

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

FLEXIBLE LOAD MANAGEMENT IN ACTIVE DISTRIBUTION SYSTEM



M.Sc. THESIS

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Department of Electrical Engineering

Electrical Engineering Programme

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To my mother and father,



FOREWORD

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ABBREVIATIONS

AGC	: Automatic Generation Control
AHP	: Analytical Hierarchy Process
BPSO	: Binary Particle Swarm Optimization
CB	: Circuit Breaker
DABC	: Discrete Artificial Bee Colony
DCS	: Disturbance Control Standard
DG	: Distribution Generator
FD	: Feeder
GA	: Genetic Algorithm
GAMs	: General Algebraic Modeling System
KV	: Kilo Volts
LMP	: Location Marginal Price
MVA	: Mega Volt Ampere
MW	: Megawatt
ODNR	: Optimal Distribution Network Reconfiguration
PSO	: Particle Swarm Optimization
PU	: Per-Unit
SS	: Substation
SVC	: Static VAR Compensator
TS	: Tie Switch
UFLS	: Under-Frequency Load Shedding
UVLS	: Under-Voltage Load Shedding



SYMBOLS

c_1, c_2	: Acceleration coefficient
f	: Fit
$gbest_i$	: Best position for all particles
$gbest$	: Best position the swarm has obtained
i	: Particle
I_1	: Current in the first branch
I_{max}	: Maximum current
I_s	: Systems technical loss after self-healing
$I_{s_{tot}}$	: Total loss of system in all buses
N	: Number of particles
N_{eq}	: Equality constraints
N_{ueq}	: Inequality constraints
P	: Real Power
$pbest_i$	: Best solution for the $i - th$ particle
$pbest_{i,t}$	: Best previous position for each particle
$Ploss_{tot}$	: Amounts of total loss
Q	: Reactive Power
$rand$	: Random number between 0 and 1
r_1, r_2	: Uniform random number
sw	: Amount of commutation of the switches
S	: Load supplied after self-healing
St	: Total power of the system
S_{tot}	: Maximum supplied load
t	: Iteration
$Uprior$	: Identity matrix to prioritize the buses to be cut in geographic areas
V	: Voltage
V_{it}, V_i^t	: Velocity of particle i
$V_i^k(t)$	: Velocity of particle i at iteration t in $k - th$ dimension
w	: Inertia weight

w_1, w_2, w_3 : Weights for objective functions
 w_g, w_h : Penalty factors
 $X_{i,t}$: Current position of particle i at iteration t
 Z : Loss or cost function
 φ_1, φ_2 : Acceleration constraints



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FLEXIBLE LOAD MANAGEMENT IN ACTIVE DISTRIBUTION SYSTEM

SUMMARY

Power networks have been developing since they appeared, and this development has accelerated because of developed technology. Along with the changing living conditions, the amount of electricity consumed in the networks has increased regularly every year. On the other hand, industrialization has caused the more big-amount loads to be added to the network, especially industrialization has been a major factor in the increase of electricity demand of developing countries such as southeast Asia and in this direction, their increase in electricity generation capacities or towards them to the import of electricity.

As a result of these changes and developments in the networks, the power systems have grown over time and interconnected or wide area synchronous networks have emerged. Sometimes these networks have emerged as sub-networks of a national network, and sometimes by connecting the national networks of different countries. Interconnected networks were created in order to meet the consumption in the network more comfortably, especially in networks where power plants and load weights are distant, in order to carry the generated power to other regions more easily.

Moreover, another reason for the emergence of these networks was to increase network stability, security, and reliability. In fact, some international interconnected grids were also helped to improve the operating standards and monitoring mechanisms of some of the countries they include, since the main principle of these networks is that they are fully synchronous in some factors such as frequency. As a result of the synchronous drift that would occur for any reason in the existing sub-networks of the interconnected network, the sub-network is disconnected and immediately separated from the interconnected network. Failure of disconnection or late separation of the network that has synchronous slippage may drag the entire network to a collapse.

In addition to the increase in electricity consumption, the nature of the network and type of elements such as load and generators have changed in recent years. Moreover, the inclusion of renewable and distribution generators, which are producing on a small scale, the fact that some loads enter and exit to the network rapidly, and the emergence of a fact like electricity market, in spite of the benefits they add to the network, can be caused some problems if not properly managed. For instance, there are some issues that should be managed well in the electricity market such as taking the offers for the next day and make the necessary preparations by making the day ahead load forecast very carefully. Furthermore, some power plants refrain from bidding for economic reasons, or they may prefer to stay out of the market by placing higher bids, so that the control authority must impose necessary preventive practices in this regard in order to avoid generation deficiencies.

It is very important to schedule a planned maintenance in power plants, also small generation sources should be evaluated and planned very well. Even if the market conditions of the day before have been well evaluated, it is inevitable that some

problems in the network will still be experienced. These problems may be encountered when the generation and consumption capacity balance is on the border, or when the reserves do not meet the total consumption.

The balance of generation and consumption should always be equal in the network, that is, generation or consumption should not be less or more than one another, so the network operator tries to keep the frequency and voltage values in the network within the acceptable range by observing the balance between generation and consumption at any time. In case of severe disturbances in the network, there is a loss of generation generally, which starts to change the frequency and voltage value in the network. In this case, the network operator needs to drop the excess load to ensure balance, this operation is called Load Shedding (LS).

Load shedding is generally divided into Under-Frequency Load Shedding (UFLS) and Under-Voltage Load Shedding (UVLS). The difference between these methods is the load shedding is performed by observing the frequency value in one and the load shedding done by observing the voltage value in the other. Conventional methods are available for both load shedding, these conventional methods often attempt to balance the network by removing the load in predetermined steps. These methods are generally decentralized, that is, they do not provide a specific solution for every situation, but they go towards reducing the load in certain buses and at certain levels. Of course, this situation can sometimes lead to under-shedding or an over-shedding of the desired amount, which in turn causes the network to collapse. In addition to the amount of load to be thrown, the time to apply the load shedding is also very important. If the operation is not carried out in time, the network goes to the collapse again and the load to be thrown is not important anymore. The buses where the load shedding is to be applied is another important aspect so that when conventional load shedding methods cannot produce a solution to the situation, they apply the load shedding process at the previously determined buses.

In developing power networks, developing new methods for load shedding is at the forefront of experts for a long time. Almost all of the newly developed methods are centralized and they have the ability to generate solutions by observing all the buses in their own responsibility areas and collecting data, evaluating the status of the network in case of problems by using the communication infrastructures. When the grid condition is evaluated and processed with the help of computers, the amount of load, time and place to be thrown can be selected and applied more accurately.

These methods proposed in recent years due to increase in the amount of data, limited response time, and most importantly, to achieve the best answer are generally developed with supporting of optimization algorithms. The performance and usability of optimization algorithms in power systems can be clearly seen in other studies topics such as protection systems.

In this thesis, flexible load management optimization by using load shedding and optimal reconfiguration in active distribution power networks were studied. Hence, in the first chapter of this thesis, the development, structure, basic concepts, network values which were taken from different countries, and consumption data with real data were shown and compared. Furthermore, information and evaluations about previous studies and the purpose of the thesis were included in this chapter. In the second chapter, voltage stability, voltage collapse, load shedding definition, and classifications were discussed. In the third chapter, the amount, location and timing of load shedding, load shedding, and power flow formulations were discussed. Also, the

definition of various optimization algorithms like Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Binary Particle Swarm Optimization (BPSO) were discussed. Finally, an explanation about Optimal Distribution Network Reconfiguration (ODNR), also explanation and formulation of voltage stability index which was used in the second study case are also available.

In the fourth chapter, for the first study case, simulation and results of the applied method were given. At this stage, after evaluating a 69-bus and 33-bus IEEE distribution test system under normal conditions, the system was self-healing with optimal switching with the help of the BPSO optimization algorithm, and the results were shared. Then, the BPSO optimal switching and load shedding through the power flow process were performed together, and the results were given for each evaluated in three cases. A novel method was proposed in the second study case. In this study case, in the 33-bus IEEE distribution test system, a smart grid was considered. load management was carried out with controllable loads in smart homes by load shedding with the help of the PSO optimization algorithm. The results of this newly proposed method were given for two different analysis cases.

In the last chapter, conclusions and recommendations regarding both study cases of the thesis were presented in the fifth chapter.



ESNEK DAĞITIM SİSTEMLERİNDE YÜK YÖNETİMİ

ÖZET

Güç şebekeleri ortaya çıktıkları zamandan beri gelişmekte, bu gelişim özellikle son yarım asırda aşırı derecede hızlanmıştır. Değişen yaşam şartları ile beraber, şebekelerde tüketilen elektrik miktarı genel olarak her yıl düzenli şekilde artmıştır. Öte taraftan sanayileşme daha fazla ağır yüklerin şebekeye eklenmesine sebep olmuştur, özellikle sanayileşme güneydoğu Asya gibi gelişmekte olan ülkelerin elektrik ihtiyacının artması ve bu doğrultuda bu ülkelerin elektrik üretim kapasitelerinde artışa gitmeleri veya elektrik ithalatına doğru yönelmelerinde büyük bir etken olmuştur. Şebekelerdeki bu değişim ve gelişim neticesinde şebekeler zaman içerisinde daha da büyüyerek enterkonnekte veya geniş alanlı senkron şebekeler ortaya çıkmıştır.

Bu şebekeler bazen alt şebkelerden oluşan milli bir şebeke olarak, ve bazen de değişik ülkelerin milli şebekelerini bir birine bağlanarak ortaya çıkmıştır. Enterkonnekte şebekeleri, şebekede tüketimi daha rahat karşılamak için, özellikle üretim santrallerinin ve yük ağırlığının uzak olduğu şebekelerde, üretilen gücü başka bölgelere daha rahat taşımak adına oluşturulmuşlardır. Ayrıca, bu şebekelerin ortaya çıkmalarının bir başka nedeni ise, şebeke stabilitesi, güvenliğini, ve güvenilirliğini artırmaktır. Hatta, bazı uluslararası enterkonnekte şebekeleri, içine aldıkları bazı ülkelerin işletim standartlarını ve denetleme mekanizmalarının gelişmesine de yardımcı olmuştur, bunun nedeni ise bu şebekelerin ana prensibinin frekans gibi değerlerin tamamen senkron olmasıdır, enterkonnekte şebekesinde mevcut olan alt şebekelerde her nedenle yaşanacak senkron kayması neticesinde o şebekenin enterkonnekte şebekesiyle irtibatı kesilerek hemen ayrılır. Senkron kayması yaşayan şebekenin ayrılmaması veya geç ayrılması tüm şebekeyi çöküşe sürükleyebilir.

Elektrik tüketiminin artmasının yanı sıra, son yıllarda şebekelerin doğası ve turu da değişmiştir. Bir taraftan, küçük çapta üretim yapan yenilenebilir ve dağıtım generatörlerin şebekeye katılması, diğer taraftan yüklerin şebekeye girip çıkmasının daha hızlı yaşanması, öte taraftan elektrik piyasası diye bir gerçeğin ortaya çıkması, güç şebekelerine her ne kadar olumlu etkiler katsalar da iyi şekilde yönetilmediklerinde bazı sorunları da beraberlerinde getirmektedirler.

Örnek olarak, elektrik piyasası başlı başına iyi yönetilmesi gereken bir konudur, öncelikle gün öncesi yük tahmini çok dikkatli yapılarak sonraki gün için tekliflerin alınması ve gerekli hazırlıkların yapılması çok önemlidir. Üretim santrallerindeki yapılacak planlı bakımlar, ekonomik açıdan bazı santrallerin teklif vermemesi ya da yüksek teklif vermesi sonucunda kasten dışarda kalmak istemeleri, küçük üretim kaynaklarının şebekeye eklenme ve çıkış zamanları gibi konular çok iyi değerlendirilip, planlanmalı, ve denetilmelidir.

Kısa, orta, ve uzun vadeli elektrik ihtiyacı değerlendirilmesi ve gerekli planlamalar ve yatırımların yapılması halinde, ve ayrıca gün önceki piyasa şartlarının da her ne kadar iyi değerlendirilmiş olsa bile, yine de şebekede bazı sorunların yaşanması

kaçınılmazdır. Üretim ve tüketim kapasitesinin sınırdaki olduğu zamanlar, ya da rezervlerin tüketim ihtiyacını karşılamadığı zaman bu sorunla karşılaşabiliriz. Bu konuda dikkat edilmesi gereken nokta, kurulu olan güç üretim kapasitesi ile belirli gün ya da zaman içerisinde üretime hazır olan kapasite arasında fark vardır, bu fark neticesinde kurulu gücümüzün fazla olduğu durumlarda bile üretim için hazır olan kapasite ile yük miktarı sınırdaki olabilir.

Üretim için hazır olmayan üretim santrallerinin sebebi için planlı ve plansız bakımlar, enerji kaynağı yetersizliğini ya da bazı santrallerin devreye girmesinin uzun zaman almasını sayabiliriz. Bu sebepler dışında şebekede yaşanacak bazı olumsuzluklar nedeni ile de üretim ve tüketim arasındaki denge bozulması ile karşılaşabiliriz, bunlarda ana iletim hatlarının çıkışı, büyük kapasiteli üretim santrallerinin şebekeden çıkışı, ithalat yapılan şebekelerde güç akışının kesilmesi gibi örnekleri sayabiliriz.

Genellikle günlük operasyonlar şebekede böyle olumsuzluklar ile çok sık karşılaşılır, bu tür durumlar yaşandığında şebeke operatörü yapacağı operasyonlar ile rezerv kaynaklar, ya da rezerv hatları devreye sokarak yaşanacak sorunların önüne geçer. Ancak, üzerinde durulması gereken konu, şebekede yaşanacak şiddetli olumsuzluklarda yani saydığımız bazı durumların beraber meydana geldiklerinde, ya da çapları çok büyük olduğunda, ve şebekedeki rezervlerin ya da beklenen durumlarda yapılacak operasyonların yetersiz kaldığı durumlarda ne yapmamız gerektiğidir.

Şebekede her an üretim ve tüketim dengesinin sabit olması gerekmektedir, yani üretim veya tüketimin bir diğerinden az ya da fazla olmaması gerekir, bunun için şebeke operatörü üretim ve tüketim arasındaki dengeyi her an gözetleyerek, şebekedeki frekans ve gerilim değerlerinin Kabul edilir aralıkta tutmaya çalışır. Şebekede yaşanan şiddetli olumsuzluklar ya da ciddi hatalarda genellikle üretim kaybı yaşarız, bu durumda şebekemizde frekans ve voltage değeri değişmeye başlar. Bunun sonucunda şebeke operatörü dengeyi sağlamak için fazla yükü atması gerekir, bu yük atma operasyonuna Load Shedding (LS) denilir.

Load shedding de yapılan işlem, yükten belirli bir miktar atılarak, yani o kullanıcıları elektriksiz bırakarak, tüketimi düşürerek, üretim ile dengelemeye çalışılır. Load shedding bazen de elektrik arzının yetersiz olduğunun önceden tahmin edilmesi durumunda planlı olarak da yapılması mümkündür. Elektrik piyasası şartlarında bazı elektrik dağıtıcı firmaları, yaptıkları anlaşmada, meydana gelecek böyle durumlarda kullanıcıların kendi istekleriyle şebekeden ayrılmaları durumunda onlara elektrik fiyatları konusunda avantajlar sağlamaktadır.

Ama günümüz şebeke yönetiminde önemli konu olan, plansız şekilde ve aniden gelişen durumlar neticesinde hızlıca uygulanması gereken yük atmadır. Yük atma genellikle Under-Frequency Load Shedding (UFLS) ve Under-Voltage Load Shedding (UVLS) olarak ayrılır. Bu metodlar arasındaki fark, birinde frekans değeri gözetlenerek yapılan yük atma ve diğerinde gerilim değeri gözetlenerek yapılan yük atmadır. Her iki yük atma için de konvansiyonel metodlar mevcuttur, bu konvansiyonel metodlar genellikle daha önceden belirlenen kademeler şeklinde yükü atarak dengeyi sağlamaya çalışır.

Bu metodlar genellikle merkezi olmayan yöntemlerdir, yani yaşanacak her duruma özel çözüm vermemekle beraber daha önceden belirli baralarda ve belirli kademelerde yük azaltmaya doğru giderler. Tabi bu durum bazen atılacak yük miktarının altında kalınması (Under-Shedding) ya da istenilen miktardan fazla yük atılmasına (Over-Shedding) sebep olabilmektedir, ki bu durumda şebeke çökmeye doğru gider. Atılacak yükün miktarının yanı sıra, yük atmanın uygulanması gereken zaman da çok

önemlidir, yük atma operasyonu zamanında yapılmadığı durumda, şebeke yine çöküşe gider ve atılacak yükün önemi kalmaz.

Yük atmanın uygulanacağı baralar da bir başka önemli ayaktır, öyle ki konvansiyonel yük atma metodları yaşanacak duruma karşı çözüm üretemedikleri için, daha önceden belirlenen baralarda yük atma işlemini uyguladılar. Gelişen güç şebekelerinde, yük atma için yeni metodlar geliştirilmesi uzun zamandır uzmanların çalıştığı konuların başındadır. Yeni geliştirilen metodların tamamına yakını, merkezi olan, yani mevcut olan iletişim altyapılarını kullanarak kendi sorumluluk alanlarındaki tüm baraları gözlemleyerek, ve verileri toplayarak, yaşanacak sorunlarda şebekenin durumunu değerlendirerek çözüm üretme kabiliyetleri vardır.

Şebeke durumu değerlendirildiği ve bilgisayarlar yardımı ile veriler işlendiği zaman, atılacak yük miktarı, zamanı, ve yeri daha doğru şekilde seçilip, ve uygulanabilir. Veri miktarının fazla olması, verileri işleme ve uygulama zamanının kısıtlı olması, ve en önemlisi en iyi cevaba ulaşmak için, son yıllarda önerilen metodlar genellikle optimizasyon algoritmaları yardımı ile geliştirilen metotlardır. Optimizasyon algoritmalarının performansı ve kullanılabilirliği güç şebekelerinin koruma sistemleri gibi diğer alanlarda yapılan çalışmalarda da açıkça görülmektedir.

Bu doğrultuda, bu tez çalışmasında yük atma optimizasyonu ve sistemin yeniden düzenlenmesi ile kendi kendini geri getirme yani self-healing optimizasyon işlemleri üzerinde çalışılmıştır. Buna göre, bu tez çalışmasının ilk bölümünde, güç şebekelerinin gelişimi, yapısı, temel kavramlar, değişik ülkelerde kullanılan şebeke değerleri, ve gerçek veriler ile tüketim değişimleri gösterilip ve karşılaştırılmıştır. Ayrıca tez konusu içinde kullanılan optimizasyon algoritmaları ve optimal yeniden şebeke düzenlemesi hakkında daha önce yapılan çalışmaların bazıları tanıtılıp, yapılan işlemler, alınan sonuçlar, avantaj, ve dezavantajları üzerine konuşulmuştur.

İkinci bölümde, gerilim stabilite kavramları üzerinde konuşulduktan sonra, voltaj çökmesi, load shedding ve load shedding tanıtılmıştır. Daha sonra, yük atmayla ilgili kategoriler, tanımlar, ve terimler paylaşılmıştır.

Üçüncü bölümde ise, under-voltage load shedding ile ilgili açıklamalar yer aldıktan sonra, yük atma işleminin en önemli ayakları olan, miktar, yer, ve zaman kavramları anlatıldıktan sonra, yük atma matematik formülleri verilmiştir. Bu bölümün en son kısımları ise bazı optimizasyon algoritmaları ile ilgili açıklamalar, matematiksel formüllerine değinilmiştir.

Dördüncü bölümde, birinci çalışma örneğinde uygulanan metodun simülasyon ve cevapları verilmiştir. Bu aşamada ilk önce 69-baralı ve 33- baralı değiştirilmiş IEEE standart dağıtım sistemlerinde normal şartlar altında değerlendirildikten sonra, ilk önce BPSO optimizasyon algoritması yardımıyla optimum anahtarlama ile sistemi geri döndürme yani self-healing işlemi üzerinden optimal yeniden şebeke düzenlemesi yapıp ve sonuçları paylaşılmıştır, daha sonra BPSO optimum anahtarlama ile güç akışı ile beraber yük atma işlemi birlikte yapılarak sistemi geri döndürme üzerinden optimal yeniden şebeke düzenlemesi sonuçları verilip ve sonuçlar her üç durumda değerlendirilip, ve karşılaştırılmıştır. Birinci çalışmanın son kısmında, uygulanan algoritma performansı her iki sistem için yan yana verilen veriler ile karşılaştırılmıştır.

Bu bölümde, ikinci çalışma örneğinde, yük yönetimi için yeni bir metod önerilmiştir. 33-baralı IEEE standart dağıtım sisteminde ele alınan akıllı şebekede, akıllı evlerde kontrol edilebilir yüklerin yönetimi ile, ve ayrıca PSO optimizasyon algoritmasından yararlanarak, optimum yük atma işlemi yapıp ve sonuçları paylaşılmıştır. Buna göre,

bu çalışma iki farklı analiz üzerinde yapılmıştır, birinci analiz tam yüklenme (100% yüklenme) ve ikinci analiz 10% aşırı yüklenme (110% yüklenme) üzerinden ele alınmıştır ve sonuçlar, ve düzenlenmiş gerilim değerleri bazı saat ve baralar üzerinden paylaşılıp ve karşılaştırılmıştır.

Tezin beşinci kısmında yapılan çalışmalar ile ilgili sonuç ve önerilen sunulmuştur. Burada optimum load shedding gereksinimi ve performansına vurgu yapılarak, bu konuda bazı öneriler sunulmuştur.



1. INTRODUCTION

Electricity distribution systems are quite complex systems. System structure or topology varies depending on many factors, some of which are budget, climate, system requirements, security, and reliability factors. Furthermore, the amount, type, and location of load, and the capacity, location, and type of power plants play an important role in the shaping of the structure of the network. Nowadays, most of the electricity transmission networks and distribution networks, designed by complex mesh networks structures.

The main frequency is one of the most important parameter in interconnection networks. If two or more networks are to be connected to each other, the main frequency of those networks must be synchronous. Moreover, in national networks, as a synchronous network, all generators which are connected to the network must generate at the same frequency and must stay very nearly in phase with each other and also with the grid. Both generation and consumption side should be in balance at any time, with occur any increase in load side or any loss in the generation side, the balance must be established and frequency should be kept in the acceptable range, otherwise partial or total collapse in the network will be accrued [1].

There is daily and annual generation and consumption patterns in power systems. These generation and consumption patterns change according to the location and circumstances of the countries, industrialization, user types such as industrial users, the amount of consumption of agriculture industry users, and the number of home users. Also, these patterns depend on the calendar days, for example, the pattern of a day in summer is so different from a day in winter. For instance, Fig. 1.1 was taken from the Iranian power network and it shows the 5-year hourly consumption values for the same day.

The day was based on July 23, the day which was occurred maximum consumption. When this daily consumption chart was examined, which takes place on the same day but in five different years, the same consumption pattern and annual increase amount are clearly visible [2].

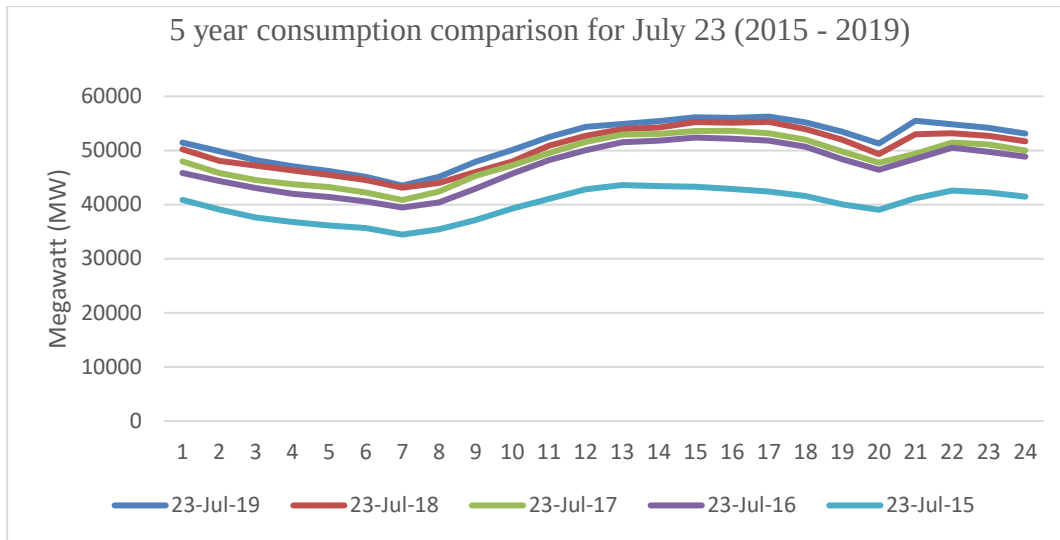


Figure 1.1 : 5-year consumption comparison for July 23 (2015 - 2019) of Iranian network.

In general, the consumption pattern is preserved despite the increase in consumption every year. In Fig. 1.2, annual consumption in peak hours of 2018 and 2019 in the Iranian network was compared.

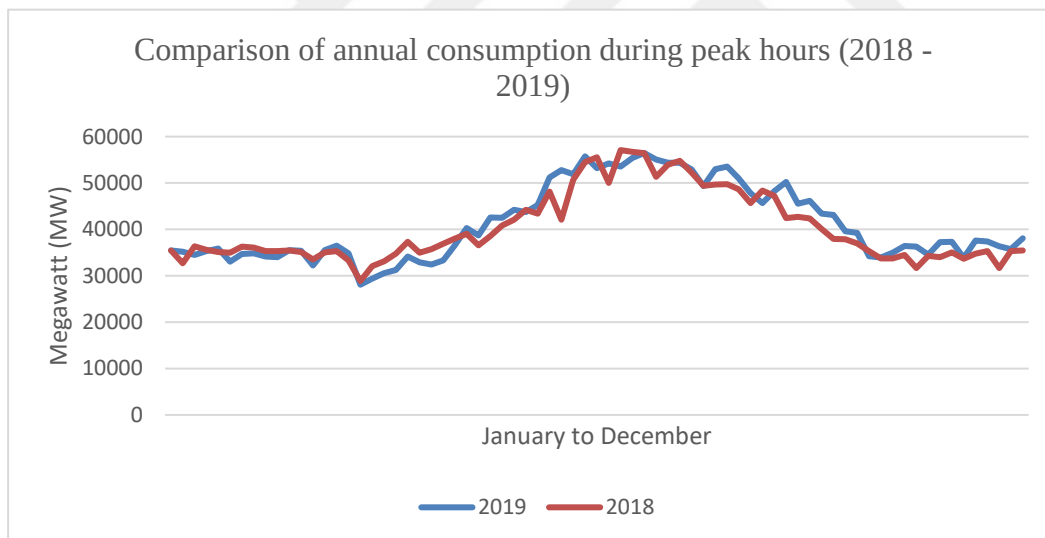


Figure 1.2 : Comparison of annual consumption during peak hours (2018 - 2019) of Iranian network.

When the annual consumption curves were compared, it can be easily seen from figure that load patterns are same, but they have annual consumption increase.

1.1 Main Frequency

To better understand these The main frequency, which is also known as system frequency or main frequency, is the nominal frequency of a whole system such as

synchronous grid or wide area synchronous grid. This frequency has been set among all the elements connected to a network and this constant frequency value is used in the whole system from generators to end-users. One of the most important efforts of power system operators is to maintain the generation and consumption balance in the system and to keep the frequency in the entire system at the main frequency, or within the acceptable range of the main frequency [3].

The two main frequencies and two voltage ranges are used in power networks. While 50 Hz is used in most countries of the world, 60 Hz is used in some parts of the American continent and the Asian continent. Fig. 1.3 shows the frequency and voltage values used in different countries around the world. Also, Table 1.1 gives these values for some countries [4].

1.2 Voltage in Power Systems

The voltage level of the generated power in the power plants is generally between 11 - 25 kV. This voltage level is inappropriate for transmitting electricity between long distances over transmission lines due to losses and voltage drop. For this reason, high voltage tie-lines constitute almost all of the transmission network. The voltage of power generated in the power plants increases step-by-step by one or more step-up substation.

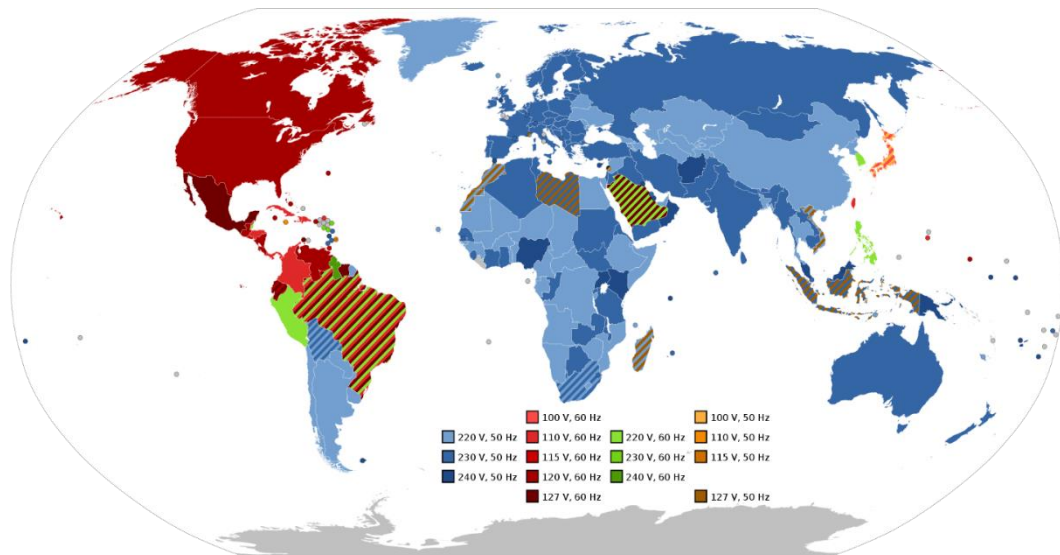


Figure 1.3 : Main frequency and voltage by countries.

Likewise, at the end of the transmission lines, the voltage level is lowered step-by-step by step-down substations and given to the distribution network.

This level varies between 110 - 127 V and 220 – 240 V depending on the standard of each country.

Table 1.1 : Main frequency and voltage by countries.

Country Name	Frequency (Hz)	Voltage (V)
Turkey	50	220
Iran	50	220
United Kingdom	50	230
United States of America	60	120
Germany	50	230
Japan	50/60	100
Korea, Republic of	60	220
France	50	230
Brazil	60	127/220
Canada	60	120
Australia	50	240
India	50	230

Changes in the voltage level made in substations are made by power transformers and distribution transformers. The simplest working principle of transformers is that they do not change the frequency level, although they change the voltage and current level.

1.3 Power System Stability

The stability of power networks depends on different factors. For stable working of the power network, it is essential that the network operates within the specified values. Temporary or permanent problems or faults that may occur, may change these values, and changing these values may impair the stability of the network. If the network stability is impaired, the network can go to the point of collapse. Fig. 1.4 shows the classification of power system stability [5].

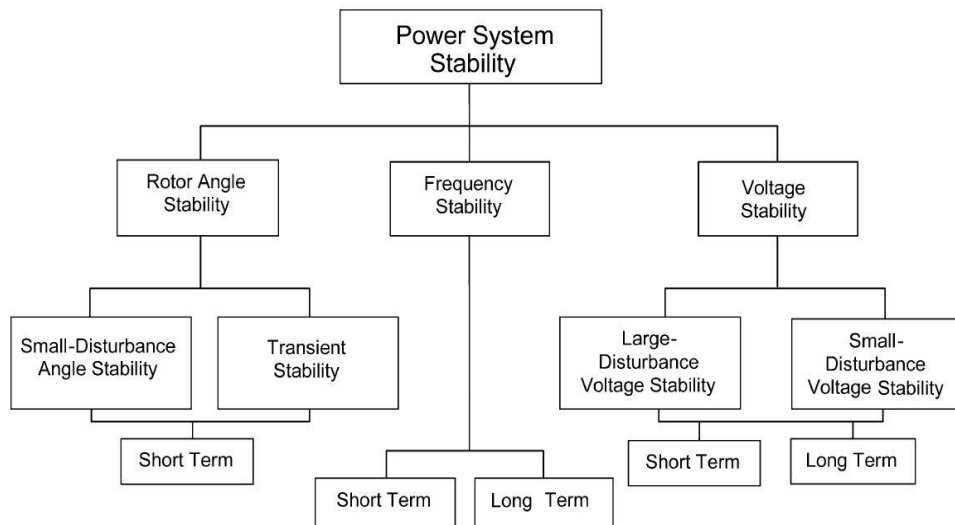


Figure 1.4 : Classification of power system stability.

Protection systems in the network can eliminate some of the reasons that may cause this problem by separating it from the network. However, in some cases, the operator on the network has to make some adjustments. From these arrangements, manual or automatic separation, reserve utilization, load reduction can be counted.

1.4 Literature Survey

For two study cases that were studied in this thesis, different studies that have been done before by different authors were used. Accordingly, especially in the second study by using the results and methods from previous researchs which were mentioned below, a new method was proposed for flexible load management, some of these studies are as follows.

1.4.1 Location for load shedding

It was studied in detail on determining the location where load shedding should applied with PF in [6]. Good approaches are also available for studies to identify and rank the weakest buses in [7], and [8]. Novel multiport network is suggested for minimum amount of load shedding at the proper location with using the multistage methodology in nonlinear programming in [9].

1.4.2 Genetic algorithm optimization

GA and Particle Swarm Optimization (PSO) were handled for the optimal load shedding problem in the 30-bus IEEE system in [10]. Weighting factor, Analytical Hierarchy Process (AHP), and minimization of maintenance outputs were considered as fitness functions. When the performance of these two algorithms was compared, it was seen that the GA faster at the minimum load shedding, while the PSO solution reached faster convergence time.

The GA approach was addressed to return supply in the distribution system in [11]. This method was reported to restore supply for post fault and has been tested on the United Kingdom real system, but the usage restriction on the distribution system can be shown as a problem of this system.

Another version of GA for the solution of the steady-state load shedding problem was discussed in another study in [12]. In this technique, the objective function was to minimize the level of the sum of the square of the difference between connected active and reactive loads.

GA optimization was evaluated on IEEE 14-bus and 30-bus test systems with the general solution in studies [13], and [14]. In this evaluation, it was observed that GA gives less load shedding solutions in different events and almost all of these solutions are very good. On the other hand, it can be said that it is not suitable for on-line applications and operations since it has a long convergence time.

A new centralized improved GA-based algorithm was proposed. In this optimization model, voltage stabilization was used for objectives function. The attempts of this algorithm on the IEEE 39-bus New England test system is remarkable. In order to estimate and implement the best load shedding, another GA based optimization was investigated in [15].

1.4.3 Particle swarm optimization

In study [10], a research-based on market-oriented load shedding and static voltage stability was applied with PSO on a 30-bus IEEE system and the result was compared with Location Marginal Price (LMP). However, this method is only suitable for reducing system power.

In order to reduce the cost of service interruptions with high load amount, the amount of precision, and static stability margin, another method was proposed in study [16]. The problem with this technique is to stay below the optimal standard in load shedding. On the other hand, another study was compared between the General Algebraic Modeling System (GAMs) and GA and PSO methods, and the results obtained with PSO were found to be better than GA and GAMs in [17].

In a study on the 14-bus IEEE test system, PSO achieved an optimum result much more quickly compared to other optimization algorithms. On the other hand, although the lowest amount of load to be taken was achieved by GA, but this method was failed at optimum load shedding.

1.4.4 Optimal distribution network reconfiguration

Various researches were done on this subject in recent years. As an instance, a new algorithm was proposed for network regulation based on the maximum load of the network in [18]. Bifurcation theorem is known as Continuation Power Flow (CPF) theorem and radial distribution load flow analysis were used to find the maximum loadable point in 33-bus and 69-bus distribution test systems. In the proposed method

of that research, to find the optimum tie-switch position, a Discrete Artificial Bee Colony (DABC) approach light was applied.

In [19], an efficient meta-heuristic method was presented by authors for reconfiguration of 69-bus and 119-bus distribution test systems. A modified tabu search algorithm was used to reconfigure distribution systems so that active power losses were globally minimized with switching sectionalizing switches. An improved tabu search algorithm for loss-minimization reconfiguration in the 119-bus distribution test system was introduced by authors in [20].

Such segments were applied and tested in other optimization, optimal switching, and optimal load shedding studies in [6], [21], and [22].

1.5 Purpose of Thesis

The purpose of this thesis is to ensure that the end-users are least affected by this adversity and to prevent the distribution companies and users from the least financial damage.

It has an important place both in terms of network management and in terms of network security and reliability. In this thesis, optimal load shedding and self-healing problems were studied in two study cases by using optimization algorithms. Accordingly, the aim in the first study case was to perform optimal self-healing with optimal switching and load shedding with the help of Binary Particle Swarm Optimization (BPSO) algorithm and Power Flow (PF) in 69-bus and 33-bus distribution test systems and to compare them with normal operating conditions.

In the second study case, which was handled within the smart grid structure, load management was applied by optimal load shedding by using the management of controllable loads in smart home, which was carried out with the help of the PSO optimization algorithm, and it was aimed to prevent network collapse due to excessive load.

In both approaches, the aim was to ensure both network security and stability, better network management under severe disturbances and prevent it from collapsing, and to ensure that the end-users were least affected by the adverse events resulting from these operations.



2. VOLTAGE STABILITY AND LOAD SHEDDING DEFINITIONS

Table In the case of imbalance, if the electric power consumption is more than a generation, that is, if there is an excessive and unnecessary generation in the network, the frequency value will be higher than the main frequency, this amount will increase with load reduction or generation increase, or vice versa.

Recently, a lot of power networks, generators, and control mechanisms equipped with systems such as automatic generation control (AGC) that they automatically and immediately respond to a change in grid frequency. Depending on the level of consumption, generation capacity is increased or decreased. This mechanism ensures that the frequency remains stable within an acceptable range.

2.1 Frequency Monitoring During Ongoing Operation

Frequency is the most important indicator for the stable and secure operating of the whole interconnected network. The system frequency changes at any time depending on the factors mentioned above and the system operator tries to keep this frequency value within the acceptable range.

2.2 Voltage Stability

Voltage stability means that the power grid keeps the voltage level steady in all buses. The voltage level must return to operational and acceptable ranges after any disturbance in the power network. The instability that can lead the system towards collapse, occurs when the balance between power generation and consumption is not achieved.

Voltage instability causes in some cases it is likely that synchronization between generators will go out of hand and the network will go into larger collapse with successive collapses.

Also due to trips by the protection systems of some lines or lack of generation due to overhaul operations or outages in power plants [23].

2.3 Voltage Instability and Voltage Collapse

The typical voltage collapse scenario is as follows:

- As a result of the abnormal operation conditions, some large generators close to the load centers can be out of service. This situation causes some of the transmission lines to be overloaded due to the decrease in reactive power. This overload occurs to provide sufficient reactive power to the problematic region of the network.
- As a result of the tripping of the overloaded transmission lines, the remaining lines also go towards overloading. The need for reactive power in lines also increases since reactive power requirement increases rapidly for loads above surge impedance loading.
- The voltage of the load is reduced due to the need for extra reactive power. Generator's voltage control systems increase the voltage by increasing field excitation. The flow of additional reactive power from transformers and transmission lines causes an increase in voltage drop in each of these elements.
- The voltage drop in the transmission system is then reflected in the distribution system. The voltage level is tried to be restored with the tap changing system in the transformers in substations. The response time of this system depends on the tap changer's time delay. Tap changer has different stages, with the change of each stage, the voltage, and thus the load causing the increase in reactive power demand increases. When the transmission lines are loaded above surge impedance, every Mega Volt Ampere (MVA) increase in the system creates a huge need for reactive power.
- The output reactive power of the generator increases as a result of the tap changing operation in the transformers. Voltage drops after the generator reach its reactive power capacity limit. The sharing of reactive power is also transferred to other generators, resulting in more generators going into an overload state. This situation goes towards voltage instability and voltage collapse by making a domino effect.

In different scenarios that may arise, it is necessary to ensure the voltage stability of the system by making the right decisions at the required time to prevent the network from any voltage collapse. Some changes that can cause voltage collapse in the power system are as follows:

- Increasing the load on the network, especially the load increase occurring in some buses, has more impact.

- Generators, synchronous condensers, switchable shunt Static VAR Compensators (SVC) reach their own reactive power limits.
- Load recovery dynamics
- The outage of generators and power plants due to different reasons.
- Transformer tap changing actions.
- Tripping of transmission lines for reasons such as a fault [24].

2.4 Load Shedding

Severe system disturbance cases such as the generation amount do not meet the increase in the load, the output of the large generators from the network, the sudden load increases in the network, and the failure of the important transmission lines lead to frequency and voltage decrease, due to the lack of real and reactive power.

These situations may lead the system to electrical islanding due to cascaded outages and area isolation. As a result of the lack of generation and frequency reduction in the case of islanding, and the tripping of the generators due to the operation of under-frequency protection relays in the power plants, may cause further loss of generation and cause the system to collapse.

This situation would lead the network to the blackout direction. Under these conditions, load shedding is the emergency action taken to prevent the collapse of the system. The most important issue in load shedding is to apply the most accurate shed at the desired time with the least loss in the network. The most important problem of load shedding is which load and what amount of load can be thrown in the shortest time. Although it is a technical issue in which load is to be taken from, there is also an economic aspect of the issue.

Cutting off some loads in accordance with the user agreement with energy providers may impose huge obligations on the energy provider. On the other hand, some users, according to the deal they made, want to give priority in load shedding to them, in order to get a better offer price.

When such energy market issues are added to technical issues, it becomes more complicated. Increasing the impact of Distribution Generators (DG) in today's electrical networks can be seen. This issue and the strategies that can be implemented for it are also mentioned in [25].

Distribution Generators, smart buildings, smart homes, and some renewable energy sources whose generation amounts vary, or are constantly entering and leaving the network have made it more important to dominate the network at all times and to make the right decisions in different events.

Therefore, the adaptive and optimal load shedding issues that were discussed in chapter 3 have become even more important methods. In addition, applying these methods and monitoring the network with the mentioned factors at any time and correctly made it inevitable to get instant and accurate information from the entire network needs reliable communication systems.

Load shedding can be done both automatically and manually. Manual load shedding is generally preferred for long-term voltage instability problems. However, automatic load shedding is preferred for short-term voltage instability problems.

2.5 Classification of Load Shedding

Load Shedding can be classified as:

- 1) Scheduled outages
- 2) Forced outages

2.5.1 Scheduled outages

In this case, the network manager has trouble meeting the demand in the network, and reserves and other alternative routes are also insufficient. As a result, the balance of generation and consumption in the network is disturbed and the network goes towards collapse.

To prevent this, planned load shedding is applied, in planned load shedding, the amount, duration, and regions of the load to be thrown are determined in advance.

2.5.2 Forced outages

This is the last resort that is used automatically when the imbalance between generation and consumption, as a result of sudden disturbances in the system, goes towards voltage collapse. In these conditions, the amount and location of the load to be shed may vary depending on the operational conditions that will occur.

Recently, by using different methods and decision-making mechanisms, it is aimed to minimize the load to be thrown out of the network. Furthermore, after determining the

minimum load to be shed, it is also important to determine the location of the load to be shed, so that the end-users and the network can suffer the least damage.

2.6 Types of Load Shedding

To determine the load to be thrown in the best way, some parameters in the system must be mastered. Depending on the parameters used in the load shedding, load shedding can be categorized in two ways [26-28]:

- 1) Voltage-based load shedding is known as Under-Voltage Load Shedding (UVLS)
- 2) Frequency-based load shedding is known as Under-Frequency Load Shedding (UFLS)





3. UNDER-VOLTAGE LOAD SHEDDING OPTIMIZATION AND OPTIMAL NETWORK RECONFIGURATION

As mentioned in the previous chapters, the load shedding in the power system is the last rescuer solution applied before going towards voltage collapse. In conventional load shedding applications, methods that were used included different problems.

The most important of these problems were over-shedding or under shedding cases, which often appeared as over-shedding. Furthermore, these methods did not work adaptively since they worked on predetermined conditions and values.

As power grids became larger and more complex, as well as existing conditions of the electricity market, every load amount and location of the load to be cut must be carefully selected. In some cases, electricity providers or users may be in a very difficult situation, or electricity supplier bursts may suffer great penalties or sanctions in line with their commitments.

Therefore, adaptive and optimal load shedding is very important today. Countries experience major economic losses in case of major system outages (blackout), which can be seen in the cases during interruptions and when proper load shedding is not implemented.

The aim of this thesis was under-voltage load shedding (UVLS) application as a result of the instability of the network due to voltage instability. The UVLS optimization to be made was aimed to be performed by the optimization algorithm and the best result was obtained.

3.1 Amount of Load Shedding

When load shedding is applied, the amount of load to be thrown must be selected correctly. Situations, where the load to be thrown, is more than the required amount is called over shedding. Although over shedding situations cause the unnecessary excessive load to be thrown, they can also cause some other problems such as over frequency, in this case, the system may lose its stability again.

On the contrary, if the amount of load is less than the required amount, it is called under shedding. In the load shedding process in order to restore system stability, if the actual amount of load shedding is less than the amount of load to be shed, it does not arrest voltage instability and the system goes towards voltage collapse.

In different situations to be experienced, the character of the load is also a very important factor in order to determine the amount of load to be thrown in the best way. High reactive loads are given priority in load shedding because these loads can lead to voltage collapse since they can cause a dangerous level of reactive power requirement in the network. Some typical loads include induction motors, discharge type bulbs, thermostatically controlled loads such as air conditioners or heaters, and under-load tap changers (ULTC), which their nature is dynamic and time-varying.

The actual amount of load shedding is generally not exactly the same as the calculated minimum amount of load to be shed by the system. The difference between these two values depending on various reasons such as load quantities, load types, and penalty factors of the loads. One of the most important tasks of system operators and load shedding algorithms is that the actual amount of load shedding as close to the calculated minimum load shedding amount as possible, so the balance in the system is preserved.

3.2 Location for Load Shedding

In this thesis, the location and buses to be applied load shedding was determined in two different study cases from two different perspectives. Conventional load shedding methods are applied as soon as the set values at certain bus fall below the specified values. Due to new network needs and emerging recent technologies, the location where the load shedding will take place may differ according to each scenario.

Even though, there are different ways to determine the location of load shedding, in this thesis, the study was being carried out in two different study cases to best match this location. In the first study case, the buses where the loads were being thrown was selected with Power Flow (PF).

In the PF formulation, active and reactive power balance equations were modeled using the rectangular representation of the voltage phasors. In the second study case,

the locations where load shedding was applied were selected from the weakest buses by using the voltage stability index.

The buses that have the most impact on the voltage stability margin are shown as weak buses. Generally, weak buses are located further away from generators and generally, no reactive source is connected to these buses.

Identifying these buses is very important for the long-term operation, planning, and management of power networks so that these weaknesses can be revealed and the network can be improved towards improvement. The main buses where load shedding should be applied are the buses that are most vulnerable to voltage collapse, that is, buses with the highest dV/dQ value, which indicates very fast voltage drop.

3.3 Timing of Load Shedding

Another leg of load shedding to be effective and preventing the system from going towards collapse is the time of load shedding operate. Applying load shedding faster than necessary can cause other unintended problems in the network or change the existing situation. Late application of load shedding will be ineffective in saving the system from voltage collapse. UVLS takes over when all control, protection, and reactive sources are exhausted.

Also, before UVLS is applied, enough time is given for all other systems to return the system. As mentioned before, load shedding is the last solution that can prevent system collapse, as a result of this solution, some financial losses will be inevitable because some loads will be thrown away and some users will remain without electricity. Before using the last path, it is necessary to try to return the system to stable conditions by using all other systems and solutions. The maximum time delay that can be assumed for load shedding was investigated in detail with researches and dynamic simulations in [29].

3.4 Various Load Shedding Approaches

Load shedding can be divided into two statically and dynamically depending on the roads they use during load shedding. In the static schemes, a constant amount of load is thrown at each stage [30]. The amount of the load to be thrown depending on the dynamic response of the system and the disturbance experienced at each stage of

dynamic load shedding is determined by the information and modeling received from the system [31].

In [32], system behavior was evaluated on a time scale for static and dynamic load shedding. Depending on the change in the voltage value of the system, the load can be automatically or manually thrown. If the system voltage drops within minutes, manual load shedding can be applied.

If the voltage value in the network does not decrease within seconds, load shedding is applied automatically to restore system stability. In addition, operations in power systems depend on the conditions of the initial operation, before and after the contingency.

3.5 Heuristic Algorithms for Solving Load Shedding

Different optimization algorithms were used for load shedding and self-healing optimization, each optimization algorithm has some advantages and some disadvantages. These algorithms should be adapted or used and should be chosen in the best way according to the place, conditions, and infrastructure.

3.5.1 Genetic algorithm application

Genetic algorithm (GA) is one of the widely used optimization algorithms for the solution of nonlinear, and multi-objective problems, and has attracted great attention as a robust stochastic search algorithm. GA is seen as a symbol of biological evolution and has the principle of best survival by giving the best estimates to the solutions. As a result, GA has emerged to achieve new, well-fitted with better populations of individuals results. There are three operators in the GA simple form, which are as follows.

- Selection.
- Crossover.
- Mutation.

3.5.2 Particle swarm optimization

Particle Swarm Optimization (PSO) introduced in 1995. In the development of this algorithm, it was inspired by social behaviors such as the training of fish or the influx of birds. This herd intelligence technique has been found to be fast and effective in

solving large-scale nonlinear multi-objective optimization problems. PSO is addressed for analysis in different engineering fields.

A swarm with N particles are considered, in generation t each particle is in its own position, namely $x_{i,t}$ and its own flight velocity in $v_{i,t}$. One fit for each particle, f , can be calculated on its own position, $x_{i,t}$. This value evaluates the quality of the position of that particle.

In general, this fit value is a function value of the target function of optimization problems. If supposes the optimization problem is a minimization problem, so the less the value means the better position is.

The best previous position for each particle is represented by $pbest_{i,t}$. The best position for all particles is the $gbest_i$. In other words, $gbest_i$ is the best of $pbest_{i,t}$. Hence, the position and velocity of the particle i for the next generation can be calculated as follows.

$$v_{i,t+1} = w \cdot v_{i,t} + \varphi_1 \cdot r_1 \cdot (pbest_{i,t} - x_{i,t}) + \varphi_2 \cdot r_2 \cdot (gbest_t - x_{i,t}) \quad (3.1)$$

$$x_{i,t+1} = x_{i,t} + v_{i,t+1} \quad (3.2)$$

Where, w is the inertia weight, φ_1 and φ_2 is the acceleration constraints, r_1 and r_2 is teh uniform random number in the range of $[0,1]$.

After generation the new generatios using above equations, the $pbest_i^{t+1}$ and $gbest^{t+1}$ could be calculated by.

$$pbest_i^{t+1} = \begin{cases} pbest_i^t & \text{if } f(x_i^{t+1}) > pbest_i^t \\ x_i^{t+1} & \text{if } f(x_i^{t+1}) < pbest_i^t \end{cases} \quad (3.3)$$

$$gbest^{t+1} = best(pbest_1^{t+1}, pbest_2^{t+1}, ..., pbst_N^{t+1}) \quad (3.4)$$

If there are constraints in optimization problems, this is usually addressed using additional penalty functions. For instance, if N_{eq} equality constraints and and N_{ueq} inequality constraints were considered, the general format of the optimization problem is as follows.

$$\begin{aligned} \min f(x) \\ g_i(x) &= 0 \quad i = 1, 2, ..., N_{eq} \\ h_j(x) &\leq 0 \quad j = 1, 2, ..., N_{ueq} \end{aligned} \quad (3.5)$$

The problem with the restrictions which was shown above can be converted to the following problem without restrictions.

$$\min f(x) + w_g \sum_{i=1}^{N_{eq}} |g_i(x)| + w_h \sum_{j=1}^{N_{ueq}} \max(0, h_j(x)) \quad (3.6)$$

Where, w_g and w_h are penalty factors. These penalty factors are usually chosen from large numbers, selecting large numbers causes the algorithm to avoid these constraints, and the control variable must change until it encounters any constraints [33].

Generally, the flowchart of PSO optimization algorithm can be shown in the way which was shown in Fig. 3.1. Since the Binary Particle Swarm Optimization (BPSO) algorithm is also developed over the PSO algorithm, its flowchar is very close to the overall operation of the PSO.

3.5.3 Binary particle swarm optimization

The PSO binary version (BPSO) appeared in 1997. Two important features that distinguish the continuous and binary versions are a different position update procedure and a new transfer function. In binary search space to switch the positions of particles between 0 and 1 the updating process is designed, and for mapping a continuous search space to a binary search space the transfer function is used.

BPSO original version also has some problems, it is possible to count trapping in local minima from these problems, for this, different modifications were made on BPSO to fix such problems.

In PSO, each particle must consider their own instant positions, their speed, and their distance to their best solutions, $pbest$ and their global best solution distances $gbest$, so that they can edit their own positions accordingly. PSO was explained as follows in terms of the mathematical model.

$$v_i^{t+1} = wv_i^t + c_1 \times rand \times (pbest_i - x_i^t) + c_2 \times rand \times (gbest - x_i^t) \quad (3.7)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad (3.8)$$

Where, v_i^t is the velocity of particle i at iteration t , w is the weighting function, c_j is an acceleration coefficient, $rand$ is a random number between 0 and 1, x_i^t is the current position of particle i at iteration t , $pbest_i$ is so far the best solution for the $i - th$ particle, $gbest$ indicates the best solution the swarm has obtained so far.

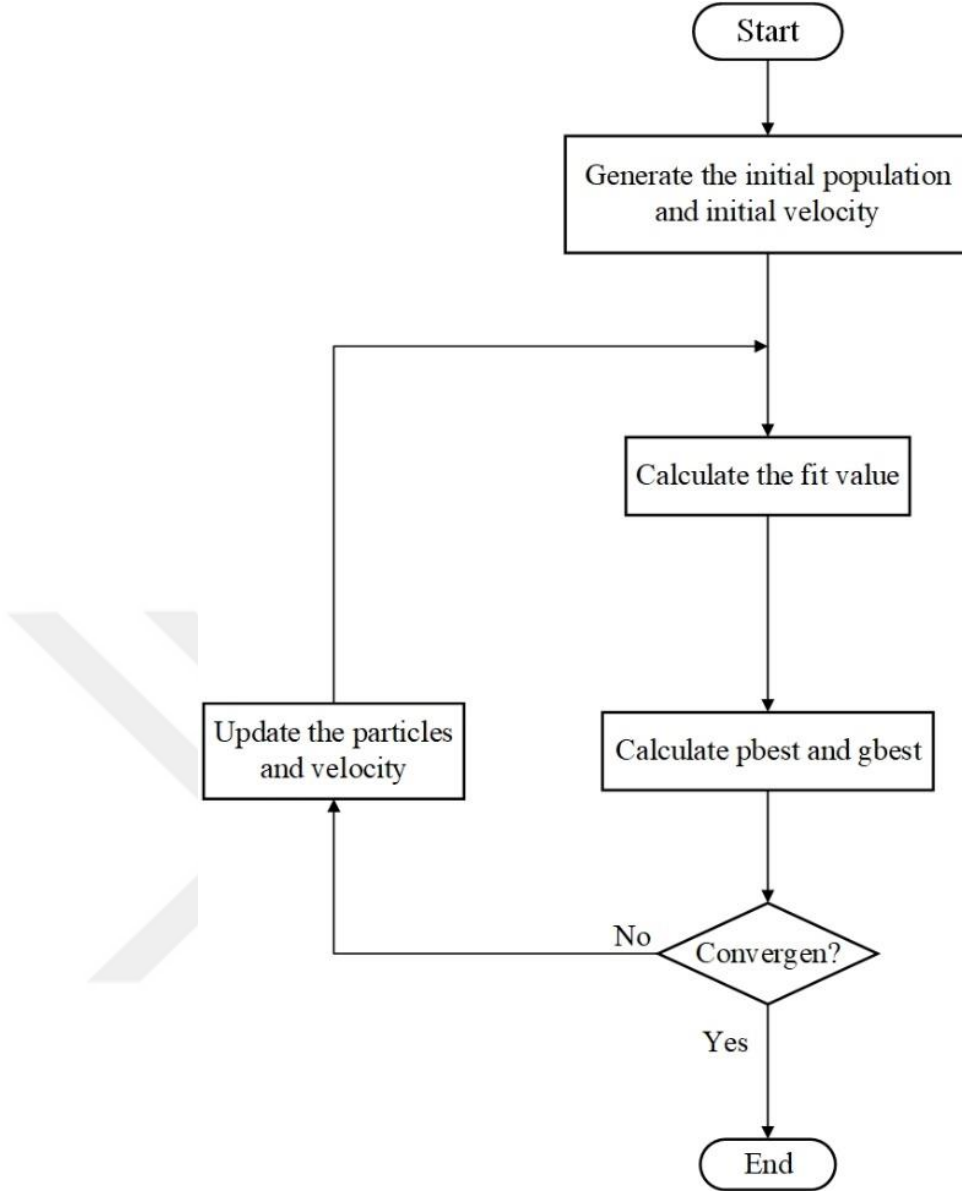


Figure 3.1 : Flowchart of the PSO.

In the first part of equation (3.7), wv_i^t offers the ability to search for PSO. The second and third parts of the equation, $c_1 \times rand \times (pbest_i - x_i^t) + c_2 \times rand \times (gbest - x_i^t)$ also represent private thinking and cooperation of particles, respectively.

A binary search space also could be thought of as a hypercube, and by flipping various numbers of bits, the particle of a binary optimization algorithm could only shift to the nearer and farther corners of that hypercube [34].

Simply, in discrete binary spaces, positions vary between 0 and 1. The velocity's roles are to show the probability of a bit to get the value 0 or 1. The transfer function part of the equation (3.9) was employed to transform all real values of velocities to probability values in the interval [0,1].

$$T(v_i^k(t)) = \frac{1}{1 + r^{-v_i^k(t)}} \quad (3.9)$$

Where, $v_i^k(t)$ shows the velocity of particle i at iteration t in $k - th$ dimension. After converting the velocities to probability values, with the probability of velocities vectors, position vectors can be updated as below.

$$x_i^k(t+1) = \begin{cases} 0 & \text{if } rand < T(v_i^k(t+1)) \\ 1 & \text{if } rand \geq T(v_i^k(t+1)) \end{cases} \quad (3.10)$$

In general, the steps in the BPSO algorithm are as follows.

- a) All particles are handled by giving random values.
- b) For all particles, velocities are defined using equation (3.5).
- c) Using the equation (3.9), the probability of change of elements of position vectors is calculated.
- d) The positions of the elements are updated according to the rules given in (3.8).
- e) Steps b to d are repeated until you reach the final conditions [35].

3.6 Optimal Distribution Network Reconfiguration

The demand for electricity in power networks is increasing. As well as, this increase is not distributed equally, electricity consumption is increasing more in city centers and in areas where the consumption is intense, so that, in recent years more studies were made on Optimal Distribution Network Reconfiguration (ODNR).

These reconfigurations were made by different techniques, the most common method is the reconfiguration made with optimum switching and tie-switches.

4. SIMULATION RESULTS

In this thesis, two study cases were examined details and both of these methods were compared with each other.

MATLAB 2018b program was used for solve problems in both study cases. In this respect, in both study cases optimization algorithms were applied, which some of them were mentioned in the previous chapter, and the algorithm that gives the best and faster results was tried to be chosen.

Selection of the algorithm and adapting the algorithm to the desired purpose is a very important step.

4.1 Optimal Distribution Network Reconfiguration to Support Self-Healing and Optimal Switching (Study Case 1)

In the first study case, the study was carried out to minimize load shedding of end-users due to tripping some distribution feeders, distribution stations, distribution transformers, or outage of distribution generators (DG) due to any event or failure.

Minimize of load cut in this study itself consist of two parts, the first was in the form of network reconfiguration by optimal switching and the other was in the form of network reconfiguration by optimal switching and optimal load shedding through power flow.

Since manual switching is performed in such events in most countries, most of the users connected to that distribution area remain without electricity, and so that it is getting problems both users and electricity producers.

This study case consists of three study analysis. All study analysis were implemented with the MATLAB program, optimization processes were applied in two of the study cases to achieve network reconfiguration and optimal switching. After the results were obtained, they compared with each other.

For the first study case, modified IEEE 69-bus and 33-bus distribution test systems were chosen.

4.1.1 Applied method

The applied method for this study case consists of two phases, in the first phase, after any fault occurred, to isolate the place where the fault occurred, then to decide whether to perform load shedding or not, depending on the circumstances, needs, and system operator decision, and after all the optimal switching to be applied later to reconfiguration of the network.

Depending on whether load shedding was applied or not, voltage and current constraints in the performed switching operations were considered.

The second phase was carried out in the case of load shedding application, the buses where the load will be thrown and the amount of the load will be determined and the load will be thrown. Fig. 4.1 shows the flowchart of this method.

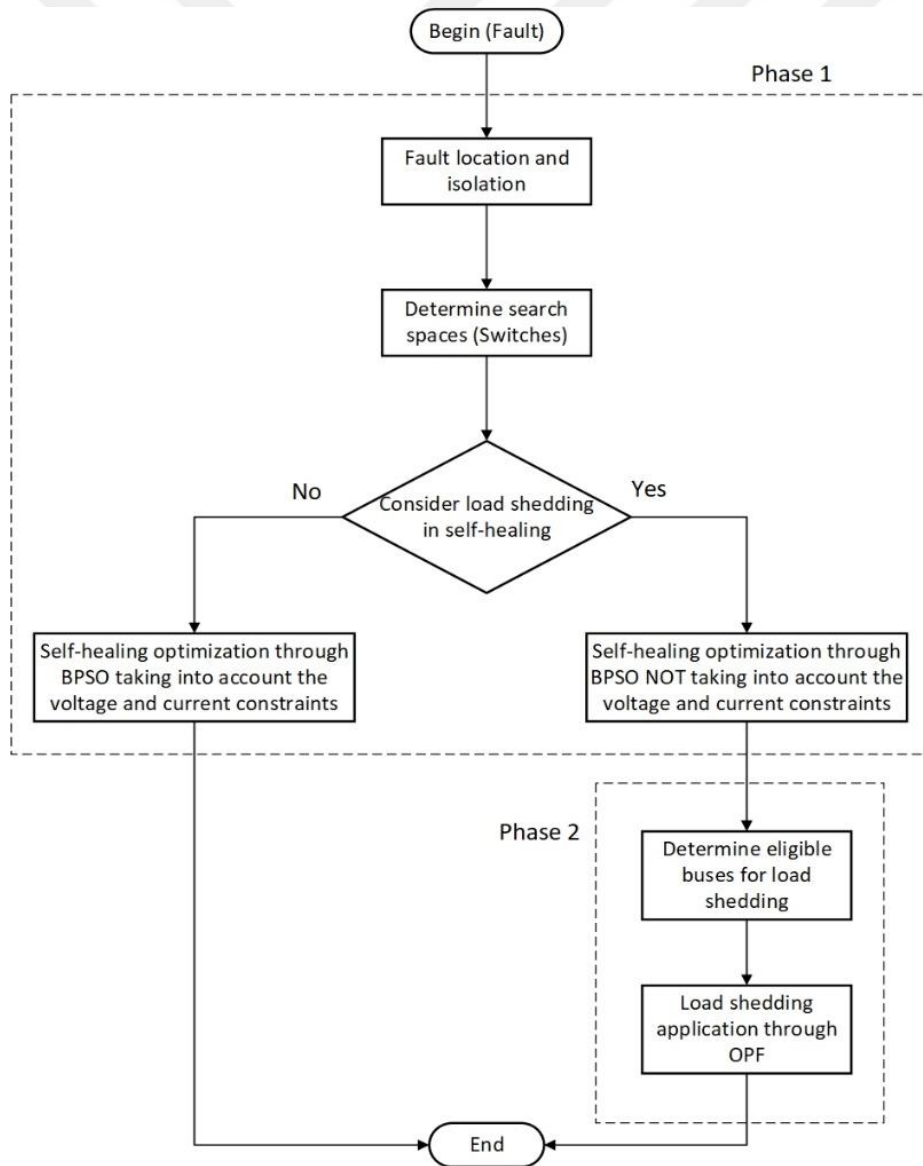


Figure 4.1: The flowchart of applied method for first study case.

4.1.2 Results for modified IEEE 69-bus distribution test system

The single-line diagram of the IEEE 69-bus distribution test system as shown in Fig 4.2, as can be seen, this network consists of 4 long feeders and 4 short feeders. Some modifications were made on this system to be more suitable for study purpose.

However, it was assumed that the system is fed from two substations. The first substation feeds the system from buses 3, 28, and 36, while the second substation feeds the system from buses 27 and 65. In addition, the connection between buses 11 and 12, and buses 9 and 53 was also cut off.

To adapt to the distribution network and this work, the network was divided into 5 separate areas. Also, The voltage level of this system is 12.66 kV.

The correct selection of these regions is very important and may affect the results of the switching and optimization processes.

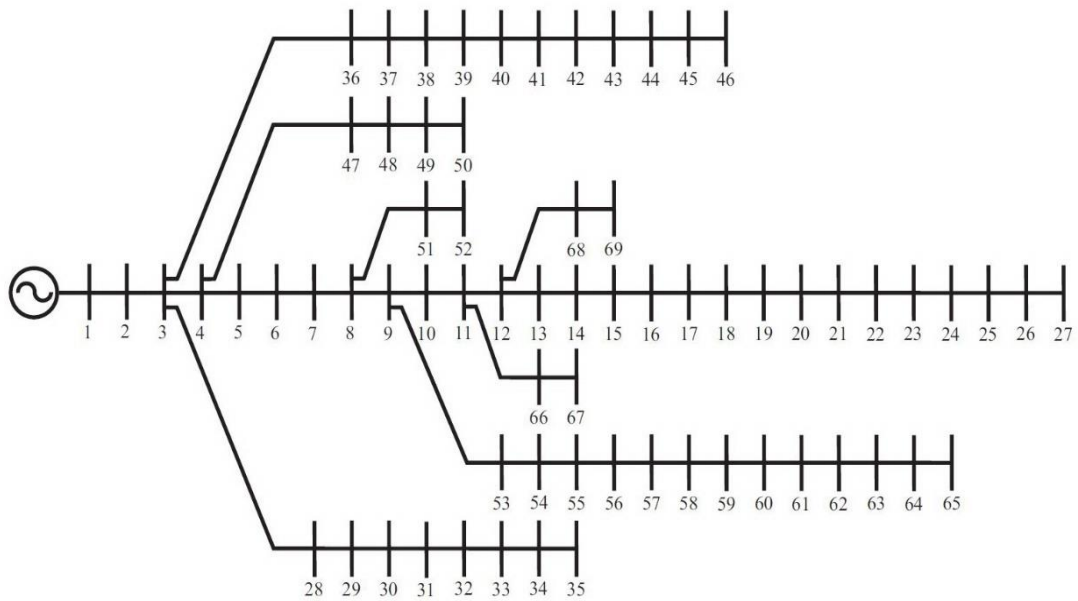


Figure 4.2 : Single-line diagram of IEEE 69-bus test system.

The five-separate area of the reconfigured IEEE 69-bus distribution system as shown in Fig. 4.3. Since the network is a distribution network, this 5-area can be considered as 5 feeders. The new numbers of the feeders that created accordingly, were determined in Fig. 4.3. Accordingly, in this study, it was assumed that the system was connected to two different distribution substation, in order to implement optimal switching, load shedding, and network reconfiguration in the system, in case of events to be experienced 6 different tie switches were assumed. Hence, the schematic illustration of the reconfigured system was shown in Fig. 4.4.

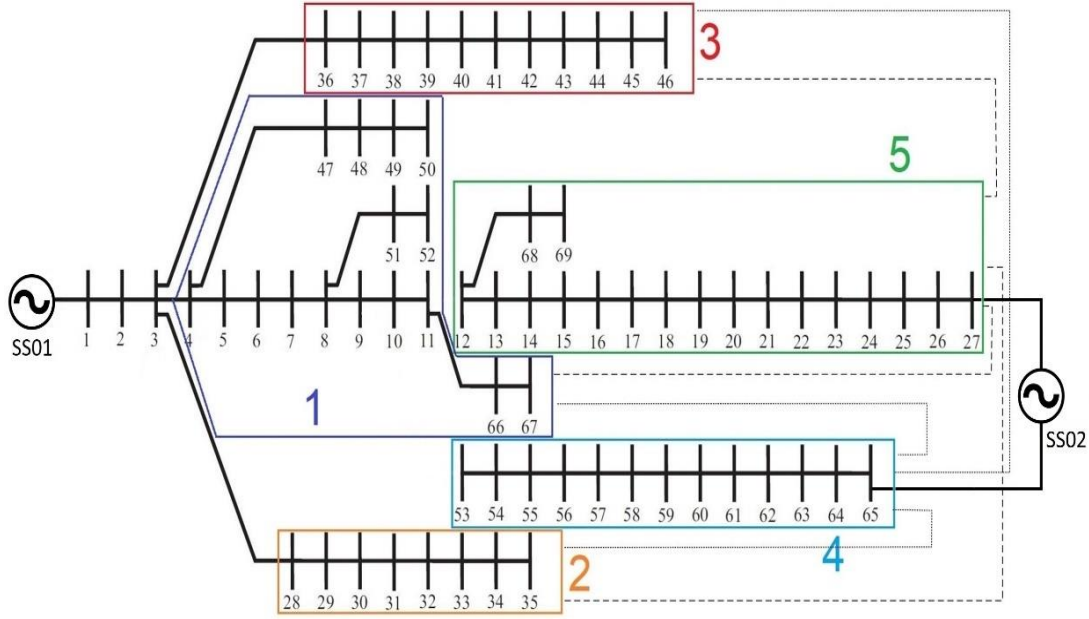


Figure 4.3 : 5-area single-line diagram of reconfigured IEEE 69-bus test system.

Thus, in the new network, the feeders 1,2, and 3 were assumed to be connected to the first distribution substation SS01, and feeder 4 and 5 were assumed to be connected to the second distribution substation SS02. In addition, the connections made with feeder 4 in Fig. 4.3 were determined by the thin dot line and the connections made with the feeder 5 was determined by the thick dot line.

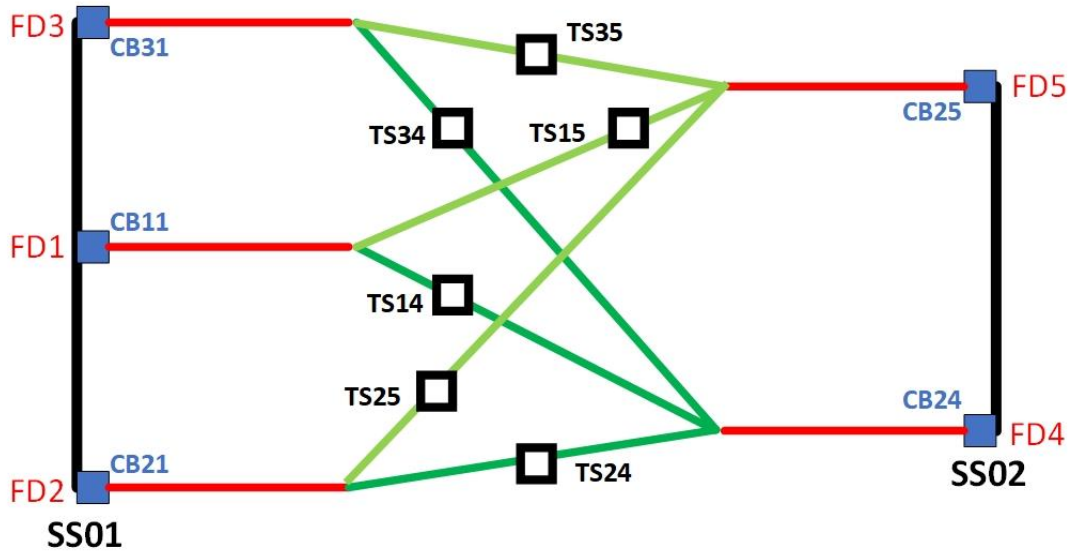


Figure 4.4 : Schematic illustration of the reconfigured system.

Where,

FD stands for feeder and their numbers which were created by new areas in the network,

CB stands for circuit breaker and was numbered based on its location,

SS stands for substation and represents the distribution substations,
TS shows the tie switches which were placed for the switching operation.

TS14 switches were assumed to be placed between feeder 1 and 4, TS15 switches were assumed to be placed between feeder 1 and 5, switches between feeder 2 and 4 was applied by TS24, TS25 switches between feeder 2 and 5, switches between feeder 3 and 4 was applied with TS34, and finally TS35 switches between feeder 3 and 5.

4.1.2.1 Operation under normal conditions (phase 1 - stage 1)

Accordingly, this study case consists of three analysis cases. The first analysis case was that the network worked under normal conditions, all CB's were closed, and while working under normal operating conditions, the power flow analysis was performed and the results were shown.

In this analysis case, all lines and all substations were activated and lines receive power from the distribution substation in which they were connected.

In this analysis case, the maximum current limit of each bus which was connected to the distribution substation was assumed as 3 per-unit (PU), and the minimum acceptable voltage level in the network was considered as 0.93 PU.

As a result, the voltage values obtained from the buses were shown in Fig. 4.5 and current values were shown in Fig. 4.6. According to the results, under normal conditions, bus voltage and bus currents were within the acceptable range in the system.

This was an important different point to be noted between these results and other results. In Fig. 4.5, the results for bus voltages were shown for the first and second distribution substations. In Fig. 4.6, the bus current for the first and second distribution substations were shown.

Nevertheless, for other analyses, the results were shown via feeder 4 and feeder 5. The reason for this situation is that both distribution substations were active in the first analysis, which was, under normal operating conditions.

But in the second and third analyses, the first distribution station was out of service and feeder 1,2, and 3 they try to connect to the second distribution substation via feeders 4 and 5.

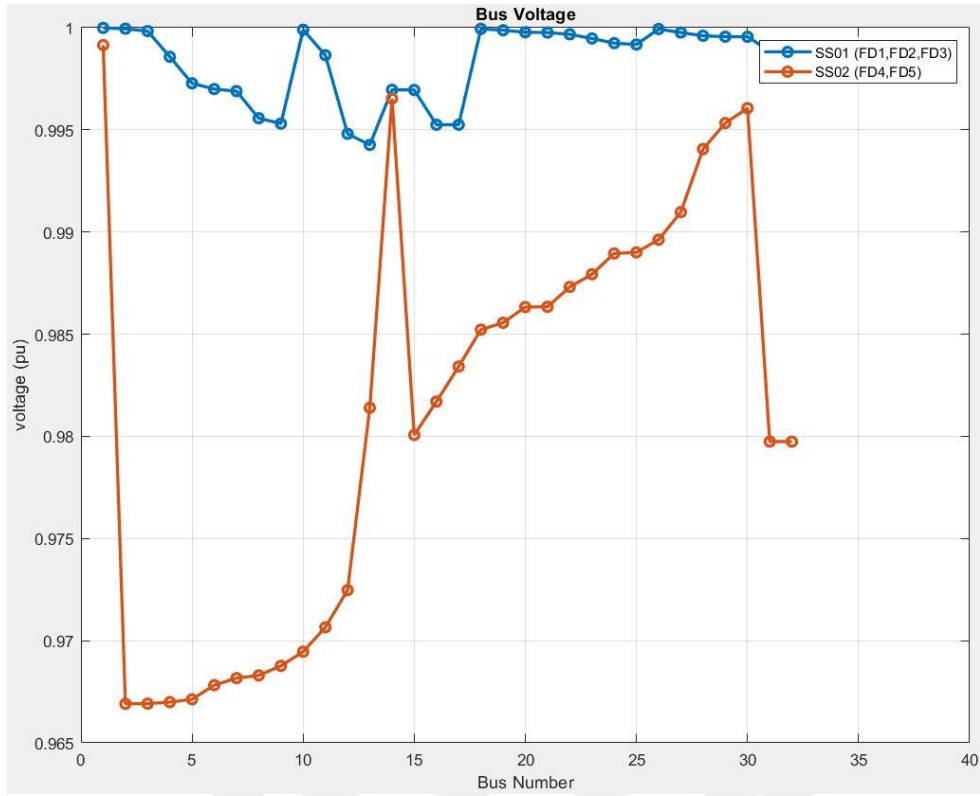


Figure 4.5 : Bus voltages under normal operation conditions in 69-bus system.

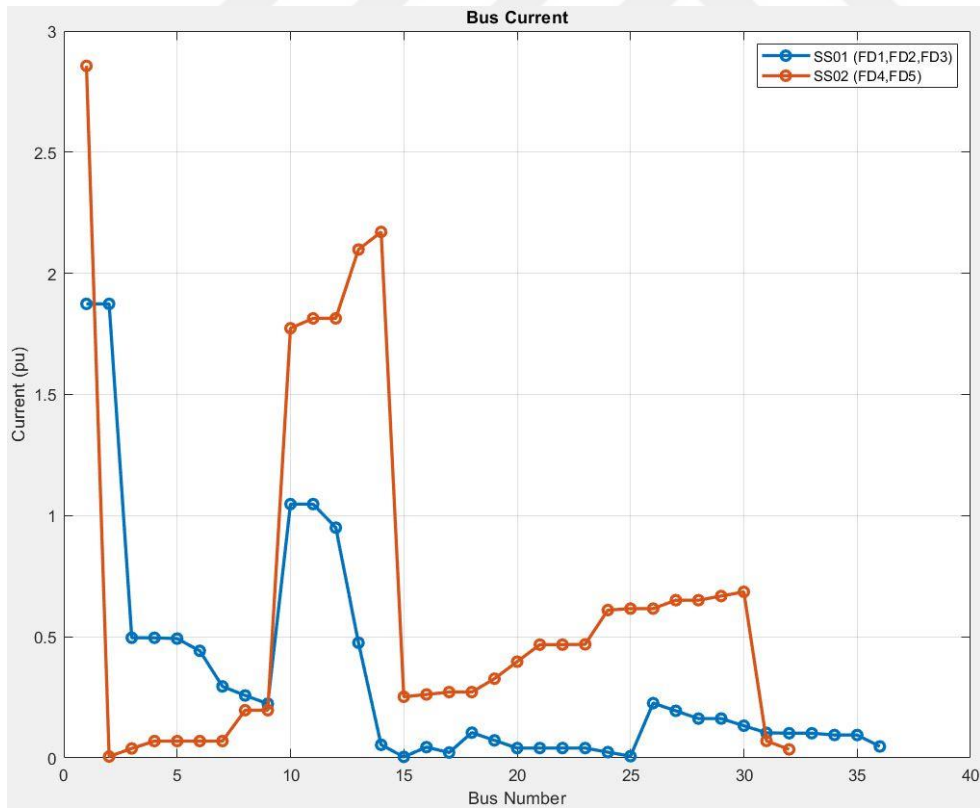


Figure 4.6 : Bus currents under normal operation conditions in 69-bus system.

According to Fig. 4.6, all values fell within the determined limits. Total Power (S_t) in the system, and total power for SS01, and SS02 were given in Table 4.1.

Table 4.1 : System data under normal conditions for 69-bus system.

Data	Amount (in kW)
Total Power	4652.9797
SS01 Power	1867.5509
SS02 Power	2785.4288

4.1.2.2 Self-healing optimization without load shedding (phase 1 - stage 2)

After evaluating the network under normal conditions, the system's ability for self-healing with optimal switching for a possible problem scenario was investigated in the second analysis case. At this stage, self-healing was done by optimal switching, and in this way, the feeders that remain without electricity and the amount of interruption were tried to be minimized.

However, it was assumed at this analysis case that the first distribution substation SS01, which feeding feeders 1,2, and 3, out of service as a result of a fault, and the lines which were connected to SS01 were de-energized as a result of automatic opening of CB11, CB12, and CB13. In this analysis case, it was aimed to achieve the best result with optimal switching without any load shedding. Binary Particle Swarm Optimization (BPSO) algorithm was chosen as the optimization algorithm of the switches to reconfigure the network. As mentioned in chapter three, the BPSO algorithm has some advantages compared to GA, fewer parameters handled, fewer probability transitions, more convenient implementation can be counted. In general, since the PSO is not based on differential equations, it has lower sensitivity to the objective function and it's an advantage of PSO, so there is no need for a very good initial solution. The parameters used for the BPSO algorithm were shown in Table 4.2.

Table 4.2 : BPSO algorithm parameters.

Parameters	Value
Transfer Function	$T(x) = \left \frac{2}{\pi} \arctan \left(\frac{\pi}{2} x \right) \right $
Iteration	200
Population	50
Maximum inertia weight	0.9
Minimum inertia weight	0.4
c1 (cognitive parameter)	2
c2 (social parameter)	2
Maximum particle's velocity	6

The first stage of the algorithm is trying to estimate search space via faults isolations, then trying to bring the best switching solution to restore the load through the BPSO algorithm.

Since load shedding was not be applied at this analysis case, voltage and current constraints were considered, but if the application was to be carried out with power flow and load shedding, it was not necessary to consider the voltage and current constraints.

$$OF_{SH} = w1 \cdot \left(\frac{S_{tot}}{S+1} \right) + w2 \cdot \left(\frac{sw}{sw_{tot}} \right) + w3 \cdot \left(\frac{Is}{Is_{tot}} \right) \quad (4.1)$$

Constraints;

$$1.05 \geq V \geq 0.93 \text{ p.u.} \quad (4.2)$$

$$I_1 \leq I_{max} \quad (4.3)$$

Where, w_1, w_2 and w_3 are the weights for objective functions, S_{tot} is the maximum supplied load, S is the load supplied after self-healing, sw is the amount of commutation of the switches, the total number of switches, Is is the systems technical loss after self-healing, Is_{tot} is the total loss of system in all buses, I_1 is the current in the first branch witch is connected to substation.

The self-healing phase was modeled as a multi-objective function in equation (4.1). This multi-objective function consists of three separate objective functions, the first objective function was supported to maximize the load supply. The second objective function was to minimize the switching required for self-healing, and the third objective function was to minimize the system's technical losses after the new arrangement of the network.

In equation (4.2), the voltage constraints of the network and in (4.3), the maximum current (I_{max}) were given in the first branch connected to the substation. Also, the first objective function S is summed with “1” so even when the optimization would not be able to restore any loads the fraction would be mathematically as well feasible.

Thanks to this algorithm, the most optimal switching position was selected. The total loss and power of the system was solved according to the previous analysis case. Besides, an additional constraint was set which is as follows with (4.4), so that the network did not take the form of a ring.

$$\begin{aligned}
Lop &= X(1) \times X(2) + X(3) \times X(4) + X(5) \times X(6) \\
\text{if } Lop &> 0 \\
z &= 1e^6
\end{aligned} \tag{4.4}$$

In this respect, before calculating the loss function (z), the code is evaluated that the system as a result of the switching would be a ring system or not via (4.4), if there is a ring occurrence, the loss function is evaluated as $1e^6$, and in this case, the BPSO algorithm detects this as a big value and the wrong answer and escapes from it.

As a result of this analysis case, the positions of tie switches will be based on the matrix to be given. The variables of this matrix are 0 or 1, each matrix element indicates the state of a specified switch, when the element of matrix is 0, the switch is open and indicates no connection, when it is 1, the switch is closed and the connection exists.

For instance, the first element $X(1)$ represents TS14 switch status, and means that when 0, the switch is open and there is no connection between feeder 1 and feeder 4, when 1, the switch is closed and feeder 1 and feeder 4 are connected. The switches positions shown by the matrix elements are as follows.

$$X = [TS14 \ TS15 \ TS24 \ TS25 \ TS34 \ TS35] \tag{4.5}$$

Accordingly, after applying the self-healing with BPSO optimization algorithm, the X matrix was as follows.

$$X = [0 \ 0 \ 0 \ 1 \ 0 \ 1] \tag{4.6}$$

According to this matrix, feeders 2 and 3, were connected to feeder 5, but feeder 1 could not be connected to any feeder because it could not meet its loads and it was left without power.

After this step, Fitness code was used by BPSO algorithm to avoid calculating loss function which is also known as cost function. At this stage, X matrix was taken as inputs and (4.1) as output. Accordingly, some variables were valued globally first and then the total loss, total power, and weight coefficients are described as follows.

$$\begin{aligned}
St &= 4.6530e^6 \\
Ploss_{tot} &= 8.0547e^4 \\
SW_{tot} &= 6 \\
w1 &= 20 \\
w2 &= 1 \\
w3 &= 1
\end{aligned} \tag{4.7}$$

The total power of the system (St), and the amounts of total losses ($P_{loss_{tot}}$) were arranged following with the values obtained under normal operation conditions in the first step. SW_{tot} was given according to the number of switches, where there were 6 switches, it was evaluated as 6. Also, w_1, w_2 and w_3 are the weight coefficients. Voltage of buses in self-healing with BPSO without load shedding algorithm was given in Fig. 4.7.

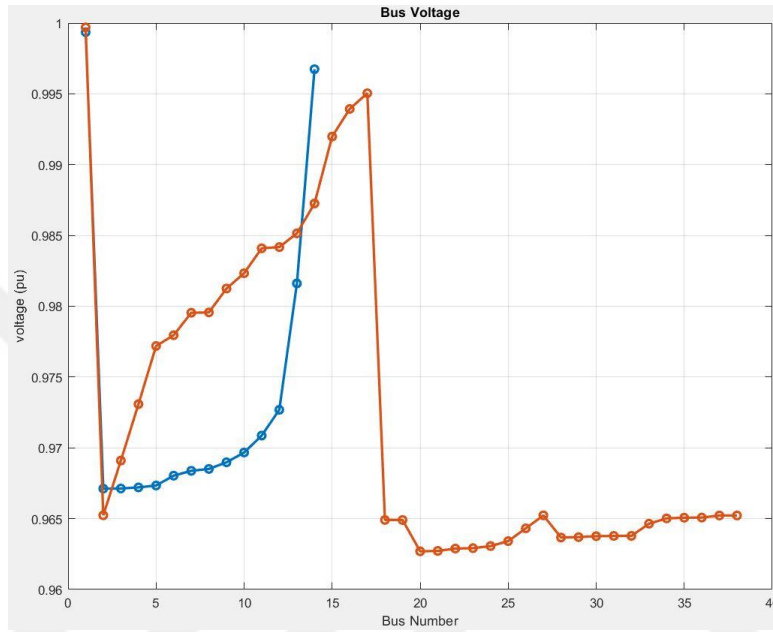


Figure 4.7 : Voltage of buses for self-healing with BPSO algorithm in 69-bus system.

The bus currents were shown in Fig. 4.8 for self-healing by using BPSO algorithm without load shedding.

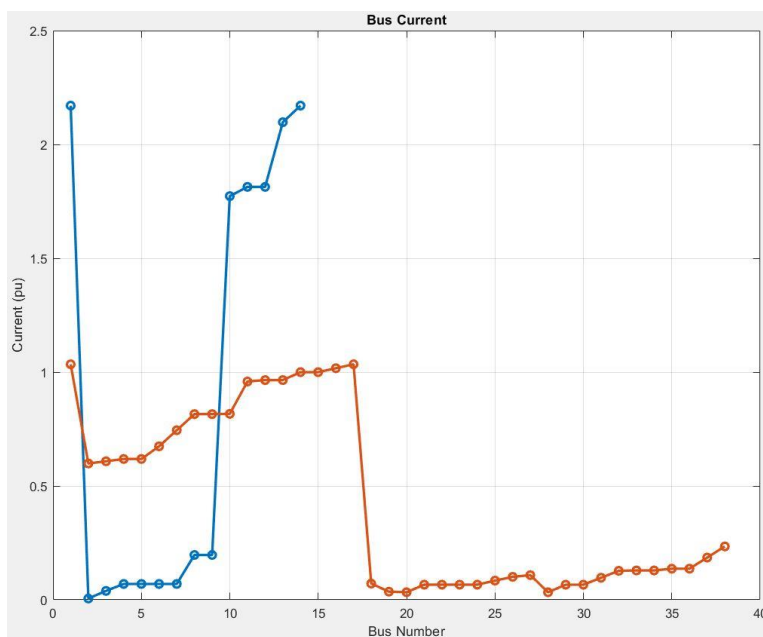


Figure 4.8 : Bus currents for self-healing with BPSO algorithm in 69-bus system.

The total power, and the amount of power that cannot be met for this analysis case was shown in Table 4.3.

Table 4.3 : Data for self-healing without load shedding in 69-bus system.

Data	Amount (in kW)
Total Power	3116.7869
FD4 Power	2109.6687
FD5 Power	1007.1183
Non-Supplied Power	1536.2131

4.1.2.3 Self-healing by using BPSO and load shedding (phase 2 – stage 1)

In the last analysis case, both optimal switching, and load shedding through power flow were performed together to get the best results. Thus, optimal switching was solved with the BPSO algorithm in the first step, this time the voltage and current limitations of the system were not considered by algorithm. As a result, the X matrix showing the tie switch position were as follows.

$$X = [0 \ 1 \ 1 \ 0 \ 1 \ 0] \quad (4.8)$$

In the load shedding phase, furthermore, an extra restriction (3.6) was applied. Thus, it can be said that the feeder 1 was connected to feeder 5, feeder 2 and 3 were connected to feeder 4. Also, Fig. 4.9 shows the voltage for buses for first step of self-healing with BPSO not taking into account of voltage and as well current constraints.

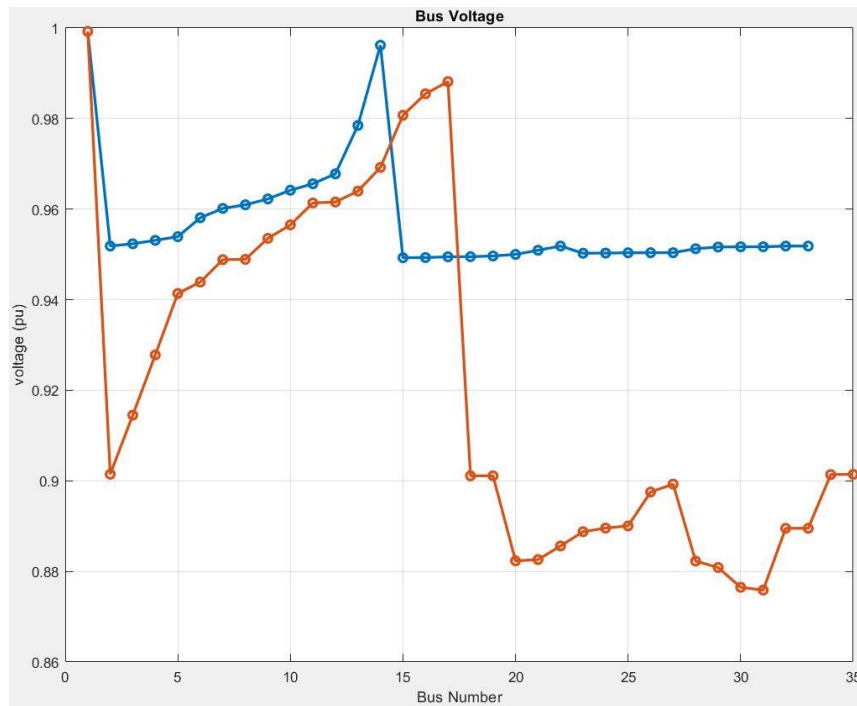


Figure 4.9 : Voltage of buses for step 1 of BPSO self-healing with power flow and load shedding in 69-bus system.

Also, bus currents were shown in Fig. 4.10. The non-supply load in this step was almost 0 kW. Nonetheless, there was a voltage drop in feeder 5 in the network which was also connected to feeder 1, and falls below acceptable values.

In this case the system immediately goes towards voltage collapse, and there was a clear unbalance between generation and load, and some buses in SS02 were under voltage acceptable range. To prevent the network from going towards the voltage collapse, the load shedding process in the second step should be applied.

The data of the system for self-healing by using BPSO algorithm without voltage and current constraints were given in Table 4.4.

Table 4.4 : Data for self-healing without voltage and current constraints in 69-bus system.

Data	Amount (in kW)
Total Power	4652.9796
FD4 Power	2441.0268
FD5 Power	2212.9529

4.1.2.4 Self-healing by using BPSO and load shedding (phase 2 – stage 2)

On this basis, as a result of the self-healing and load shedding with power flow application in the second step, The algorithm first identified the buses that were at the critical point of the voltage level.

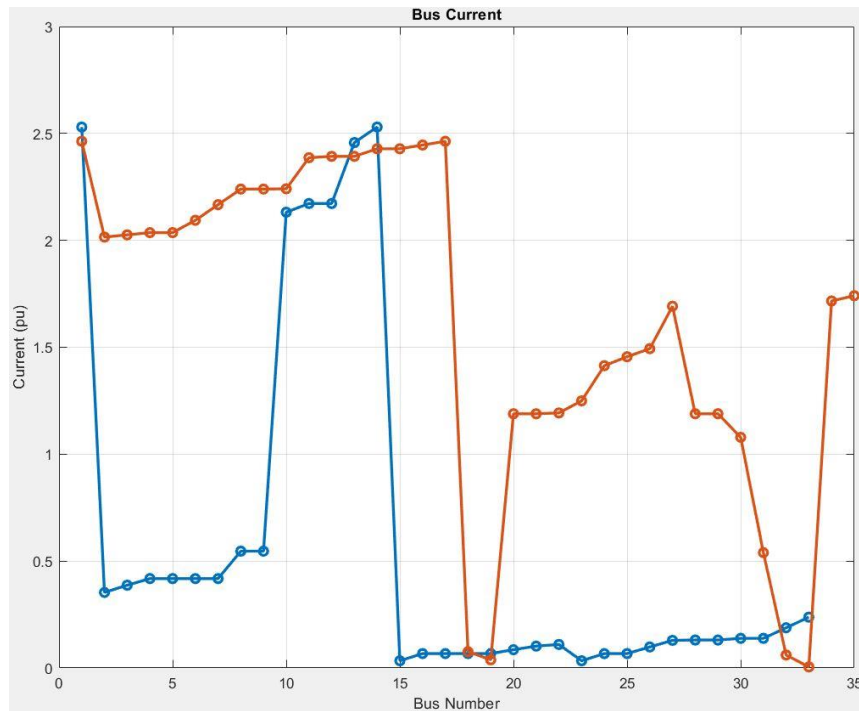


Figure 4.10 : Bus currents for step 1 of BPSO self-healing with power flow and load shedding in 69-bus system.

After the bus which were at the critical point of the voltage level was identified by the algorithm, then it threw the required amount of load to bring the voltage value to the acceptable point.

According to Fig. 4.9, the voltage level of feeder 4 after connection of feeder 2 and 3 was acceptable, but the voltage level of feeder 5 after connected to feeder 5 was below the acceptable level.

The system data for simulation results for BPSO self-healing with load shedding were given in Table 4.5.

Table 4.5 : Data for self-healing with load shedding in 69-bus system.

Data	Amount (in kW)
Load Shedding	412.4589
Total Power	4240.5411
FD4 Power	2441.0268
FD5 Power	1799.494

Hence, the amount of load that should be thrown optimally by the algorithm was given as 412.4582 kW. After shedding this amount from different buses of feeder 5 and feeder 1, it is seen that the voltage values were returned to the acceptable range as Fig. 4.11.

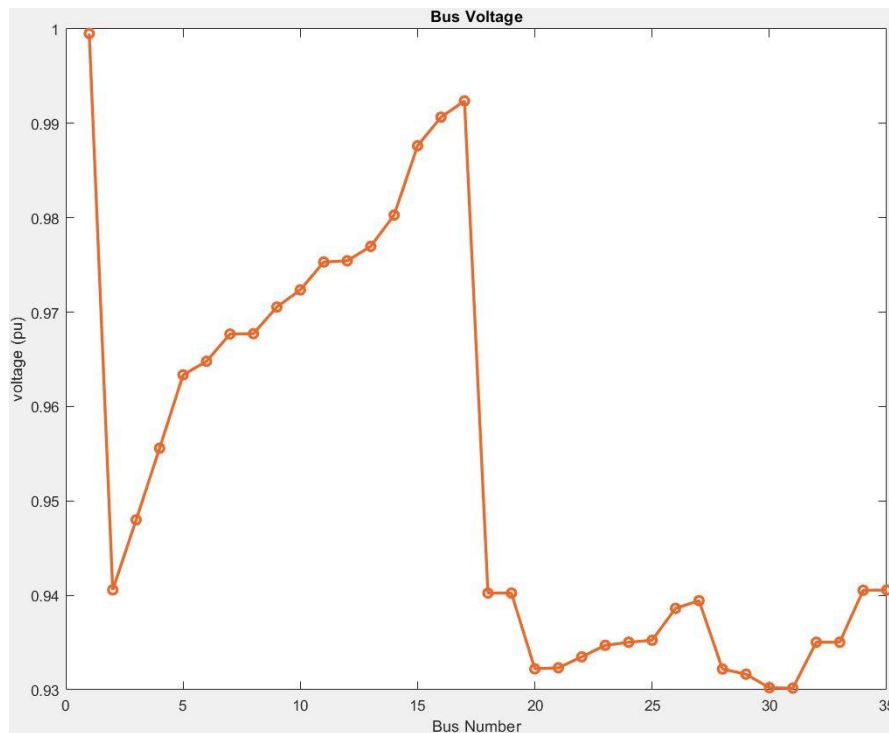


Figure 4.11 : Feeder 5 voltage after power flow and load shedding in 69-bus system.

Fig. 4.12 shows the feeder 4 voltage values for all three analysis case, normal operation conditions, BPSO self-healing without load shedding, and BPSO self-healing with load shedding and power flow. Also, the numerical values of these data were shared in Table 4.6.

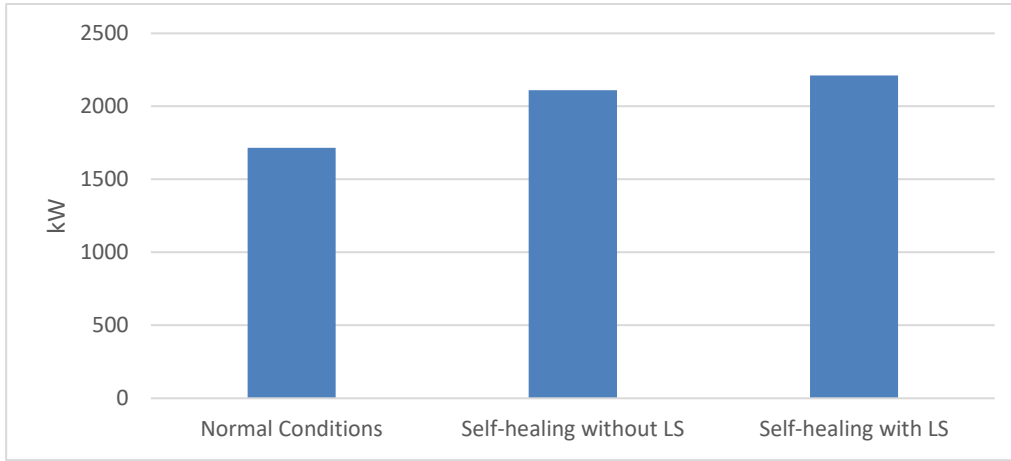


Figure 4.12 : Comparisson between self-healing with and without load shedding for FD 4 in 69-bus system.

Table 4.6 : Numerical values for FD 4 in three cases for 69-bus system.

Case	Amount (in kW)
Normal conditions	1716.35
Self-healing without LS	2109.668
Self-healing with LS	2211.9529

Furthermore, Fig. 4.13 shows the feeder 5 voltage values for all three states which were counted above. The numerical values of these data were also shown in Table 4.7.

When these data were compared, it can be better to analyze and evaluate the performance of the given algorithm and BPSO self-healing in both the analysis case.

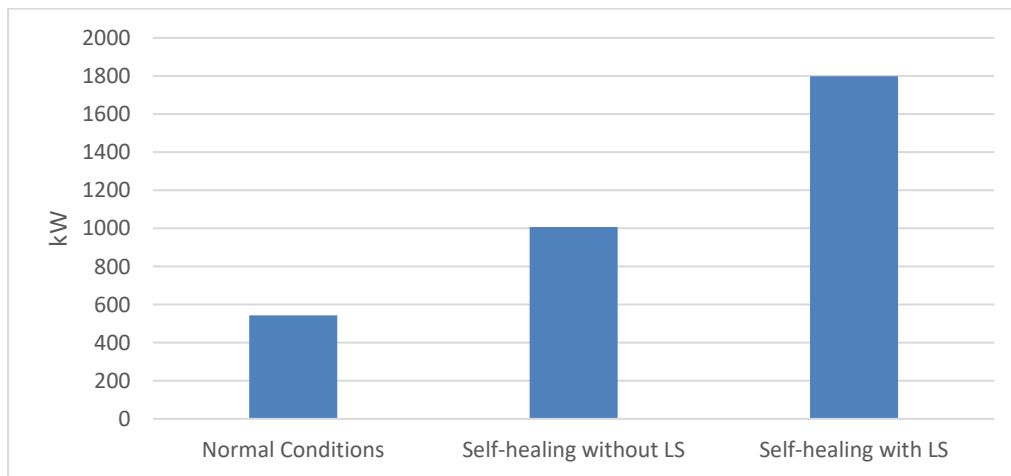
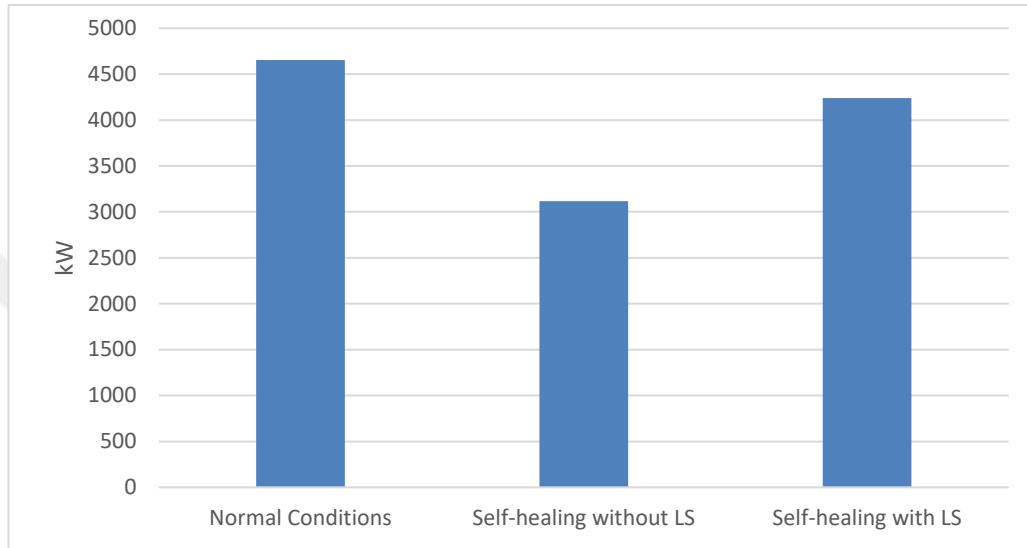


Figure 4.13 : Comparisson between self-healing with and without load shedding for FD 5 in 69-bus system.

Table 4.7 : Numerical values for FD 5 in three cases for 69-bus system.

Case	Amount (in kW)
Normal conditions	543.5
Self-healing without LS	1007.1183
Self-healing with LS	1799.494

The most important indicator, the total power of the system, was shown in Fig. 4.14 for all three cases.

**Figure 4.14 :** Comparisn for total power of the system for three cases in 69-bus system.

On this basis, when all results were considered, it can be seen that, as a result of an unexpected situation occurring in the substation 1 (SS01) in the distribution network, the feeders 1,2, and 3 remained without power.

After solving the problem by the BPSO algorithm, only feeder 2 and 3 could be connected to the still active substation 2 (SS02), and as a result, the total amount of 1536.2131 kW of the feeder remains without power.

Finally, when optimal switching and optimal load shedding with power flow were applied, the amount of load without power was significantly reduced. The corresponding numerical data were given in Table 4.8.

Table 4.8 : Numerical values for total power of the system for three cases for 69-bus system.

Case	Amount (kW)
Normal conditions	4652.9797
Self-healing without LS	3116.7869
Self-healing with LS	4240.5411

The amount of non-supplied loads were shown in Fig. 4.15, and their numerical values were given in Table 4.9.

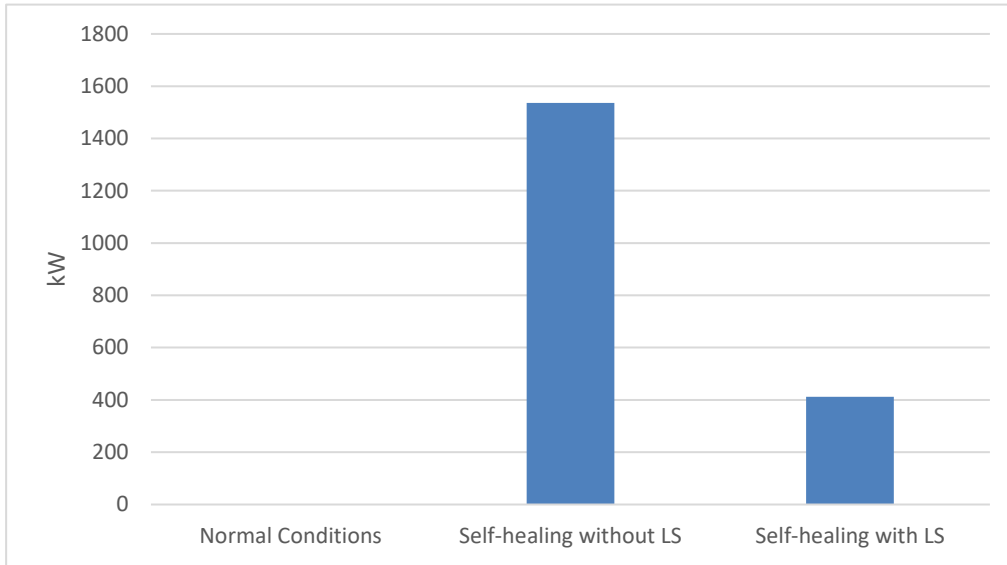


Figure 4.15 : Comparisson for non-supplied load for three cases in 69-bus system.

Table 4.9 : Numerical values for non-supplied load for three cases for 69-bus system.

Case	Amount (kW)
Normal conditions	0
Self-healing without LS	1536.2131
Self-healing with LS	412.4589

Although the system stability was not deteriorated with the optimal switching, but 33.01% of loads were remains without power. Depend on increasing amount of the existing loads in the system, the stability problem might be occurred if there was changed load.

In this case, load shedding matching, with BPSO without considering voltage and current constraints, as well as restoring the network stability, it can be shown less load will remain without electricity with the load shedding with power flow over the specified buses.

In this case, the number of loads left without power supply was 412.4589 kW, which was 8.86% of the total load, so it was led to a significant decrease in the total load.

4.1.3 Results for modified IEEE 33-bus distribution test system

In this analysis case of the first study case, the performance of the algorithms was also applied on the IEEE 33-bus test system using the same algorithms and the same process which was available in Fig. 4.1. The single line diagram of the IEEE 33-bus

distribution test system, which is voltage level is 12.66 kV was given in Fig. 4.16. Some modifications were made on this system too, to made the system more suitable for study purpose. It was assumed that the system is fed from two substations. The first substation feeds the system from buses 1, 19, and 23, while the second substation feeds the system from buses 18 and 33. In addition, the connection between buses 8 and 9, and buses 6 and 26 was also cut off. The system was suitable to be divided into 5 areas due to the better comparison of the results.

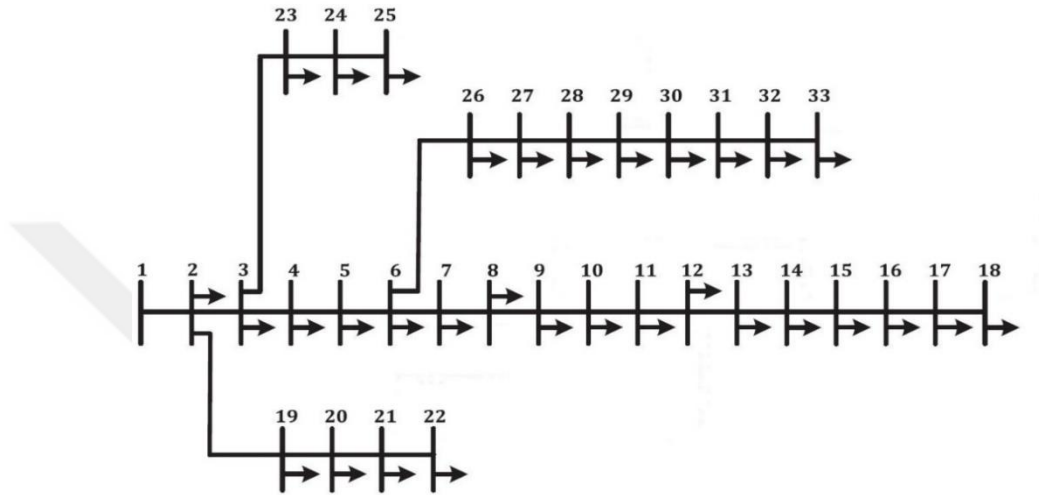


Figure 4.16 : Single-line diagram of IEEE 33-bus test system.

Five areas and the connections envisaged for the arrangement between them were shown in Fig. 4.17. For this system, 2 distribution substations and 6 tie switches were provided. The schematic representation of the reconfigured system was also available in Fig. 4.4. In the reconfigured system, connections for area 4 were shown with thin dot lines, and the connection for area 5 were shown with thick dot lines.

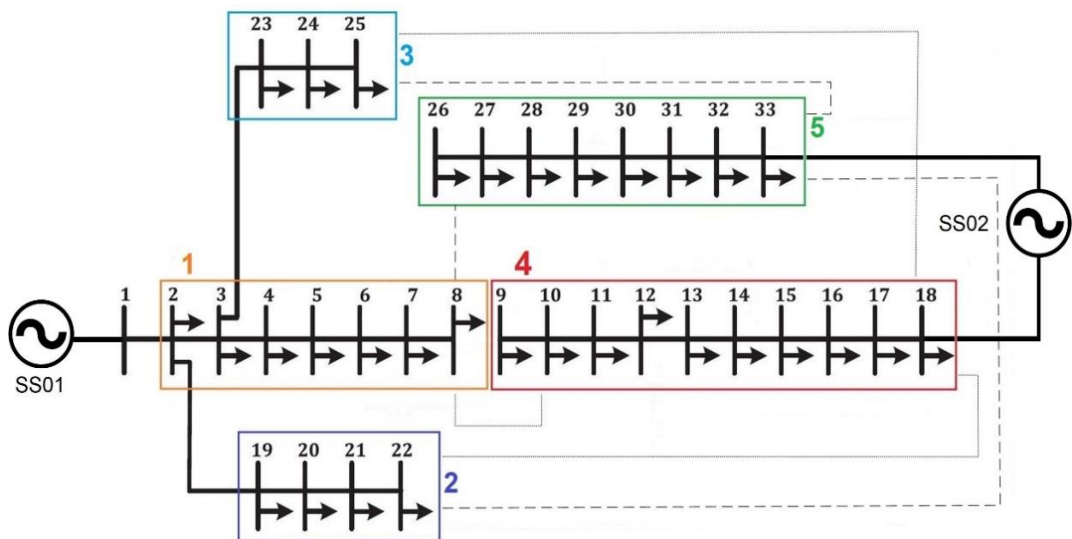


Figure 4.17 : 5-area single-line diagram of reconfigured IEEE 33-bus test system.

4.1.3.1 Operation under normal conditions (phase 1 - stage 1)

Like the previous system, the state of the system under normal operating conditions was examined first, in this analysis case both distribution substations were in service, and tie switches were in their open position. System constraints were assumed as the previous system. Accordingly, the voltage values of the buses were shown in Fig. 4.18.

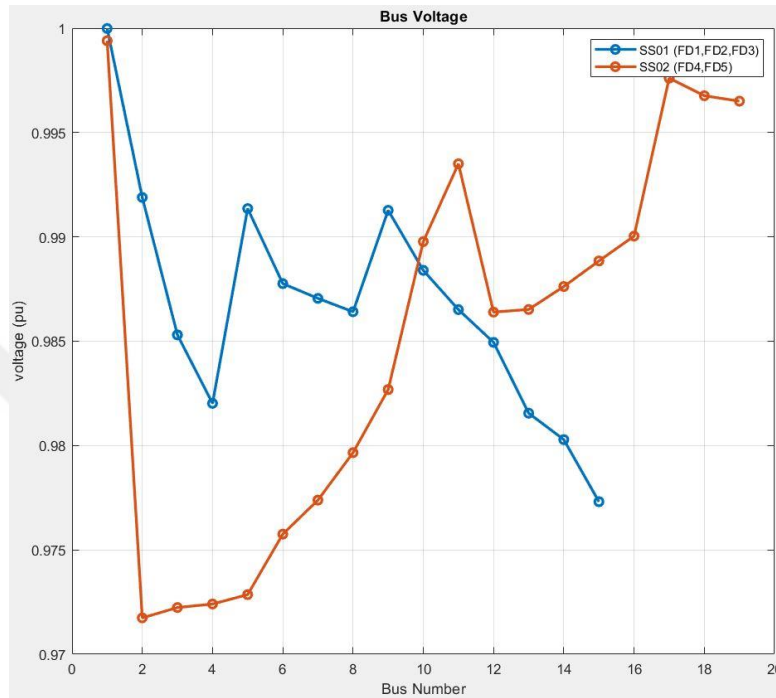


Figure 4.18: Bus voltages under normal operation conditions in 33-bus system.

Fig. 4.19 shows the current values of the buses in the 33-bus system.

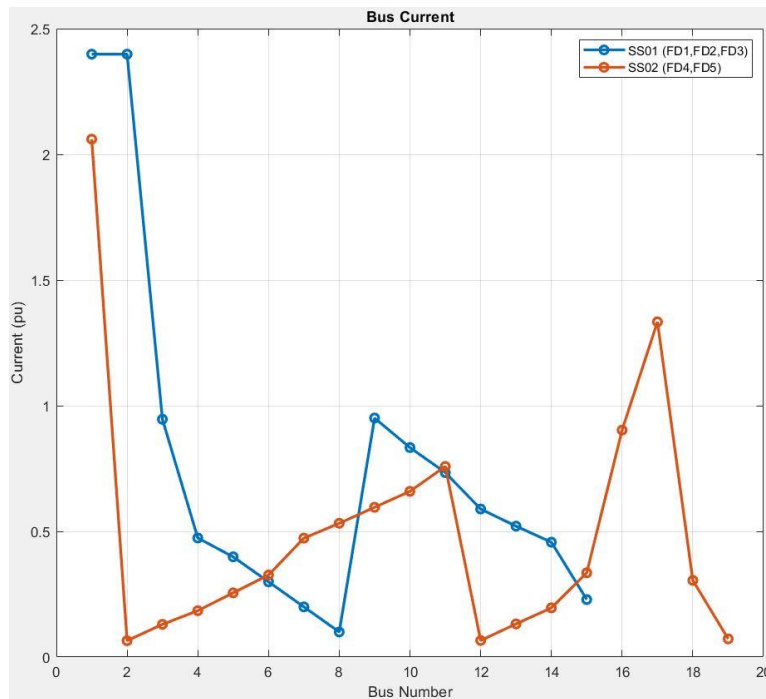


Figure 4.19 : Bus currents under normal operation conditions in 33-bus system.

In this direction, under normal operating conditions, the system operated properly within its constraints. The total power (P_t) of the system, and power of SS01, and SS02 were given in Table 4.10

Table 4.10 : System data under normal conditions for 33-bus system.

Data	Amount (in kW)
Total Power	4548.546
SS01 Power	2364.1577
SS02 Power	2184.3882

4.1.3.2 Self-healing optimization without load shedding (phase 1 - stage 2)

At this stage, as in the previous system, first, it was studied to self-healing the system, taking into account its constraints, using only optimal switching.

Hence, for an unknown reason, the first distribution substation (SS01) is out of service. Thus, the self-healing system was activated and tried to transfer the feeder 1,2 and 3 to the second distribution substation (SS02).

Switch positions were handled as shown in (4.5). As a result of optimal switching, the X matrix solution was given by the BPSO algorithm was as follows.

$$X = [0 \ 0 \ 1 \ 0 \ 0 \ 1] \quad (4.9)$$

By analyzing at the result of self-healing done by BPSO algorithm, the feeder 2 was connected to feeder 4, and feeder 3 was connected to feeder 5. Hence, since feeder 1 cannot be connected to any feeder, it remained completely without power. The voltages of the system buses were given in Fig. 4.20.

System data such as total power and non-supplied power available in Table 4.11.

Table 4.11 : Data of system for self-healing without load shedding in 33-bus system.

Data	Amount (in kW)
Total Power	3611.6751
FD4 Power	1143.4825
FD5 Power	2468.1926
Non-Supplied Power	936.8709

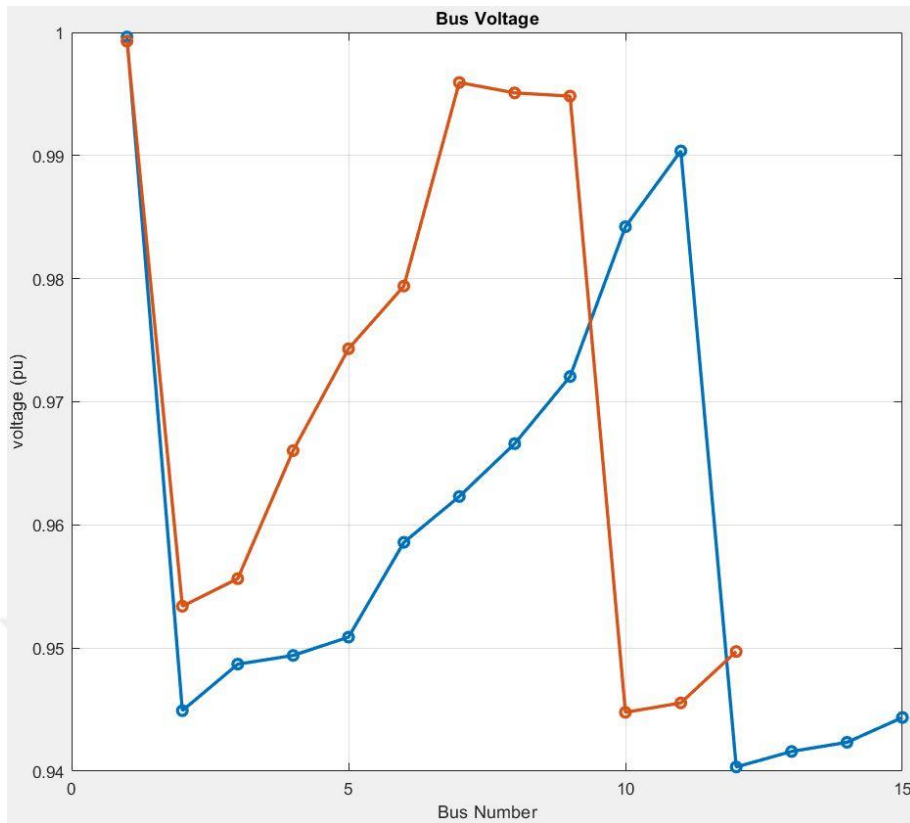


Figure 4.20: Voltage of buses for self-healing with BPSO algorithm in 33-bus system.

Moreover, the current of buses were shown in Fig. 4.21.

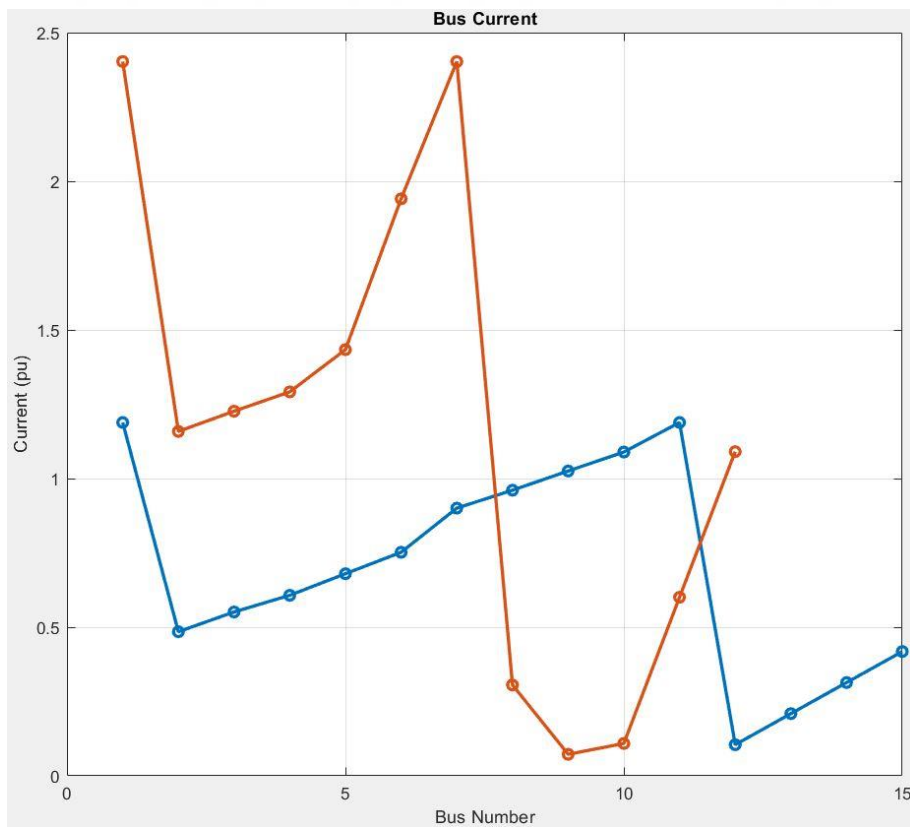


Figure 4.21 : Bus currents for self-healing with BPSO algorithm in 33-bus system.

4.1.3.3 Self-healing by using BPSO and load shedding (phase 2 – stage 1)

For the self-healing process with the help of load shedding through power flow, as in the previous system, first, the optimal switching without considering the system constraints was performed. Hence, the X matrix, obtained by the BPSO algorithm was as follows.

$$X = [1 \ 0 \ 0 \ 1 \ 0 \ 1] \quad (4.10)$$

According to the solution, feeder 2 and 3 were connected to feeder 5, and feeder 1 was connected to feeder 4 at the same time. The voltages of the system buses were given in Fig 4.22.

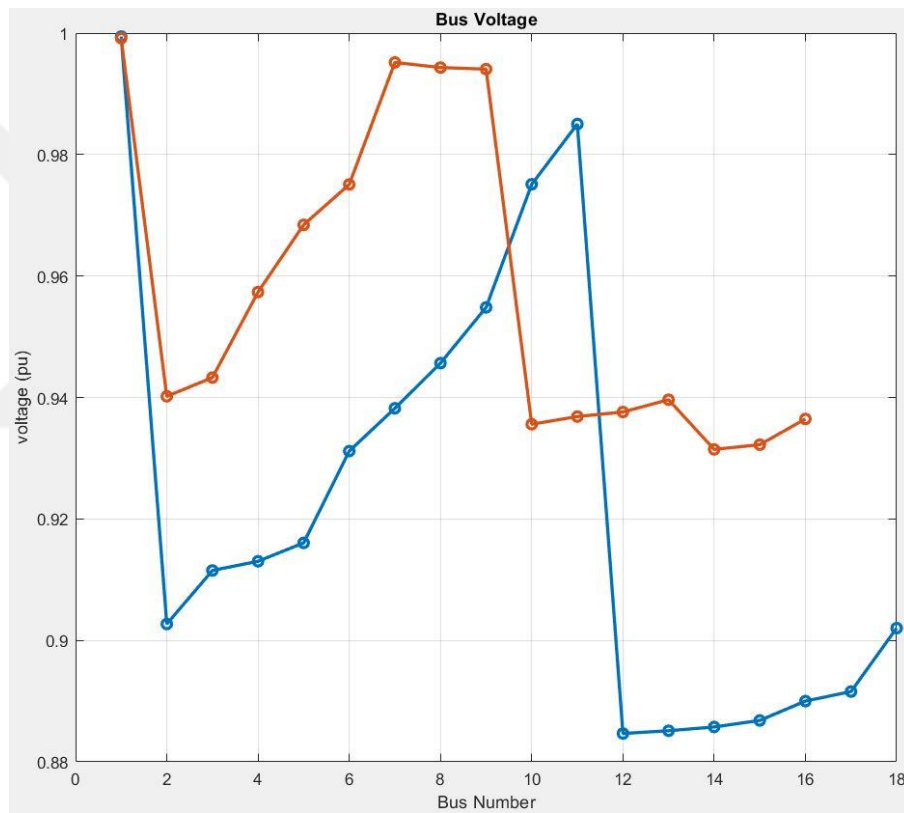


Figure 4.22 : Voltage of buses for step 1 of BPSO self-healing with power flow and load shedding in 33-bus system.

Also, The system data for this step were given in Table. 4.12.

Table 4.12 : Data for self-healing without voltage and current constraints in 33-bus system.

Data	Amount (in kW)
Total Power	4548.546
FD4 Power	1686.399
FD5 Power	2862.147

In addition, the currents of the system buses were shown in Fig. 4.23.

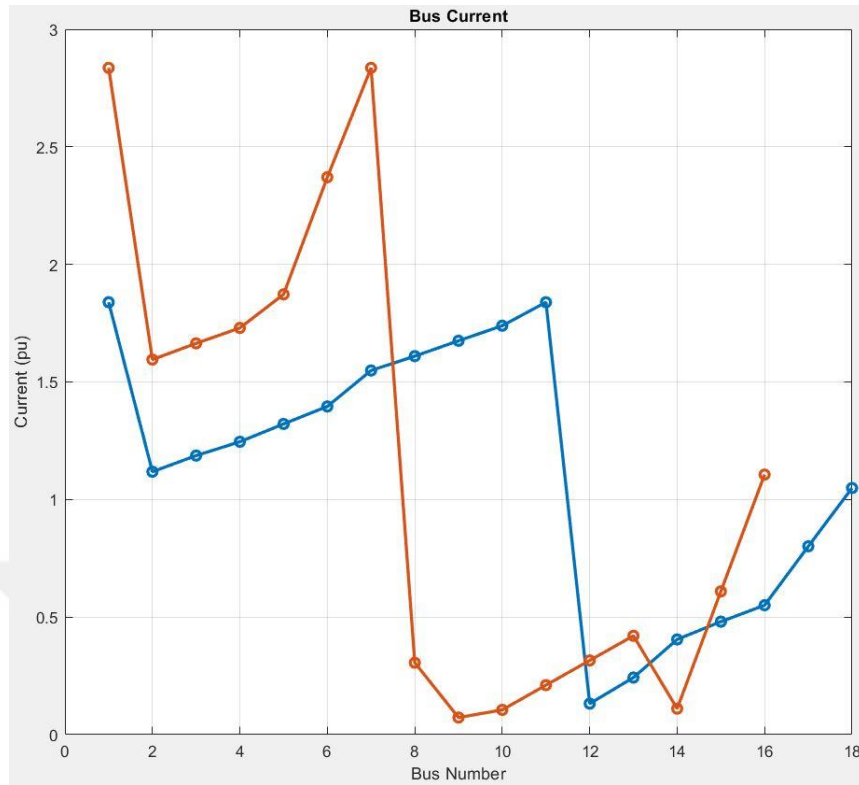


Figure 4.23 : Bus currents for step 1 of BPSO self-healing with power flow and load shedding in 33-bus system.

Thus, as a result of connecting these lines to SS02, it was observed that voltage constraints was violated in feeder 4. Since the system cannot operate under these conditions and the system goes towards voltage collapse, load shedding operation was performed in the determined buses in the system.

4.1.3.4 Self-healing by using BPSO and load shedding (phase 2 – stage 2)

At the final stage, power flow with load shedding was performed to prevent system collapse and also to ensure that the least load was de-energized.

Hence, the voltage of the buses obtained as a result of throwing the loads can be seen in the Fig. 4.24. The system data for simulation results for BPSO self-healing with load shedding is available in Table 4.13.

Table 4.13 : Data for self-healing with load shedding in 33-bus system.

Data	Amount (in kW)
Load Shedding	225.308
Total Power	4323.238
FD4 Power	1461.091
FD5 Power	2862.147

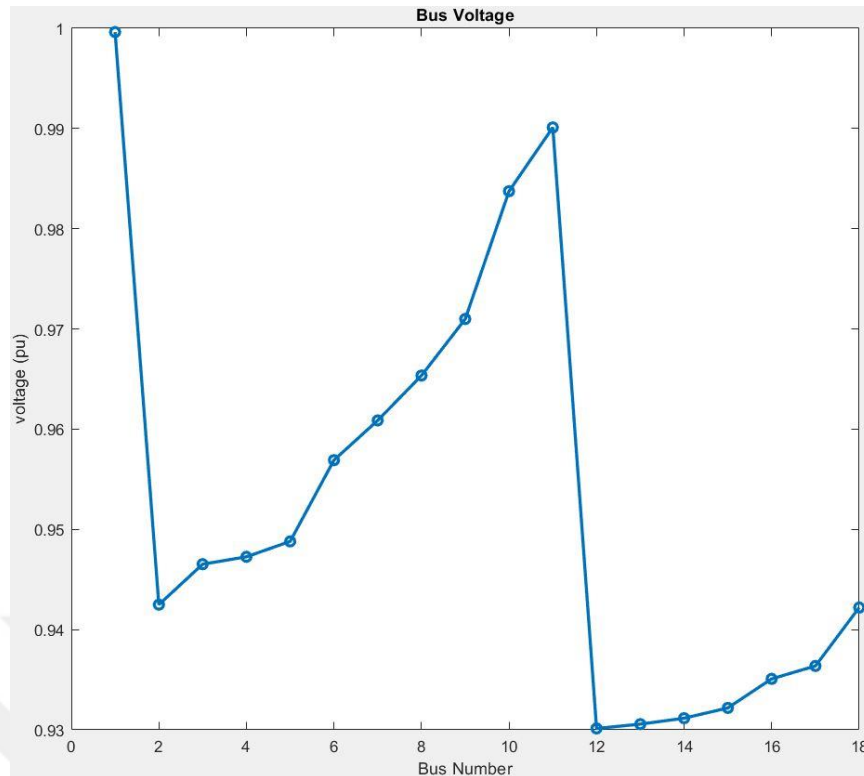


Figure 4.24 : Feeder 4 voltage after load shedding in 33-bus system.

In addition, feeder 4 data can be seen numerically in Table 4.14.

Table 4.14 : Numerical values for FD 4 in three cases for 33-bus system.

Case	Amount (in kW)
Normal conditions	675.00
Self-healing without LS	1143.4825
Self-healing with LS	1461.091

Feeder 4 power quantity was shown in Fig. 4.25 for all three analysis case.

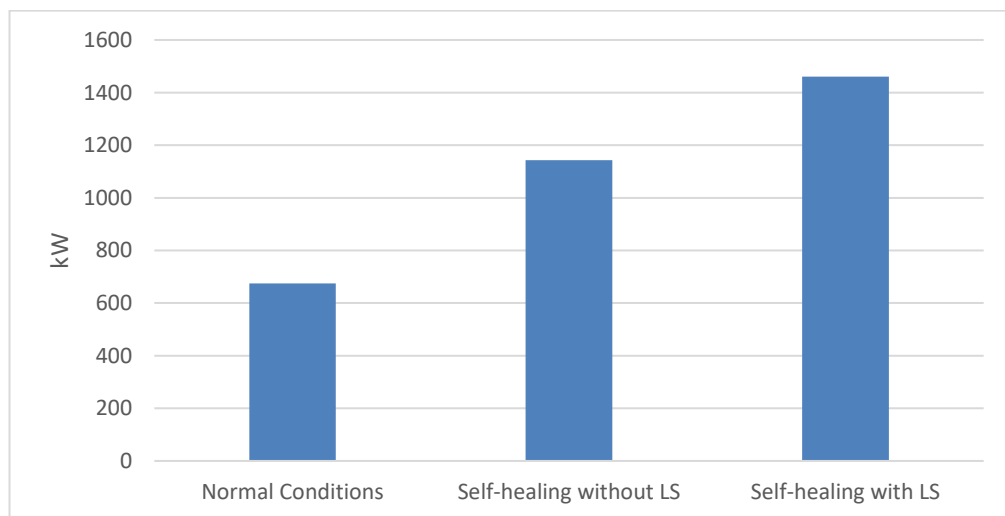


Figure 4.25 : Comparisson between self-healing with and without load shedding for FD 4 in 33-bus system.

Likewise, feeder 5 data for all three analysis case were shown in Fig. 4.26.

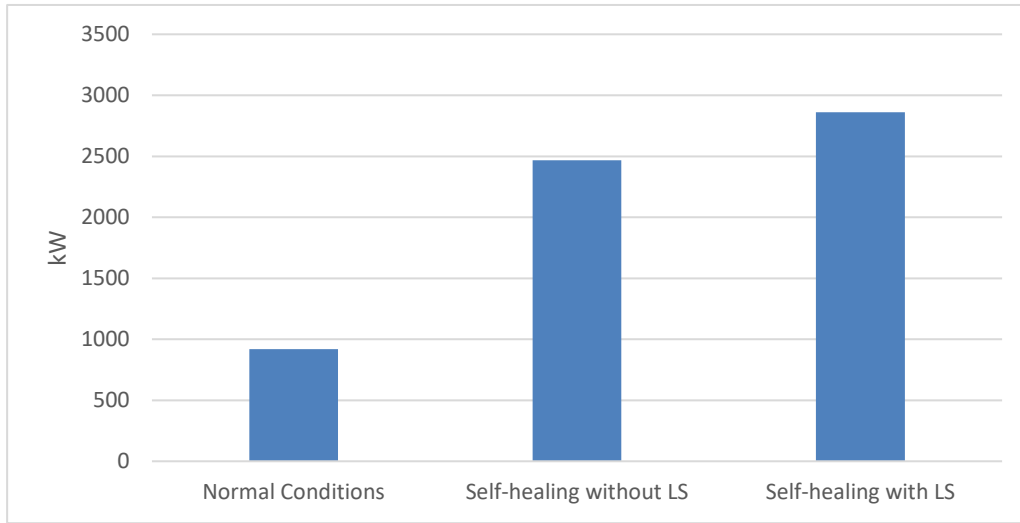


Figure 4.26 : Comparisson between self-healing with and without load shedding for FD 5 in 33-bus system.

In addition, feeder 5 data can be seen numerically in Table 4.15.

Table 4.15 : Numerical values for FD 5 in three cases for 33-bus system.

Case	Amount (in kW)
Normal conditions	920.00
Self-healing without LS	2468.1926
Self-healing with LS	2862.147

The best indicator for a better understanding of the system performance is the total power of the system. By obtaining this information, the amount of self-healing effect and the number of powerless loads performed in both methods as a result of the outage of the first distribution substation (SS01) can be seen clearly. Fig. 4.27 shows the total amount of power for this system.

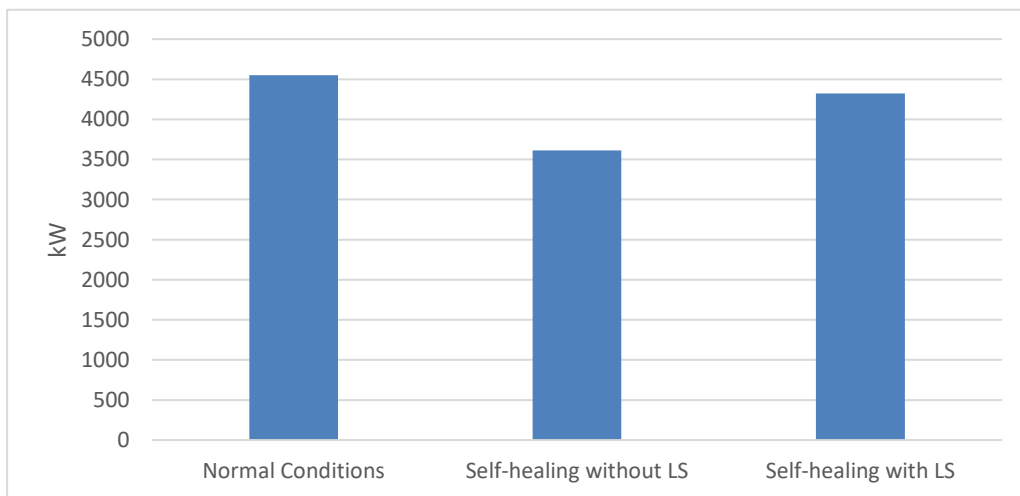


Figure 4.27 : Comparisson for total power of the system for three cases in 33-bus system.

The numerical data of the total power of the system were shown in Table 4.16, based on these data, the difference between self-healing with load shedding and self-healing with only optimum switching appears.

Table 4.16 : Numerical values for total power of the system for three cases for 33-bus system.

Case	Amount (in kW)
Normal conditions	4548.546
Self-healing without LS	3611.6751
Self-healing with LS	4323.238

Also, the amount of non-supplied load was shown in Fig. 4.28 for each stage. Furthermore, the amount of non-supplied loads were given numerically in Table 4.17.

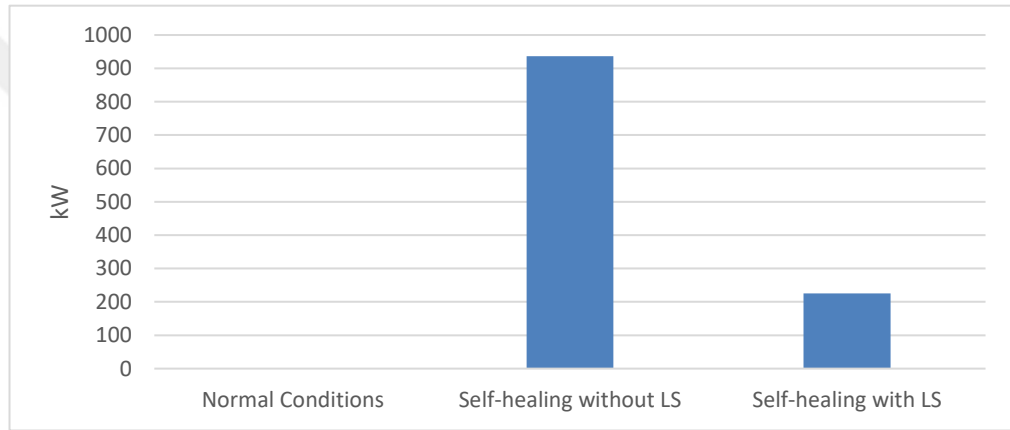


Figure 4.28 : Comparisson for non-supplied load for three cases in 33-bus system.

Table 4.17 : Numerical values for non-supplied load for three cases for 33-bus system.

Case	Amount (in kW)
Normal conditions	0
Self-healing without LS	936.8709
Self-healing with LS	225.308

When the data were examined, the amount of non-supplied loads was significantly reduced by the self-healing process with load shedding in the 33-buses system too. Accordingly, in the self-healing with the help of the BPSO algorithm, the 936.8709 kW load remained powerless, which corresponds to 20.6% of the total load amount.

However, in self-healing with the help of load shedding, the amount of non-supplied load was 225.308 kW, which corresponds to 4.95% of the total load. The performance of the work done in the first study case was shown in Fig. 4.29 for 33-bus and 69-bus systems, where the total power and non-supplied load for both systems are seen in all 3 analysis cases. Also, Table 4.18 compares these data numerically.

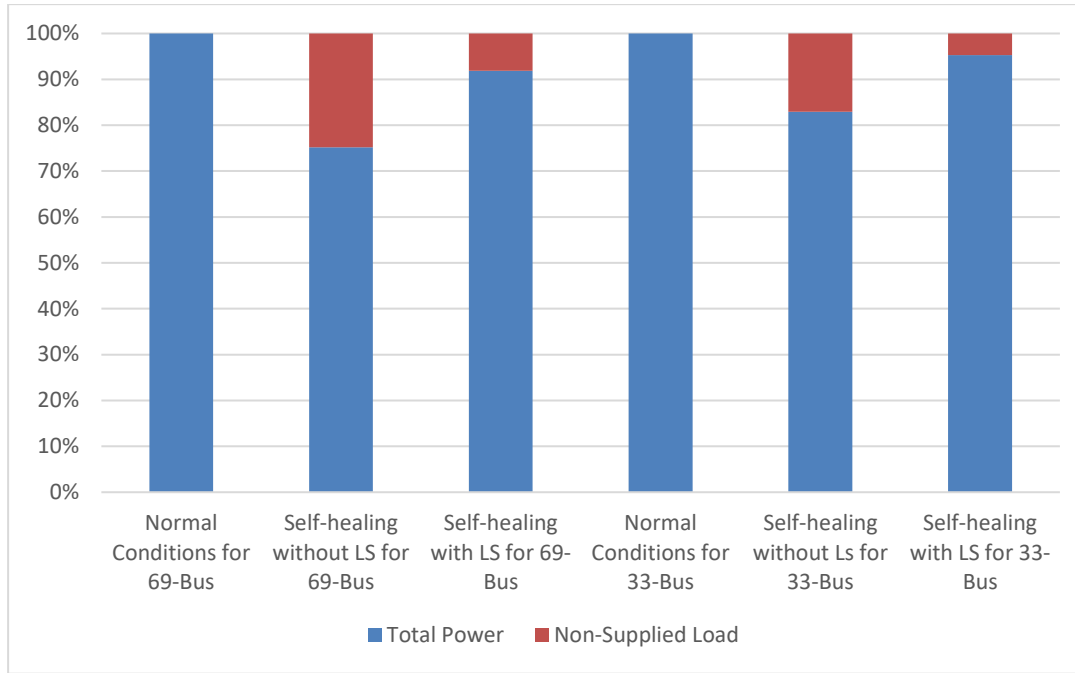


Figure 4.29 : Total power and non-supplied load comparison for 69-bus and 39-bus systems.

Table 4.18 : Numerical comparison of Total power and non-supplied load for 69-bus and 39-bus systems.

Case	33-bus test system	69-bus test system
Total power under normal conditions (kW)	4548.546	4652.9797
Total power for self-healing without LS (kW)	3611.6751	3116.7869
Non-supplied load for self-healing without LS (kW)	936.8709	1536.2131
Non-supplied load percentage	20.6 %	33.01 %
Total power for self-healing with LS (kW)	4323.238	4240.5411
Non-supplied load for self-healing with LS (kW)	225.308	412.4589
Non-supplied load percentage	4.95 %	8.86 %

4.2 Demand Side Load Management by Load Shedding for Load Management in Distribution Systems (Study Case 2)

In the second study case of this thesis, a new demand response method for load shedding was proposed on a smart grid in the distribution network, to increase the stability of the network, as well as to the least affected users due to the increased load to be experienced. In this section, the load types were the smart homes with different and controllable loads (devices) in each home connected to the 33-bus IEEE test system were studied for 24 hours with the voltage level of 12.66 kV.

The 33-bus IEEE distribution test system was shown in Fig. 4.16. Relevant loads were determined in which buses and at what hours they were connected to the network for a day. Besides, the importance of the loads connected to the network at different hours in terms of user comfort was determined by different penalty factors.

In the working principle of this method, the algorithms normally calculate the voltage index for all buses using the voltage stability index. During the hours when the system was overloaded, the optimal load shedding algorithm that runs by the PSO optimization algorithm determined the minimum amount of load to be shed from the system to prevent the network from collapsing in the first place, and to keep the voltage stability index and bus voltage values within the acceptable range.

Moreover, it was determined the weakest buses, taking into account the voltage stability indices of all buses. Once the weakest buses were identified, with considering the importance of the loads in smart home and the penalty factors of loads, it was determined which loads from which buses should be thrown out optimally. Furthermore, it was checked if values of stability index and bus voltage levels return to the acceptable range or not.

The significant point that the algorithm takes into consideration is, it does not take into account the loads that were not already in effect at that time and chooses the loads that had the lowest penalty factor among the loads which were connected to the system, which prevents the consumers from being without power.

However, it is considered as a factor that will increase consumer satisfaction and comfort by leaving the loads which are important and vital for the consumer in that period connect to the system.

Furthermore, Fig. 4.30 shows the flow chart of the newly proposed method. With the help of communication infrastructures, collected data from the system were sent to the control center for processing and taking the necessary actions at the required time by the algorithm.

In addition to being able to apply the proposed method in real time, in this thesis, load management and network reconfiguration were discussed. Accordingly, for the next day or the next hour, load management can be carried out so that users within the smart grid would least affected by the increase in the amount of load as a result of the load control authorization which were given by the users for load management.

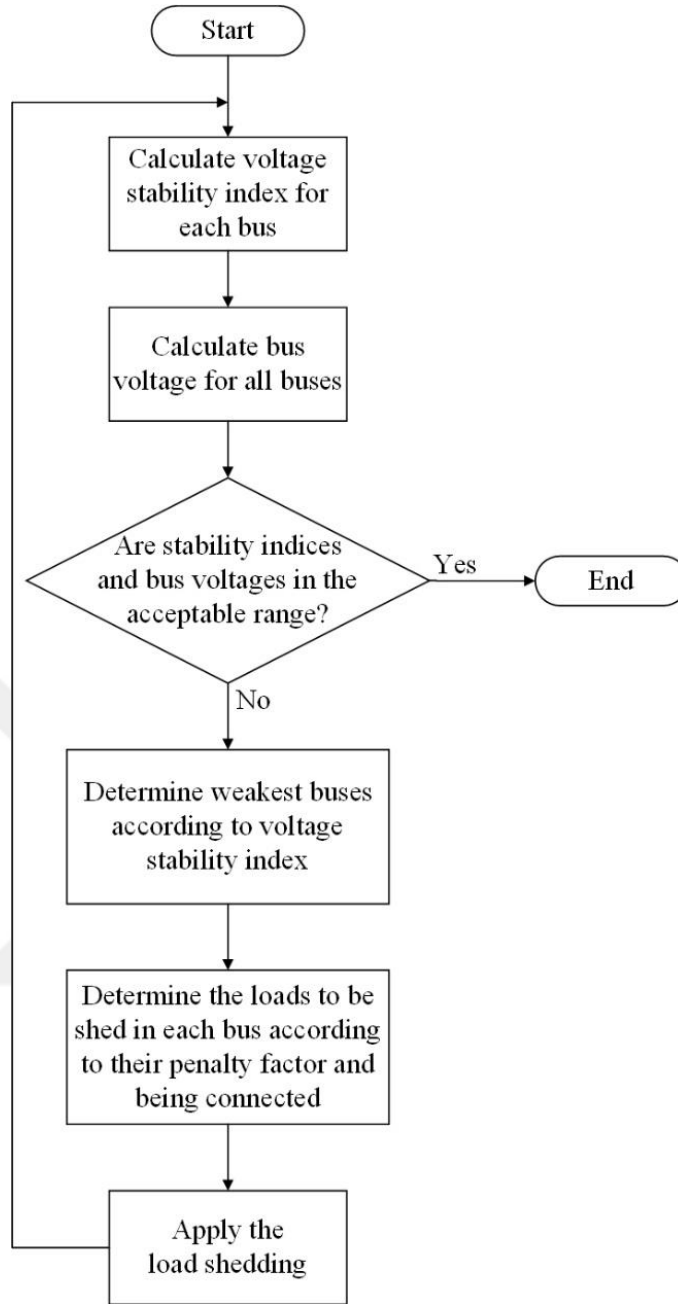


Figure 4.30 : Flow chart of proposed method.

4.2.1 System and load details

Table 4.19 shows the number of houses in each bus in the 33-bus system. In this study, consumption amount and consumption patterns of all smart homes were accepted to be same. Thus, it was assumed that all homes have 18 controllable loads with the same number and the same consumption amount. The times when these loads were connected to the network, and also their importance when they were connected, were also handled in the same way. The load factor is another important consideration. The total power in the 33-bus system is 3.71 MW. Table 4.20 shows the total power of the system for 24 hours. According to this table, the peak hour in the system was on 19.

Table 4.19 : Number of smart homes in each bus of 33-bus system.

Bus No.	Num. of homes	Bus No.	Num. of homes	Bus No.	Num. of homes
1	0	12	5	23	7
2	8	13	5	24	35
3	7	14	10	25	35
4	10	15	5	26	5
5	5	16	5	27	5
6	5	17	5	28	5
7	16	18	7	29	10
8	16	19	7	30	16
9	5	20	7	31	12
10	5	21	7	32	17
11	4	22	7	33	5

Table 4.20 : Total power of the system during 24 hours.

Hour	Total Power (MW)	Hour	Total Power (MW)	Hour	Total Power (MW)
1	3.28	9	3.43	17	3.44
2	3.16	10	3.48	18	3.55
3	3.09	11	3.47	19	3.71
4	3.06	12	3.45	20	3.68
5	3.06	13	3.43	21	3.60
6	3.11	14	3.38	22	3.47
7	3.23	15	3.35	23	3.29
8	3.35	16	3.36	24	3.11

For the algorithm to study optimally and properly, in smart homes, it is necessary to determine whether the controllable loads are connected to the system or not, and if they are connected to the system, the importance of the loads for the consumer during that period should be determined for the algorithm with the penalty factors.

These values were prepared in study [36], with time and device priority and taking into account budget limitations, and were presented in Table 4.21 with some modifications. The minimum voltage level was assumed as 0.92 , and the minimum predicted value for the voltage stability index in this thesis was 0.7.

The voltage stability index used for this thesis was taken from study [37] and [38]. The maximum amount of load that the algorithm could throw from the system was determined by 30% of the total load. Hence, the results from the algorithm were given for two different analysis cases. In the first study analysis, the amount of the load to be shed, that would be required for demand management was determined in the case if all existing loads were activated simultaneously and 100% loading has occurred. In the second study analysis, it was investigated how the results were affected if a 10% overload was experienced in the system.

Table 4.21 : Load status and penalty factor for each smart home.

Appliance	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
LCD TV	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.7	0.8	1.0	1.0	0.7	0.4
Lighting	0.0	0.0	0.0	0.0	0.0	0.7	0.9	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.6	0.6	0.8	1.0	0.9	0.7	0.3
AC	0.0	0.0	0.0	0.1	0.2	0.3	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.3	0.5	1.0	0.9	0.5	0.2
W. Heater	0.0	0.0	0.0	0.2	0.4	1.0	0.5	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.0	0.0
Lighting 2	0.0	0.0	0.0	0.1	0.4	1.0	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.3	0.4	0.7	0.5	0.3	0.2
W. Machine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	1.0	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.0	0.0	0.0
C Dryer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	1.0	0.2	0.1	0.1	0.0	0.0	0.0	0.1	0.2	0.4	0.0	0.0	0.0
Lighting 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.0	0.8	0.3	0.1	0.1	0.0	0.0	0.0	0.1	0.2	0.2	0.0	0.0	0.1
M. Oven	0.0	0.0	0.0	0.0	0.3	0.8	1.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7	0.7	0.4	0.4	0.1	0.0	0.0
Juicer	0.0	0.0	0.0	0.1	0.2	0.8	0.9	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.3	0.2	0.5	0.7	0.3	0.1	0.1	0.0
Dishwasher	0.0	0.0	0.0	0.1	0.2	0.2	0.4	0.7	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	1.0	0.2	0.5	0.0	0.0
Refrigerator	0.2	0.1	0.0	0.2	0.4	0.8	0.6	0.3	0.1	0.1	0.1	0.1	0.4	0.5	0.0	0.1	0.6	0.9	1.0	0.5	0.3	0.2	0.1	0.0
Lighting 4	0.0	0.0	0.0	0.1	0.2	0.2	1.0	0.3	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.6	0.0	0.0	0.1
Lighting 5	1.0	1.0	1.0	1.0	0.9	0.4	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.7	0.8	1.0	1.0
CCTV	1.0	1.0	1.0	0.9	0.9	0.4	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	0.7	0.6	0.6
Lighting 6	0.1	0.1	0.1	0.1	0.3	0.8	0.6	0.5	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	0.7	1.0	0.3
Laptop	0.1	0.1	0.2	0.2	0.3	0.4	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.4	0.6	1.0	0.8	0.9
Charger	1.0	0.8	0.6	0.4	0.3	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.4	0.9

According to Table 4.21, every smart home had 18 controllable devices, or in other words, 18 controllable loads. Hence, Table 4.22 shows the amount of these loads.

Table 4.22 : Loads consumption for each smart home.

Load No.	Section	Appliance	Power (kW)	Quantity	Total power (kW)
1	TV lounge	LCD TV	0.15	1	0.15
2		Lighting	0.02	5	0.10
3		AC	1.20	1	1.20
4	Bathroom	W. Heater	2.00	1	2.00
5		Lighting 2	0.02	2	0.04
6	Laundry	W. Machine	0.70	1	0.70
7		C Dryer	0.80	1	0.80
8	Kitchen	Lighting 3	0.03	2	0.06
9		M. Oven	0.50	1	0.50
10		Juicer	0.40	1	0.40
11		Dishwasher	1.40	1	1.40
12		Refrigerator	2.10	1	2.10
13	Surveillance	Lighting 4	0.03	3	0.09
14		Lighting 5	0.02	8	0.16
15		CCTV	0.009	3	0.27
16	Master bedroom	Lighting 6	0.02	5	0.10
17		Laptop	0.06	1	0.06
18		Charger	0.006	1	0.006

4.2.2 First study analysis

As mentioned above, in the first study analysis, under full loading operating conditions, the amount of load required to shed from the system was calculated, so that the network did not go towards collapse and the bus voltage and voltage stability index remain within the specified acceptable range after necessary load shedding. Table 4.23 shows the percentage of load to be shed from each bus of the 33-bus system within 24 hours by the optimization algorithm. Based on these percentages, which were taken into account by the ongoing loads and their penalty factors, the amount of load to be removed from the system at every hour for each bus was obtained. Hence, under full loading conditions, the load quantities to be removed from the system were shown in Table 4.24 for each hour and each bus. Besides, this table also gave the total loads to be removed from the system for each hour. It is noteworthy that Table 4.24 determined the amount of minimum load that needs to be shed from the system, to prevent the system from collapse, and keep specified parameters above the minimum determined quantities, but the actual amount of load shedding was not the same due to factors such as amount of each load, and penalty factors. Accordingly, the actual load shedding amount were shown in Table 4.25.

Table 4.23 : Percentage of load to be shed from each bus for first study analysis during 24 hours.

Bus No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	11.69	0.6	3.63	0	0	0	0	0.91	30.78	6.02	39.75	3.84	8.86	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	8.64	0	0	0	0	0	0	0	34.84	15.25	39.89	0.15	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.23 (continued) : Percentage of load to be shed from each bus for first study analysis during 24 hours.

Bus No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30.31	7.92	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.24 : Amount of load (kW) to be shed from each bus for first study analysis during 24 hours.

Bus No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.24 (continued) : Amount of load (kW) to be shed from each bus for first study analysis during 24 hours.

Bus No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	13.158	0.6734	4.0507	0	0	0	0	1.0125	35.343	7.224	47.314	4.4714	9.9442	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	7.273	0	0	0	0	0	0	0	31.356	13.614	34.837	0.1263	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60.62	15.712	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	13.158	7.9464	4.0507	0	0	0	0	1.0125	35.343	99.2	76.64	39.308	10.070	0	0

Table 4.25 : Actual amount of load shedding (kW) from each bus for first study analysis during 24 hours.

Bus No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	14	0.9	21	0	0	0	0	1.5	41	7.6	53	20	15	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	14.7	0	0	0	0	0	0	0	31.43	17.5	38.5	2.8	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.25 (continued) : Actual amount of load shedding (kW) from each bus for first study analysis during 24 hours.

Bus No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
25	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	61.8	28.8	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	14	15.6	21	0	0	0	0	1.5	41	101.43	99.3	58.5	17.8	0	0

When the results obtained from the first study analysis were evaluated, it was seen that the algorithm determines the amount of load that must be shed from the system in terms of hours, buses, and load, depending on the load's being active and the load's penalty factors in order to be able to bring the values into the acceptable range.

Depending on factors such as the amount of loads, the number of homes in each buses, it is normal that the amount of load to be shed from the system is slightly different from the actual amount of shedded load.

Hence, after examining the data in the last two tables, it was seen that the amount of load thrown in the total buses for each hour was determined very close to the calculated minimum load amount. If the amount of load to be thrown is less than the calculated minimum amount, it is not possible to enter the values within the acceptable range and the system will go towards collapse.

Furthermore, if the actual amount of load shedding is much higher than the calculated minimum load amount, this time, more load is thrown, the balance between generation and consumption in the system deteriorates, so instability occurs in the system and goes towards the network collapse again.

As a result, firstly, the fastest calculation of the minimum load amount to be shed from the system is required, then the loads and buses to be thrown should be calculated in the fastest and most optimal way depending on whether the loads are active and the penalty factors of the active loads, finally load shedding process is performed and voltage stability index and voltage level should be calculated again for each bus and the results should be checked by the algorithm.

4.2.3 Second study analysis

In order to examine the performance of the proposed algorithm and measure the accuracy of its results, a second study analysis was performed, hence, the same operations were carried out with the same parameters for 10% overload, which means 110% loading.

As in the first study analysis, the algorithm first calculated the percentage of load that must be shedded from the system in order to bring the voltage stability index and the voltage level above the accepted minimum values. The percentage of minimum load amount to be shed from the system was shown in Table 4.26

The minimum voltage stability index was determined as 0.7 and the minimum voltage level was as 0.92 pu. In the second step, the algorithm calculated the minimum amount of load that should be shedded from the system, taking into account load quantities and the total power of the system. So, the minimum load amount to be shed from the system was shown in Table 4.26.

Depending on the reasons which were listed earlier, there is a difference between the minimum amount of load which were calculated by the algorithm and the actual amount of load shedding.

This values, which were close to the minimum amount of load to be shed but slightly more, was shown in Table 4.28. As a result, when both study analysis was evaluated, it was seen that the algorithm showed the same performance in both cases, as were seen in the tables and figures given below, more load was removed from the system in case of 10% overload. Also, in both cases the voltage level was corrected above 0.92 pu, and the voltage stability index was maintained over 0.7.

As in all study analysis, the issue that should be considered in this study analysis was the correct selection of the determined values to measure the algorithm and the performance of the system.

The algorithm under study was designed to be used in different systems, a range between 0.9 and 0.93 for voltage level, 0.6 to 0.75 for voltage stability index, and 1 to 1.2 for loading. The design of these ranges does not mean that the algorithm gives correct results for every system. Depending on factors such as system load amount, house numbers, controllable load numbers, under normal conditions of the system only some intervals can be chosen. If different values are selected depending on the system conditions, it is possible to encounter two situations, the first is that the system is capable of applying those values but when the required controllable loads to apply it is not obtained, the result 1 of algorithm which is shows the minimum amount of load the be shed are obtained correctly. In this case, since there is not enough controllable loads to control the system, in result 2 of algorithm, the algorithm proposes a new order according to the load amounts and penalty factors, regardless of whether the loads are active or not, which does not match the objectives of this study. In the second situation, if the system conditions do not meet the specified values, it is not possible to reach any correct result in result 1 too.

Table 4.26 : Percentage of load to be shed from each bus for second study analysis during 24 hours.

Bus No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39.96	40	11.19	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	40	1.84	0	0	0	0	29.01	30.68	39.94	39.99	37.52	39.47	36.32	32.65	16.94	35.16	8.80	40	40	40	40	25.18	8.60	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12.21	0.81	0	0	0	0
18	0.31	0	0	0	0	0	0.31	27.05	5.73	39.98	30.35	32.50	14.78	0	27.49	20.10	39.99	40	40	40	40	40	38.63	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.26 (continued) : Percentage of load to be shed from each bus for second study analysis during 24 hours.

Bus No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	4.59	9.09	0	0	0	0	1.60	6.61	39.75	19.86	27.49	18.32	34.31	39.98	20.28	11.77	39.93	35.04	39.99	40	40	30.58	1.21	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.27 : Amount of load (kW) to be shed from each bus for second study analysis during 24 hours.

Bus No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	87.912	87.288	23.888	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.27 (continued) : Amount of load (kW) to be shed from each bus for second study analysis during 24 hours.

Bus No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	46.68	1.84	0	0	0	0	33.339	36.568 8	48.742	49.514	46.076	48.449	44.324	39.264	20.191	42.033	10.771	50.523	52.8	52.373	51.235	31.087	10.067	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.0586	0.5302	0	0	0	0	0
18	0.2713	0	0	0	0	0	0.2671	24.181	5.2446	35.269	18.251	29.92	13.528	0	24.574	18.022	36.709	37.892	39.6	39.28	38.426	37.038	33.914	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	8.9276	9.09	0	0	0	0	3.0646	13.131	80.85	40.983	79.303	37.479	69.785	80.132	40.287	10.553	81.453	73.763	87.978	87.288	85.391	62.924	2.3606	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	55.879	19.102	0	0	0	0	36.671	73.88	134.83	125.76	130.99	115.85	127.64	119.39	85.052	70.608	128.93	162.18	276.35	266.76	198.94	131.05	46.342	0

Table 4.28 : Actual amount of load shedding (kW) from each bus for second study analysis during 24 hours.

Bus No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	88.32	94.4	32	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	23.76	21	0	0	0	0	34	31	36.6	53	46.9	25	46	39.6	20.1	25	12	50.7	53.7	53	29.6	35	22.6	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	3.5	0	0	0	0
18	0.42	0	0	0	0	0	1.12	28.7	9.8	37.1	28.63	32.2	17.5	0	1.47	22.75	37.45	38.01	39.69	41.3	38.5	39.2	1.82	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.28 (continued) : Actual amount of load shedding (kW) from each bus for second study analysis during 24 hours.

Bus No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	33.6	23.6	0	0	0	0	4.32	19.2	88	44.8	62.4	44.8	73.6	12.16	0.96	33.6	83.2	75.2	88.32	94.4	62.4	65.6	38.4	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	57.78	54.6	0	0	0	0	39.44	78.9	134.4	134.9	137.93	119.71	137.1	122.63	90.537	81.35	132.65	129.21	279.03	286.6	201.38	139.8	62.82	0

Finally, the performance of the algorithm and load shedding system to bring values above the accepted minimum level and prevent the system from going down to collapse were given for the entire system and some buses. Accordingly, Fig. 4.31 shows the corrections after the load shedding application by the algorithm, for peak hour (hour 19), for first study analysis for 33 buses.

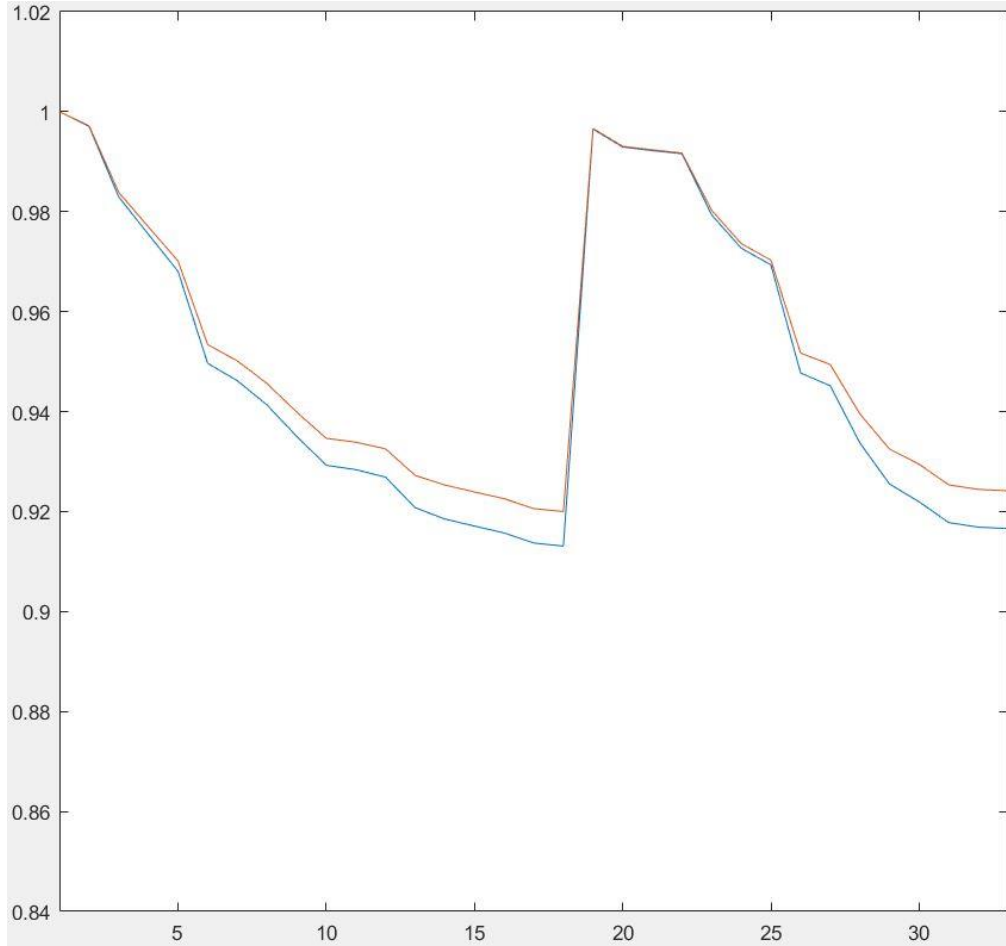


Figure 4.31 : 33-bus voltage for first study analysis for hour 19.

The numerical data for the first study analysis is as follows.

Table 4.29 : Numerical data for first study analysis befor and after load shedding.

Parameter	Befor LS	After LS
V_{min}	0.91309	0.92
VSI_{min}	0.69608	0.71699

To better understand this difference, the voltage of all buses for hour 21 was shown in Fig 4.32. Another important indicator is the values given for a bus for 24 hours. Since the highest load shedding amount is made from buses 14, 18, and 30 during the load shedding process, graphics were given for these buses. Thus, Fig. 4.33 shows the

voltage values for the first study analysis for bus 14 for 24 hours. Fig. 4.34 shows the same values for bus 18. The graph for bus 30 was shown in Fig.4.35.

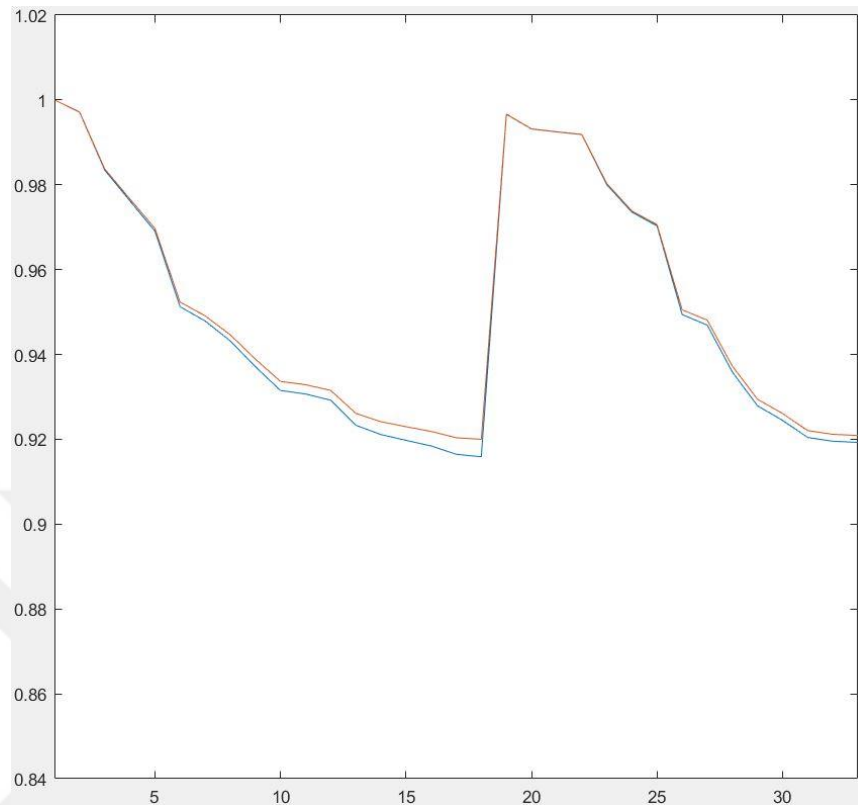


Figure 4.32 : 33-bus voltage for first study analysis for hour 21.

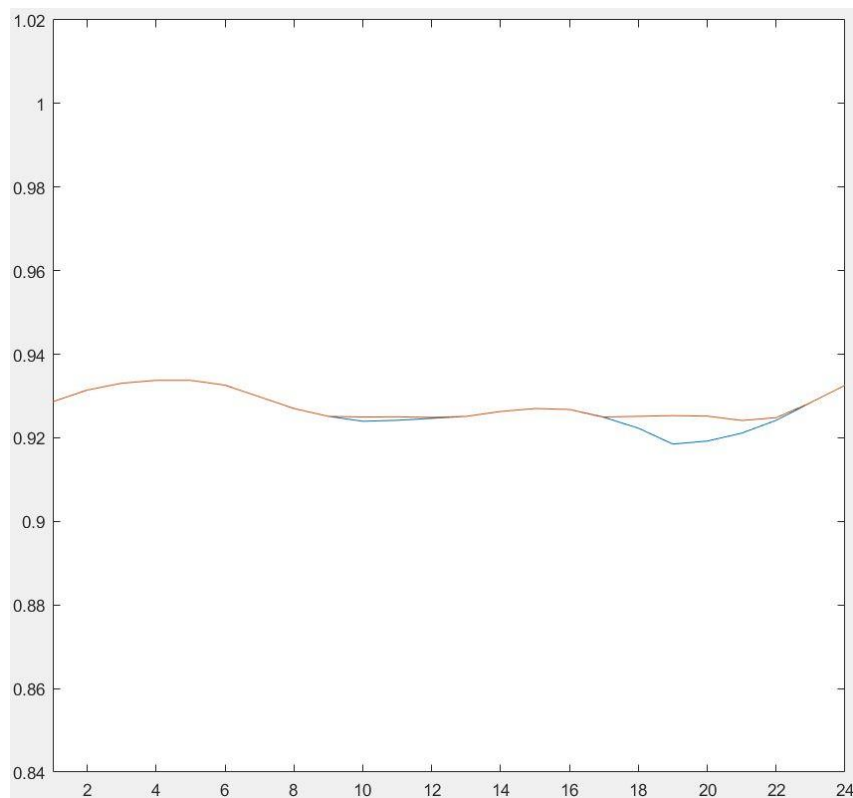


Figure 4.33 : Voltage correction for bus 14 for first study analysis.

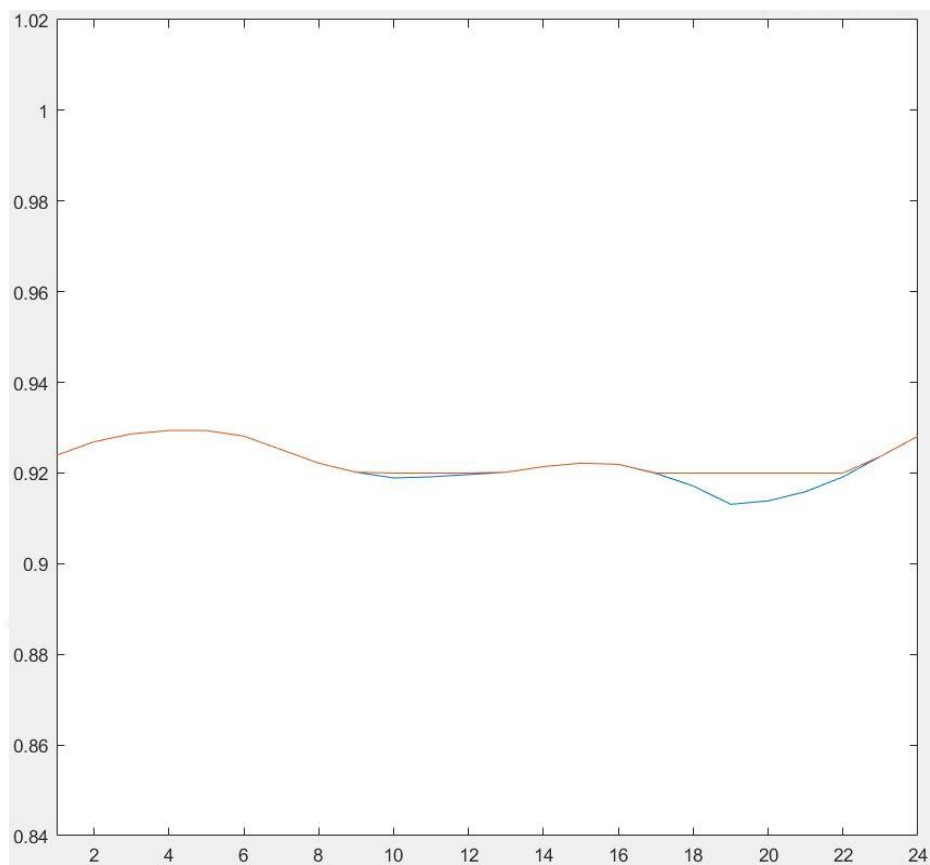


Figure 4.34 : Voltage currection for bus 18 for first study analysis.

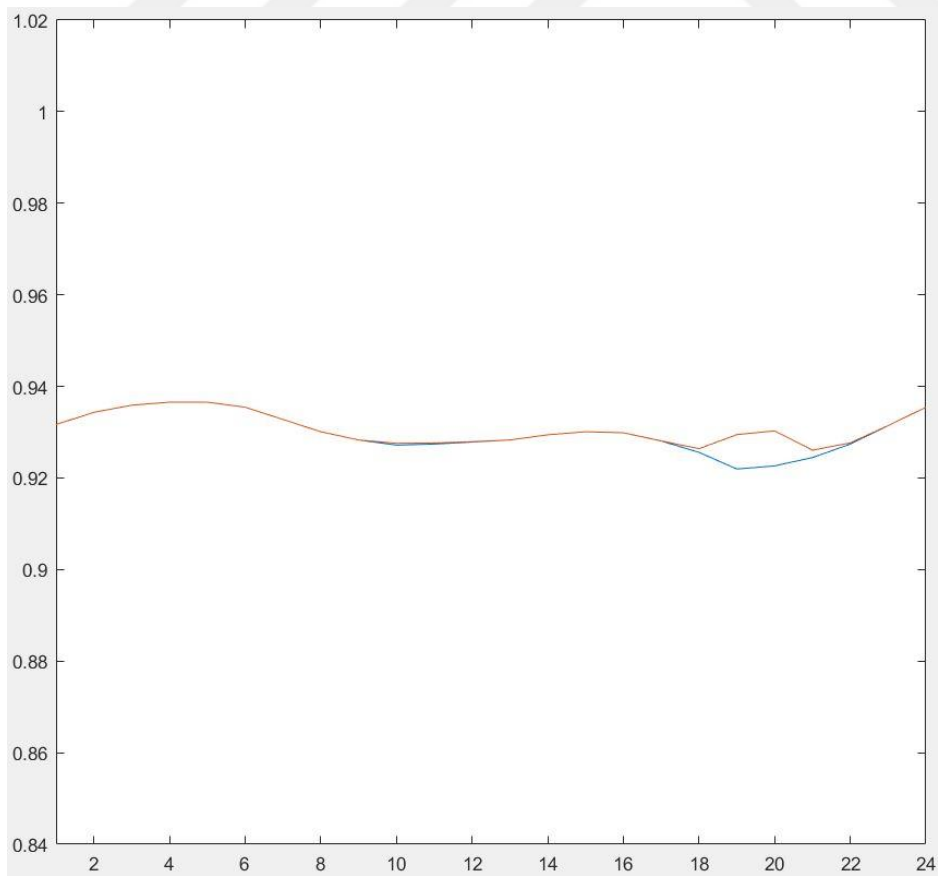


Figure 4.35 : Voltage currection for bus 30 for first study analysis.

It is possible to share the same data for the second study analysis. As a result of load shedding performed for 110% loading, the highest load shedding occurred at peak hour (hour 19). Hence, the voltage values of all 33 buses at hour 19 can be seen in Fig. 4.36.

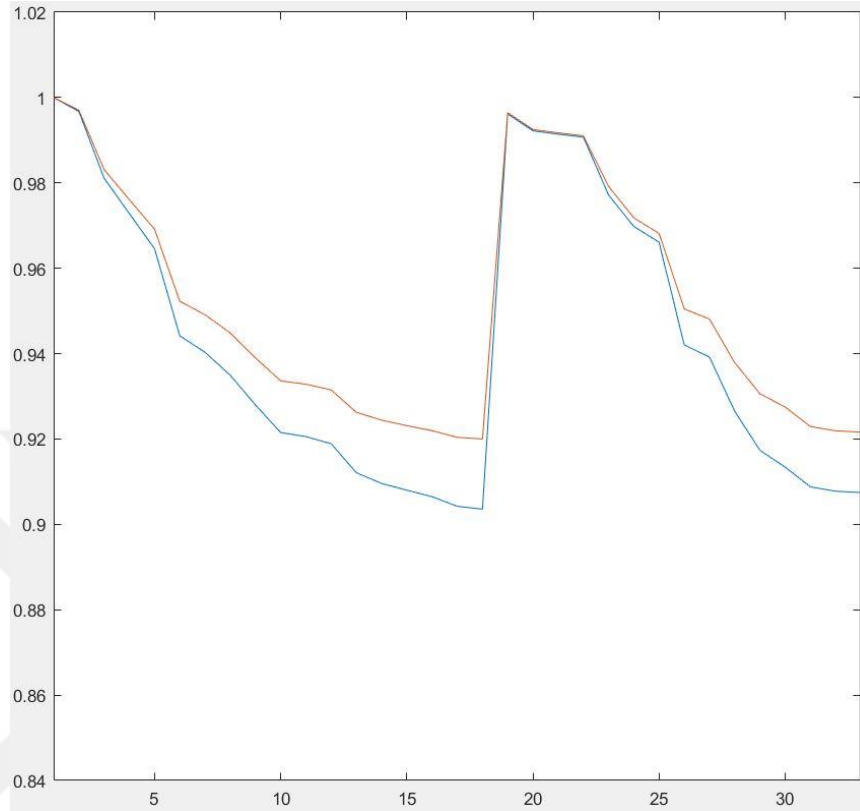


Figure 4.36 : 33-bus voltage for second study analysis for hour 19.

The numerical data for the first study analysis is as follows.

Table 4.30 : Numerical data for second study analysis befor and after load shedding.

Parameter	Befor LS	After LS
V_{min}	0.90356	0.92
VSI_{min}	0.66759	0.71696

The voltage of all buses for hour 21 was shown in Fig 4.37.

Like the previous study analysis, some of the buses were selected for load shedding by the algorithm depending on the voltage stability index and voltage level and taking into account load types and penalty factors. For a bbetter comparison, buses 14,18 and 30 were also choosen for this study analysis. voltage level and corrected voltage level were shown for bus 14 for 24 hours in Fig. 4.38. Voltage and corrected voltage level were shown during 24 hours for bus 18 in Fig.4.39. Furthermore, the chart for bus 30 was shown in Fig 4.40. When these charts were analyzed, it was seen that the algorithm successfully pulled the voltage level above the minimum accepted level of 0.92 pu in all buses.

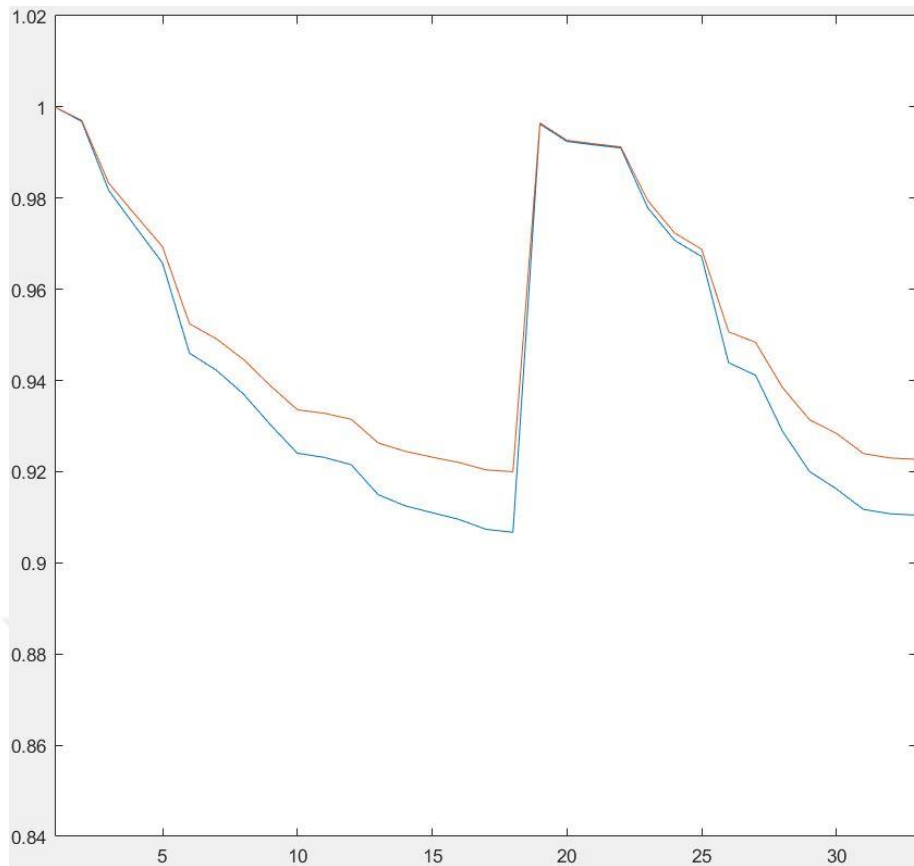


Figure 4.37 : 33-bus voltage for second study analysis for hour 21.

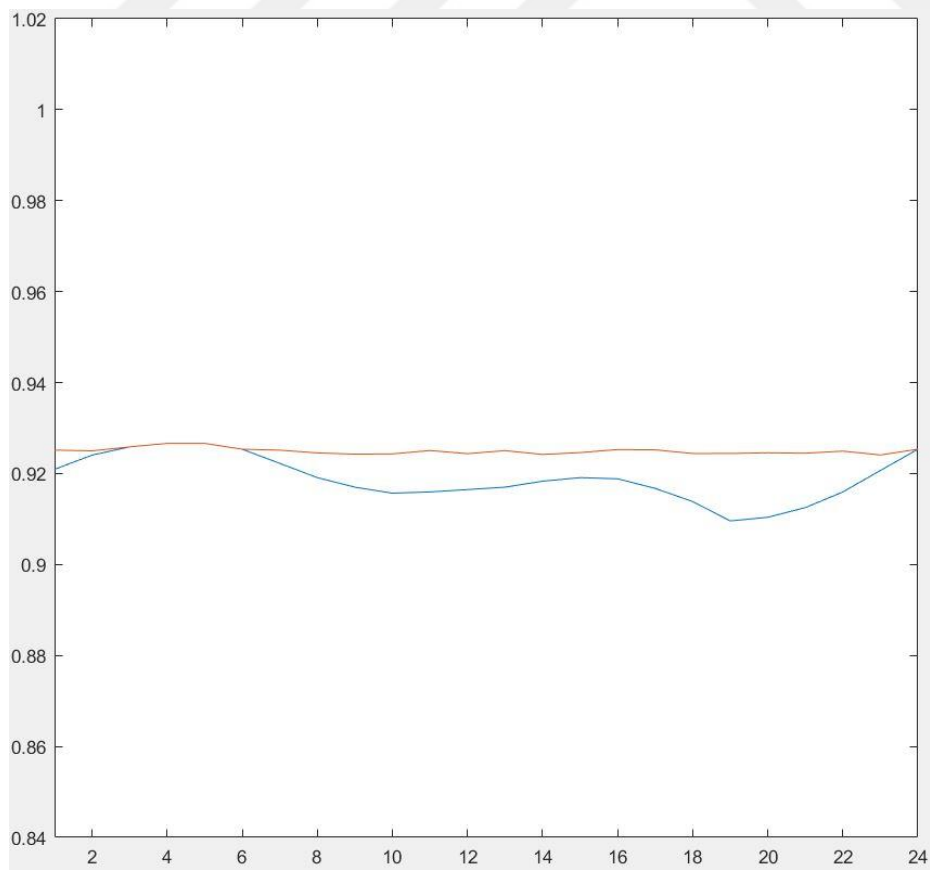


Figure 4.38 : Voltage correction for bus 14 for second study analysis.

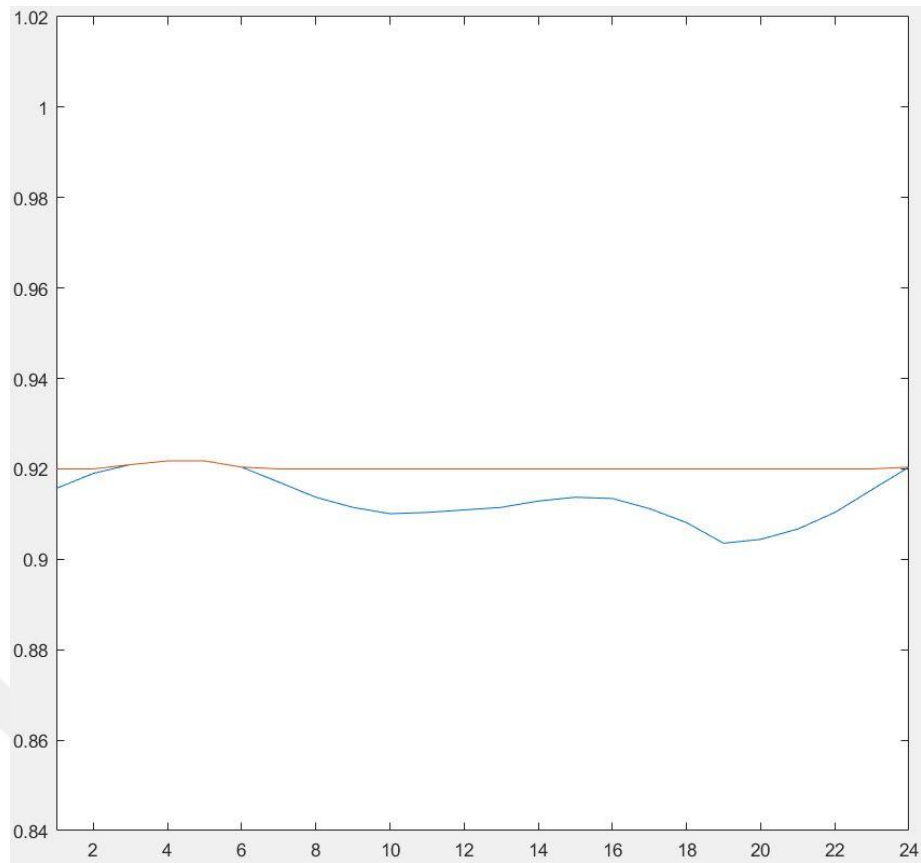


Figure 4.39 : Voltage correction for bus 18 for second study analysis.

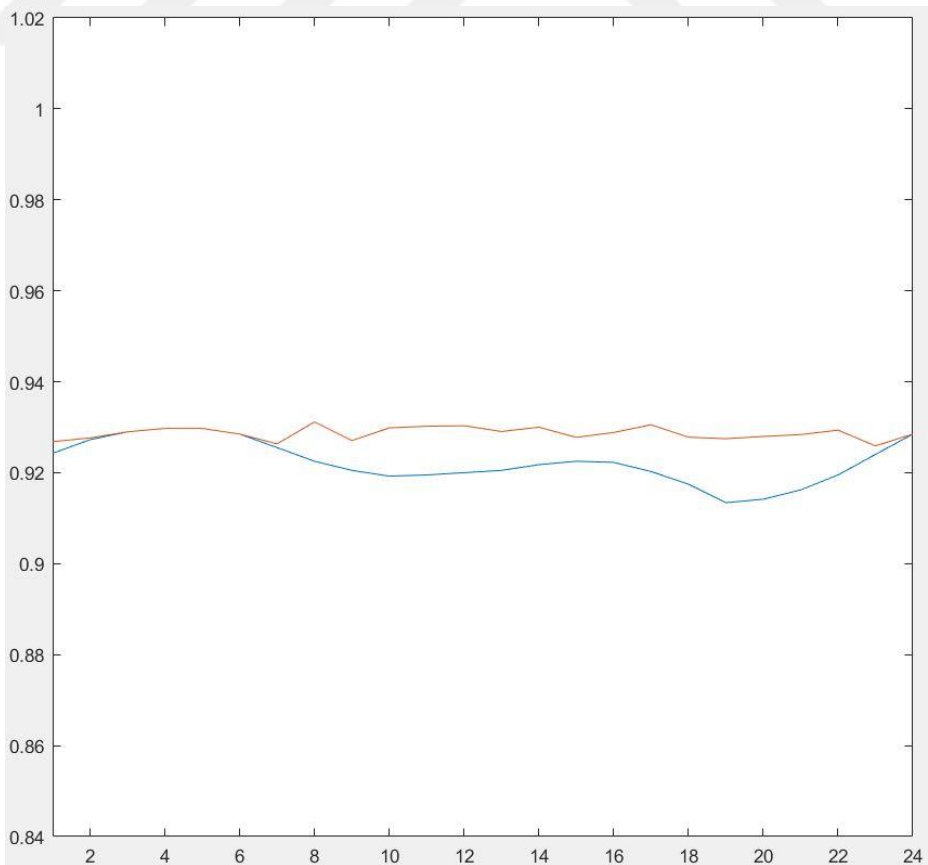


Figure 4.40 : Voltage correction for bus 30 for second study analysis.



5. CONCLUSION AND RECOMMENDATIONS

In this thesis, different load shedding and self-healing applications with optimal network reconfiguration were discussed. Accordingly, the effects of the load shedding in the distribution network were discussed in the studies carried out in both study cases. In the first case, both optimal self-healing application and load shedding through power flow for optimal network reconfiguration discussed over two distribution test system. It was observed in this encounter that, although the optimization of switching operations helped us with network reconfiguration and management, a significant portion of loads remained without electricity due to the existing voltage constraints.

It was also seen that the switching optimization in presence of power flow significantly reducing the amount of load that was left powerless, and helped by in the load management, as well as preventing the voltage drop and going to voltage collapse in the network, thus ensuring the stability, and reliability of the system.

Along with developing power networks in this direction, load nature and quantities have started to change, and distribution generators (DGs) usage and small-scale smart grids which are becoming more common today make network management more challenging. To overcome these problems, first of all, it will be necessary to add devices that measure at the required points in the network, to renew the existing equipment and to perform regular maintenance, as well as to develop and expand the communication infrastructures, which are considered more important under today's conditions, and to strengthen the existing communications infrastructure with microgrid.

As seen in the second study case, in the emerging smart grids, by increasing the number of smart home and controllable loads, more success can be achieved for flexible load management, and network stability and reliability can be increased. Besides, this method can be used in different load types and larger networks, which should be studied in future studies.

It is also possible to consider the two proposed methods in two different stages in the distribution network. Accordingly, while the method which was applied in the first study case is used for optimal reconfiguration of the network, if some or all parts of the network consists of smart grids and smart homes, the specified amount, and location of load shedding can be achieved with the method which was proposed in the second study case.

With the development of the network communication infrastructure, the optimization algorithms for centralized methods in both the distribution networks, and the transmission networks can be better handled, and as a result, the entire power network can be better managed. Hence, it is possible to have more smooth network operating conditions by using the algorithms and methods in distribution networks such as the method which were given in this thesis to reduce the computing and operating traffic of the main control centers.

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APPENDICES

APPENDIX A: IEEE test systems data



APPENDIX A

Table A.1: Data for 69-bus IEEE distribution test system.

From Bus	To Bus	$R_{i,i+1} (\Omega)$	$X_{i,i+1} (\Omega)$	P (kW)	Q (kVAR)
1	2	0.0005	0.0012	0	0
2	3	0.0005	0.0012	0	0
3	4	0.0015	0.0036	0	0
4	5	0.0251	0.0294	0	0
5	6	0.366	0.1863	2.6	2.2
6	7	0.381	0.1941	40.4	30
7	8	0.0922	0.045	75	54
8	9	0.0493	0.0251	30	22
9	10	0.819	0.2707	28	19
10	11	0.1872	0.0619	145	104
11	12	0.7114	0.2351	145	104
12	13	1.03	0.34	8	5
13	14	1.044	0.345	8	5.5
14	15	1.058	0.3496	0	0
15	16	0.1966	0.065	45.5	30
16	17	0.3744	0.1238	60	35
17	18	0.0047	0.0016	60	35
18	19	0.3276	0.1083	0	0
19	20	0.2106	0.069	1	0.6
20	21	0.3416	0.1129	114	81
21	22	0.014	0.0046	5	3.5
22	23	0.1591	0.0526	0	0
23	24	0.3463	0.1145	28	20
24	25	0.7488	0.2475	0	0
25	26	0.3089	0.1021	14	10
26	27	0.1732	0.0572	14	10
3	28	0.0044	0.0108	26	18.6
28	29	0.064	0.1565	26	18.6
29	30	0.3978	0.1315	0	0
30	31	0.0702	0.0232	0	0
31	32	0.351	0.116	0	0
32	33	0.839	0.2816	14	10
33	34	1.708	0.5616	19.5	14
34	35	1.474	0.4873	6	4
3	36	0.0044	0.0108	26	18.55
36	37	0.064	0.1565	26	18.55
37	38	0.1053	0.123	0	0
38	39	0.0304	0.0355	24	17
39	40	0.0018	0.0021	24	17
40	41	0.7283	0.8509	1.2	1
41	42	0.31	0.3623	0	0
42	43	0.041	0.0478	6	4.3
43	44	0.0092	0.0116	0	0

Table A.1 (continued) : Data for 69-bus IEEE distribution test system.

From Bus	To Bus	$R_{i,i+1}$ (Ω)	$X_{i,i+1}$ (Ω)	P (kW)	Q (kVAR)
44	45	0.1089	0.1373	39.22	26.3
45	46	0.0009	0.0012	39.22	26.3
4	47	0.0034	0.0084	0	0
47	48	0.0851	0.2083	79	56.4
48	49	0.2898	0.7091	384.7	274.5
49	50	0.0822	0.2011	384.7	274.5
8	51	0.0928	0.0473	40.5	28.3
51	52	0.3319	0.1114	3.6	2.7
9	53	0.174	0.0886	4.35	3.5
53	54	0.203	0.1034	26.4	19
54	55	0.2842	0.1447	24	17.2
55	56	0.2813	0.1433	0	0
56	57	1.59	0.5337	0	0
57	58	0.7837	0.263	0	0
58	59	0.3042	0.1006	100	72
59	60	0.3861	0.1172	0	0
60	61	0.5075	0.2585	1244	888
61	62	0.0974	0.0496	32	23
62	63	0.145	0.0738	0	0
63	64	0.7105	0.3619	227	162
64	65	1.041	0.5302	59	42
11	66	0.2012	0.0611	18	13
66	67	0.0047	0.0014	18	13
12	68	0.7394	0.2444	28	20
68	69	0.0047	0.0016	28	20
FD01 for SS01	0.0005	0.0012			
FD02 for SS02	0.0005	0.0012			

Table A.2: Data for 33-bus IEEE distribution test system.

From Bus	To Bus	$R_{i,i+1} (\Omega)$	$X_{i,i+1} (\Omega)$	P (kW)	Q (kVAR)
1	2	0.0922	0.0477	100	60
2	3	0.493	0.2511	90	40
3	4	0.366	0.1864	120	80
4	5	0.3811	0.1941	60	30
5	6	0.819	0.707	60	20
6	7	0.1872	0.6188	200	100
7	8	1.7114	1.2351	200	100
8	9	1.03	0.74	60	20
9	10	1.04	0.74	60	20
10	11	0.1966	0.065	45	30
11	12	0.3744	0.1238	60	35
12	13	1.468	1.155	60	35
13	14	0.5416	0.7129	120	80
14	15	0.591	0.526	60	10
15	16	0.7463	0.545	60	20
16	17	1.289	1.721	60	20
17	18	0.732	0.574	90	40
2	19	0.164	0.1565	90	40
19	20	1.5042	1.3554	90	40
20	21	0.4095	0.4784	90	40
21	22	0.7089	0.9373	90	40
3	23	0.4512	0.3083	90	50
23	24	0.898	0.7091	420	200
24	25	0.896	0.7011	420	200
6	26	0.203	0.1034	60	25
26	27	0.2842	0.1447	60	25
27	28	1.059	0.9337	60	20
28	29	0.8042	0.7006	120	70
29	30	0.5075	0.2585	200	600
30	31	0.9477	0.963	150	70
31	32	0.3105	0.3619	210	100
32	33	0.341	0.5302	60	40

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