Sheets("LINE-5").Select
    Range("A1").Select
End Sub

Sub SUBSTATION5()
' SUBSTATION5 Makro
    Sheets("SS-5").Select
    Range("A1").Select
End Sub

Sub LINE6()
' LINE6 Makro
    Sheets("LINE-6").Select
    Range("A1").Select
End Sub

Sub SUBSTATION6()
' SUBSTATION6 Makro
    Sheets("SS-6").Select
    Range("A1").Select
End Sub

Sub LINE7()
' LINE7 Makro
    Sheets("LINE-7").Select
    Range("A1").Select
End Sub
```

```
Sub SUBSTATION7()
' SUBSTATION7 Makro
   ActiveWindow.ScrollWorkbookTabs Position:=xlLast
   Sheets("SS-7").Select
   Range("A1").Select
End Sub

Sub LINE8()
' LINE8 Makro
   ActiveWindow.ScrollWorkbookTabs Position:=xlLast
   Sheets("LINE-8").Select
   Range("A1").Select
End Sub

Sub PEAK_DEMANDS()
' PEAK_DEMANDS Makro
   ActiveWindow.ScrollWorkbookTabs Position:=xlLast
   Sheets("2013_YAZ_PUANTI").Select
End Sub

Sub LINE_PARAMETERS()
' LINE_PARAMETERS Makro
   ActiveWindow.ScrollWorkbookTabs Position:=xlLast
   Sheets("LINES").Select
   Range("A1").Select
End Sub
```

```
Sub ABBR_DEF()
' ABBR_DEF Makro
    ActiveWindow.ScrollWorkbookTabs Position:=xlLast
    Sheets("ABBR.&DEF.").Select
    Range("E1").Select
End Sub

Sub FORMULAS()
' FORMULAS Makro
    ActiveWindow.ScrollWorkbookTabs Position:=xlLast
    Sheets("FORMULAS").Select
    Range("A1").Select
End Sub

Sub NOTES()
' NOTES Makro
    ActiveWindow.ScrollWorkbookTabs Position:=xlLast
    Sheets("NOTES").Select
    Range("A1").Select
End Sub

Sub TEİAŞ1()
' TEİAŞ1 Makro
    Sheets("TS-1").Select
End Sub

Sub TEİAŞ2()
' TEİAŞ2 Makro
    ActiveWindow.ScrollWorkbookTabs Sheets:=12
```

```
    Sheets("TS-2").Select
End Sub

Sub CONTACTRES()
' CONTACTRES Makro
    ActiveWindow.ScrollWorkbookTabs Position:=xlLast
    Sheets("CONTACT RESISTANCE").Select
End Sub

Sub RESTORE()
' RESTORE Makro
    Sheets("TS-1").Select
    Range("E2").Select
    Selection.ClearContents
    Range("G2").Select
    Selection.ClearContents
    Sheets("LINE-1").Select
    Range("E2").Select
    Selection.ClearContents
    Range("E3").Select
    Selection.ClearContents
    Range("E4").Select
    Selection.ClearContents
    Sheets("SS-1").Select
    Range("D2").Select
    Selection.ClearContents
    Sheets("LINE-2").Select
    Range("E2:E4").Select
    Selection.ClearContents
```

```
Sheets("SS-2").Select
Range("D2").Select
Selection.ClearContents
Sheets("LINE-3").Select
Range("E2:E4").Select
Selection.ClearContents
Sheets("SS-3").Select
Range("D2").Select
Selection.ClearContents
Sheets("LINE-4").Select
Range("E2:E4").Select
Selection.ClearContents
Sheets("SS-4").Select
Range("D2").Select
Selection.ClearContents
Sheets("LINE-5").Select
Range("E2:E4").Select
Selection.ClearContents
Sheets("SS-5").Select
Range("D2").Select
Selection.ClearContents
Sheets("LINE-6").Select
Range("E2:E4").Select
Selection.ClearContents
Sheets("SS-6").Select
Range("D2").Select
Selection.ClearContents
Sheets("LINE-7").Select
Range("E2:E4").Select
```

```
    Selection.ClearContents
    Sheets("SS-7").Select
    Range("D2").Select
    Selection.ClearContents
    Sheets("LINE-8").Select
    Range("E2:E4").Select
    Selection.ClearContents
    Sheets("TS-2").Select
    Range("E2").Select
    Selection.ClearContents
    Range("G2").Select
    Selection.ClearContents
    ActiveWindow.ScrollWorkbookTabs Position:=xlFirst
    Sheets("NETWORK").Select
    Range("A1").Select
End Sub
```

C.2. Peak Short Circuit Currents of TS Busbars

Table 1. Peak short circuit currents of TS busbars

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
921621	A.CIMENTO	154	13,8	-78,1	9,7	-78,2
811121	A.GOLBASI	154	4,2	-67,9	2,8	-71,0
421121	A.HOYUGU	154	6,4	-82,5	4,3	-82,0
421131	A.HOYUGU66	66	3,3	-83,9	3,0	-84,0
522421	ACARSOY DGKC	154	15,3	-84,4	11,2	-83,0
521521	ACIPAYAM	154	5,1	-84,0	3,5	-82,0
914321	ACSPAYAS	154	14,9	-77,0	13,8	-79,2
210410	ADA_1_DG	380	36,1	-83,3	37,8	-84,8
210510	ADA_2_DG	380	35,7	-83,3	37,0	-84,6
910010	ADANA	380	15,5	-78,5	14,0	-77,6
910021	ADANA_BANK_A	154	27,1	-79,5	24,3	-80,7
910022	ADANA_BANK_B	154	27,1	-79,5	24,3	-80,7
210310	ADAPAZARI	380	38,4	-82,6	31,3	-81,6
210321	ADAPAZARI_A	154	17,9	-85,1	16,4	-86,1
210322	ADAPAZARI_B	154	24,3	-88,9	23,3	-89,3
520721	ADIGUZEL	154	5,9	-79,6	5,0	-81,0
712421	ADILCEVAZ	154	3,9	-66,2	2,7	-67,6
820921	ADIYAMAN	154	5,4	-73,5	4,4	-72,4
820821	ADIYAMANCIM	154	5,8	-75,7	5,2	-73,8
520221	AFYON	154	15,7	-82,8	11,3	-81,6
520021	AFYON_2	154	19,2	-84,8	14,5	-83,5
520010	AFYON2	380	15,2	-83,8	9,4	-79,2
522121	AGEDGKC	154	12,9	-81,9	12,3	-83,8
710821	AGRI	154	3,1	-62,2	2,0	-59,7
710921	AGRI_2A	154	3,3	-62,0	2,2	-59,6
922621	AKBELEN	154	11,5	-82,0	10,0	-84,5
331021	AKBUK	154	3,9	-81,3	2,8	-79,5
333521	AKBUK_RES	154	3,8	-81,3	2,7	-79,5
821021	AKCAKALE	154	6,3	-77,8	4,1	-78,5
231521	AKCAKOCA	154	8,8	-72,2	6,2	-71,3
221721	AKCALAR	154	8,8	-81,4	7,3	-79,3
111621	AKCANSA_A	154	7,1	-93,2	6,8	-95,1

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
311421	AKCAY_A	154	2,1	-72,7	1,5	-73,3
422121	AKDAGMADENI	154	1,5	-58,5	0,9	-59,4
514221	AKDENIZENJ	154	16,8	-86,1	15,6	-87,7
214421	AKEN_YALOVA	154	3,5	-91,0	4,0	-93,9
223721	AKENJBOZUYU	154	7,7	-80,6	8,1	-82,9
312321	AKHISAR	154	8,1	-75,8	6,5	-76,8
315421	AKHISAR_RES	154	7,9	-76,3	6,2	-77,1
410621	AKKOPRU	154	7,1	-84,0	5,6	-80,2
332421	AKKOPRU_HES	154	3,2	-89,4	2,6	-90,9
622421	AKKOY	154	11,9	-45,4	13,7	-45,7
323621	AKNJ_KPASA_A	154	13,7	-82,0	13,1	-83,6
622921	AKOCAK	154	4,9	-48,1	3,3	-49,4
511421	AKORSAN	154	17,0	-86,1	15,8	-87,8
514310	AKSA	380	13,7	-84,2	15,0	-85,7
323821	AKSA_MORSAN	154	17,3	-81,0	14,1	-82,4
611121	AKSA_SAMSUN	154	15,9	-53,7	16,4	-54,7
713221	AKSA_VAN	154	3,0	-66,4	3,3	-69,0
513821	AKSAENERJI	154	15,2	-86,7	14,3	-88,6
122421	AKSARAY_A	154	11,2	-99,0	10,7	-98,4
122422	AKSARAY_B	154	3,9	-102,9	4,6	-99,8
512221	AKSEHIR	154	3,3	-81,2	1,8	-82,9
511921	AKSEKI	154	7,6	-89,6	5,3	-87,4
713721	AKSU	154	2,5	-55,2	3,0	-55,2
427721	AKSU_RES	154	5,1	-83,2	3,7	-82,6
612821	ALACA_A	154	4,5	-67,1	3,3	-67,7
320521	ALACATI	154	2,9	-74,8	2,3	-73,1
424921	ALAKOVA	154	7,3	-87,9	4,8	-87,6
511321	ALANYA	154	5,7	-86,9	4,4	-90,1
511621	ALARA	154	6,2	-86,7	4,6	-88,4
312421	ALASEHIR	154	5,0	-78,8	3,5	-81,4
320621	ALCUK	154	24,5	-80,3	24,5	-81,5
333821	ALES DGKC	154	9,3	-81,2	7,6	-83,0
333822	ALES DGKC	154	9,3	-81,2	7,6	-83,0
320010	ALIAGA	380	24,4	-78,7	27,4	-80,2
320121	ALIAGA_1	154	18,9	-78,2	17,0	-79,1

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
320022	ALIAGA_2A	154	25,2	-80,9	26,4	-82,0
320021	ALIAGA_2B	154	27,2	-80,9	29,0	-82,5
324221	ALIAGA_RES	154	7,8	-80,9	7,1	-79,7
320221	ALIAGAOSB_A	154	19,6	-79,5	19,1	-79,4
320222	ALIAGAOSB_B	154	19,6	-79,5	19,1	-79,4
120310	ALIBEYKOY	380	25,4	-87,5	24,1	-88,2
120321	ALIBEYKOY_A	154	21,6	-95,8	21,0	-98,2
120322	ALIBEYKOY_B	154	21,6	-95,8	21,0	-98,2
833521	ALKUMRU_A	154	5,5	-78,9	5,3	-82,5
320821	ALMAK	154	24,3	-80,3	23,8	-81,3
621221	ALMUS	154	4,8	-58,6	4,9	-60,3
712221	ALPARSLAN	154	3,4	-64,3	3,9	-66,7
324121	ALSANCAK	154	15,5	-81,2	11,2	-81,9
425121	ALTINEKIN	154	2,1	-83,7	1,3	-85,3
610410	ALTINKAYA	380	11,4	-57,4	7,1	-51,9
610421	ALTINKAYA	154	7,5	-55,7	6,7	-56,1
223421	ALTINTAS	154	5,7	-77,1	3,6	-76,2
123121	ALTINTEPE_A	154	18,2	-96,5	17,2	-94,9
123122	ALTINTEPE_B	154	18,2	-96,5	17,2	-94,9
612621	AMASYA	154	7,7	-60,8	5,5	-61,3
120210	AMBARLI A	380	16,7	-92,3	16,7	-94,3
120221	AMBARLI_FO	154	22,0	-95,9	23,5	-98,6
120121	AMBARLI_TM_	154	21,7	-95,9	23,1	-98,5
120010	AMBARLIB	380	16,8	-92,2	16,8	-94,5
120021	AMBARLIDG_A	154	22,1	-96,0	24,0	-98,7
120022	AMBARLIDG_B	154	26,1	-94,1	28,8	-96,6
922821	ANAMUR	154	2,6	-81,7	2,1	-84,0
912810	ANDIRIN	380	12,4	-77,7	9,3	-75,3
912821	ANDIRIN	154	19,6	-78,0	17,2	-76,4
915321	ANDIRIN_HES	154	8,5	-72,0	7,7	-73,3
413121	ANK_ZORLU	154	13,4	-83,0	12,3	-83,5
410721	ANKARASAN	154	12,2	-82,1	10,7	-82,7
910221	ANTAKYA_1	154	6,8	-81,4	5,5	-84,1
910321	ANTAKYA_2	154	9,0	-79,0	7,4	-81,5
510321	ANTALYA_SB	154	15,2	-84,7	11,7	-86,5
624521	ARAKLI	154	4,9	-48,1	3,4	-49,4
720121	ARDAHAN	154	2,2	-53,4	1,8	-54,1

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
720021	ARDESEN	154	6,4	-50,3	4,7	-51,0
713521	ARMAMURATLI	154	3,3	-54,7	2,6	-54,7
726221	ARPA-HES	154	7,2	-55,2	7,0	-54,7
620321	ARSIN	154	7,8	-47,0	5,4	-48,3
215021	ARSLANBEY	154	10,6	-87,5	8,4	-87,5
622221	ARTOVA_CIM	154	2,6	-57,9	1,8	-58,9
720221	ARTVIN	154	3,1	-51,1	2,9	-52,8
511821	ASCIM_A	154	6,7	-83,3	5,0	-83,5
220621	ASILCELIK	154	8,3	-73,7	6,2	-73,3
710721	ASKALE	154	3,5	-52,6	2,8	-53,4
711721	ASKALECIM	154	3,5	-52,6	2,8	-53,4
320921	ASLANLR	154	9,5	-79,8	6,8	-79,4
910521	ASLANTAS	154	10,1	-76,4	9,4	-79,2
324321	ATAER	154	14,6	-80,4	13,5	-82,9
914710	ATAKAS	380	12,4	-79,0	11,5	-78,6
820010	ATATURK	380	26,0	-74,6	29,1	-76,2
820121	ATATURK	154	9,7	-75,2	8,5	-74,3
820021	ATATURK_2	154	13,6	-78,1	13,6	-79,0
916221	ATIKRES	154	8,9	-79,9	6,7	-82,3
120410	ATISALANI	380	21,5	-89,5	18,0	-91,0
120421	ATISALANI_A	154	18,3	-96,0	16,6	-96,1
120422	ATISALANI_B	154	12,0	-99,0	11,4	-101,2
422321	AVANOS	154	10,1	-75,2	7,8	-76,3
610021	AYANCIK	154	2,3	-57,2	1,4	-57,8
331121	AYDIN	154	7,1	-79,4	5,4	-81,0
331122	AYDIN	154	7,1	-79,4	5,4	-81,0
312521	AYVALIK	154	2,0	-73,9	1,4	-74,9
223521	AZOT	154	11,8	-77,8	8,2	-77,6
920931	B.ADANA66_A	66	5,7	-79,1	6,1	-77,0
920932	B.ADANA66_B	66	5,7	-79,0	6,2	-78,2
211021	B.BAKKALKY_	154	18,7	-93,7	15,0	-95,8
211022	B.BAKKALKY_B	154	14,0	-94,4	14,1	-94,8
110721	B.CEKMECE	154	7,4	-93,3	7,3	-95,3
122321	B.DUZU_A	154	9,4	-96,9	8,6	-99,2
122322	B.DUZU_B	154	9,4	-96,9	8,6	-99,2
122221	B.EVLER_A	154	22,2	-94,6	21,6	-92,6
122222	B.EVLER_B	154	16,1	-96,6	14,2	-94,6

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
427321	B.HACILI	154	6,2	-77,0	5,4	-79,3
110821	B.KARISTIRAN	154	12,0	-87,9	14,5	-87,8
110310	BABAESKI	380	13,1	-92,1	11,2	-89,9
110321	BABAESKI	154	15,0	-90,1	13,4	-90,7
610221	BAFRA	154	7,3	-53,5	6,0	-54,0
121321	BAGCILAR_A	154	18,1	-95,8	15,6	-97,0
121322	BAGCILAR_B	154	18,1	-95,8	15,6	-97,0
712821	BAGISLI	154	2,4	-83,1	2,3	-83,7
814521	BAGISTASHES	154	3,2	-62,2	2,5	-64,4
410510	BAGLUM	380	16,9	-79,3	10,4	-75,4
410521	BAGLUM_A	154	10,9	-84,3	9,3	-84,2
410522	BAGLUM_B	154	13,5	-81,9	11,3	-81,3
910621	BAHÇE	154	13,8	-75,8	11,8	-77,0
914521	BAHCE_RES	154	12,0	-76,4	10,3	-77,7
122721	BAHCESEHIR_A	154	11,1	-97,0	10,9	-99,3
321521	BAHRIBABA	154	17,8	-80,6	14,2	-77,5
410821	BALGAT	154	14,2	-80,8	10,9	-81,2
310010	BALIKESIR	380	13,2	-80,1	9,6	-77,1
310121	BALIKESIR_1	154	11,4	-74,4	8,3	-75,4
310021	BALIKESIR_2	154	20,2	-79,3	17,1	-78,4
315821	BALIKESIRRES	154	11,4	-80,2	10,0	-79,7
313121	BALIKESR_OSB	154	7,5	-74,4	5,5	-74,7
310221	BALISEKA	154	9,4	-74,4	7,0	-75,0
514910	BALKUSAN	380	4,0	-88,9	2,4	-83,1
310321	BANDIRMA_2	154	3,8	-76,9	3,3	-79,1
310421	BANDIRMA_3A	154	4,6	-77,4	4,1	-79,9
314910	BANDIRMA_DG	380	14,0	-75,8	15,6	-76,1
224321	BANDIRMA_RE	154	4,6	-85,7	4,4	-85,0
315021	BANDRMA3_RE	154	3,7	-77,7	2,8	-75,2
311621	BARES	154	4,0	-77,9	3,5	-80,1
512321	BARLA	154	4,7	-81,7	3,3	-83,3
232321	BARTIN	154	4,2	-64,0	2,9	-64,5
712721	BASKALE	154	3,8	-87,5	3,7	-86,3
712710	BASKALE2	380	4,6	-86,8	3,5	-81,5
410921	BASTAS	154	5,6	-80,3	3,8	-79,3
830310	BATMAN	380	7,9	-77,1	7,3	-79,6
830421	BATMAN_1	154	13,1	-79,1	11,6	-81,8

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
830321	BATMAN_2A	154	13,5	-79,1	12,3	-81,9
830521	BATMANHES_A	154	6,2	-80,4	4,5	-80,3
710521	BAYBURT	154	3,7	-51,9	2,8	-50,8
315710	BEKIRLI_TES	380	13,0	-74,9	13,2	-74,9
914621	BELEN_RES	154	8,3	-78,3	6,9	-79,4
823521	BELKIS	154	2,9	-78,9	1,9	-79,5
312621	BERGAMA	154	9,3	-76,4	6,6	-75,0
910721	BERKEHES_A	154	22,9	-76,3	24,5	-78,5
910722	BERKEHES_B	154	22,9	-76,3	24,5	-78,5
915021	BERKMAN	154	7,1	-75,1	5,8	-77,2
221321	BESEVLER_A	154	16,3	-81,9	14,0	-82,7
214510	BEYKOZ	380	22,0	-89,2	16,4	-88,4
411021	BEYLIKKOPRU	154	3,9	-76,2	2,6	-76,8
411121	BEYPAZARI	154	6,3	-75,4	4,4	-75,1
512121	BEYSEHIR_A	154	4,7	-83,0	3,2	-82,8
310521	BIGA	154	4,2	-70,7	2,8	-72,3
311821	BIGADIC	154	7,0	-80,7	5,0	-77,4
222321	BILORSA	154	8,4	-81,0	6,3	-81,3
831121	BINGOL	154	6,7	-68,7	4,7	-68,7
821221	BIRECIK	154	10,0	-76,3	9,7	-77,3
821110	BIRECIKHES	380	15,0	-76,2	14,9	-77,0
821121	BIRECIKHES	154	9,4	-77,4	8,9	-78,4
923721	BIRKAPILIHES	154	3,7	-82,3	3,4	-82,4
833621	BISMIL_2	154	4,1	-78,8	2,8	-79,4
832721	BISMIL_A	154	5,4	-75,2	3,8	-76,5
832722	BISMIL_B	154	5,4	-75,2	3,8	-76,5
814621	BIZNA HAVZA	154	3,5	-67,8	2,3	-70,4
331221	BODRUM	154	5,8	-80,7	3,9	-81,0
331421	BODRUM_2	154	4,1	-82,9	2,6	-82,5
422221	BOGAZLIYAN	154	3,8	-73,0	2,3	-74,1
231921	BOLU	154	6,9	-72,2	5,1	-72,9
232021	BOLU_2A	154	5,8	-71,9	4,7	-73,4
232121	BOLUCIM	154	5,4	-71,4	4,3	-72,8
422421	BOR	154	5,1	-80,1	3,8	-82,8
721110	BORCKA	380	6,1	-55,8	6,4	-56,4
721121	BORCKA_A	154	8,7	-55,4	9,3	-55,8
114121	BOREAS_RES	154	1,7	-93,2	1,1	-91,9

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
321021	BORNOVA	154	19,8	-81,2	16,5	-82,1
221221	BOSEN	154	16,9	-80,2	17,4	-81,0
321121	BOSTANLI_A	154	17,7	-81,0	14,4	-79,8
110621	BOTASME	154	13,3	-89,0	15,4	-91,3
613610	BOYABAT	380	5,5	-66,8	6,4	-67,2
611621	BOYABAT	154	2,7	-61,6	1,7	-61,9
333021	BOZDOGAN	154	5,6	-80,5	4,9	-81,2
521621	BOZKURT	154	9,8	-81,7	7,1	-81,3
222521	BOZUYUK	154	8,1	-80,9	8,2	-82,6
225121	BOZUYUKOSB_	154	6,2	-81,4	5,6	-82,0
321421	BUCA_A	154	18,2	-79,5	14,3	-80,3
512421	BUCAK	154	6,2	-84,2	5,3	-85,5
716321	BULANIK	154	3,2	-65,4	3,0	-66,0
624321	BURCAK	154	2,9	-55,8	2,2	-56,3
512521	BURDUR	154	5,2	-84,2	3,7	-85,3
113021	BURGAZ_RES_A	154	1,8	-87,5	1,7	-84,3
221021	BURSA_1	154	14,9	-80,9	15,7	-74,3
221121	BURSA_3	154	13,1	-80,7	11,8	-78,0
220010	BURSADG	380	26,1	-80,5	26,4	-81,3
220021	BURSADG_A	154	11,6	-81,4	13,2	-83,7
220022	BURSADG_B	154	21,8	-80,5	26,7	-81,6
220110	BURSASAN	380	23,4	-80,3	20,7	-79,5
220121	BURSASAN_A	154	19,8	-82,6	19,3	-83,8
220122	BURSASAN_B	154	18,4	-80,9	19,9	-82,0
623622	BUYUKDUZHES	154	8,5	-43,7	8,8	-43,0
623621	BUYUKDUZTM	154	8,6	-43,8	9,0	-43,1
720421	C.KAYA_NOKT	154	7,8	-54,1	7,7	-53,5
113221	C.KOY_ENJ_A	154	11,8	-86,7	10,9	-89,5
114221	C.KOY_OSB_A	154	11,0	-87,6	9,6	-89,7
832931	CAGCAG	66	0,6	-79,2	0,8	-83,8
832921	CAGCAG_A	154	4,7	-85,9	3,6	-85,8
814221	CAGLAYAN	154	5,1	-71,6	3,8	-71,0
720321	CAKMAKKAYA	154	5,4	-51,6	4,9	-51,3
324821	CAKMAKTEPE	154	19,6	-79,6	19,2	-79,5
920521	CAMIS_MRSN_	154	6,3	-86,4	6,2	-89,3
920522	CAMIS_MRSN_B	154	6,3	-86,3	6,2	-89,3
422521	CAMLICA_A	154	6,3	-83,8	4,7	-83,2

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
427121	CAMLICA3_A	154	5,3	-83,9	4,0	-83,2
716121	CAMOLUK	154	2,3	-54,7	1,6	-55,0
314621	CAMSEKI_RES	154	3,0	-76,5	2,4	-76,6
310621	CAN	154	9,1	-74,5	8,2	-74,8
113121	CAN_ENJ_A	154	8,0	-87,4	7,4	-89,7
310721	CANAKKALE	154	3,3	-69,6	2,5	-71,1
310821	CANAKKALECIM	154	4,6	-75,1	5,0	-77,9
612221	CANKIRI	154	8,0	-66,9	5,4	-66,2
310921	CANTERMIK	154	8,1	-74,9	7,4	-75,6
620610	CARSAMBA	380	14,1	-55,7	13,8	-54,6
620621	CARSAMBA	154	20,7	-54,3	20,4	-55,0
920021	CATALAN	154	7,4	-85,4	8,2	-87,9
333721	CATALBUK_RE	154	6,4	-80,0	5,0	-79,6
113521	CATALCA_RES	154	4,0	-89,6	3,2	-91,9
522321	CAY DGKC_A	154	6,5	-84,0	3,0	-81,5
230721	CAYCUMA_2A	154	6,0	-65,4	4,8	-64,7
721421	CAYELI	154	5,9	-49,8	4,4	-51,1
410010	CAYIRHAN	380	13,6	-81,8	12,7	-82,3
410021	CAYIRHAN	154	9,7	-79,3	8,7	-80,3
722521	CAYKARA	154	3,7	-50,6	2,9	-50,3
520921	CAYSEKA	154	6,7	-83,6	3,1	-81,3
611221	CENGIZ_DKCS	154	16,2	-53,9	18,6	-55,5
110921	CERKEZKOY	154	11,8	-86,6	11,0	-89,5
325310	CESME	380	7,5	-82,7	5,8	-80,2
722221	CEVIZLIK	154	4,2	-52,3	2,8	-49,4
910821	CEYHAN_1	154	18,2	-76,7	13,1	-77,5
910921	CEYHAN_2	154	18,9	-76,9	13,8	-77,7
610521	CIDE	154	2,9	-63,4	1,9	-63,7
222921	CIFTELER	154	3,7	-76,1	2,4	-75,7
911021	CİHADİYE	154	26,8	-79,4	23,9	-80,6
422621	CIHANBEYLI	154	2,2	-81,5	1,4	-83,2
720521	CILDIR	154	2,2	-55,5	1,8	-53,8
813421	CIMKO_A	154	10,2	-75,8	8,0	-75,2
413621	CIMPOR_A	154	4,2	-80,2	2,6	-80,4
923321	CIMSA	154	12,3	-82,3	11,1	-85,0
333121	CINE	154	6,9	-78,7	4,8	-79,0
422721	CINKUR	154	14,3	-75,8	12,8	-77,3

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
623521	CIRAKDAMI	154	5,9	-46,1	3,7	-46,1
831321	CIRCIP	154	4,9	-85,1	3,3	-85,3
520821	CIVRIL	154	5,8	-81,1	3,9	-81,3
833021	CIZRE_A	154	5,7	-82,6	4,6	-82,9
211510	COLAKOGLU	380	17,7	-89,6	16,2	-91,0
211521	COLAKOGLU_A	154	25,2	-92,1	28,2	-95,7
814021	COLLOLAR	154	10,9	-76,3	8,4	-76,1
814321	COPLER_GOLD	154	2,6	-62,5	1,9	-64,3
111021	CORLU	154	14,7	-87,5	13,7	-89,2
612421	CORUM	154	7,9	-62,4	5,9	-62,8
612521	CORUM_2	154	7,5	-65,1	6,4	-66,2
421421	CUMRA	154	7,4	-82,7	5,0	-82,2
921131	D.ADANA_66	66	2,6	-59,1	3,0	-59,4
830021	D.BAKIR_2	154	10,2	-76,6	8,0	-78,4
830110	D.BAKIR_3	380	9,3	-74,0	7,7	-74,9
830121	D.BAKIR_3A	154	13,1	-76,6	11,6	-78,9
830122	D.BAKIR_3B	154	3,3	-64,8	2,6	-65,5
830221	D.BAKIR_4A	154	9,4	-78,3	7,2	-79,1
924021	D.PAZARI_RES	154	3,5	-82,5	3,1	-82,8
331721	DALAMAN	154	4,1	-87,2	3,6	-90,1
811321	DARENDE	154	2,1	-63,2	1,7	-63,2
514721	DARENHAVZA	154	1,9	-92,9	1,8	-93,2
622621	DARICA	154	3,8	-46,5	4,2	-48,5
331821	DATCA	154	3,5	-84,4	2,4	-82,8
333321	DATCA_RES	154	3,5	-84,4	2,5	-82,6
120510	DAVUTPASA	380	24,2	-88,1	25,1	-88,7
120521	DAVUTPASA_A	154	12,3	-99,4	12,3	-101,2
120522	DAVUTPASA_B	154	16,7	-96,4	14,5	-95,2
833421	DBAKIR_1	154	5,1	-75,6	3,5	-77,0
427421	DDY-A.PINAR	154	4,6	-88,1	2,8	-84,2
427621	DDY-CAYIRBAS	154	3,8	-85,7	2,3	-81,4
427521	DDY-GOZLU	154	3,7	-87,2	2,2	-82,9
413921	DDY-K.HACILI	154	5,8	-83,9	3,7	-80,0
810510	DECEKO	380	7,7	-67,0	6,7	-65,8
224621	DEDELIDG_1	154	9,5	-80,9	6,4	-81,0
113621	DELTA ENJ	154	11,1	-88,0	13,9	-89,6
223021	DEMIRCI	154	1,9	-77,6	1,3	-78,1

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
811421	DEMIRDAG	154	5,0	-60,7	3,8	-61,1
312721	DEMIRKOPRU	154	3,8	-79,0	3,2	-84,6
221821	DEMIRTAS_A	154	12,3	-77,6	12,4	-77,8
221822	DEMIRTAS_B	154	7,8	-78,4	5,8	-76,7
520110	DENIZLI	380	16,0	-83,0	13,5	-80,7
522210	DENIZLI DKC	380	15,1	-83,3	16,0	-84,1
521221	DENIZLI_2	154	16,3	-82,4	13,7	-82,8
521321	DENIZLI_3A	154	12,8	-81,3	10,0	-81,2
520121	DENIZLI_A	154	18,9	-84,1	17,2	-84,7
521421	DENIZLICIM	154	14,0	-83,4	11,4	-83,1
312921	DERBENT	154	5,2	-76,4	3,4	-79,3
610321	DERBENTHES	154	6,6	-54,3	6,0	-55,8
722310	DERINER	380	5,8	-56,5	6,1	-57,0
422821	DERINKUYU_A	154	7,7	-79,4	5,3	-78,3
831221	DICLE_A	154	4,0	-79,1	4,6	-80,5
832421	DIKMEN_A	154	5,7	-85,6	4,1	-89,2
214710	DILERCELIK	380	17,7	-89,6	16,2	-91,0
211721	DILISKELESI	154	23,8	-92,2	24,8	-95,3
214321	DILOVSIOSB_1	154	24,1	-92,2	25,4	-95,3
516021	DINAR_RES	154	3,7	-87,0	2,9	-87,0
522721	DINAR-OSB	154	5,1	-86,8	3,7	-85,9
830721	DODAN	154	4,1	-75,7	3,0	-76,6
621021	DOGANKENT	154	6,1	-43,0	6,1	-45,2
812921	DOGANKOY_A	154	10,2	-73,7	7,4	-73,9
711021	DOGUBEYAZIT	154	1,7	-84,4	1,4	-81,0
332721	DORA_3 JEO	154	6,4	-80,6	6,2	-84,1
821421	DSIP3_A	154	8,0	-75,3	6,0	-74,6
212021	DUDULLU	154	9,4	-96,6	9,0	-93,8
311921	DURSUNBEY	154	5,0	-79,5	3,2	-76,3
314721	DUZOVA_RES	154	4,6	-74,9	3,3	-74,6
227121	DVECIKNG_A	154	5,8	-81,2	3,7	-81,7
321621	EBSO	154	16,0	-80,2	14,4	-82,2
313421	EDINCIK_RES	154	3,4	-78,6	3,0	-80,4
112521	EDIRNE	154	4,4	-86,6	3,1	-87,4
112621	EDIRNECIM	154	4,2	-88,0	3,0	-88,3
311721	EDREMIT	154	4,5	-71,3	3,4	-74,2
512621	EGIRDIR	154	3,9	-82,6	2,9	-84,4

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
924221	EGLENCE_1	154	3,2	-82,4	2,6	-83,8
924121	EGLENCE_2	154	3,3	-82,2	2,7	-83,6
813121	ELAZIG	154	9,5	-64,6	7,0	-65,7
810610	ELBISTAN_A	380	18,3	-75,8	15,9	-75,6
810621	ELBISTAN_A1	154	15,3	-78,1	14,1	-78,9
810710	ELBISTAN_B	380	18,4	-76,1	16,1	-75,9
810721	ELBISTAN_B	154	13,5	-77,0	11,5	-77,2
813810	ELBSTN_TES	380	17,8	-76,1	15,7	-76,0
223821	EMET	154	5,9	-76,6	4,4	-75,9
521021	EMIRDAG	154	3,3	-79,8	1,9	-79,6
411321	EMIRLER	154	4,1	-79,6	2,5	-79,3
114021	ENES TM	154	1,8	-93,0	1,2	-91,6
712621	ENGIL	154	1,4	-81,1	1,4	-83,3
314221	ENJSA_C.KALE	154	4,6	-75,1	5,0	-78,0
212421	ENJSAKOSEKOY	154	6,7	-94,2	7,1	-96,4
921721	ENRJS_ADAN_A	154	11,4	-81,3	11,1	-85,1
920421	ENRJS_MER_A	154	11,8	-82,4	11,0	-85,6
223921	ENTEK_A	154	11,2	-77,6	12,0	-79,0
212821	ENTEK_KOSEK	154	11,7	-86,6	10,9	-88,9
621121	ERBAA	154	4,4	-52,9	3,4	-53,1
712321	ERCIS	154	3,6	-64,2	2,8	-65,2
311321	ERDEK	154	3,2	-75,0	2,4	-77,3
231321	ERDEMIR_1	154	14,8	-73,9	15,2	-75,0
231421	ERDEMIR_2	154	14,8	-74,0	15,2	-75,0
231331	ERDEMIR66	66	5,4	-67,0	5,3	-65,5
923021	ERDEMLİ	154	9,5	-83,5	8,2	-85,9
322021	EREGEMETAL	154	22,7	-80,7	20,8	-81,2
230010	EREGLI	380	12,9	-75,8	10,4	-72,7
230121	EREGLI_1	154	9,5	-70,3	7,9	-68,9
230131	EREGLI_1_66	66	6,4	-69,5	6,3	-68,8
230021	EREGLI_2	154	16,0	-74,1	16,3	-74,6
722121	ERENLER	154	3,9	-51,5	3,9	-53,7
831021	ERGANICIM	154	3,6	-63,9	2,7	-65,1
514810	ERMENEK	380	3,9	-89,0	2,3	-83,1
910110	ERZIN	380	18,6	-76,9	19,1	-77,3
910121	ERZIN	154	27,4	-77,8	28,2	-80,0
710221	ERZINCAN_1	154	4,1	-54,5	3,3	-56,1

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
710321	ERZINCAN_2A	154	3,3	-53,9	2,4	-55,6
710121	ERZURUM_1	154	2,5	-53,4	2,1	-55,0
710010	ERZURUM_2	380	5,2	-62,3	4,1	-60,8
710021	ERZURUM_2A	154	3,0	-52,4	2,6	-54,4
710022	ERZURUM_2B	154	8,5	-63,4	8,0	-62,9
710131	ERZURUM66	66	1,7	-43,0	1,6	-44,4
333621	ESEN_1	154	3,3	-92,6	3,7	-96,1
332921	ESEN_2A	154	3,4	-92,3	3,8	-95,8
411421	ESENBOGA	154	10,8	-81,2	8,2	-79,8
122821	ESENYURT_A	154	10,3	-97,3	10,6	-100,2
222621	ESKISEHIR_1	154	3,4	-77,4	2,2	-78,0
222721	ESKISEHIR_2	154	9,8	-79,9	7,7	-81,7
222821	ESKISEHIR_3A	154	15,4	-84,3	13,0	-83,8
222810	ESKISEHIR3	380	14,6	-83,5	10,2	-79,7
830921	ETIFOSFAT	154	2,5	-76,2	1,8	-77,2
224421	ETIGUMUS	154	8,3	-75,6	6,7	-71,1
121821	ETILER	154	19,1	-96,4	18,6	-94,8
413821	ETI-SODA	154	4,9	-76,1	3,2	-76,3
311021	EZINE	154	4,2	-74,2	3,9	-75,9
114321	F.PLSTIK_A	154	7,3	-93,3	7,2	-94,8
620521	FATSA_A	154	5,6	-47,9	3,4	-48,4
915621	FEKE_2HES	154	6,5	-76,4	4,3	-73,4
915521	FEKE_HAVZA	154	8,5	-77,6	6,0	-73,9
511721	FERROKROM	154	10,8	-84,9	8,3	-85,1
810821	FERROKROM	154	6,0	-65,6	3,9	-67,1
331921	FETHIYE	154	3,9	-89,5	3,7	-93,0
823221	FEVZIPASA	154	4,0	-71,4	2,6	-71,9
510721	FINIKE	154	3,6	-86,0	2,3	-87,8
213521	FORD_A	154	7,0	-84,0	5,3	-84,7
921821	G.ADANA	154	13,4	-79,4	9,5	-79,5
833921	GARZAN_A	154	4,4	-81,1	3,5	-81,6
820321	GAZIANTEP_1	154	8,6	-78,5	7,2	-80,0
820410	GAZIANTEP_2	380	16,1	-76,2	14,8	-76,4
820421	GAZIANTEP_2A	154	14,6	-79,4	14,7	-80,6
820422	GAZIANTEP_2B	154	12,5	-80,8	12,3	-83,2
820521	GAZIANTEP_3	154	9,6	-79,5	8,0	-81,9
820621	GAZİANTEP 4 TM	154	9,7	-68,7	6,9	-71,0

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
820622	GAZİANTEP 4 TM	154	9,7	-68,7	6,9	-71,0
820710	GAZIANTEP_5	380	15,3	-76,5	13,7	-76,2
510821	GAZIPASA	154	2,7	-89,8	2,0	-92,5
215121	GEBKIM_A	154	18,3	-92,7	15,9	-94,8
215122	GEBKIM_B	154	6,7	-85,1	5,8	-86,2
211821	GEBZEOSB_A	154	23,8	-92,0	20,6	-94,8
833321	GEC_DIKMEN	154	3,8	-83,2	2,6	-85,4
833821	GECILISU	154	4,7	-85,6	3,3	-84,4
112321	GELIBOLU	154	1,8	-87,3	1,7	-84,4
220721	GEMLIK	154	4,5	-72,5	3,0	-73,4
231821	GERKONSAN	154	4,5	-69,3	3,1	-69,6
332210	GERMENCIK	380	10,8	-81,8	8,1	-79,7
332221	GERMENCIK	154	16,7	-82,6	14,9	-82,8
923621	GEZENDE_HES	154	5,9	-83,8	6,6	-86,0
620121	GIRESUN	154	8,5	-45,0	5,8	-44,9
311121	GOBEL	154	9,6	-78,5	7,8	-78,7
410110	GOKCEKAYA	380	16,9	-84,4	15,7	-84,5
421331	GOKSU66	66	1,3	-77,4	1,3	-82,9
811521	GOKSUN	154	4,5	-70,5	3,1	-69,5
410210	GOLBASI	380	18,2	-80,3	12,8	-78,4
410221	GOLBASI	154	19,5	-81,6	18,6	-81,9
410222	GOLBASI_2	154	19,5	-81,6	18,6	-81,9
620421	GOLKOY	154	4,3	-46,2	3,9	-46,7
513521	GOLTAS	154	4,1	-82,6	2,8	-84,5
311221	GONEN	154	5,7	-78,5	4,4	-75,7
221621	GORUKLE_A	154	10,8	-82,3	8,7	-81,0
215210	GOYNUK	380	14,8	-84,6	10,9	-80,7
210821	GOZTEPE_A	154	18,1	-95,4	18,5	-92,0
714121	GULLUBAG	154	2,7	-55,1	3,7	-56,8
710621	GUMUSHANE	154	2,8	-53,8	2,0	-54,0
421821	GUNEYSINIR	154	3,4	-87,4	2,1	-85,2
333421	GURMAT JEO	154	13,7	-82,3	11,5	-82,7
321721	GUZELYALI_A	154	18,4	-80,8	14,5	-79,0
814421	H.OGLU_A	154	7,5	-77,9	4,9	-75,9
620910	H.UGURLU1	380	10,8	-55,1	10,0	-53,9
620911	H.UGURLU2	380	10,6	-55,2	9,8	-54,1
321821	HABAS	154	25,4	-80,4	26,1	-81,9

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
321921	HABASDG_A	154	25,3	-80,4	25,9	-81,9
120710	HABIBLER	380	23,9	-89,1	20,0	-89,8
120721	HABIBLER_A	154	14,7	-96,2	12,8	-97,4
120722	HABIBLER_B	154	14,5	-97,4	14,6	-99,3
411521	HACILAR	154	6,5	-78,6	6,3	-81,9
122121	HADIMKOY	154	14,0	-94,3	9,9	-93,6
712921	HAKKARI_A	154	1,7	-83,5	1,6	-84,3
110210	HAMITABAT	380	15,6	-92,8	16,5	-93,1
110221	HAMITABAT_A	154	22,0	-91,6	23,1	-92,5
813321	HANKENDI_A	154	8,1	-66,0	5,6	-67,0
811621	HASANCELEBI	154	4,8	-63,8	3,8	-64,8
412821	HASKOY_A	154	7,2	-84,2	5,8	-81,0
412822	HASKOY_B	154	7,7	-81,9	6,2	-77,8
910421	HATAY	154	6,8	-81,6	5,9	-84,5
322121	HATAY_A	154	18,7	-80,7	14,9	-79,4
921331	HAVAALANI_66	66	4,1	-55,1	4,1	-59,7
111921	HAVSA	154	5,5	-86,4	3,9	-86,5
810921	HAZAR_1	154	6,4	-64,1	4,5	-64,8
811021	HAZAR_2	154	5,9	-64,1	4,1	-64,6
212921	HENDEK	154	7,0	-79,7	5,3	-78,8
224521	HGGEDIZTES	154	5,1	-78,8	4,8	-82,0
322221	HILAL_A	154	10,9	-77,3	7,5	-78,7
820210	HILVAN	380	13,6	-74,4	10,1	-71,4
820221	HILVAN_A	154	11,0	-78,1	9,7	-77,5
711121	HINIS	154	3,3	-62,3	2,6	-62,5
412921	HIRFANLI	154	7,2	-78,7	7,3	-82,4
720621	HOPA	154	6,0	-51,8	4,4	-51,7
711221	HORASAN	154	3,8	-62,3	2,6	-58,7
210621	HYUNDAI	154	11,7	-86,4	9,1	-87,1
211621	ICMELER_A	154	7,2	-93,0	4,6	-95,4
211622	ICMELER_B	154	7,2	-93,0	4,6	-95,4
711321	IGDIR	154	1,7	-60,8	1,2	-57,4
120610	IKITELLI	380	25,6	-87,9	26,3	-89,5
120621	IKITELLI_A	154	21,2	-96,0	21,0	-98,3
120622	IKITELLI_B	154	27,0	-93,8	26,3	-96,2
721331	IKIZDERE66	66	0,9	-36,5	0,6	-35,3
911121	İKİZLER	154	23,5	-77,0	20,1	-78,5

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
514521	ILGIN	154	2,9	-82,3	1,8	-83,1
322321	ILICA_A	154	14,0	-81,8	10,0	-81,3
412721	IMRAHOR_A	154	8,4	-80,1	5,9	-81,0
921221	İNCİRLİK	154	15,7	-78,6	11,4	-78,8
921231	INCIRLIK_66	66	4,5	-54,2	4,9	-57,1
613021	INEBOLU	154	2,7	-60,6	1,7	-61,5
222121	INEGOL	154	5,8	-79,4	3,8	-82,4
314321	INTEPE_RES_A	154	3,3	-70,0	2,6	-71,4
214021	ISAKOY_A	154	3,6	-93,2	2,4	-90,6
913110	ISDEMIR	380	10,7	-79,6	9,7	-78,7
913121	ISDEMIR_A	154	12,8	-82,5	14,5	-81,8
913122	ISDEMIR_B	154	12,8	-82,5	14,5	-81,8
320310	ISIKLAR	380	21,9	-79,8	18,7	-78,8
320321	ISIKLAR_A	154	23,3	-81,2	22,6	-83,2
320322	ISIKLAR_B	154	22,0	-81,6	19,7	-82,8
911221	ISKENDERUN_1	154	9,1	-77,4	7,3	-78,5
911321	ISKENDERUN_2	154	15,6	-77,4	13,3	-80,1
911421	ISKENDERUN_3	154	7,7	-80,6	5,3	-83,2
231721	ISMETPASA	154	5,6	-68,0	3,8	-67,8
512721	ISPARTA_A	154	4,4	-82,4	3,0	-84,5
714021	ISPIR	154	2,8	-55,0	3,6	-56,0
721221	IYIDERE	154	9,1	-49,3	6,8	-49,9
721231	IYIDERE66	66	1,0	-32,2	0,9	-29,9
321321	IZMIR_3	154	19,3	-80,7	15,2	-80,2
321210	IZMIRDG	380	24,1	-78,8	27,4	-80,4
212321	IZMIT_A	154	6,5	-93,7	5,9	-95,3
521821	JEOTERMAL	154	10,7	-81,1	9,9	-83,0
322521	K.BAGLAR_A	154	21,5	-80,4	17,9	-81,0
322522	K.BAGLAR_B	154	21,5	-80,4	17,9	-81,0
210910	K.BAKKALKOY	380	18,9	-89,1	18,5	-89,8
210921	K.BAKKALKOY	154	20,4	-94,7	19,8	-95,1
110410	K.CELIK	380	17,1	-91,6	17,3	-92,5
513721	K.DUZ_SAHMAL	154	2,2	-89,5	1,6	-91,4
112921	K.ELI_DG_A	154	5,1	-90,7	6,4	-93,2
420910	K.EREGLI	380	6,7	-83,8	4,3	-78,3
420921	K.EREGLI	154	4,9	-87,2	4,1	-86,5
811921	K.MARAS	154	9,7	-73,9	8,1	-75,9

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
922321	KADINCIK_1	154	10,9	-82,4	10,6	-85,9
922421	KADINCIK_2	154	11,7	-82,3	10,6	-85,4
911621	KADİRLİ	154	6,5	-76,0	4,3	-77,2
832221	KAHTA	154	3,0	-65,2	1,9	-65,9
422921	KALABA	154	4,9	-73,6	3,2	-74,4
913021	KALEALTI	154	6,2	-70,8	5,6	-70,0
411621	KALECIK	154	7,7	-75,4	5,7	-74,0
723010	KALKANDERE	380	5,9	-53,8	4,3	-49,6
723021	KALKANDERE_	154	8,8	-52,7	7,1	-51,4
723022	KALKANDERE_	154	8,8	-52,7	7,1	-51,4
814821	KANDIL_A	154	6,7	-77,7	4,3	-75,3
230231	KANDILLI66	66	5,6	-65,3	4,7	-66,3
810210	KANGAL	380	8,9	-67,8	7,8	-67,3
810221	KANGAL	154	7,7	-65,9	8,1	-67,7
313521	KAPIDAG_RES	154	3,2	-75,1	2,3	-77,4
411721	KAPULUKAYA	154	6,3	-78,6	6,1	-81,9
311510	KARABIGA	380	13,3	-74,8	13,2	-74,3
311521	KARABIGA	154	10,9	-75,1	10,2	-76,3
231021	KARABUK	154	5,6	-68,3	4,1	-69,2
232521	KARABUKOSB	154	5,6	-68,6	4,0	-68,8
823021	KARACA	154	5,9	-76,7	3,9	-75,1
224021	KARACABEY_A	154	7,0	-78,3	6,0	-74,0
512821	KARACAOREN_	154	4,1	-85,6	4,2	-88,1
512921	KARACAOREN_	154	3,5	-85,8	3,7	-88,6
230531	KARADON66	66	6,5	-64,2	5,8	-66,0
922021	KARAHAN	154	17,3	-80,4	13,7	-82,2
923121	KARAISALI	154	4,5	-80,5	3,6	-80,7
830610	KARAKAYA	380	20,7	-70,3	23,1	-71,8
830621	KARAKAYA	154	10,6	-73,5	10,5	-75,1
823421	KARAKECILI	154	7,2	-77,3	5,1	-75,7
421621	KARAMAN	154	5,4	-81,1	4,1	-82,5
421721	KARAMANOSB_	154	4,6	-81,1	3,4	-82,0
421722	KARAMANOSB_	154	4,6	-81,1	3,4	-82,0
213621	KARAMURSEL	154	4,5	-85,6	3,6	-87,0
421521	KARAPINAR	154	2,4	-87,3	1,4	-86,6
421231	KARASINIR66	66	1,9	-78,6	1,6	-81,4
231221	KARASU_A	154	3,8	-77,3	2,3	-77,5

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
612121	KARGI	154	3,5	-61,5	2,2	-61,8
912921	KARGILIK	154	9,0	-72,3	8,1	-73,4
822621	KARKAMIS_A	154	8,3	-76,8	9,1	-79,1
832821	KARKEY	154	6,3	-82,3	7,4	-85,5
711821	KARS	154	2,5	-56,7	1,9	-55,1
322421	KARSIYAKA_A	154	17,8	-81,0	14,4	-79,8
322422	KARSIYAKA_B	154	17,8	-81,0	14,4	-79,8
211221	KARTAL	154	19,4	-92,5	14,9	-95,2
510621	KAS	154	2,9	-87,5	2,0	-89,0
122921	KASIMPASA_A	154	18,5	-96,4	17,4	-95,1
611421	KAST_OSB	154	3,4	-61,5	2,1	-63,0
611321	KASTAMONU	154	3,7	-61,3	2,3	-63,1
613421	KAVAKOSB	154	6,3	-52,8	4,3	-52,0
420421	KAY_ZORLU	154	14,6	-76,3	14,4	-79,0
612710	KAYABASI	380	13,6	-64,0	10,1	-60,6
612721	KAYABASI	154	10,9	-64,1	9,2	-64,6
613321	KAYADUZU	154	7,0	-57,8	5,3	-58,7
624121	KAYAKOPRU	154	5,2	-46,5	3,2	-45,8
213221	KAYNARCA	154	4,6	-80,6	3,1	-79,9
232221	KAYNASLI	154	7,7	-73,6	5,5	-73,3
420121	KAYSERI_1	154	5,3	-71,2	3,9	-75,6
420221	KAYSERI_2	154	17,4	-76,6	15,4	-77,5
420321	KAYSERI_3	154	14,9	-76,2	14,6	-78,8
420010	KAYSERIKAP	380	12,8	-76,0	9,6	-75,0
420021	KAYSERIKAP	154	20,2	-77,6	19,3	-78,1
412621	KAZAN_A	154	6,2	-84,1	4,4	-82,4
810310	KEBAN	380	22,1	-69,3	23,3	-69,9
810321	KEBAN	154	16,6	-69,5	16,1	-70,6
813710	KEBAN_I	380	21,3	-69,3	23,4	-70,4
810421	KEBAN_TM	154	11,4	-66,5	9,5	-65,4
513021	KECIBORLU	154	4,6	-86,5	3,1	-85,8
624421	KELKIT	154	3,3	-54,9	3,5	-55,5
322621	KEMALPASA_A	154	14,3	-81,9	13,5	-83,8
510421	KEMER_ANT	154	8,4	-86,6	5,7	-87,2
331521	KEMER_MUGLA	154	5,7	-80,9	5,3	-83,0
330210	KEMERKOY	380	14,8	-80,8	15,0	-81,5
330221	KEMERKOY	154	10,7	-80,0	10,1	-80,1

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
510931	KEPEZ66	66	1,7	-64,9	2,0	-68,9
510921	KEPEZHES	154	15,0	-86,0	12,6	-87,0
426021	KEPEZKAYA	154	3,3	-85,5	2,8	-87,4
112221	KESAN_A	154	2,8	-89,0	2,0	-88,6
413021	KESIKKOPRU_A	154	5,9	-79,2	5,4	-82,3
221921	KESTEL	154	6,6	-80,9	4,7	-82,8
811821	KILAVUZLU_A	154	12,7	-75,6	11,3	-77,1
621921	KILICKAYA	154	4,7	-55,7	4,9	-57,2
813021	KILILI_A	154	8,1	-77,0	6,2	-76,8
821321	KILIS_A	154	3,3	-80,8	2,1	-80,7
623421	KILLIK_RES	154	4,0	-61,0	3,3	-62,3
411821	KIRIKKALE	154	7,5	-77,7	6,3	-79,6
223621	KIRKA	154	3,9	-75,4	2,5	-74,8
112721	KIRKLARELI	154	5,4	-89,3	5,5	-90,8
822721	KIRLIK	154	7,0	-77,7	5,0	-79,4
423021	KIRSEHIR	154	5,0	-74,3	3,5	-75,2
813521	KISIK	154	5,0	-71,5	3,7	-70,8
916521	KIYHES	154	7,1	-78,0	5,4	-74,9
111521	KIYIKOY	154	3,2	-90,5	2,1	-89,2
522821	KIZILDERE2	154	10,0	-81,6	9,4	-83,5
832110	KIZILTEPE	380	7,3	-78,1	6,8	-81,7
832121	KIZILTEPE	154	10,5	-81,9	9,7	-86,6
421021	KIZOREN_A	154	3,6	-87,4	2,2	-85,4
324521	KOCADAG_RES	154	4,6	-75,2	3,9	-72,6
915821	KOCCELIK	154	13,7	-77,6	9,4	-78,9
621721	KOKLUCE	154	4,2	-59,7	4,7	-61,5
425021	KOLUKISA	154	3,6	-86,7	2,2	-82,5
721531	KONAK66	66	1,3	-45,8	1,3	-49,6
420621	KONYA_1	154	6,4	-85,7	4,1	-87,5
420721	KONYA_2	154	5,0	-85,0	3,1	-87,7
420821	KONYA_3	154	6,0	-89,0	3,3	-90,1
420510	KONYA_4	380	8,3	-84,5	4,3	-81,0
420521	KONYA_4A	154	10,9	-87,0	7,4	-84,9
420522	KONYA_4B	154	10,8	-87,9	7,2	-86,9
232821	KOPRUBASI	154	3,8	-76,2	4,0	-78,4
916121	KOPRUHES	154	9,2	-79,1	9,3	-79,1
513621	KORKUTELI	154	5,3	-81,1	3,5	-80,8

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
212521	KOSEKOY	154	14,3	-86,4	13,1	-88,3
513231	KOVADA_1	66	0,8	-62,9	0,8	-64,1
513121	KOVADA_2	154	4,3	-83,6	3,8	-86,7
513131	KOVADA_2	66	0,9	-62,6	0,9	-63,1
624021	KOVANLIK	154	3,5	-46,8	2,2	-46,9
622521	KOYULHISAR	154	3,8	-54,5	4,2	-55,8
911721	KOZAN	154	6,4	-75,5	4,1	-76,1
916021	KOZAN_BANK_	154	9,6	-80,1	9,2	-79,1
916022	KOZAN_BANK_	154	9,6	-80,1	9,2	-79,1
916010	KOZANHAVZA	380	8,3	-79,6	6,8	-77,8
325221	KOZBEYLI_RES	154	6,7	-83,3	5,0	-81,5
230331	KOZLU66	66	5,5	-62,5	4,3	-65,0
421921	KPZKAYATM_A	154	3,4	-85,4	2,9	-87,2
830821	KRALKIZI	154	4,8	-80,3	4,5	-79,4
211421	KROMANCELIK	154	7,2	-92,6	4,6	-95,3
123021	KUCUKKOY	154	11,5	-97,6	9,8	-99,0
513321	KULEONU	154	4,3	-82,1	3,0	-84,1
426121	KULU	154	3,4	-79,0	2,4	-79,9
112421	KUMLIMANI	154	1,2	-88,3	1,0	-86,6
514421	KUNDU	154	8,1	-89,3	5,3	-88,4
610621	KURE	154	3,3	-61,1	2,0	-62,4
612310	KURSUNLU	380	9,0	-70,3	5,9	-64,5
612321	KURSUNLU	154	11,2	-70,5	8,7	-69,1
211921	KURTKOY	154	20,8	-92,3	16,5	-95,1
621421	KURTUN_A	154	9,1	-44,1	9,7	-43,6
332121	KUSADASI_A	154	7,3	-79,6	5,2	-78,9
916421	KUSAKLIHES	154	7,4	-78,1	5,7	-75,0
223321	KUTAHYA	154	13,3	-78,4	9,4	-78,3
315321	KUYUCAK_RES	154	5,8	-81,1	4,2	-77,3
710421	KUZGUN_A	154	2,8	-54,2	3,0	-56,0
813221	KUZOVA_A	154	6,9	-67,6	4,6	-67,7
213321	KUZULUK	154	7,5	-82,2	7,8	-74,7
611921	LACIM	154	5,0	-53,9	3,4	-53,6
423121	LADIK	154	2,4	-84,9	1,4	-86,8
511521	LARA_A	154	13,7	-87,4	10,0	-87,5
121921	LEVENT_A	154	17,9	-96,8	17,1	-93,4
832621	LICE_A	154	3,6	-72,7	2,4	-72,5

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
325410	LODOS_RES	380	5,8	-83,2	5,0	-81,5
111221	LULEBURGAZ	154	13,9	-90,3	11,5	-88,5
221521	M.KEMALPASA	154	6,3	-80,2	4,2	-81,2
920121	M.TERMIK	154	10,1	-82,3	9,0	-84,8
411921	MACUNKOY_A	154	7,1	-84,0	5,5	-81,1
411922	MACUNKOY_B	154	9,3	-82,3	7,5	-82,9
811221	MADEN_2	154	3,9	-63,9	2,8	-64,9
513921	MAHMUTLAR	154	3,8	-88,7	3,4	-92,1
812021	MALATYA	154	2,8	-63,2	1,7	-65,6
812121	MALATYA_2A	154	3,1	-62,9	1,9	-65,0
112121	MALKARA	154	4,2	-86,0	3,6	-85,0
812221	MALORSA	154	3,2	-65,3	2,1	-69,0
215310	MALTEPE	380	16,2	-90,5	16,1	-87,9
412021	MALTEPE_A	154	13,2	-81,2	10,3	-79,9
412022	MALTEPE_B	154	13,2	-81,2	10,3	-79,9
412121	MAMAK	154	7,4	-81,9	5,9	-76,8
721721	MANAHOZ	154	4,1	-50,2	3,6	-50,7
511021	MANAVGAT	154	10,5	-87,0	8,4	-89,6
511121	MANAVGATHE	154	7,9	-86,6	6,6	-89,5
514121	MANCARLIK	154	14,5	-86,5	12,7	-87,7
312021	MANISA	154	18,8	-79,5	14,5	-79,7
831421	MARDIN	154	8,4	-84,2	6,9	-87,6
833721	MARDINCIM_A	154	2,1	-84,0	1,4	-86,6
323421	MARERES_A	154	4,0	-75,0	3,6	-71,2
113721	MARMARA PAMK	154	9,3	-87,3	8,8	-89,5
331621	MARMARIS	154	5,2	-84,5	3,5	-83,4
332321	MARMARIS_2	154	5,9	-84,7	4,0	-83,2
122521	MASLAK_A	154	18,2	-96,6	16,3	-96,5
122522	MASLAK_B	154	18,2	-96,6	16,3	-96,5
324021	MAZI_RES	154	3,5	-74,9	3,0	-72,3
232421	MELEN_A	154	6,4	-77,6	4,2	-77,6
915721	MENGE_HES	154	8,0	-78,2	6,3	-75,4
912621	MENTAS	154	6,0	-75,5	5,2	-78,0
812321	MENZELET	154	11,1	-74,8	10,9	-77,6
812721	MERCAN	154	1,5	-62,7	1,3	-65,3
920231	MERSIN_1_66	66	2,9	-67,6	3,2	-65,6
920321	MERSIN_2	154	11,9	-82,9	10,7	-85,7

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
923821	MERSIN_RES	154	4,6	-83,9	4,4	-85,1
611821	MERZIFON	154	8,5	-58,2	6,2	-59,0
224721	METRISTPERES	154	6,6	-82,2	6,1	-83,1
721921	MEYDANCIK	154	2,4	-52,9	1,9	-54,5
921531	MIHMANDAR_6	66	2,6	-58,2	2,9	-58,6
332021	MILAS	154	11,6	-82,5	9,1	-81,8
911821	MİSİS	154	20,8	-77,8	15,6	-79,4
423221	MISLIOVA_A	154	5,7	-78,7	3,8	-78,5
423222	MISLIOVA_B	154	5,7	-78,7	3,8	-78,5
113321	MODERN_ENJ_	154	9,3	-90,7	7,9	-90,4
320710	MORSAN	380	20,9	-80,0	17,5	-78,3
320721	MORSAN_A	154	22,6	-81,3	21,3	-82,8
324621	MOSB_2	154	21,5	-81,4	19,9	-82,7
213421	MUDURNU	154	4,9	-79,6	4,7	-67,5
331321	MUGLA	154	9,8	-82,9	7,1	-82,8
713821	MURADIYE	154	2,4	-66,2	2,0	-67,8
823821	MURAT HES	154	4,8	-75,6	4,1	-73,9
721021	MURATLI_A	154	7,4	-53,7	7,5	-54,2
713121	MUS	154	2,9	-68,2	1,9	-69,4
922121	NACARLI	154	15,2	-82,3	14,2	-84,4
824021	NAKSAN_2_A	154	9,2	-79,0	8,2	-80,8
713621	NARINKALE	154	1,8	-60,2	1,5	-55,0
812421	NARLI	154	11,6	-76,1	9,4	-75,8
332621	NAZILLI	154	6,9	-80,0	6,0	-81,9
423321	NEVSEHIR	154	6,4	-76,5	4,3	-77,6
423421	NIGDE	154	6,6	-81,0	4,6	-81,2
424821	NIGDE_OSB_1	154	5,2	-80,2	4,0	-82,1
623821	NIKSAR	154	4,0	-60,1	4,7	-62,2
212621	NUHCIMENTO	154	7,1	-85,2	7,1	-87,2
212721	NUHENERJI_A	154	6,9	-85,3	7,1	-87,6
212722	NUHENERJI_B	154	6,7	-85,1	6,4	-86,8
912721	NURSAN	154	15,8	-77,1	15,0	-80,0
612921	OBRUK	154	5,8	-67,4	6,0	-69,7
823721	ODASDGKC_A	154	13,1	-79,7	12,2	-81,3
330021	ODEMIS	154	6,3	-80,0	4,3	-80,5
720721	OLTU	154	2,3	-51,1	1,1	-52,2
623310	OMV	380	12,3	-53,7	13,7	-54,0

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
610721	ONDOKUZMAYI	154	8,8	-50,7	6,5	-50,1
620021	ORDU	154	8,2	-46,1	5,7	-46,7
221421	ORHANELI_A	154	8,8	-80,3	5,9	-81,7
220821	ORHANGAZI	154	8,2	-74,2	6,0	-73,9
823621	OSBDGKC_A	154	9,9	-76,3	8,2	-78,3
915121	OSKAN	154	8,9	-76,1	7,2	-78,1
231110	OSMANCA	380	23,4	-79,7	16,0	-75,4
231121	OSMANCA	154	14,3	-78,6	12,3	-78,7
911921	OSMANİYE	154	20,7	-77,7	17,8	-79,1
914221	OSMANIYEOSB	154	14,2	-77,6	9,7	-78,9
912021	OSMANIYETCDD	154	19,4	-77,4	16,2	-78,6
413721	OSTIM_OSB	154	9,4	-82,3	7,4	-81,8
923921	OTLUCA_1HES	154	2,2	-83,0	1,8	-85,4
220921	OTOSANSIT_I	154	7,6	-81,3	5,8	-82,9
220922	OTOSANSIT_II	154	8,6	-78,9	6,0	-77,9
514621	OVACIK	154	7,9	-88,3	5,3	-87,8
412221	OVACIK_A	154	9,0	-84,0	7,1	-83,2
230821	OYKA	154	6,0	-65,4	4,7	-64,7
510210	OYMAPINAR	380	10,6	-84,8	10,1	-86,5
510221	OYMAPINAR	154	15,1	-87,6	13,9	-90,1
324721	OZKAN_DC	154	23,2	-80,1	22,0	-80,9
810010	OZLUCE	380	6,8	-67,7	4,9	-65,0
810021	OZLUCE_A	154	8,7	-69,5	8,2	-69,3
810121	OZLUCEHES_A	154	8,6	-68,9	8,2	-69,1
213821	PAMUKOVA_A	154	7,8	-82,1	5,0	-82,4
323921	PANCAR_OSB	154	9,9	-82,2	7,5	-80,7
210210	PASAKOY	380	27,0	-86,9	20,8	-87,4
210221	PASAKOY_A	154	19,3	-94,5	16,8	-96,6
210222	PASAKOY_B	154	10,7	-96,7	10,2	-98,0
222221	PASALAR	154	10,7	-80,8	7,6	-81,1
713421	PATNOS	154	3,0	-62,6	2,1	-62,3
912121	PAYAS	154	16,7	-76,9	16,6	-79,7
912221	PAYAS_TCDD	154	12,8	-77,1	11,1	-78,8
822821	PEKMEZLI_A	154	6,1	-81,1	4,0	-81,2
322721	PETKIM_A	154	20,7	-80,3	19,8	-81,2
423521	PETLAS	154	4,8	-74,2	3,3	-75,2
812521	PINARBASI	154	2,3	-74,2	1,4	-71,2

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
112021	PINARHISAR	154	5,6	-87,0	4,4	-86,9
322821	PIYALE_A	154	18,2	-81,2	15,3	-79,1
412321	POLATLI	154	5,3	-75,4	3,8	-76,7
723121	POSOF	154	1,6	-56,5	1,3	-55,9
313321	POYRAZ_RES	154	7,9	-80,2	6,6	-79,1
831621	PS3	154	6,3	-82,3	7,4	-85,4
831721	PS3_A	154	4,5	-82,9	3,6	-81,3
831821	PS4	154	4,9	-82,6	4,0	-81,3
821521	PS4A	154	6,0	-77,7	4,1	-77,6
821621	PS4B	154	2,6	-72,4	2,5	-68,3
821721	PS5	154	1,7	-71,5	1,7	-66,5
711421	PULUMUR	154	4,1	-55,7	3,1	-56,3
711521	REFAHIYE	154	3,0	-53,5	2,2	-53,7
622721	RESADIYE	154	3,1	-55,0	3,4	-55,7
720821	RIZE	154	7,0	-49,9	5,2	-50,3
814721	S.GUZEL_A	154	6,9	-78,0	4,5	-75,6
513421	S.KARAAGAC	154	2,3	-83,9	1,3	-84,7
423621	S.KOCHISAR	154	3,8	-78,3	2,7	-79,5
621321	S.UGURLU	154	16,2	-52,3	14,6	-52,4
822221	S.URFACIM	154	8,4	-75,8	5,9	-75,8
230921	SAFRANBOLU	154	4,9	-67,2	3,4	-67,8
121121	SAGMALCLAR_A	154	11,4	-98,7	10,4	-100,8
315521	SAH_RES	154	4,3	-84,7	3,7	-84,3
213121	SAKARYA_A	154	9,1	-81,9	6,4	-81,1
312821	SALIHLI_A	154	3,7	-78,3	2,7	-82,9
314421	SAMLI_RES	154	6,1	-78,8	4,5	-79,1
610821	SAMSUN_1	154	16,6	-53,4	15,6	-53,9
610921	SAMSUN_2	154	16,0	-53,8	17,3	-54,9
611021	SAMSUN_3A	154	16,3	-53,5	16,5	-54,0
613721	SAMSUNOSB_D	154	13,9	-53,9	14,5	-55,4
325121	SAMURLU_RES	154	10,9	-78,3	8,5	-77,9
521121	SANDIKLI	154	3,5	-80,4	2,2	-80,9
822021	SANLIURFA	154	12,9	-77,8	10,0	-78,9
821910	SANLIURFA_2	380	12,2	-76,8	9,6	-76,7
821921	SANLIURFA_2A	154	17,6	-78,9	16,2	-80,2
822121	SANLIUROSB_A	154	9,3	-76,4	7,4	-77,8
521921	SARAYKOY	154	13,0	-81,7	12,4	-83,3

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
313021	SARES	154	3,6	-75,0	3,2	-75,7
113821	SARIKAYA RES	154	2,7	-90,8	2,4	-86,6
412421	SARIYAR	154	9,5	-77,4	9,6	-79,2
423721	SARKISLA	154	0,9	-59,9	0,6	-60,9
722021	SARMASIK	154	4,4	-51,6	3,6	-51,3
313221	SARUHANLI_A	154	10,1	-76,8	7,1	-76,5
314521	SAYALAR_RES	154	4,2	-80,3	3,2	-78,1
914121	SEBENOBA	154	4,2	-82,8	3,7	-82,5
623021	SEBINKHISAR	154	2,8	-55,8	2,2	-56,3
920831	SEHITLIK66_A	66	4,7	-75,5	4,8	-68,9
920832	SEHITLIK66_B	66	4,7	-75,3	5,2	-70,3
210721	SELIMIYE_A	154	18,3	-95,4	18,9	-92,2
323521	SEMIKLER_A	154	17,9	-81,1	14,5	-80,2
323522	SEMIKLER_B	154	17,9	-81,1	14,5	-80,2
423821	SENDIREMEKE	154	7,1	-76,9	4,8	-75,3
510521	SERIK	154	9,7	-88,1	6,4	-88,1
510010	SEYDISEHIR	380	13,1	-83,9	9,8	-83,8
510021	SEYDISEHIR	154	14,1	-87,3	15,3	-88,5
921031	SEYHAN_66	66	7,3	-84,6	8,7	-85,1
921021	SEYHAN_A	154	14,2	-78,6	11,6	-80,7
325021	SEYITALI_RES	154	8,5	-80,8	7,6	-79,1
220510	SEYITOMER	380	19,5	-82,6	14,4	-80,6
220521	SEYITOMER	154	15,3	-80,9	12,1	-81,2
831921	SIIRT	154	5,7	-77,7	5,2	-80,9
832021	SIIRTCIM	154	5,7	-77,7	4,9	-80,4
121421	SILAHTAR	154	18,9	-95,6	17,2	-96,6
212221	SILE	154	4,7	-93,3	3,2	-90,9
111721	SILIVRI_A	154	5,1	-88,4	3,9	-90,8
833221	SILOPI_TES	154	5,6	-84,0	6,3	-86,8
832521	SILVAN_A	154	4,8	-79,1	3,3	-78,5
223121	SIMAV_A	154	2,5	-77,6	1,9	-78,5
410310	SINCAN	380	27,1	-79,5	19,8	-77,9
410321	SINCAN_A	154	20,2	-82,4	17,3	-83,6
410322	SINCAN_B	154	14,6	-83,3	13,9	-84,0
610121	SINOP	154	2,4	-54,7	1,6	-55,3
912321	SIRHES_A	154	20,6	-76,0	19,9	-77,2
912322	SIRHES_B	154	20,6	-76,0	19,9	-77,2

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
831521	SIRNAK_A	154	4,9	-81,0	4,2	-82,0
122021	SISLI_A	154	18,5	-96,6	18,0	-94,8
812621	SIVAS	154	5,6	-61,4	4,0	-62,3
813921	SIVAS_OSB	154	5,1	-62,0	3,6	-63,1
833121	SIVEREK	154	2,6	-64,9	1,7	-66,8
414021	SIVRIHISAR	154	3,2	-77,7	2,0	-77,9
423921	SIZIR	154	1,1	-58,7	0,7	-59,7
211121	SOGANLIK_A	154	17,0	-93,2	12,8	-95,2
222421	SOGUT	154	6,9	-78,7	5,2	-78,4
613121	SOGUTSEN	154	7,6	-67,9	5,4	-66,5
332821	SOKE	154	7,9	-78,6	6,1	-78,6
312221	SOMA_A	154	16,0	-79,3	15,0	-78,4
312110	SOMA_B	380	19,2	-79,2	17,3	-78,4
312121	SOMA_B	154	16,8	-79,3	16,4	-78,5
314810	SOMA_RES	380	13,2	-80,0	9,9	-76,9
315121	SOMA_RES_1	154	10,1	-80,7	8,4	-79,2
315221	SOMA_RES_2	154	5,2	-79,1	3,8	-77,3
520521	SONMEZ_ENJ_A	154	6,3	-81,3	6,2	-84,8
424021	SORGUN	154	3,6	-72,8	2,2	-73,6
912510	SUGOZU	380	16,7	-77,2	17,7	-78,3
912521	SUGOZU	154	14,3	-79,9	12,7	-81,2
121021	SULTANMRAT_	154	18,6	-95,6	17,4	-97,0
121022	SULTANMRAT_	154	18,6	-95,6	17,4	-97,0
613221	SUNGRLOSB	154	2,4	-71,9	1,5	-70,6
821821	SURUC	154	9,0	-75,9	7,4	-76,0
621821	SUSEHRI	154	5,1	-56,1	5,2	-56,7
315621	SUSURLUK_RES	154	4,8	-78,9	3,6	-78,1
813621	SYRNTEPHES_A	154	4,6	-69,2	3,4	-66,6
322921	TAHTALI_A	154	6,9	-80,2	4,4	-78,8
424121	TAKSAN	154	8,1	-75,2	5,8	-74,3
920721	TARSUS	154	14,9	-81,4	13,7	-82,8
920731	TARSUS_66	66	4,8	-67,9	5,6	-64,2
611521	TASKOPRU	154	2,9	-62,2	1,8	-63,0
122621	TASOLUK_A	154	10,2	-96,5	8,0	-97,2
922721	TAŞUCU	154	5,5	-81,8	4,0	-83,1
822921	TATARHOYUK	154	5,8	-76,4	3,9	-74,7
713021	TATVAN	154	5,0	-70,9	3,4	-71,8

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
522021	TAVAS	154	6,7	-78,9	4,6	-78,1
521721	TEFENNI	154	5,7	-81,1	3,8	-80,6
111421	TEGESAN	154	13,2	-87,9	12,1	-89,0
111121	TEKIRDAG	154	7,0	-86,4	5,8	-87,2
822321	TELHAMUT	154	5,2	-82,2	3,4	-82,5
410410	TEMELLI	380	24,9	-81,8	17,9	-80,1
410421	TEMELLI_A	154	22,3	-82,6	23,0	-83,8
410422	TEMELLI_B	154	20,7	-83,2	20,3	-84,1
210110	TEPEOREN	380	29,0	-85,7	26,8	-87,7
210121	TEPEOREN_A	154	25,4	-92,4	23,2	-95,7
210122	TEPEOREN_B	154	14,6	-96,4	14,3	-97,4
711621	TERCAN	154	3,2	-53,8	2,5	-54,3
330121	TIRE	154	9,8	-81,9	8,2	-83,5
620210	TIREBOLU	380	7,4	-52,3	5,8	-49,0
620221	TIREBOLU_2	154	15,4	-48,4	13,3	-46,6
330521	TIRENDA	154	8,9	-82,1	7,6	-84,2
621521	TOKAT	154	5,6	-59,1	4,4	-60,2
621621	TOKATOSB_A	154	5,4	-59,3	4,5	-60,5
121221	TOPKAPI_A	154	11,7	-99,1	11,2	-100,6
121222	TOPKAPI_B	154	10,4	-99,2	9,6	-98,5
924321	TOROS_HES	154	4,2	-80,8	3,2	-81,1
922521	TOROSLAR	154	4,8	-81,5	3,6	-83,0
720921	TORTUM	154	1,7	-52,4	0,8	-52,0
720931	TORTUM66	66	1,1	-48,9	1,3	-53,5
622321	TORUL	154	8,7	-43,9	9,3	-43,6
914410	TOSCELIK	380	15,3	-77,6	15,7	-78,1
612021	TOSYA	154	4,3	-62,6	2,7	-63,2
213921	TOYOTASA	154	12,3	-83,1	8,9	-82,2
620721	TRABZON	154	7,0	-46,2	4,7	-47,7
113421	TRACIM	154	3,9	-89,3	2,8	-88,2
110521	TRAKYA_ELK_	154	13,6	-89,0	16,2	-91,6
424221	TUMOSAN	154	2,8	-78,4	1,8	-82,3
623921	TUNA	154	2,9	-54,5	3,2	-55,6
220210	TUNCBILEK	380	15,8	-82,0	12,5	-81,1
220321	TUNCBILEK_A	154	18,3	-81,4	15,3	-82,4
220421	TUNCBILEK_B	154	19,0	-81,5	15,9	-82,3
811721	TUNCELI_A	154	4,2	-60,1	3,5	-61,4

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
214621	TUPRAS	154	6,6	-94,2	6,0	-95,2
224821	TURANKOY_A	154	4,9	-80,1	3,4	-81,6
622121	TURHAL	154	5,5	-59,7	3,9	-59,6
220221	TUTESSALT	154	20,9	-81,8	18,1	-82,6
211321	TUZLA	154	6,3	-94,1	3,8	-95,9
113921	UGUR ENJ	154	11,8	-86,7	10,9	-89,6
111321	ULAS_A	154	10,4	-90,6	8,8	-90,2
224221	ULUABATHES_	154	8,6	-82,7	7,9	-80,9
323121	ULUCAK	154	19,1	-80,3	16,7	-81,6
832321	ULUDERE	154	2,6	-80,9	1,9	-81,2
412521	UMITKOY	154	20,9	-81,5	15,8	-81,9
210010	UMRANIYE	380	20,8	-88,3	20,0	-90,3
210021	UMRANIYE_A	154	21,1	-94,6	21,3	-96,0
210022	UMRANIYE_B	154	21,1	-94,6	21,3	-96,0
624221	UMUT	154	2,8	-61,4	3,0	-62,6
110110	UNIMAR	380	17,5	-91,6	17,9	-92,6
323021	UNIVERSITE_A	154	20,0	-80,9	17,1	-82,4
323022	UNIVERSITE_B	154	20,0	-80,9	17,1	-82,4
620821	UNYE	154	5,4	-48,5	3,3	-49,3
323221	URLA	154	5,9	-75,3	4,5	-74,0
520421	USAK	154	6,3	-80,1	5,9	-82,8
520621	USAK_OSB_A	154	5,8	-81,3	4,9	-83,2
814121	UZUNCAYIR_A	154	4,9	-61,7	4,5	-64,4
320410	UZUNDERE	380	13,4	-80,6	10,5	-78,7
320421	UZUNDERE_A	154	22,0	-80,6	18,7	-81,1
724921	UZUNDERE1	154	4,0	-50,1	3,2	-52,0
721631	UZUNDERE66	66	1,2	-47,4	1,2	-51,6
111821	UZUNKOPRU	154	5,0	-86,2	3,5	-85,9
623121	VAKFIKEBIR	154	6,0	-46,9	3,8	-46,8
712521	VAN	154	4,1	-86,4	3,0	-83,0
713910	VAN_II	380	2,9	-86,2	1,9	-80,3
713921	VAN_II_A	154	5,0	-87,0	3,6	-83,0
713922	VAN_II_B	154	3,1	-66,3	3,3	-68,6
214121	VANIKOY_A	154	16,4	-96,0	16,9	-90,3
510110	VARSAK	380	13,6	-83,7	12,3	-83,8
510121	VARSAK_A	154	22,9	-85,0	21,3	-87,1
121621	VELIEFENDI_A	154	11,0	-99,6	11,1	-98,1

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
121622	VELIEFENDI_B	154	4,1	-103,0	4,9	-101,7
611721	VEZIRKOPRU	154	4,4	-58,9	2,9	-59,3
323321	VIKING	154	18,9	-79,1	17,6	-78,6
822421	VIRANSEHIR	154	10,3	-79,4	8,3	-82,9
823921	VIRANSEHIR_3	154	4,9	-85,4	3,3	-85,0
823110	VSEHIR_2	380	8,4	-78,2	7,6	-80,7
823121	VSEHIR_2	154	11,3	-80,1	9,9	-84,0
222021	Y.SEHIR_A	154	2,9	-79,4	1,9	-80,4
222022	Y.SEHIR_B	154	3,7	-77,8	2,4	-78,0
916321	Y.SENBUK_RES	154	8,6	-78,6	7,1	-80,1
623721	YAGLIDERE	154	5,2	-46,5	3,2	-45,8
922221	YAKAKOY	154	12,4	-82,3	11,2	-85,0
516921	YALNIZARDIC	154	2,5	-91,8	2,2	-92,5
213721	YALOVA	154	3,5	-89,6	3,5	-92,2
915921	YAMANLI3	154	5,6	-77,5	3,7	-73,3
424321	YAMULA_A	154	6,9	-76,2	6,7	-78,7
623221	YAPRAK	154	5,4	-51,2	4,4	-52,4
822521	YARDIMCI	154	5,6	-75,9	3,6	-77,1
212121	YARIMCA	154	6,7	-94,0	6,1	-95,2
213021	YARIMCA_2	154	6,6	-84,6	4,8	-85,3
330310	YATAGAN	380	18,4	-81,0	17,7	-81,1
330321	YATAGAN	154	21,4	-82,5	19,7	-84,0
911521	YAZICI	154	14,6	-77,8	12,0	-80,4
514021	YDOGAN	154	8,1	-89,2	5,6	-88,7
915410	YEDIGOZE	380	10,6	-79,4	9,4	-79,0
215410	YENI_DG	380	17,6	-89,8	14,0	-88,9
121510	YENIBOSNA	380	21,3	-79,1	22,1	-80,3
121521	YENIBOSNA	154	25,9	-93,6	24,6	-95,9
230621	YENICATES	154	10,4	-68,8	10,9	-70,8
230631	YENICATES66	66	7,0	-65,6	6,8	-67,1
224121	YENICE	154	3,8	-81,3	3,4	-84,0
613521	YENIDERE	154	5,6	-64,0	4,0	-64,5
223221	YENIGEDIZ	154	5,0	-78,5	4,5	-81,1
121721	YENIKAPI_A	154	3,9	-102,9	4,6	-99,9
330410	YENIKOY	380	15,3	-80,8	15,0	-80,9
214921	YENIKOY	154	7,0	-84,0	5,3	-84,7
330421	YENIKOY	154	15,1	-82,8	14,9	-83,6

Busbar No	Busbar Name	Voltage	3-Phase Current (kA)	Three Phase Angle	Phase To Ground Current(kA)	Phase To Ground Phase Angle
424421	YERKOY	154	3,6	-72,1	2,3	-72,9
622821	YESILBAS	154	3,0	-54,3	2,8	-54,9
422010	YESILHISAR	380	12,8	-82,6	7,1	-76,3
422021	YESILHISAR_A	154	14,5	-83,2	11,0	-80,7
424521	YIBITAS	154	3,8	-71,1	2,5	-72,1
411221	YILDIZ	154	9,3	-79,6	6,4	-80,3
120810	YILDIZTEPE	380	24,2	-88,0	24,3	-87,0
120821	YILDIZTEPE_A	154	15,0	-95,9	12,3	-96,1
120822	YILDIZTEPE_B	154	20,0	-95,8	18,7	-97,1
722421	YOKUSLU	154	4,8	-52,3	3,3	-49,6
914810	YOLBULAN	380	14,1	-78,0	13,6	-77,9
424621	YOZGAT	154	4,3	-70,3	2,8	-71,3
923421	YSEHITLIK	154	14,0	-81,9	10,2	-83,7
912421	YUMURTALIK	154	16,7	-77,9	13,7	-78,3
512021	YUNAK	154	1,7	-82,6	1,0	-84,5
323721	YUNTDAGI_RES	154	5,6	-73,5	3,9	-72,0
923521	YUREGIR	154	12,9	-78,5	10,1	-80,2
921431	YUREGIR_66	66	3,6	-55,9	3,8	-60,0
716921	YURTÃIM	154	2,8	-68,1	1,8	-68,9
812821	ZARA	154	4,6	-58,2	3,4	-57,6
120910	ZEKERIYAKOY	380	20,9	-90,2	15,7	-89,7
120921	ZEKERIYAKY_A	154	7,1	-99,3	6,8	-98,8
232610	ZETES	380	10,5	-71,5	11,5	-71,9
232621	ZETES	154	10,2	-69,2	10,4	-70,9
921921	ZEYTİNLİ	154	13,3	-80,9	12,0	-83,8
915221	ZIYARET_RES	154	4,7	-82,8	4,4	-83,0
231621	ZONGULDAK	154	8,3	-67,3	6,9	-67,0
230431	ZONGULDAK66	66	5,7	-62,7	4,6	-65,1
112821	ZORLUENERJ_A	154	11,9	-88,1	13,9	-88,0

C.3. Line Parameters

Table 2. The distribution system lines

	r (mm)	GMR (mm)	Rdc-20C° (Ω/km)	Rac-90C° (Ω/km)	mH/km	X (Ω)/km	µF/km
240 mm^2 CU	8,74	6,81	0,075	0,099	0,51	0,161	139,5971
95 mm^2 CU	5,50	4,28	0,193	0,256	0,60	0,190	87,8516
400 mm^2 AL	11,28	8,79	0,078	0,103	0,46	0,145	180,2005
150 mm^2 AL	6,91	5,38	0,206	0,273	0,56	0,176	110,3746
477 MCM (HAWK)	8,81	6,86	0,117	0,155	1,19	0,374	0,0098
3/0 AWG (PIGEON)	5,20	4,05	0,329	0,436	1,30	0,407	0,0089
1/0 AWG (RAVEN)	4,13	3,21	0,523	0,694	1,34	0,422	0,0086
3 AWG (SWALLOW)	2,91	2,27	0,887	1,176	1,41	0,444	0,0082

Table 3. Calculation parameters for distribution system lines

$\mu_{\circ}$	1,26E-06	H/m
$\varepsilon_{\circ}$	8,85E-12	F/m
D (Cables)	0,008	m
GMD (Cables)	0,088194	m
GMD (ACSR)	2,645834	m
XLPE Dielectric Cons.	2,3	
Proximity and skin effect factor	1,04	

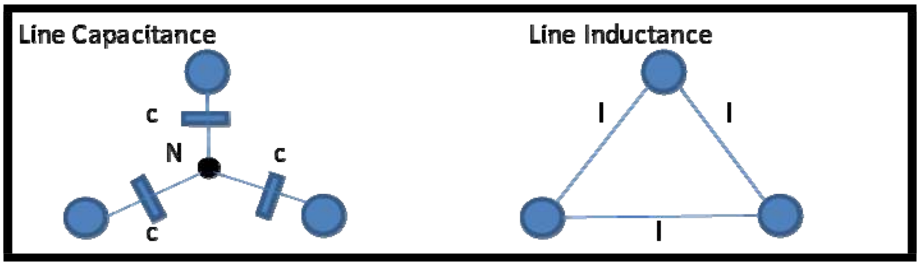

Figure 11. The triangle configuration of lines

The distance value of underground cables having common earth connection by the shield is the insulation thickness value. This is true for capacitance calculation but inductance calculation.

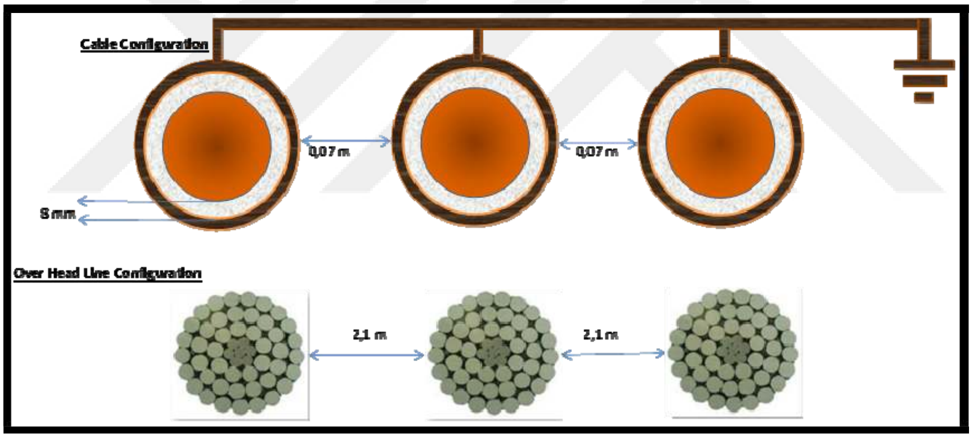

Figure 12. Cables and overhead line configurations

There is no need for the tower length value. Since the earth point is transferred to the upper side of the tower by the metal chassis of the tower.

The capacitance of a one-conductor-shielded-cable is given by the formula below (Nepsi, 2018).

Equation 13:

$$C = \frac{7.35 \times SIC}{\log(\frac{D}{d})} \times \frac{L}{10^6} \quad (10)$$

Equation 14:

$$I_{CHARGE} = \frac{V_{LL} \times 2\pi fC}{\sqrt{3} \times 1000} \quad (11)$$

Equation 15:

$$KVAR_{charge} = \frac{V_{LL}}{\sqrt{3}} \times I_{charge} \quad (12)$$

Where:

C = Total capacitance of the cable (microfarads)

I_{charge} = Charging current of the cable

SIC = Dielectric constant of the cable insulation

D = Diameter over the insulation (in)

d = Diameter of the conductor (in)

VLL = System operating voltage in (kV)

f = System operating frequency (Hz)

L = Length of the Cable in Feet

I_{charge} = Charging current (amps)

$KVAR_{charge}$ = Single-phase KVAR or charging VARs per cable

When operating at a different temperature, the resistance varies and is given by the following formula (Nepsi, 2018).

Equation 16:

$$R_{AC} = \frac{R_{AC20c}(1 + .00393 \times (T - 20)) \times L}{1000} \quad (13)$$

Where:

R_{AC} = AC resistance of the conductor at operating temperature (ohms)

R_{AC20C} = AC resistance of the conductor at 20°C (ohms)

T = operating temperature of the conductor (°C)