**ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY**

# NETWORK RECONFIGURATION IN BALANCED DISTRIBUTION SYSTEM FOR LOSS REDUCTION AND SERVICE RESTORATION WITH OPTIMALLY LOCATED DISTRIBUTED GENERATION

**M.Sc. THESIS**

**Mahmod Abusall**

**Department of Electrical and Electronic Engineering**

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**İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ**

# Kayıp Azaltma ve Hizmet Restorasyonu için Optimal Yerleştirilen Dağıtılmış Üretim ile Dengeli Dağıtım Sistemlerinde Şebekenin Yeniden Yapılandırması

**YÜKSEK LİSANS TEZİ**

**Mahmod Abusall**
**(504111043)**

**Elektrik ve Elektronik Mühendisliği Anabilim Dalı**

**Elektrik Mühendisliği Programı**

**Tez Danışmanı: Prof.Dr.Mustafa Bağrıyanık**

**Kasım 2013**

**Mahmod Abusall**, a **M.Sc.** student of ITU **Graduate School of Science, Engineering and Technology,** student ID **504111043**, successfully defended the **thesis** entitled "**Network Reconfiguration in Balanced Distribution Systems for Loss Reduction and Service Restoration with Optimally Located Distributed Generation**", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

| | | |
|---|---|---|
| **Thesis Advisor :** | **Prof. Dr. Mustafa BAĞRIYANIK**<br>Istanbul Technical University | .............................. |
| **Jury Members :** | **Prof. Dr. Belgin Türkay**<br>Istanbul Technical University | ............................. |
| | **Yrd.Doç.Dr. Oktay Arıkan**<br>Yıldız Technical University | .............................. |

**Date of Submission : 03 Octobar 2013**
**Date of Defense : 25 November 2013**

***To my family,***

## FOREWORD

I am deeply indebted to my major advisor, Prof. Dr. Mustafa Bağrıyanık, for his constant support. I would like to thank him not only for his support in the academic research, but also for his ongoing advices in the field of electrical engineering.
Finally, I would like to thank my lovely parents for supporting me every moment , I would say that they fighted the impossible to make me survived in Palestine .

November 2013 Mahmod Abusall
(Electrical Engineer)

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## ABBREVIATIONS

| | |
|---|---|
| **DA** | **:** Distribution Automation |
| **DS** | **:** Distribution System |
| **PDS** | **:** Primary Distribution System |
| **SDS** | **:** Secondary Distribution System |
| **DG** | **:** Distributed Generation |
| **MF** | **:** Membership Function |
| **PLI** | **:** Power Loss Index |
| **DÜ** | **:** Dağıtılmış Üretimi |
| **FIS** | **:** Fuzzy Inferencing System |
| **GUI** | **:** Graphical User Interface |

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**Network Reconfiguration in Balanced Distribution Systems for Loss Reduction and Service Restoration with Optimally Located Distributed Generation**


## ABSTRACT

There are two types of switches to manage protection and configuration in distribution systems; normally closed sectionalizing switches and normally opened tie switches. As the effeciency of power transferred from substation to load is affected by system configuration; power companies are interested in reconfiguring the network to find the most efficient configuration that maximizes loss reduction.Network reconfiguration basicly means changing the status ( open/close) of sectionalizing and tie switches. Network is reconfigured during normal operation to achieve loss reduction and during emergency situation to achieve service restoration by isolating the faulted area and supplying power to non-faulted but out of service area with minimun load shedding.

Due to topological constraints,electrical constraints and operational constraints that must not be violated while seeking an optimal configuration ,distribution system reconfiguration is said to be a complex problem. The benefits of reconfiguration are as following:

- Maximizing loss reduction.
- Achieving load balancing.
- Modifying voltage profile.
- Maximizing the restored load after fault occurance.

During normal operation , because of asymmetric load variations at each primary feeder, distribution companies are obsessed with the possible increase in total real power losses . Therefore, they try their efforts to change the status of sectionalizing and tie switches to maintain favorable configuration for best loss reduction.Network reconfiguration can also be applied during normal operation for feeder load balancing in order to make all feeders loaded at the same rate. An amount of load can be transfered from heavily loaded feeder to lightly loaded feeder by closing feasible tie switch and opening neigbour sectionalizing switch .

During emergency, when fault occurs the faulted area is isolated by opening feasible sectionalizing switch. The resulted non faulted but out of service area can be restored by closing feasible tie switch. By this, service can be restored with new configuration.

On another side , small sized distributed generation are becoming widely used and attractive to both utility and customer due to power quality, emession, economic , security and reliabiity benifits.Integrating these distributed generations are sensetive such that the benefits are conditional and dependent on the installation characteristics specially on the location and on size limitation

This thesis presents simple and effective approach for reconfiguration of radial distribution system in both normal operation and emergency to emphasize the

effectiveness of loss reduction and service restoration plans in the cases : 1) without distributed generation (DG) , 2) with optimally located DG using Fuzzy logic model. A semi optimal presence of DG is presented by optimal DG placement to ensure it's positive behaviour.

The effectiveness of the proposed approach has been emphasized by applying it on 33-node balanced radial distribution sysetm.Power System Analaysis Toolbox (PSAT) has been used to simulate the distribution system and to run apparent power flow .Switching Index has been coded using MATLAB script window. Fuzzy Inferencing System (FIS) has been used to place DG optimally and the replacement has been evaluated again using MATLAB SIMULINK and FUZZME for educational purpose and for extra knowledge. The optained results uncover that the proposed approach is favorable in distribution system reconfiguration when it is compared with similar works results.

**Kayıp Azaltma ve Hizmet Restorasyonu için Optimal Yerleştirilen Dağıtılmış Üretim ile Dengeli Dağıtım Sistemlerinde Şebekenin Yeniden Yapılandırması**

## ÖZET

Elektrik şebekeleri, çeşitli bozucu etkenlere karşı tedbirli ve dayanıklı bir şekilde tasarlanmalarına rağmen, özellikle kararlılık sınırlarına yakın işletme durumlarında meydana gelebilecek ciddi arızalarda kararsız hale gelebilmektedirler. Şebekeyi etkileyen büyük bozucuların sebepleri olarak deprem, fırtına gibi çeşitli doğal afetler, insan kaynaklı işletme hataları, kontrol sistemlerinde karşılaşılabilen sorunlar, koruma sistemi tarafından tespit edilemeyen arızalar, sanal saldırılar, zayıf bağlantılar ve daha birçok çeşitli faktör sıralanabilir. Şebekenin tüketici kısmında ise, kullanıcılar ve yüklerin hassas kontrol, kaliteli ve kesintisiz enerji beklentileri yükselmektedir. Bu nedenlerden ötürü, şebekenin kapsamlı yönetimi ile ilgili araştırmalara ve çözümlere duyulan ihtiyaç gün geçtikçe artmaktadır.

Otomatik olarak kontrol edilen sistemler daha az sorunlara maruz kalmaktadır. Fakat bazı yerlerde sistemin otomatik olarak kontrol edilmesi projeye daha büyük bir masraf getirmektedir. Harcanan masraf ve elde edilebilecek yararlar arasında kıyaslama yapılırsa , böyle yerlerin otomatik olarak değil , geleneksel yöntemleri uygulayarak kontol edilesi tercih söz konusudur.Benzer durumlarda , müşterilerin ihtiyaclarını karşılamak amacıyla dağtım şirketleri sistemin istikrarını sağlamak adına sürekli planlamaktadır. Hem otomatik hem geleneksel kontrollerde ağ'ın yeniden yapılandırılması bu çözülmesi gereken sorunlardan biridir.

Dağıtım sistemlerinde koruma ve yapılandırmasını yönetmek için, normalde kapalı olan ayırıcı anahtarlar ve normalde açık olan bağlantı anahtarları olmak üzere iki türü anahtar vardır. Bu iki anahtar türü, yapılandırmayı yönetmek için inşaa edilmektedir. Trafo merkezinden yüke aktarılan güç verimliliği sistem yapılandırmasında etkilenir ki enerji şirketleri de kayıpları azaltmayı en üst düzeye çıkarmak amacıyla en verimli yapılandırmayı bulmak için şebekeyi yeniden yapılandırma ile ilgileniyorlar.

Şebekenin yeniden yapılandırılması temelde ayırıcı ve bağlantı (açık/kapalı) anahtarlarının durumunun değiştirilmesi demektir. Şebeke normal çalışma sırasında kayıpların azaltılmasını sağlamak için ve acil durumlarda hizmet restorasyonunu sağlamak için, hatalı alan izole edilerek ve kaçaksız enerji verilerek yeniden yapılandırılır.

Topolojik kısıtlamalar, elektriksel kısıtlamalar ve işletme kısıtlamaları nedeniyle bir optimum yapılandırmayı aramanın ihlal edilmemesinin gerekliliği, dağıtım sistemi yeniden yapılandırılmasında karmaşık bir sorun olduğu söyleniyor. Yeniden yapılandırmanın yararları şunlardır:

- Kayıpları azaltmayı en üst düzeye çıkarma
- Yük dengelemesinin sağlanması
- Gerilim profili değiştirme
- Hata oluşumundan sonra iade edilen yükü en üst düzeye çıkarma

Ağı yeniden yapılandırma sorunu eşitlik ve eşitsizlik kısıtlamaları ile genellikle tek objektif optimizasyon sorunu olarak formüle edilmektedir. Yapılandırılması karmaşık bir bileşik optimizasyonu sorundur. Bunun nedeni,bir optimal bulurken birden fazla kısıtlamaların olmasıdır.

Normal çalışma sırasında , her birincil besleyici asimetrik yük değişikliklerine maruz kalabilmektedir.Bu nedenle dağıtım şirketlerinin gerçek güç kayıpları olası artış ile saplantısı vardır ve kaybının azaltılması için uygun yapılandırmayı korumak için bağlantılı ve ayırıcı anahtarlarının durumunu değiştirerek gerekli işlemleri yapmaya önem göstermektedir.

Ağ'ın yeniden yapılandırılması , tüm besleyiciler aynı oranda yüklenmiş hale getirmek için besleyici yük dengelemesini sağlayarak normal işlem sırasında uygulanabilmektedir .Bir yük miktarı ağır yüklü besleyiciden hafif yüklü besleyiciye transfer edilmesi için uygun bağlantılı anahtarı kapatarak ve uygun komşu ayırıcı anahtarı açarak gerçekleştirilebilmektedir.

Acil durumlarda , hata oluştuğunda, hatadan etkilenen bölümler gerekli ayırıcı anahtarı açarak izole edilmektedir . Etkilenmeyen ama hizmet dışında sonuçlanan bölümler uygun bağlantılı anahtarı kapatarak restore edilmektedir . Bu sayede, hizmet, yeni yapılandırma ile restore edilebilir.

Normal çalışma sırasında ise , her birincil besleyici asimetrik yük değişikliklerine maruz kalabilmektedir.Bu nedenle dağıtım şirketlerinin gerçek güç kayıpları olası artış ile saplantısı vardır ve kaybının azaltılması için uygun yapılandırmayı korumak için bağlantılı ve ayırıcı anahtarlarının durumunu değiştirerek gerekli işlemleri yapmaya önem göstermektedir.

Makul yapılandırma elde etmek için kapatılacak bağlantılı anahtarlar ve açılacak ayırıcı anahtarlar uygun olması gerekmektedir. Bu nedenle bir planlayıcı sorumluluğu uygun yöntemi uygulayarak şu anahtarın uygun olup olmayacağını ortaya çıkarmaktadır.

Başka bir tarafta, küçük ölçekli Dağıtılmış Üretiminin güç kalitesi, ekonomik ve güvenlik yararları için yaygın olarak kullanılmaya başlanan hem müşteri için hem de dağıtım firmaları için cazip hale gelmektedir. Güneş, rüzgar veya fosil yakıt olarak dağıtılmış üretimin teknolojileri yenilenebilir kaynaklardır.Bu sayede DÜ , geleneksel üretimden daha az merkeziyetçidir ve genellikle doğa daha az zarar vermektedir.

Bu dağıtılmış üretimi faydaları özel konumu ve boyutu sınırlaması koşullu ve kurulum özelliklerine bağlıdır . Ayrıca, hem koruma konularına hem de fiyat zorluklar yoluyla maliyetine bağlıdır.Asgari kayıplar için, DÜ boyutu yeterli derece küçük olması gerekmektedir ve yerleştirildiği bölüm yeterli şekilde yüklere yakın olması gerekmektedir.

Bu tez o dağıtım sistemleri için arıza izolasyonu ve yeniden yapılandırma algoritması önermekte olup dağıtım üretimleri yerleştirmek için bir yöntem geliştirmektedir.. Dağıtım sistemlerindeki standart olan yapıların ve yüklerin sisteme dahil olmasıyla, normal koşullarda ve anormal koşullarda çalışamktadır.

Bu tez, kayıpların azaltılması ve hizmet restorasyon etkinliğini vurgulamak için hem normal hem de acil çalışmada radyal dağıtım sisteminin yeniden yapılandırılması için: 1) Dağıtılmış Üretim olmadan, 2) Optimal yerleştirilen Dağıtılmış Üretim ile Bulanık mantık modeli kullanılarak durumları için basit ve etkili bir yaklaşım sunuyor.Bulanık mantık modeli, en büyük hata azaltma oranı ve en iyi gelirim profiline göre dizayn edilmektedir .Bu sayede Tez DÜ optimum şekilde yerleştirerek yarı optimum kurulum özelliklerini sunmaktadır.

Bu tez karmaşık hesaplamaları önlemektedir. Yapılandırılmanın en iyi açılış noktası ve DÜ yerleştirmek için en iyi bölüm için basit yaklaşımlarla değerlendirilmektedir.Bir mühendis, bir sorunu çözmek istediği zaman , çözümün süresini en aza indirmelidir . Karmaşık hesaplar daha iyi bir çözüm sunabilmesine rağmen , çözüm süresi uzun olması takdirde , bu süre yeni ve gereksiz bir kayıp sayılmaktadır .

Sunulan yöntemler, dengeli radyal sistemlere uygulanabilmektedir. Dengeli olmayan sistemlerin üç akımının ortalamasını hesaplayarak dengeli olarak değerlendirilmektedir. Değişmekte olan yükler değil , tümü yükleri dikkate alarak uygulanabilen sunulan yöntemler çözüm süresi söz konusu olunca daha uygun bir çözüm sunmaktadır.

Önerilen yaklaşımın etkinliği 33-düğüm dengeli radyal dağıtım sistemi üzerinde uygulayarak vurgulanmıştır.32 bölüm, 32 ayırıcı anahtar ve 5 bağlantılı anahtarı içeren sistem, bir besleyici kaynak sistemidir.

Güç Sistemi Analiz Araç Çubuğu (Power System Analysis Toolbox) dağıtım sistemini simüle etmek ve görünür güç akışını çalıştırmak için kullanılmıştır. Anahtarlama Dizini MATLAB komut penceresi kullanılarak kodlanmıştır. Bulanık Çıkarım Sistemi (Fuzzy Inferencing System) Dağıtılmış Üretimi (DÜ) en iyi şekilde yerleştirmek için kullanılmıştır ve yerine eğitim amaçlı ve ekstra bilgi için MATLAB/SIMULINK ve FUZZME yazılımı kullanarak tekrar değerlendirilmiştir.

Elde edilen yapılandırma sonuçları ve DÜ optimum yerleşimi için her bölümün uygunluk derecesi, benzer çalışmaları sonuçları ile kıyaslandığında, önerilen yaklaşım dağıtım sisteminin yeniden yapılandırılmasının olumlu olduğunu ortaya çıkarmaktadır.
Yapılandırmaya çalışan araştırmaların sadece az sayısı DÜ'ün sistemde var olmasını dikkate alarak uygulanmıştır.Yalnız bu tez yapılandırmaya çalışırken DÜ optimum şekilde yerleştirerek yarı optimum kurulum özelliklerini sunan ilk araştırmadır.

# 1. INTRODUCTION

Thanks to a group of advances in communication and data processing ,Distribution Automation (DA) has been developed to make utilities able to realize the required improvement in customer service by solving the problems of distribution system's performance [1] ; (i.e., voltage level at load, frequency and duration of service interruption, energy losses , theft, forced shedding of loads and location and isolation of fault). Utilities ,as well , became interested in automating some tasks that were done manually.These technologies allowed electric companies to save around 10% of their annual maintanance [2].

One of DA's tasks is network reconfiguration to minimize losses and to increase system security[1],[3]. Network Reconfiguration refers to the change in the structure of distribution feeder by changing the status of normally open tie switches and normally closed sectionalizing switches [4].

Distribution system (DS) can be reconfigured during normal operation to make feeders and transformers loaded at the same rate by transfering load from heavily loaded transformers/feeders to lightly loaded transformers/feeders which is known as load balancing[4]. As well, real power losses can be reduced during normal operation by reconfiguration. DS can be also reconfigured during emergency situations for service restoration by isolating the faulted area and supplying power to out-of service area with minimum load shedding[5].

Moreover, over the last decade small scaled generators known as Distributed Generation (DG) became widely used in distribution systems. The benefits of developed DG technologies such as wind,solar and fuel cells and its contribution in minimizing losses and improving security made utilities interested in locating DGs near the end customers [6],[7].

In this thesis , simple approach for network reconfiguration is proposed for both loss reduction and service restoration .The benefits of DGs and its contibution in improving distribution system performance is uncovered in the proposed approach .

The effectiveness of DGs changes according to its location ; a simple Fuzzy logic model has been built in this thesis to determine the optimal location of DGs.

### 1.1 Literature Review

Many algorithms have been proposed to reduce losses and to restore out-of-service loads, these methods can be classified into four: heuristic _ expert systems _ meta heuristic _ mathematical programming [8]. A few of these algorithms based on the assumption that load is variable, while the most considered fixed load. Most of these works applied reconfiguration for loss reduction or for service restoration while a few number of works applied the reconfiguration for both of them. DGs have been included in a very few number of researches.

- Leonardo M.O,Queiroz and Christiano Lyra proposed an approach for loss reduction using hybrid genetic algorithm considering load variations, but they neither studied network reconfiguration in emergency situations nor included DG [9].
- Enrique Lopez, Hugo Opuzu, Luis Garcis and Patricj Bastard proposed online reconfiguration for loss reduction considering variability demand [10]. They solved minimal loss reconfiguration by dynamic programming approach with graph compression and radial load flow.
- E.Zehra,M.Moghavvem and K.amuttagi presented costly and time consuming approach for network reconfiguration to reduce losses in distribution system branches . They used PSAT to run power flow analysis and applied the approach on simple 16-bus radial distribution system [11].
- Refined genetic algorithm has been used in W.M.Lin , F.S.Cheg and Tsay's research [12]. They used the algorithm for feeder reconfiguration in normal operation and applied the algorithm on balanced system providing overall switching decision.
- Distribution feeder scheduling considering variable load profile and outage costs has been proposed by Shin-An Yin and Chan- Nan Lu [13].A binary particle swarm optimization (BPSO) search was adopted to determine the feeder switching schedule.

- C.S Chen and M.Y.Cho represented a systematic method to derive an optimal switching plan to achieve energy loss minimization. DG's are not included in Chen and Cho's study, and they considered hourly loading [14].
- Robert, Asif and Hesham used data structure to model loads and to store switch reconfiguration as a function of time to reduce distribution losses through reconfiguration [15].
- Unlike [9-15], Men.Shen Tsai proposed the reconfiguration for service restoration. Men considered the load level at the time just before the fault occurred ‘’ pre-fault load ‘’ to build restoration plans. In Tsai's paper, a rule based system has been used to solve service restoration [16].
- Power restoration control in an electric distribution network after a permanent fault has been concerned by Vaibhav Donde , Zhenyan Wang, Fang Yang and James Stoupis. They presented a methodology to determine back feed strategy for distribution network power restoration taking into account short term load forecasts [17].
- Differently , Chao.Chen ,Yu.Lung.Ke and Jaw.Shyang applied the artifically intelegent PETRI-NET approach for power distribution system to find optimal switching operation for service restoration and load balancing.In this study [18] , PETRI-NET with parallel like inference capability has been applied to find the switching operation for fault detection,isolation and restoration.
- Node-Depth Encoding (NDE) has been served as feeder reconfiguration and the objective function and constraints have been presented by Fuzzy numbers based on Fuzzy goal,Fuzzy constraints and on Fuzzy decesion in the research presented by Jutanun.K and Somporn.S [19].

The case studies proposed in [9-12, 15, 16] are balance distribution systems. [9-15] focused on energy loss minimization. Moreover, most of the proposed algorithms didn't include DGs. A few number of researches intigrated DGs while studying network reconfiguration .

- A simple approach for balanced and unbalanced distribution networks with DGs has been presented in Ziden.A and El-Saadany.F paper. They studied reconfiguration for both loss reduction and service restoration with DGs included. Zidan and El-saadany located DGs randomly and paid the attention to the type of load used in tested results considering load variations [20].

- Joon-Ho.Choi and Jae-Chul.Kim represented an integration of distributed generation to automated network for reconfiguration [21].They introduced an algorithm to achieve the positive effect of DG located in DS. Joon and Jae proposed reconfiguration for both loss reduction and service restoration paying the attention to the type of DG located in the system .There is no optimal replacement of DG detected in this study.

This thesis uses Fuzzy logic model to find the optimal location for each DG and proposes simple approach to reconfigure network for loss reduction and for service restoration in the cases :

1) Without DGs.
2) With DGs included and optimally replaced based on largest loss reduction and best voltage profile according to specific constraints.

### 1.2 Thesis Organization

An introduction and literature review have been presented in this chapter.Chapter 2 will be about the proposed network reconfiguration approach for loss reduction and service restoration.Benefits of Distributed Generation and it's impact on loss reduction are the main parts of Chapter 3.Then, an introduction of fuzzy logic controller and step by step implementation of DGs placement using fuzzy will be the subject of Chapter 4 attention.Chapter 5 will test the proposed methods on case study and compare the results with previous results.Finally , thesis is concluded and an overview on the future work is represented.

## 2.PROPOSED RECONFIGURATION ARRPOACH

Produced electricity reaches customers through generation,transmission and distribution system, where the load of service area is met by installed power generating stations.Then electric power is step down to subtransmission level and again to primary distribution level through transmission network. Feeders come out of the distribution substation and it's voltage level is then step down to secondary distribution level for the end user, where voltage level is step down by distribution transformers [22].

### 2.1 Electric Power Distribution Systems

This thesis pays the attention to distribution networks where network reconfiguration can be applied. The main components of overall distribution system are as following :

- Subtransmission system.
- Distribution substation.
- Primary distribution system (PDS).
- Secondary distribution system (SDS).

#### 2.1.1 Subtransmission system.

Subtransmission system supplies distribution substation with energy taken from the transmission grid through lines.The range of subtransmission lines is 30 – 250 MVA and it's range of operation is 34.5 – 230 KV.In order to ensure the reliability of supplied energy, one distribution substation is supplied through at least two subtransmission lines [23].

#### 2.1.2 Distribution substation

Each distribution substation lies at the end of subtransmission lines and serves one or more primary feeder after stepping down the voltage level of subtransmission to lower distribution level through substation transformers [24].

### 2.1.3 Primary distribution system

PDS receives electricity from distribution substation and delivers it to distribution transformers which in turn supply industrial, commercial and residential loada. Voltages of PDS are usually in the range 4 – 35 KV. The main equipments of PDS are: distribution transformers, reclosers, fueses and switches [43].

### 2.1.4 Secondary distribution system

Distribution transformers step down the voltage level of distribution system to secondary distribution level and feed SDS. SDS , the connection of energy meter of each customer with utility, are mostly radial networks [25].

## 2.2 Network Reconfiguration

Regulation and customer’s rising awareness make utilities more interested in network management. Network reconfiguration is substantial to improve distribution network quality [26]. Distribution networks containing normally closed and normally open switches are normally operated as ‘’radial’’ networks. Normally closed sectionalizing switches connect the line sections while normally open tie switches connect two substations or loop type laterals. These switches are built to allow configuration management and other protection purposes.Distribution network is reconfigured periodically opening and closing switches so as to reduce losses in line sections , transfer load from heavily loaded feeders to lightly loaded feeders or to help service to be restored after fault occurs.

Figure 2.2.1 shows an illustrative radial distribution system with one feeder and 3 laterals.

***The proposed network reconfiguration approach in this thesis is based on the research done by El-Saadany [20]. However,this thesis modifies the inclusion of DGs by optimal DG placement using Fuzzy Logic Model.***

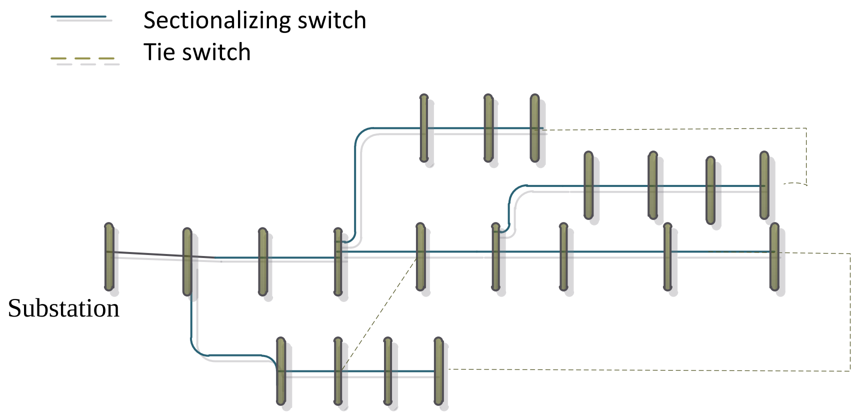



**Figure 2.1**: Illustrative Radial Distribution System

### 2.3 Reconfiguration For Loss Reduction.

There are asymmetric commercial,residantial and industrial loads variations at each feeder in the distribution system.Consequently,a possible increase in real power losses needs to be reduced periodically by utilities to enhance the quality and the security of distribution system. In another words, the current configuration needs to be changed in order to reduce losses in line sections.Some of sectionalizing switches must be opened and some of tie switches must be closed to reconfigure the network .Therefore, there are an optimal and specific switches can achieve loss reduction.

This thesis presents a little bit altered simple approach from [20] to be feasible for balanced distribution system with fixed loads in order to find these specific switches that achieve largest loss reduction taking in account the necessary constraints.

#### 2.3.1 Problem formulation and objectives.

The main objective of network reconfiguration for loss reduction is minimizing real power losses in line sections and can be formulated as :

$$min \sum_{i=1}^{n} I_i^2 \, R_i \qquad (2.1)$$

$n$ : number of lines.

$R_i$: resistance of line i.

$I_i$: current in line i.

It is understood from eq. (2.1) that minimizing line current causes minimization in losses subject to all necessary constraints.

### 2.3.2 Constraints.

The switch to be closed or opened must be feasible to make configuration reasonable according to a group of constraints can be classified into four:

1. Topological constraints.
2. Electrical constraints.
3. Operational constraints.
4. Load constraints.

#### *2.3.2.1 Topological constraints.*

The structure of the network must be radial which means that no meshes are allowed as shown in Figure 2.2.1 . Each node must be included Via at least one path to substation.

#### *2.3.2.2 Electrical constraints.*

Electrical constraints refers to satisfying Kirchoff's voltage and current laws.

#### *2.3.2.3 Operational constraints.*

Maximum allowable current is restricted to certain thermal limitation in every component in the system.Therefore, current must not exceed maximum value.

$$I_i \leq Imax \tag{2.2}$$

$I_i$: Current in line i.

$I_{max}$: Maximum line current.

#### *2.3.2.4 Load constraints.*

A certain voltage level at each node must be maintained to meet customer's requiremenets. As well, all loads need to be fed.

$$V_{min} \leq V_i \leq V_{max} \qquad (\mathbf{2.3})$$

$V_i$: voltage at ith node.

$V_{min}, V_{max}$ : minimum and maximum bus voltages respectively.

### 2.3.3 Proposed approach switching index.

The method starts with meshed network by closing all tie switches forming closed loops. The best point in each loop for higher loss reduction is determined by evaluating the apparent power flow index. The radial topology of the network is then restored by opening one switch in each loop. Complex power flow between node i and node j can be formulated as:

$$\mathrm{A}_{\mathrm{ij}} = \mathrm{P}_{\mathrm{ij}} + j\mathrm{Q}_{\mathrm{ij}} \qquad (\mathbf{2.4})$$

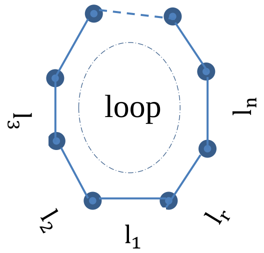
$\mathrm{P}_{\mathrm{ij}}$: Active power flow from ith node to jth node.
$\mathrm{Q}_{\mathrm{ij}}$: Reactive power flow from ith node to jth node.

Thus, minimizing apparent power flow by minimizing line current provides lower active and reactive losses. Switching index for each branch n to determine switches to be opened can be defined as :

$$\mu A_n = abs\left(e^{-w\left(\frac{A_n}{A_{av}}\right)}\right) \qquad (\mathbf{2.5})$$

$A_n$: Apparent power flow in branch n.
$A_{av}$: Average apparent power of all branches in the loop.
w: Weighting factor [27].

Weighting factor is calculated as the degree of closeness between each closed switch and the open switch , divided by the total number of switches in a loop as shown in Figure 2.3.3.1.




| Branch | w |
|---|---|
| $l_1, l_2, l_r$ | 1/m |
| $l_3, l_n$ | 3/m |
| $l_4, l_l$ | 5/m |

Number of switches = m

**Figure 2.2**: Switch Weighing Factor in A loop.

Figure 2.3.3.2 shows the flow chart of the proposed method for loss reduction and can be explained in steps:

- Convert the radial network to meshed one by closing all tie switches. Radial network will be restored by closing single optimal switch in each meshed loop for largest loss reduction.
- Select the meshed groups and close tie switches in these loops one by one.
- To set apparent power flow values, AC power flow solution is performed.
- Switching index for each branch in the meshed loop is calculated .Therefore; the switch with the largest switching index is selected to be opened.
- If the chosen switch causes any violation, the switch with the next largest index is opened instead.

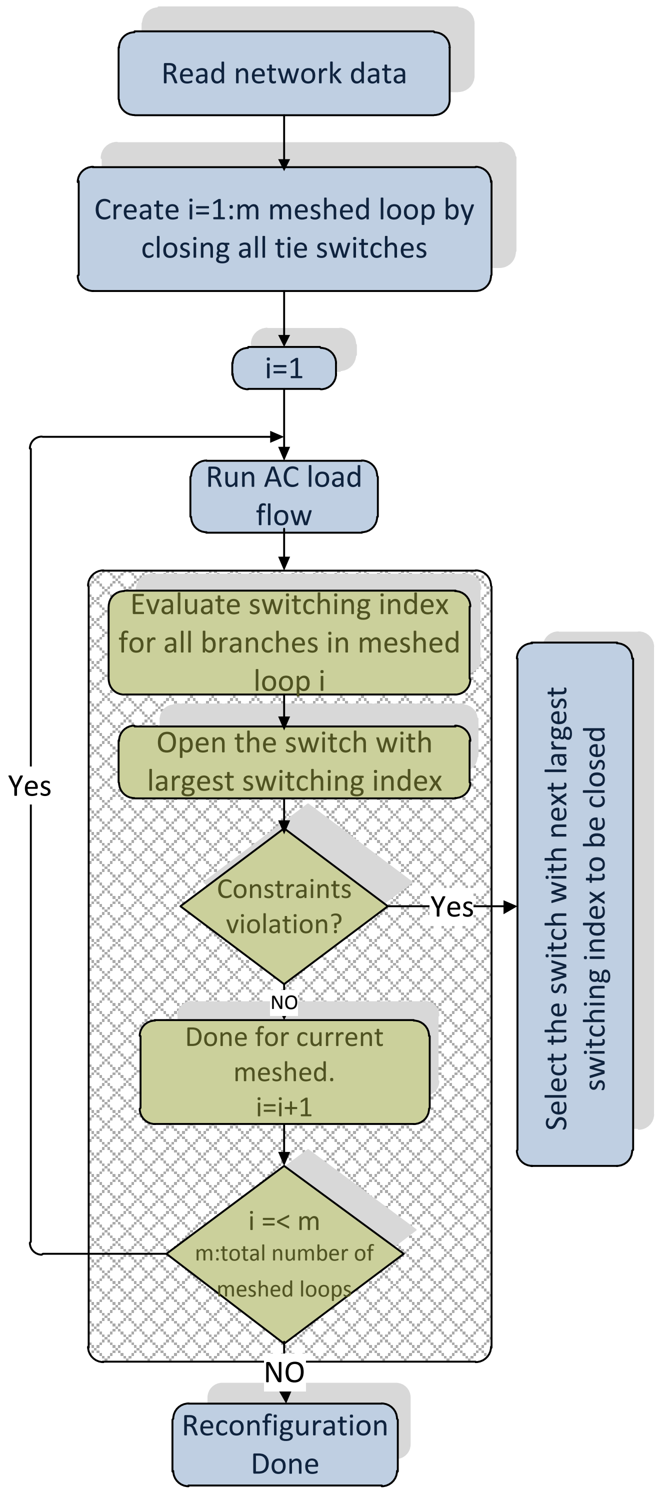



**Figure 2.3**: Flow Chart of The Proposed Method, Recon. for Loss Reduction.

### 2.4 Reconfiguration For Service Restoration

As an inevitable response to a fault, normally closed sectionalizing switch needs to be opened to isolate the fault. Consequently, some of loads loose the connection with main feeder to be out-of–service . The stages of service restoration can be summarized as following :

- Occurance of fault.
- Isolating fault.
- Restoring out-of-service loads.

In order to restore out-of-service loads , one or more of tie switches must be closed. Some of tie switches are feasible to be closed and some are not feasible and cause constraints violation.

This thesis presents simple approach to detect these feasible tie switches in order to maximize the restored loads taking into account the necessary constraints.

#### 2.4.1 Problem formulation and objectives.

The main objective of network reconfiguration for service restoration is maximizing restored load [20],and can be formulated as :

$$\max \sum_{i=1}^{n} X_i \times L_i \qquad \mathbf{(2.6)}$$

n: Number of energized nodes after restoration

$L_i$: load at ith node.

$X_i$: Status of load at ith node; 1 for restored load and 0 for un-restored load.

#### 2.4.2 Constraints.

The tie switch to be closed must be feasible to make restoration reasonable according to a group of constraints can be classified as mentioned before in section 2.3.2 into four:

1. **Topological constraints.**

   Keeping the radial structure of the network.

2. **Electrical constraints.**

Satisfying Kirchoff's voltage and current laws.

3. **Operational constraints.**

Maximum allowable current is restricted to certain thermal limitation in every component in the system.

$$I_i \leq Imax \tag{2.7}$$

$I_i$: Current in line i.

$I_{max}$: Maximum line current.

4. **Load constraints.**

Voltage at each node must lie within bounds

$$V_{min} \leq \ V_i \leq \ V_{max} \tag{2.8}$$

$V_i$: voltage at ith node.

$V_{min}, V_{max}$ : minimum and maximum bus voltages respectively

**2.4.3 Proposed approach switching index.**

The same switching index calculated in section 2.3.3 is used again for servise restoration . The restoration method can be explained in steps:

- Divide network after fault occurs into groups and select out-of-service groups.
- Select all tie switches that connect out-of-service groups with feeder groups. Figure 2.4.3.1 shows an example of how network is divided into groups .The tie switch with the smallest switching index is closed for restoration.

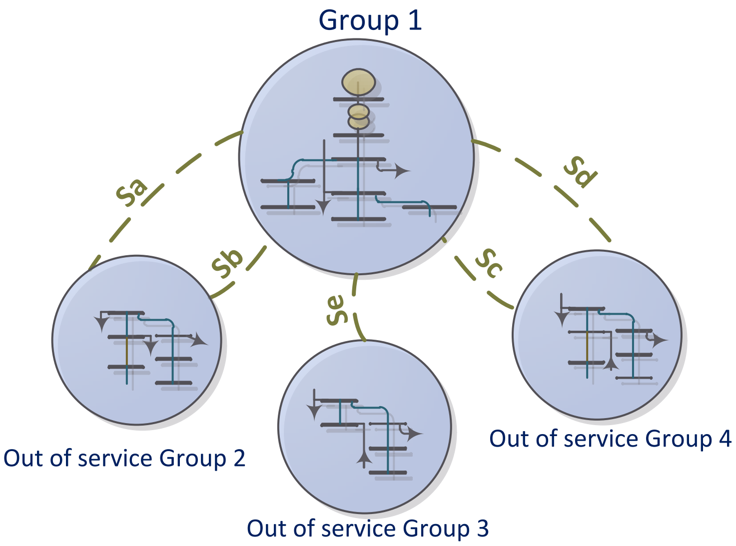



**Figure 2.4**: Dividing System into Feeder Group and Out-of-Service Groups

The figure above shows one feeder group and 3 out-of-service groups. Each one of the out-of-service grouprs needs to be restored by closing one of the tie switches that connect it with the feeder group. For group 2, the tie switch with the smallest switching index between Sa and Sb is the one to be closed for restoration.

- If the selected switch causes any violation, choose the switch with the next smallest Switching Index to be closed instead.If all candidate switches cause constraints violation, load shedding is displayed. Figure 2.4.3.2 shows flow chart of the proposed method for service restoration.

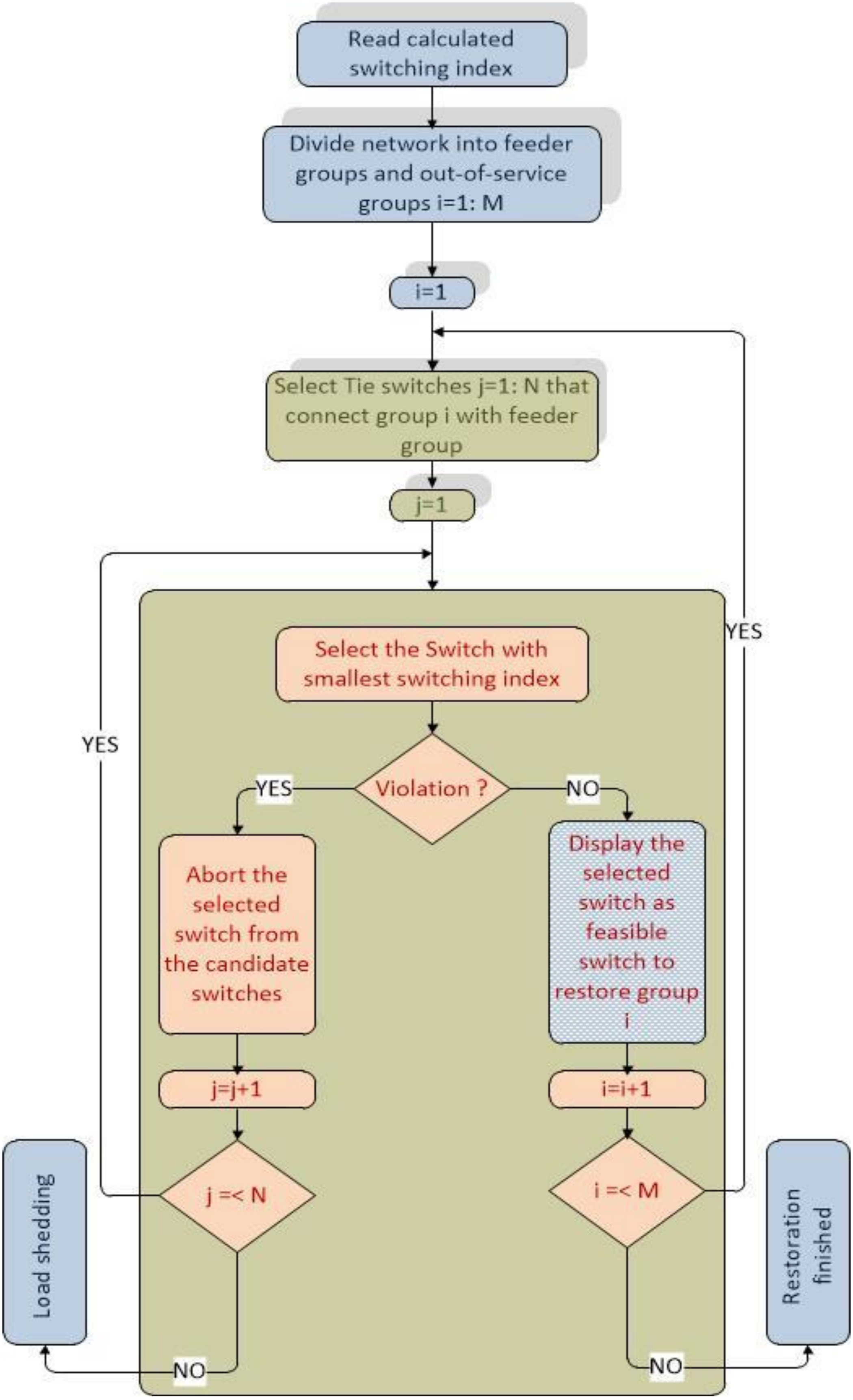



**Figure 2.5**: Flow Chart of The Proposed Method for Recon.Service Restoration.

## 3.DISTRIBUTION SYSTEM AND DISTRIBUTED GENERATION

Distributed generation DGs is being redefined continuously according to improved technologies and ongoing researches about it's range of usage, characteristic of installation and size limitation with respond to cost via price challenges. Selectively , it is defined by International Energy Agency IEA [28] , as :

***Distributed Generation:*** ''is a generating plant serving a customer or providing support to a distribution network,connected at distribution level voltages''.

In the purpose of refining power quality and reliability , these small highly effecient and easy to fit DGs,are becoming attractive to many utilities specially across United States [29].

The benefits of developed DG technologies such as wind,solar and fuel cells and its contribution in minimizing losses and improving security made utilities interested in locating DGs near the end customers [6],[7].

This thesis detects the contribution of integrated DGs to DS in enlarging the percentage of loss reduction. Size of DGs ,issues of protection and cost via price challenges are out of scope of this thesis ; only DGs optimal location is the concern.As mentioned before , there are some researches applied reconfiguration on distribution networks with hypothetically replaced DGs such as [20] and [21].

### 3.1 Benefits Of Distributed Generation.

DGs are generally located near consumption area and can be owned by utility or by the customer according to specific agreements and views. Figure 3.2.1 shows an illustrative distribution system with wind DG.

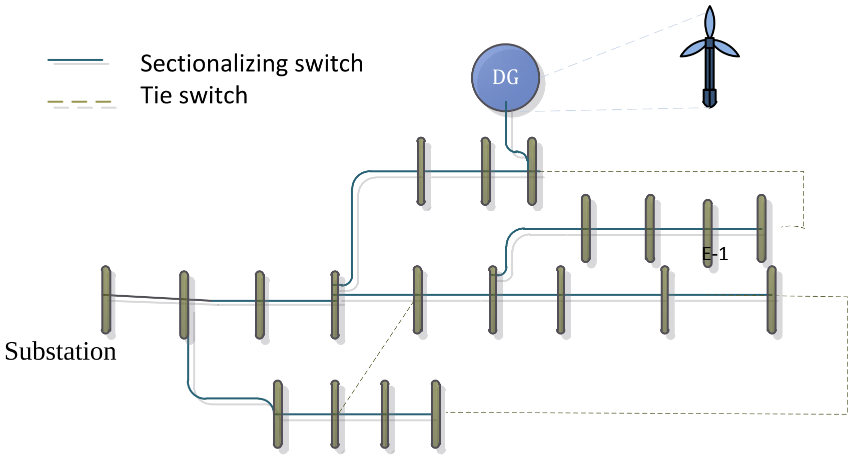



**Figure 3.1**:Illustrative Distribution System with DG Powered by Wind Energy.

Several benefits make both utility and customer being interested in integrating DG to the distribution network . These benefits can be classified as following [30],[31] :

- **Power quality benefits.**

DGs help to improve voltage profile and to reduce harmonic distortions. However,it can be a source of voltage waveform distortion without intervention of power electronics that can theoretically cancel distortion and help regulate voltage

- **Emission benefits.**

Reduce line losses . Using renewable generators realizes these benefits , but this realization is dependent on the structure of power network and the installation of DGs.

- **Economic benefits.**

DGs reduce costs associated with power losses and reduce fuel costs due to increased effeciency.

- **Reliability and security benefits.**

Increased security for critical loads , relieved distribution congestion and increased generation diversity are the summarized benefits of DGs for security and reliability. However, realizing these benefits depends on characteristics of

DG installation (size,location) and characteristics of both distribution network and power system.

Emission benefits of DGs will be noticed from the result of tested case study in chapter five before and after network reconfiguration.

### 3.2 The Impact Of DG Location On Loss Reduction.

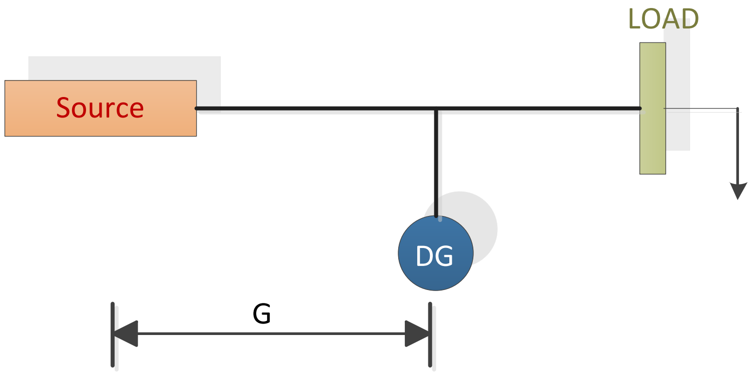



**Figure 3.2** : Schematic of A radial System with The Inclusion of DG.

Figure 3.3.1 shows DG located at distance G from the source .The amount of loss reduction after integrating DGs can be calculated according to [32] ,as following

$$\mathrm{LR} = \frac{rG}{3Vp^2}\left(2\, P_l P_G - 2\, Q_l Q_G - {P_G}^2 - {Q_G}^2\right) \qquad \mathbf{(3.1)}$$

Where :

$G$: Distance from source to DG location.

$r$: Line resistance.

$V_p$: reference voltage per Km.

$P_l$: Real power of load.

$P_G$: Real power of DG

$Q_l$: Reactive power of load.

$Q_G$: Reactive power of DG.

The result of LR in eq. 3.1 depends on two factors : 1) DG size , 2) DG location . Positive sign detects that integrating DG reduces losses in the network , DG size affects the sign of the equation .

The magnitude of LR is affected directly by the distance from the source to DG location .It is obvious that LR gets larger when DG is closer to the load.

In this thesis the interest is in the location of DG . There is an optimal location for each DG for maximum loss reduction. A simple Fuzzy logic model is applied to determine the suitability degree of each DG .The node with largest suitability degree will be chosen for maximum loss reduction.Contribution of distibuted generation in loss reduction will be examined before and after network reonfiguration to see whether DG affect reconfiguration or not . Network reconfiguration will be compared between two cases : 1) without DGs, 2) with optimally located DGs.

## 4.OPTIMAL DG PLACEMENT USING FUZZY LOGIC CONTROLLER

Fuzzy control, introduced in 1970's, occupies an obvious attention among intellegent controllers [33].Fuzzy set theory, which has been derived to overcome the roughness of classical set theory, is the kernel of fuzzy logic based on approximating rather than precision.Knowledge based systems developers developed fuzzy logic to define system values as true or false.Unlike traditional PI and PID controllers which depend on mathematical model, fuzzy logic depends on information provided by membership functions (MFs) and uses fuzzy sets and rules for controlling actions [33].

There are many available computer applications and softwares for designing and building such fuzzy logic model. In this thesis MATLAB with its Graphical User Interface (GUI) Fuzzy Logic Toolbox is used for the proposed implementation.

### 4.1 Set Theory.

Figure 4.2.1 , taken from [33], shows how fuzzy set theory differs from classical set theory.As shown on the left side of the figure, there is roughness in classical set in making decesion that is any value less than 30 is considered as short and any value equals or exceeds 30 is considered as tall, but what would 29.99 hight be considered ?. In classical set theory the output is defined by one input only, so 29,99 is considered as short and this is the main difference between classical and fuzzy set theories.

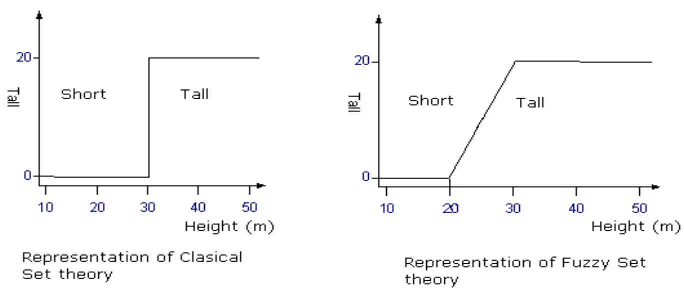



**Figure 4.1**: Set theory representation [30].

On the right side of Figure 4.2.1 , the output of fuzzy set is not defined by single input .It is defined by a set of MFs and rules as part of both inputs. Fuzzy set theory gives more realistic answer such that 29.99 hight is 90% tall and 10% short or something different according to how user defines MFs.

In fuzzy logic there is number of linguistic terms can be used in defining MFs.Table 4.2.1 shows some of these terms.These terms, however, are just representation and fuzzy set theory is the responsible for manipulation.

**Table 4.1** : Typical Linguistic Terms in Fuzzy Logic [33].

| Linguistic term | Meaning |
|---|---|
| PL | Positive large |
| PM | Positive medium |
| PS | Positive small |
| ZE | Zero |
| NS | Negative small |
| NM | Negative medium |
| NL | Negative large |

Again, fuzzy set is represented by MFs divided into regions (linguistic terms). If we apply these information to detect the price of a house keeping into account that it is dependent on the newness and the location of the house, inputs and outputs need to be defined by MFs as shown in Figure 4.2.2. Now, location and newness are the inputs while the price is the output. Next ,rules must be defined for the system such that :

*If house is old and location is far, price is cheap.*
*If house is old and location is relatively far, price is cheap.*
*If house is old and location is close, price is average.*
*If house is new and location is far, price is average.*
*If house is new and location is relatively far, price is expensive.*
*If house is new and location is close, price is expensive.*

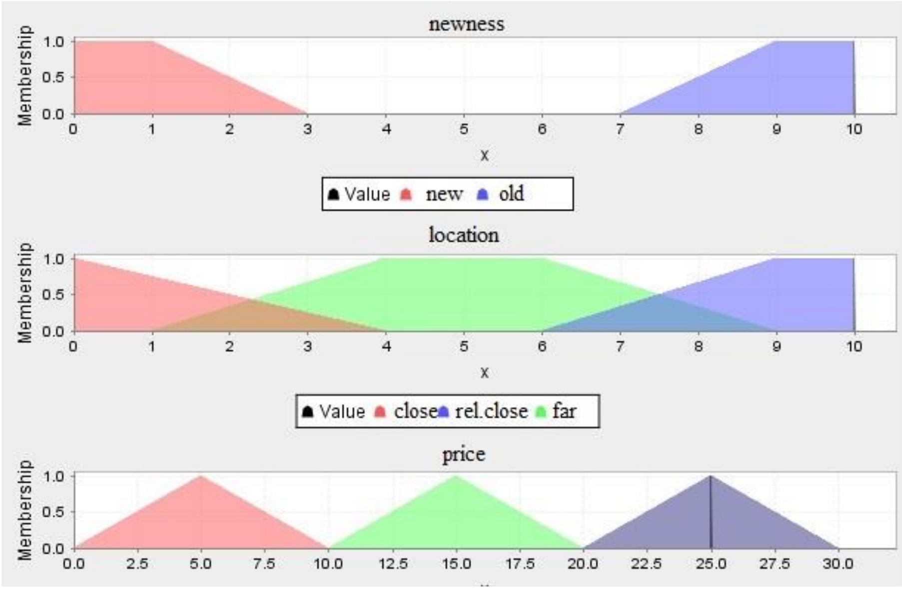



**Figure 4.2**: Fuzzy Set Membership Function Representation

### 4.2 Basic Fuzzy Logic Controller.

Fuzzy set is defined as : set F in a universe U and takes values between zero and one [33],[34]. U can be discrete or continuous and F can be characterized by μF.

If U is continuous universe, F can be formulated as [33]:

$$F = \sum_{i=1}^{n} ( \mu F(x_i) \, / \, x_i ) \qquad \mathbf{(4.1)}$$

And for discrete U :

$$F = \int_U \mu F \ (x)/x \ . \qquad \mathbf{(4.2)}$$

Fuzzy set is defined according to the representation of MFs as [34]:

#### Numerical definition

Each input in the fuzzy set is a range of numerical values and the output is evaluated only for those values.

#### Functional definition

Unlike numerical definition, MFs are represented functionally. Function can be sinusoidal, trapezoidal,triangular and sigmoid ..etc.

Figure 4.3.1 is a representation of basic Fuzzy Logic Controller (FLC).

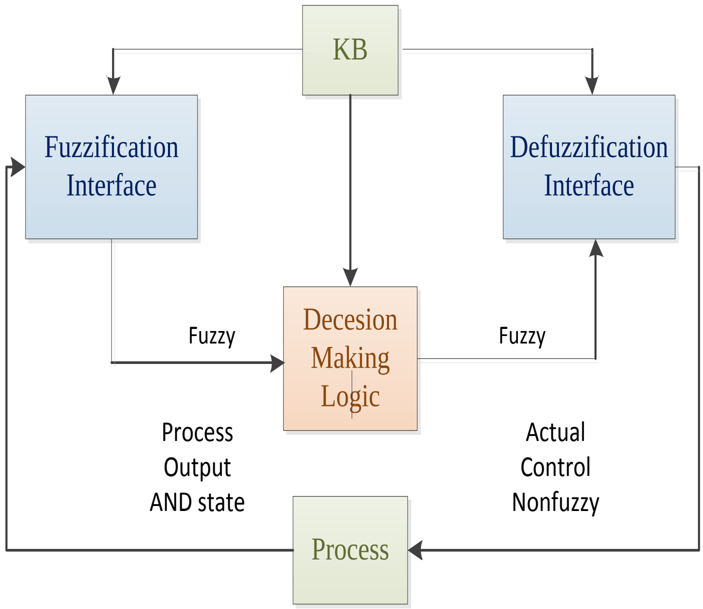



**Figure 4.3**: Basic Fuzzy Logic Controller.

The block diagram in Figure 4.3.1 contains the basic components of FLC , the most important components can be summarized as :

**Fuzzification:**

- Measures input variables [34]
- Related to fuzzy set definitions, Fuzzification converts numerical values in MFs [33].

**Knowledge base**

It is data based and rule based where , data base defines fuzzy sets and rule base defines the control rule [34].

**Desecion making logic**

In this step, fuzzy logic rules examines knowledge representations from previous step [33].

**Defuzzification**

Converts logic values taken from fuzzy set to scaled values. Away from accounting all methods, CENTROID and MAXIMUM are the most common for Defuzzification [33].

## 4.3 Implementation of DG Placement using Fuzzy Logic

### 4.3.1 Objective

Applying fuzzy logic model in this thesis is to find suitable ( optimal or semi optimal) location for DGs based on largest loss reduction and best voltage profile

**Objective**: getting real power losses minimized eq.(4.3)

$$min \sum_{i=1}^{n} I_i^2 R_i \qquad \textbf{(4.3)}$$

$n$ : number of lines.

$R_i$: resistance of line i.

$I_i$: current in line i.

**Subject to** maintaining voltage within limits:

$$V_{min} \leq V_i \leq V_{max} \qquad \textbf{(4.4)}$$

$V_i$: voltage at ith node.

$V_{min}, V_{max}$ : minimum and maximum bus voltages respectively

Firstly, load flow is run to obtain network losses.Then power loss reduction is evaluated by compensating the same minus active load at every node, so again load flow solutions are required. Power Loss index [35] can be evaluated by eq.4.5 that normalizes loss reduction to take values between zero and one [0,1] such that the highest reduction takes the value of one and the lowest reduction takes zero.

$$LRI = \frac{(lossreduction(i) - lossreduction(\mathrm{min}))}{(lossreduction(max) - lossreduction(\mathrm{min}))} \qquad \textbf{(4.5)}$$

### 4.3.2 Step by step implementation

There are many softwares used to design and build fuzzy controller.In this chapter MATLAB, Fuzzy Logic Toolbox is used. For extra knowledge and for educational purpose the model has been rebuilt using MATLAB SIMULINK and FUZZME (APPENDIX C).

First step is to define inputs and outputs to Fuzzy Inference System (FIS). Power loss index PLI and the constraint voltage VOLT are considered as inputs while Suitability-Degree is considered as output.

**PLI**

PLI is the fisrt input and represented by five triangular MFs shown in Figure 4.4.2.1. Figure has been captured from designed FIS. Table 4.4.2.1 summarizes the linguistic values description and ranges .

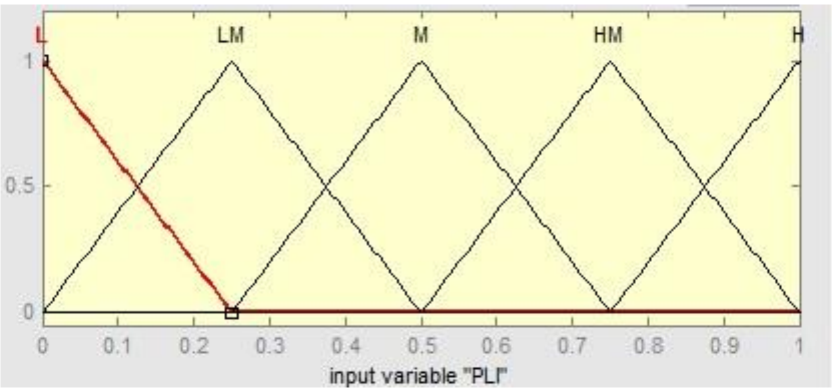



**Figure 4.4**: Specifying the First Input Variable as PLI

**Table 4.2**: Ranges for Input PLI Variable

| PLI Description | Linguistic term | Range |
|---|---|---|
| Low | L | 0 to 0.25 |
| Low medium | LM | 0 to 0.5 |
| Medium | M | 0.25 to 0.75 |
| High medium | HM | 0.5 to 1 |
| High | H | 0.75 to 1 |

**VOLT**

The second input VOLT is represented by five triangular and trapezoidal MFs shown in Figure 4.4.2.2. Figure has been captured from designed FIS. Table 4.4.2.2 summarizes the linguistic values description and ranges.

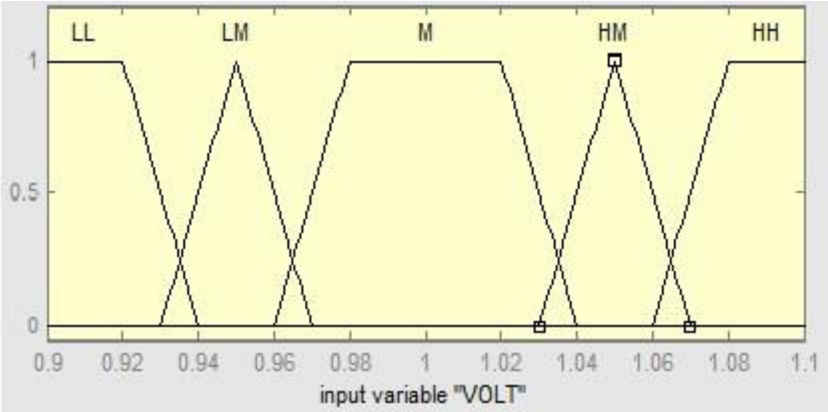



**Figure 4.5**: Specifying the Second Input Variable as VOLT

**Table 4.3** : Ranges for Input VOLT Variable

| VOLT Description | Linguistic term | Range |
|---|---|---|
| Low | LL | 0 to 0.94 |
| Low medium | LM | 0.93 to 0.95 |
| Medium | M | 0.96 to 1.04 |
| High medium | HM | 1.03 to 1.05 |
| High | HH | 1.06 to 1.1 |

**Suitability-Degree**

The output Suitability-Degree which measures the suitability of locating DGs at each bus  is represented by five triangular MFs shown in Figure 4.4.2.3. Figure has been captured from designed FIS. Table 4.4.2.3 summarizes the linguistic values description and ranges.

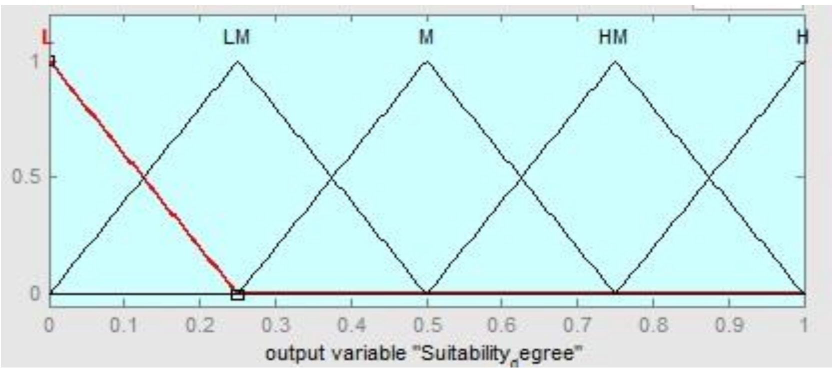



**Figure 4.6** : Specifying the Output Variable Suitability-Degree.

**Table 4.4**: Ranges for Output Suitability-Degree Variable.

| Suitability-Degree | Linguistic term | Range |
|---|---|---|
| Low | L | 0 to 0.25 |
| Low medium | LM | 0 to 0.5 |
| Medium | M | 0.25 to 0.75 |
| High medium | HM | 0.5 to 1 |
| High | H | 0.75 to 1 |

Buses with highest Suitability-Degree are detected as suitable buses for DGs replacement,such that the larger loss reduction and the smaller voltage will enhance the suitability of the ralated bus. Suitability-Degree value is evaluated by CENTROID Defuzzification depending upon the inputs and the rules defined in fuzzy inference system . IF-Then operation is the rule controller . 25 rules are written and shown in Table 4.4.2.4. Figure 4.4.2.4 shows rule editor captured from designed FIS.

**Table 4.5** : Fuzzy Decision Matrix.

| AND | | VOLT | | | | |
|---|---|---|---|---|---|---|
| | PLI | LL | LN | N | HN | HH |
| Suitability Degree | L | LM | LM | L | L | L |
| | LM | M | LM | LM | L | L |
| | M | HM | M | LM | L | L |
| | HM | HM | HM | M | LM | L |
| | H | H | HM | M | LM | L |

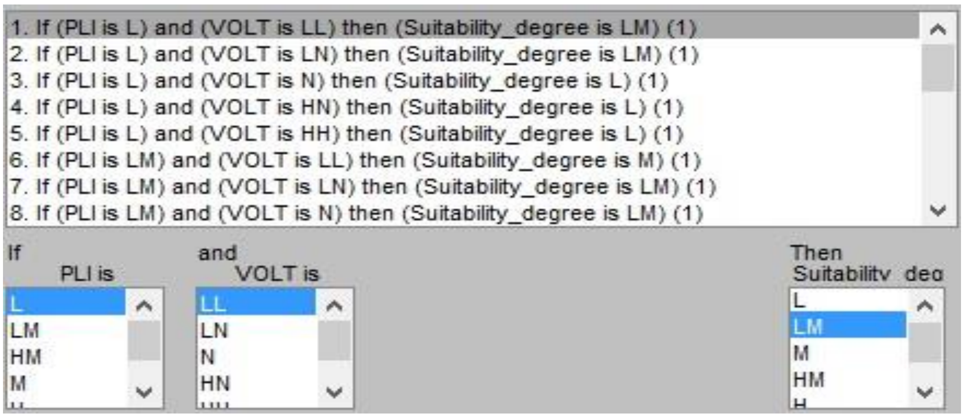



**Figure 4.7**: Rule Editor from FIS.

## 5.TESTING AND RESULTS

MATLAB is the most famous software for technical computing.It has the property of working within one environment by consolidating programming,visualisation and computation in the same environment.It can express and solve problems in frequent mathematical notation.

This thesis required running power flow many times and Power System Analysis Toolbox (PSAT) has been used for this purpose. PSAT was developed by Milano,2005 [36].It is MATLAB toolbox with GUI for power system analysis.The main lineaments of PSAT are: power flow,optimal power flow,small signal stability and time domain simulation.The tested network in this thesis has been designed by a SIMULINK based library provided by PSAT itself.

MATLAB has been also used for building fuzzy logic model ( Chapter- Four). Proposed fuzzy logic model has been rebuilt for educational purpose and for extra knowledge using MATLAB SIMULINK and using the software FUZZME (APPENDIX C).Switching Index and checking constraints violation have been coded using MATLAB script window.

### 5.1 Case Study

The feasibility of the proposed approach has been tested on 33-bus radial distribution system [37].All the available line data, load data and rating KV and MVAR are attached in APPENDIX A. Figure 5.2.1 shows one line diagram of the tested network.

33-bus radial distribution system is one source feeder system with 32 bus,32 sectionalizing switches (NO.1_32) and 5 tie switches (NO. 33_37).

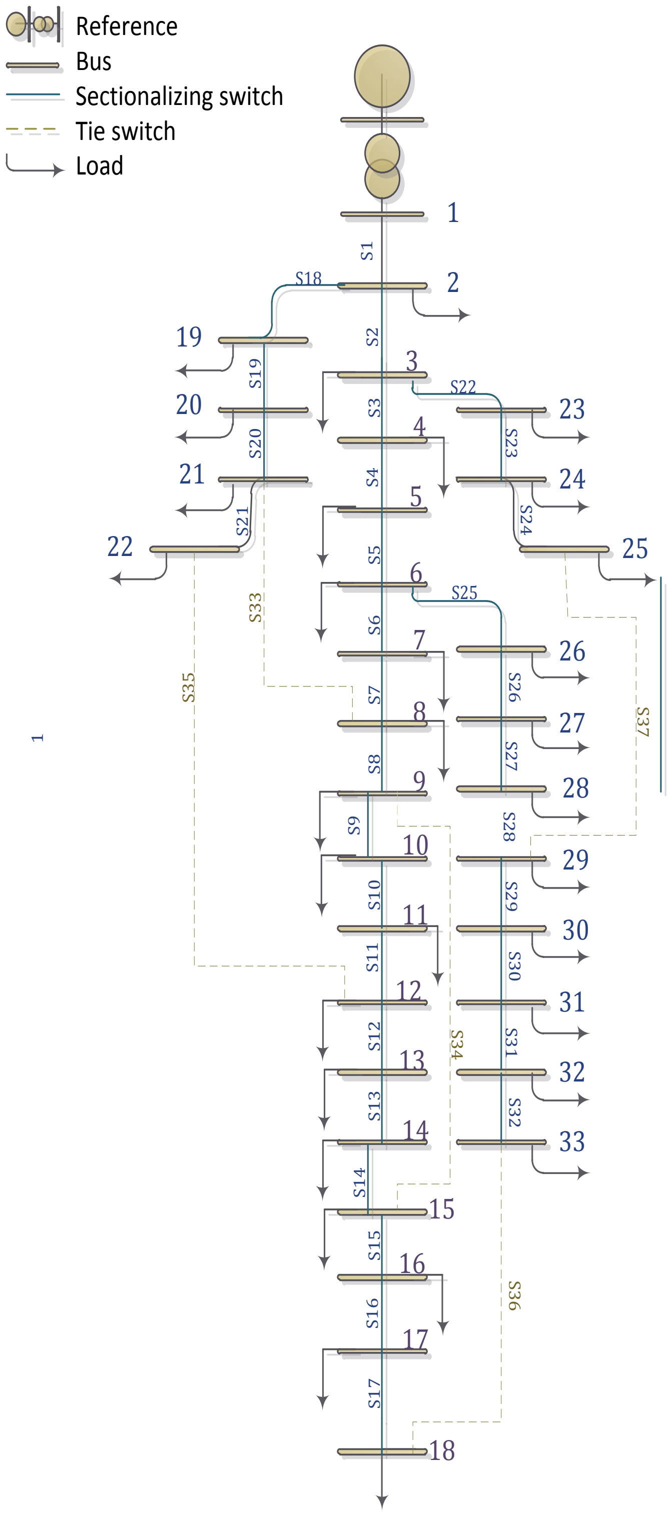



**Figure 5.1**: One Line Diagram of 33-bus Radial Distribution System.

The initial configuration of the network has total real power loss equals 211.43 KW and has minimum voltage equals 0.9040 per unit. The fuzzy logic model built in chapter four has been applied on this network to find the optimal DGs locations.Network reconfiguration for loss reduction and for service restoration have been applied on this network by the proposed approach as two cases : 1) without DGs, 2) with optimally placed DGs.

The results are compared with other methods results to emphasize how feasible the proposed approach is.

## 5.2 Results

### 5.2.1 DGs placement using fuzzy logic

In order to run power flow properly, DGs are modeled in some studies as PV bus and in other studies as PQ but with minus loads.In this thesis it has been modeled as load with minus active power and reactive power is calculated according to [32] as :

$$Q_G = \frac{\left((-1)^{nG} P_G \sqrt{1-(PF_G)^2}\right)}{PF_G} \qquad \mathbf{(5.1)}$$

$$\mathrm{nG} = \begin{Bmatrix} 1 \ \text{leading power factor} \\ 2 \ \text{lagging power factor} \end{Bmatrix}$$

$\mathrm{PF_G}$ = power factor.

Determining the optimal size of each DG is out of scope of this thesis.Thus, the capacities that have been used in similar researches are used in this thesis in order to make comparison between results.After running power flow the inputs of fuzzy logic model PLI and VOLT has been calculated and so the output as well for each node in the network. After running power flow the inputs of fuzzy logic model PLI and VOLT has been calculated and so the output as well for each node in the network. The Suitability-Degree of each node is summarized in Table 5.3.1.1 and voltage profile before and after integrating DGs is shown in Figure 5.3.1.1.

**Table 5.1** : Suitability-Degree values.

| BUS | SUITABILITY-DEGREE | BUS | SUITABILITY-DEGREE |
|---|---|---|---|
| 2 | 0.080 | **18** | **0.920** |
| 3 | 0.232 | 19 | 0.089 |
| 4 | 0.250 | 20 | 0.136 |
| 5 | 0.301 | 21 | 0.140 |
| 6 | 0.528 | 22 | 0.145 |
| 7 | 0.555 | 23 | 0.243 |
| 8 | 0.696 | 24 | 0.250 |
| 9 | 0.751 | 25 | 0.267 |
| 10 | 0.753 | 26 | 0.546 |
| 11 | 0.755 | 27 | 0.583 |
| 12 | 0.759 | 28 | 0.667 |
| 13 | 0.752 | 29 | 0.751 |
| 14 | 0.755 | **30** | **0.777** |
| 15 | 0.775 | **31** | **0.778** |
| 16 | 0.755 | **32** | **0.780** |
| 17 | 0.776 | 33 | 0.775 |

Table 5.3.1.1 shows that the optimal locations for integrating four DGs are: bus18,bus32,bus31and bus30 with Suitability-Degree values 0.92,0.78,0.778 and 0.777 respectively.Figure 5.3.1.1 shows that there is an improvement in voltage profile after integrating DGs with 1.1817% increment in minimum voltage value.

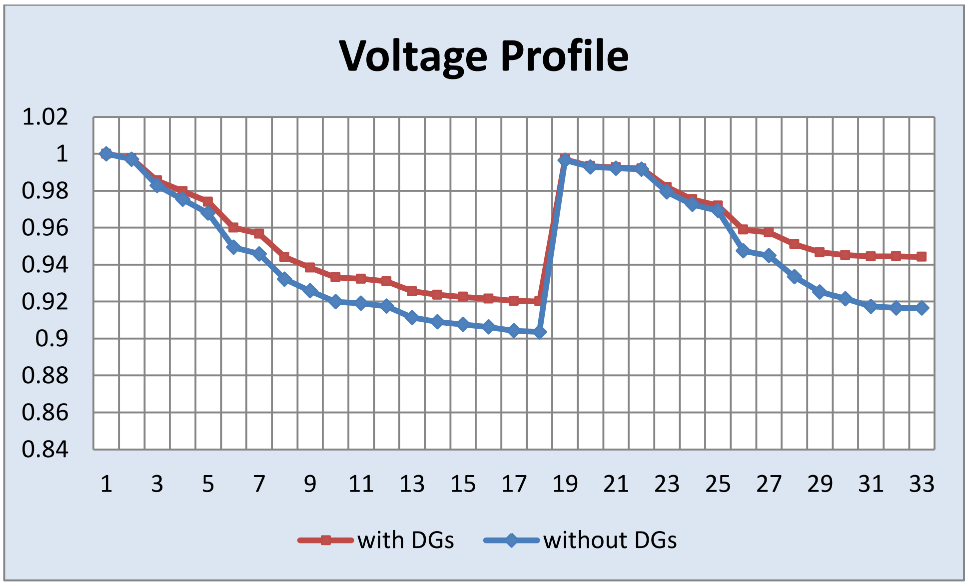



**Figure 5.2**: Voltage Profile Before and After Integrating DGs.

### 5.2.2 Network reconfiguration

**Case I: Without DGs**

**A) Network Reconfiguration for Loss Reduction.**

After running power flow and calculating Switching Index for each switch in each meshed loop it has been detected that the switches S7,S11,S14,S37 and S32 are the switches with largest Switching Index in meshed1,meshed2,meshed3,meshed4 and meshed5 respectively.Network has been reconfigured and power flow has been run for reconfigured network to examine any constraint violation.Table 5.3.2.1 summarizes Switching Index for each switch in each meshed loop.Values inside red borders in Table 5.3.2.1 are not considered in related meshed loop calculations according to topological constraints.

**Table 5.2** : Calculated Swtich Index for Case I.

| Meshed1 switch | Index | Meshed2 switch | Index | Meshed3 switch | Index | Meshed4 switch | Index | Meshed5 switch | Index |
|---|---|---|---|---|---|---|---|---|---|
| S2 | 0.1953 | S8 | 0.6031 | S9 | 0.9208 | S3 | 0.4407 | S25 | 0.1683 |
| S3 | 0.2656 | S9 | 0.6800 | S10 | 0.8268 | S4 | 0.3902 | S26 | 0.2414 |
| S4 | 0.3862 | S10 | 0.8511 | S11 | 0.6754 | S5 | 0.4132 | S27 | 0.3372 |
| S5 | 0.5212 | **S11** | **0.9684** | S12 | 0.2366 | S22 | 0.4840 | S28 | 0.4839 |
| S6 | 0.9216 | S21 | 0.8014 | S13 | 0.5073 | S23 | 0.6640 | S29 | 0.8040 |
| **S7** | **0.9892** | S33 | 0.3803 | **S14** | **0.9084** | S24 | 0.9119 | S30 | 0.9286 |
| S18 | 0.6309 | S35 | 0.8324 | S34 | 0.8569 | S25 | 0.6079 | S31 | 0.9286 |
| S19 | 0.7754 | | | | | S26 | 0.7214 | **S32** | **1.0062** |
| S20 | 0.9264 | | | | | S27 | 0.8354 | S36 | 1.0060 |
| S33 | 0.9401 | | | | | S28 | 0.9477 | S15 | 0.6800 |
| | | | | | | **S37** | **0.9511** | S16 | 0.7765 |
| | | | | | | | | S17 | 0.8659 |
| | | | | | | | | S34 | 0.4963 |
| | | | | | | | | S6 | 0.1143 |
| | | | | | | | | S7 | 0.6700 |
| | | | | | | | | S8 | 0.7760 |

No constraint violation has been detected and the switches S7,S11,S14,S37,S32 are selected as optimal switches to achieve maximum possible loss reduction . The percentage of loss reduction due to closing tie switches and opening the selected switches are 33.08%.Table 5.3.2.2 shows comparison between the resılts of proposed approach and other results.Table 5.3.2.2 uncovers that the proposed approach is feasible for network reconfiguration planning in the case without DGs.

**Table 5.3**: Comparison Between Proposed Approach Results and Similar Researches Results ,Case I

| | Goswami method1 [38] | Goswami method2 [38] | Goswami method3 [38] | Baran method1 [39] | Baran method2 [39] | Whei & Hong [39] | Yuan-Kan.... [37] | Joon-Ho-Choi.. [41] | Proposed method |
|---|---|---|---|---|---|---|---|---|---|
| **Final configuration** | S7,S9,S3, S14,S32 | S7,S9,S1, S32,S37 | S7,S9,S1, S32,S37 | S6,S11,S31,S28,S33 | S6,S34,S11,S31,S37 | S7,S9,S1,S32,S37 | S7,S9,S14,S28,S32 | S7,S9,S14,S32,S37 | S7,S11,S14,S32,S37 |
| **No of switching operations** | 14 | 14 | 8 | 10 | 6 | 8 | 10 | 8 | 8 |
| **Loss reduction percentage** | 31.148% | 31.148% | 31.148% | 27.83% | 23.83% | 31.148% | 31.259% | 33.5% | 33.08% |

## B) Network reconfiguration for service restoration

Assuming two faults occur at bus5 and bus22. After applying the first step in service restoration process which is fault isolation we had one feeder group and two out-of-service groups.Next, we select the candidate open switches that connect out-of-service-groups with the feeder group. Two switches S11 and S14 connect the out-of service group number 2 and three switches S7,S37 and S37 connect the third group with feeder main group.Figure 5.3.2.1 shows the network divided into three groups with open switches selected as candidate switches.

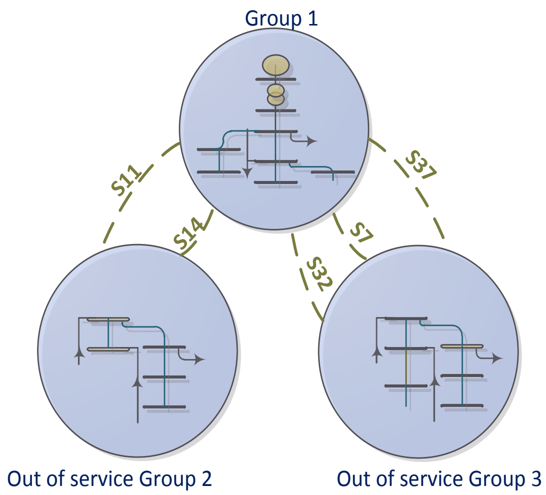



**Figure 5.3**: Candidate Switches Connect Group1 with Out-of-Service Group.

According to the presented flow chart in chapter two , for the group of switches that connect feeder group with one of out-of-service groups, the switch with smallest switching index must be closed for service restoration.If an open switch is common switch between two meshed groups ,which means that the switch has two Switching Index values,the lowest Switching Index value is chosen.

Table 5.3.2.3 summarizes the Switching Index values for each of candidate switches.Switch S11 and switch S7 are selected to be closed in order to restore out-of-service group 2 and out-of-service group 3 respectively.

**Table 5.4** :Candidate Switches for Srevice Restoration ,Case I

| Path | Switch to be closed | INDEX |
|---|---|---|
| 1(G1-G2) | **S11** | 0.9684/**0.6754** |
| 2(G1-G2) | S14 | **0.9084** |
| 3(G1-G3) | S37 | **0.9511** |
| 4(G1-G3) | **S7** | 0.9892/**0.6700** |
| 5(G1-G3) | S32 | **1.0062** |

After closing S11 and S7 power flow has been run again to check any constraint violation and there was obvious voltage violation under 0.85 at many nodes in the network.Thus, switch S11 or S7 must be closed and the switch with next smallest Switching Index must be opened. The flow chart for service restoration has been followed repeatedly until finding the optimal switches for service restoration subject to necessery constraints. Finally, switch S11 and S37 have been selected for service restoration as summarized in Table 5.3.2.4

**Table 5.5** : Optimal Switches for Service Restoration ,Case I

| Path | Switch to be closed |
|---|---|
| 1(G1-G2) | **S11** |
| 3(G1-G3) | **S37** |

The open switches in the new configuration after service restoration are S7,S22,S14,S5,S32 .The resulted total real power loss is 189.03 KW and the minimum voltage is 0.92797 per unit.

**CASE II: With optimally replaced DGs**

In order to make comparison between previous results of other approaches and proposed results,taking in consideration that DGs capacities are out of scope of this thesis, the most commonly used capacities by other approaches have been used here as following:

- 100 KW / 0.9 lagging.

- 100 KW / unity.
- 200 KW / 0.9 lagging.
- 50 KW / 0.8 lagging.

Recovering subsection 5.3.1, the optimal nodes for placing DGs are 30,31,32 and 18 with Suitability-Degree equals 0.777 , 0.778 ,0.780 and 0.920 respectively.Figure 5.3.2.2 shows one line diagram of 33-bus radial distribution system with optimally replaced DGs.

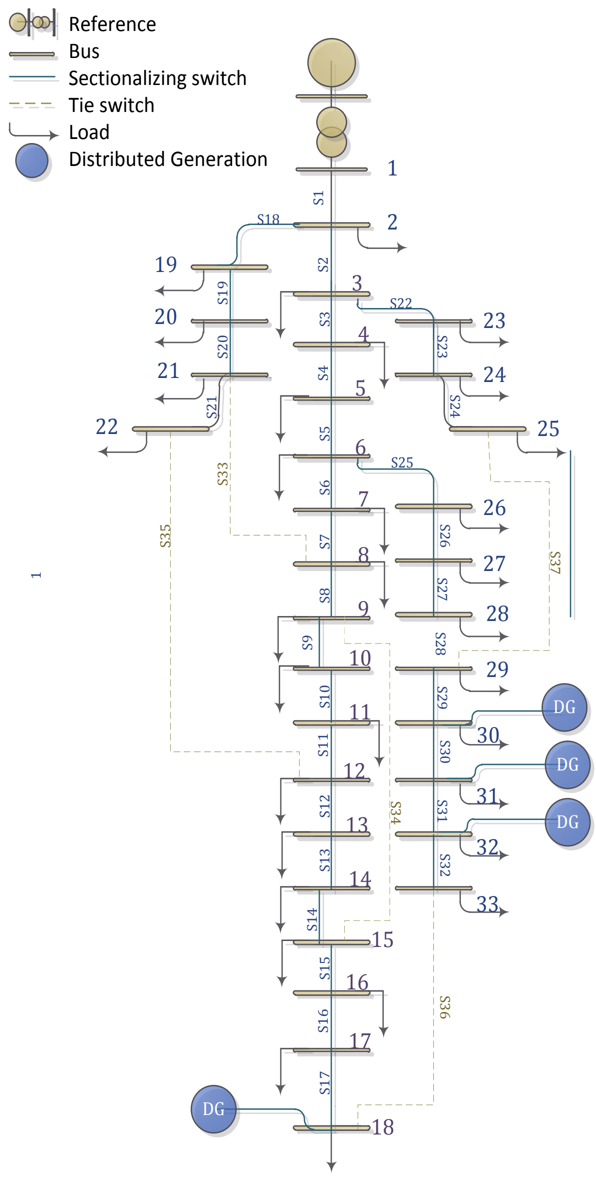



**Figure 5.4** : One Line Diagram of 33-Bus System With Optimally Located DGs.

DGs with the above capacities have been integrated at these nodes in order to uncover the contribution of DGs in loss reduction and to study network reconfiguration in distribution network as following:

### A) Network Reconfiguration for Loss Reduction

Again , power flow has been run and Switching Index has been calculated for each swich in each meshed loop.It has been found that the switches S7,S11,S14,S28 and S36 are the switches with largest Switching Index in meshed1, meshed2, meshed3, meshed4 and meshed5 respectively.Network has been reconfigured and power flow has been run for reconfigured network to examine any constraint violation.Table 5.3.2.5 summarizes Switching Index for each switch in each meshed loop.Values inside red borders in Table 5.3.2.5 are not considered in related meshed loop calculations according to topological constraints.

**Table 5.6** : Calculated Swtiching Index for Case II.

| **Meshed1 switch** | **Index** | **Meshed2 switch** | **Index** | **Meshed3 switch** | **Index** | **Meshed4 switch** | **Index** | **Meshed5 switch** | **Index** |
|---|---|---|---|---|---|---|---|---|---|
| S2 | 0.1878 | S8 | 0.5580 | S9 | 0.8926 | S3 | 0.3859 | S25 | 0.2067 |
| S3 | 0.2943 | S9 | 0.6499 | S10 | 0.8203 | S4 | 0.3450 | S26 | 0.2562 |
| S4 | 0.4240 | S10 | 0.8445 | S11 | 0.6945 | S5 | 0.3738 | S27 | 0.3128 |
| S5 | 0.5593 | **S11** | **0.9694** | S12 | 0.2316 | S22 | 0.4409 | S28 | 0.3811 |
| S6 | 0.8846 | S21 | 0.7712 | S13 | 0.5071 | S23 | 0.6358 | S29 | 0.1367 |
| **S7** | **0.9792** | S33 | 0.5061 | **S14** | **0.9129** | S24 | 0.9143 | S30 | 0.9919 |
| S18 | 0.6157 | S35 | 0.8086 | S34 | 0.8631 | S25 | 0.6067 | S31 | 0.9826 |
| S19 | 0.7675 | | | | | S26 | 0.7292 | S32 | 1.0016 |
| S20 | 0.9246 | | | | | S27 | 0.8470 | **S36** | **1.0018** |
| S33 | 0.9410 | | | | | **S28** | **0.9942** | S15 | 0.5716 |
| | | | | | | S37 | 0.9703 | S16 | 0.6674 |
| | | | | | | | | S17 | 0.9219 |
| | | | | | | | | S34 | 0.6990 |
| | | | | | | | | S6 | 0.8287 |
| | | | | | | | | S7 | 0.9775 |
| | | | | | | | | S8 | 0.6555 |

No constraint violation has been detected and the switches S7,S11,S14,S28,S36 are selected as optimal switches to achieve maximum loss reduction. Table 5.3.2.6 shows comparison between the results of proposed approach and other results.

**Table 5.7**: Comparison Between Proposed Approach Result and Similar Results,Case II.

| | **Joon-Ho-Choi [38]** | | | | **Yuan-Kang [34]** | | | | **Nattachate [40]** | | | **Murthy [39]** | | **Proposed method** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DG location** | 3 | 6 | 24 | 29 | 3 | 6 | 24 | 29 | 22 | 29 | 16 | 6 | 22 | 30 | 31 | 32 | 18 |
| **capacity (KW)** | 50 | 100 | 200 | 100 | 50 | 100 | 200 | 100 | 250 | 500 | 250 | 2560 | 960 | 100 | 100 | 200 | 50 |
| **Final conf.** | S7,S9,S14,S28,S32 | | | | S6,S10,S14,S17,S28 | | | | S33,S34,S9,S32,S28 | | | S7,S9,S31,S35,S37 | | S7,S11,S14,S28,S36 | | | |
| **No of switching** | 10 | | | | 10 | | | | 6 | | | 6 | | 8 | | | |
| **Loss Reduction** | 45.7% | | | | 44.626% | | | | 54.76% | | | 68.8% | | 56.68% | | | |

The resulted total real power loss equals 91.59 KW . The percentage of loss reduction due to closing tie switches and opening the selected switches are 56.68%. This result and Table 5.3.2.6 uncover that the proposed approach is feasible for network reconfiguration planning in the case with DGs

An improvement in voltage profile is noticed after reconfiguring network with optimally replaced DGs. The minimum voltage in reconfigured network is 0.9567 with 5.571% increment. Figure 5.3.2.2 shows the voltage profile before integrating DGs, after integrating DGs and after reconfiguration in the case with DGs.

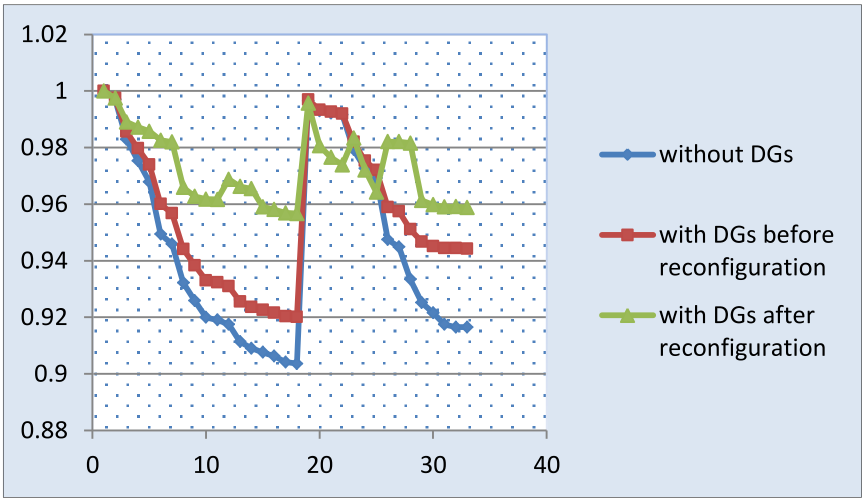



**Figure 5.5**: Voltage Profile After Network Reconfiguration ,CaseII.

**B) Network Reconfiguration for Service Restoration**

The same faults at bus 5 and bus 22 are assumed again in this case. After isolating fault by opening the sectionalizing switches S5 and S22 , two groups have been selected as out-of-service groups. Figure 5.3.2.3 shows the network divided into one feeder group and two out-of-service groups.The switches S11 and S14 are the candidate open switches that connect out-of-service group 2 with feedeg group 1 while the connection between feeder group and out-of-service group 3 can be restored by closing one of the candidate switches S7 and S28.

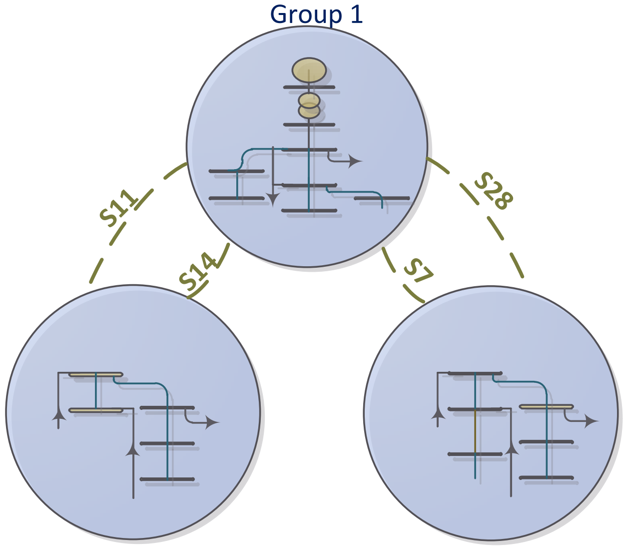



**Figure 5.6** : Candidate Switches for Restoring Service in Case II.

For each out-of-service groups, the switch with smallest switching index must be closed for service restoration.If an open switch is common switch between two meshed groups ,which means that the switch has two Switching Index values,the lowest Switching Index value is chosen.Candidate switches and Switching Index values are recorded in Table 5.3.2.7.

**Table 5.8**: Candidate Switches for Service Restoration in Case II.

| Path | Switch to be closed | INDEX |
|---|---|---|
| 1(to-G1) | S11 | 0.9694/**0.6945** |
| 2(to-G1) | S14 | **0.9129** |
| 3(to-G2) | S28 | 0.9942/**0.3811** |
| 4(to-G2) | S7 | 0.9792/**0.9775** |

Switch S11 and Switch S28 have been selected and closed to restore service in out-of-service groups 2 and 3 respectively.After running power flow to check constraints violations it has been found that S11 and S28 are the optimal switches for servicerestoration where no violation has been detected.Table 5.3.2.8 summarizes these optimal switches for service restoration .

**Table 5.9** : Optimal Switches for Service Restoration Case II.

| Path | Switch to be closed |
|---|---|
| 1(to-G2) | S11 |
| 2(to-G3) | S28 |

The open switches in the new configuration after service restoration are S7,S22,S14,S5,S36 .The resulted total real power loss is 144.47 KW.

### 5.3 Summary of Results

The resulted reconfiguration from case I and case II are the same of the results proposed by El-saadany.However, El-saadany summarized the details only for hourly loads.The total real power loss of initial configuration of 33-bus radial distribution system is 211.43 KW. The proposed approach for network reconfiguration achieved 33.08% loss reduction by reducing the total real power loss to 114.47 KW.In comparison with other results, this results shows that the proposed approach is effective and feasible in network reconfiguration planning.The total real power loss of initial configuration with optimally replaced is 133.47%.Placing DGs using the proposed fuzzy logic model achieved 38.84% loss reduction before determining the optimal configuration .Using the proposed method for network reconfiguration with DGs achieved 56.84% loss reduction and improved the minimum voltage by 5.571%. The summary of these results is written in Table 5.4.1.

**Table 5.10** :Summary of Network Reconfiguration Result.

| | Without DGS | | With DGs | |
|---|---|---|---|---|
| | initial | reconfigured | initial | reconfigured |
| Open switches | S33,S34,S35, S36, S37 | S7,S11,S14, S37, S32 | S33,S34,S35, S36, S37 | S7,S11,S14, S28, S36 |
| Minimum voltage (p.u) | 0.90359 | 0.93838 | 0.92012 | 0.9567 |
| Total loss (KW) | 211.43 | 141.47 | 133.52 | 91.591 |
| Loss reduction | -------- | **33.08%** | **38.84%** | **56.68%** |

The obvious improvement in the network shows that the proposed approach for network reconfiguration and the built fuzzy model for DGs placement are notonly feasible but also effective for balance distribution systems planners.

# 6. Conclusion and Future Work

## 6.1 Conclusion

This thesis aims to provide a favorable approach to enhance distribution network performance and can be divided into two axes :

1. As the advantages of DGs are conditional and dependent on the installation characteristics,in this thesis semi optimal installation characteristic is provided by finding the optimal location for integrated DGs**.**The size of DGs are out of scope of this installation, that is what it is considered as semi optimal.
2. Distribution companies are obsessed with keeping the network secure and reliable.For this purpose they try to maintain network automated and periodically reconfigured to find the most efficient configuration that achieves the necessary security and reliability.

This thesis tries to provide an approach to provide such a configuration for balanced distribution systems. Many researches studied network reconfiguration.Some of these researches applied network reconfiguration for either loss reduction or service restoration and some of them applied it for both. A few number of researches applied network reconfiguration on distribution system with DGs without taking into consideration that the advantages of DGs are conditional and dependant on installation characterestics.

This thesis firstly, provides a fuzzy logic model with normalized power loss reduction and voltage as inputs and Suitability-Degree as output to find the optimal location of DGs to examine the appropriate contribution of DGs in loss reduction.Then provides a simple approach of network reconfiguration for loss reduction and service restoration in balanced distribution system with optimally located DGs.

The proposed approach and the built fuzzy logic model have been applied on 33-bus radial distribution system in order to test the feasibility.Network reconfiguration has been applied as two cases : 1) without DGs , 2) with optimally located DGs.

The percentage of loss reduction and minimum voltage increment have been calculated and recorded after optimally locating DGs, after case 1 and after case 2.All the results prove that the proposed approach are not only favorable but also effective and can be applied on balanced distribution systems.

### 6.2 Future Work

Gaza Strip Distribution Systems have many problems because of Israeli occupation who bombarded the distribution systems many times. As a result, Palestinian people suffer the absence of electricity between 8 to 16 hours per day.The future work will focus on making the proposed methods more comprehensive to make it applicable for Gaza Strip Distribution Syestems by taking into account the characteristics of unbalanced distribution systems and the variable load demand.

A vision of such multi objective future work including loss minimization, load shedding minimization, cost minimization ,optimally locating DGs and optimally sizing DGs requires widespread use of artificial intelligent methods and machine learning algorithm.

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## APPENDICES

**APPENDIX A:** System data.

**APPENDIX B:** One line diagram.

**APPENDIX C:** Fuzzy logic model using SIMULINK and FUZZME.

## APPENDIX A

**Table A.1**: 33-bus Distribution Branch Data.

| **Node i** | **Node j** | **Resistance** R (Ω) | **Reactance** X(Ω) |
|---|---|---|---|
| 1 | 2 | 0.0922 | 0.047 |
| 2 | 3 | 0.493 | 0.2511 |
| 3 | 4 | 0.366 | 0.1864 |
| 4 | 5 | 0.3811 | 0.1941 |
| 5 | 6 | 0.819 | 0.707 |
| 6 | 7 | 0.1872 | 0.6188 |
| 7 | 8 | 0.7114 | 0.2351 |
| 8 | 9 | 1.03 | 0.74 |
| 9 | 10 | 1.044 | 0.74 |
| 10 | 11 | 0.1966 | 0.065 |
| 11 | 12 | 0.3744 | 0.1238 |
| 12 | 13 | 1.468 | 1.155 |
| 13 | 14 | 0.5416 | 0.7129 |
| 14 | 15 | 0.591 | 0.526 |
| 9 | 15 | 2 | 2 |
| 15 | 16 | 0.7463 | 0.545 |
| 16 | 17 | 1.289 | 1.721 |
| 17 | 18 | 0.732 | 0.574 |
| 2 | 19 | 0.164 | 0.1565 |
| 19 | 20 | 1.5042 | 1.3554 |
| 20 | 21 | 0.4095 | 0.4784 |
| *8 | 21 | 2 | 2 |
| 21 | 22 | 0.7089 | 0.9373 |
| *12 | 22 | 2 | 2 |
| 3 | 23 | 0.4512 | 0.3083 |
| 23 | 24 | 0.898 | 0.7091 |
| 24 | 25 | 0.896 | 0.7011 |
| 6 | 26 | 0.203 | 0.1034 |
| 26 | 27 | 0.2842 | 0.1447 |
| 27 | 28 | 1.059 | 0.9337 |
| 28 | 29 | 0.8042 | 0.7006 |
| *25 | 29 | 0.5 | 0.5 |
| 29 | 30 | 0.5075 | 0.2585 |
| 30 | 31 | 0.9744 | 0.963 |
| 31 | 32 | 0.3105 | 0.3619 |
| *32 | 33 | 0.341 | 0.5302 |
| *18 | 33 | 0.5 | 0.5 |

**Table A.2**: 33-bus Distribution Bus Data.

| Node | P (KW) | Q(KVAr) |
|---|---|---|
| 2 | 100 | 60 |
| 3 | 90 | 40 |
| 4 | 120 | 80 |
| 5 | 60 | 30 |
| 6 | 60 | 20 |
| 7 | 200 | 100 |
| 8 | 200 | 100 |
| 9 | 60 | 20 |
| 10 | 60 | 20 |
| 11 | 45 | 30 |
| 12 | 60 | 35 |
| 13 | 60 | 35 |
| 14 | 120 | 80 |
| 15 | 60 | 10 |
| 16 | 60 | 20 |
| 17 | 60 | 20 |
| 18 | 90 | 40 |
| 19 | 90 | 40 |
| 20 | 90 | 40 |
| 21 | 90 | 40 |
| 22 | 90 | 40 |
| 23 | 420 | 200 |
| 24 | 420 | 200 |
| 25 | 60 | 25 |
| 26 | 60 | 25 |
| 27 | 60 | 20 |
| 28 | 120 | 70 |
| 29 | 200 | 600 |
| 30 | 150 | 70 |
| 31 | 210 | 100 |
| 32 | 60 | 40 |

**APPENDIX B**

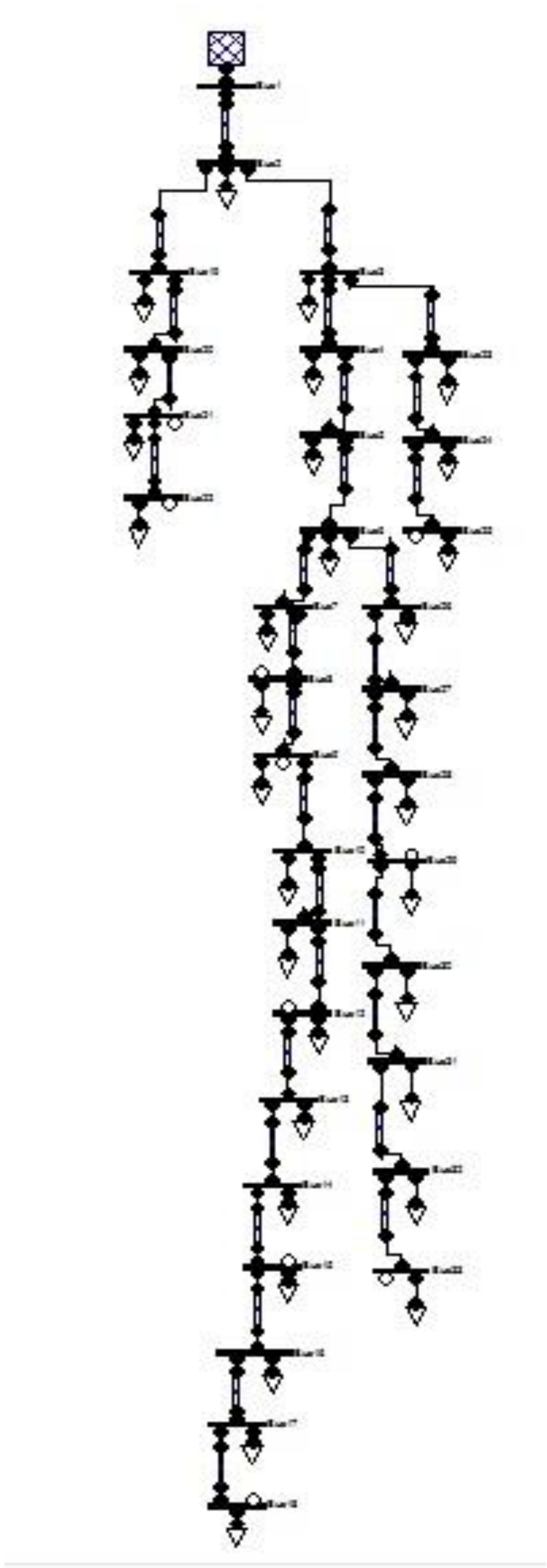

**Figure B.1**: One Line Diagram of 33-bus Distribution System Using PSAT.

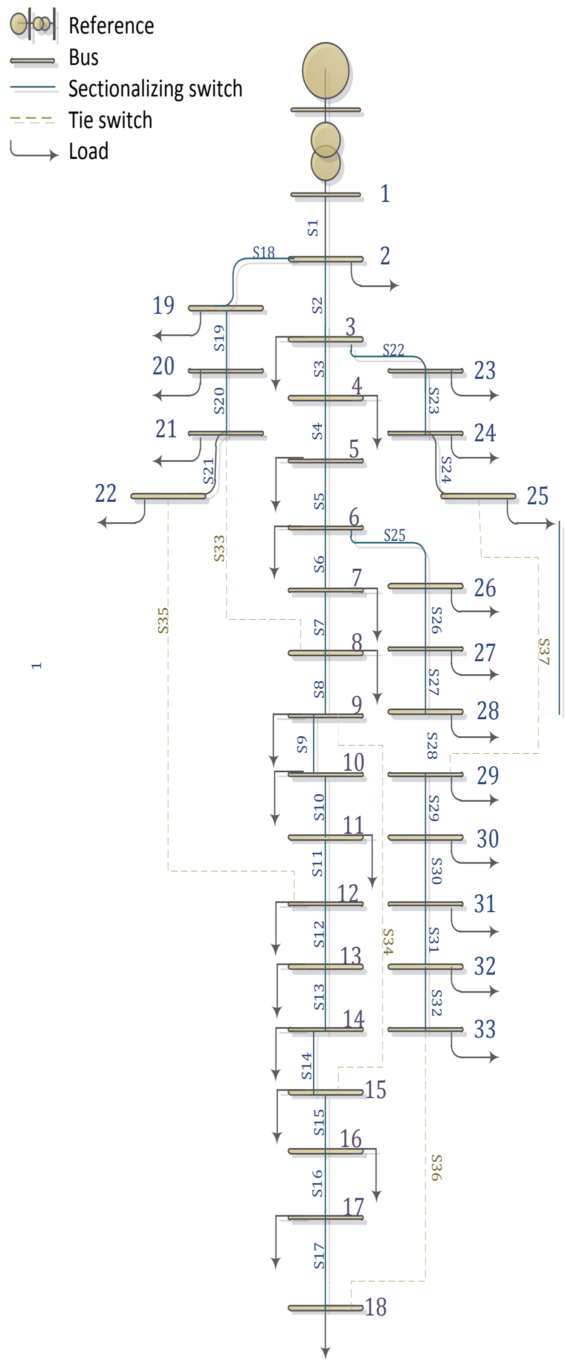


**Figure B.2**: One Line Diagram of 33-bus Distribution System Using Microsoft Visio.

**APPENDIX C**

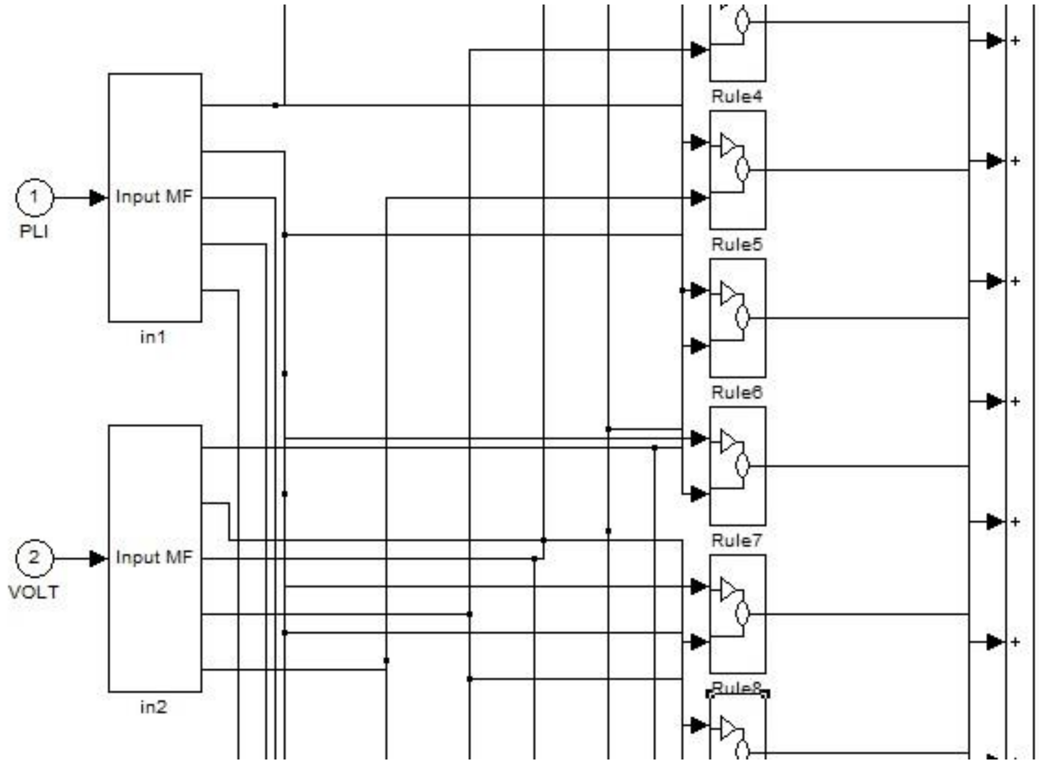


**Figure C.1**: Snapshot of The Designed Fuzzy Model Using SIMULINK.

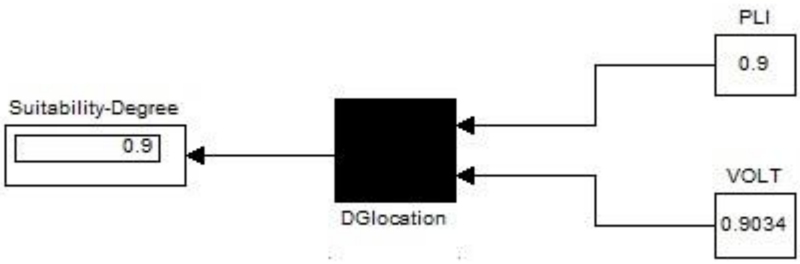


**Figure C.2**: Outer Snapshot of Designed Fuzzy, SIMULINK.

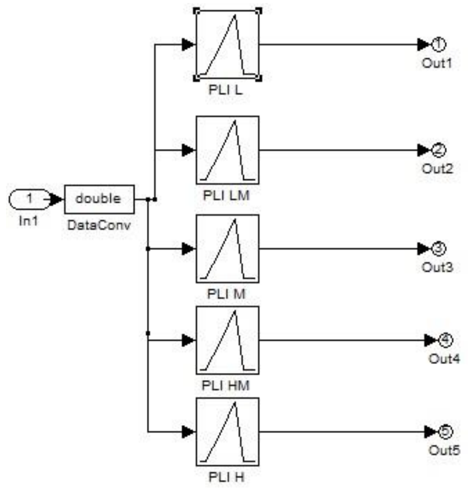


**Figure C.3**: PLI Input with Five Triangular MFs, SIMULINK.

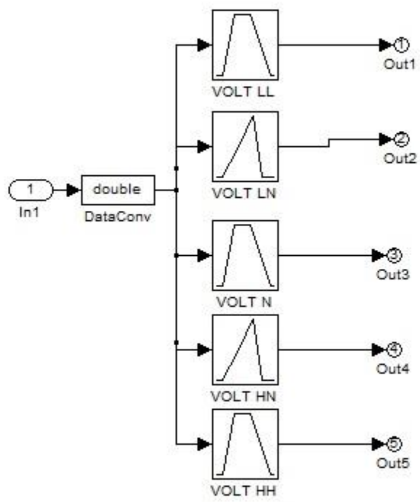


**Figure C.4**: VOLT Input with Five Triangular and Trapezoidal MFs, SIMULINK.

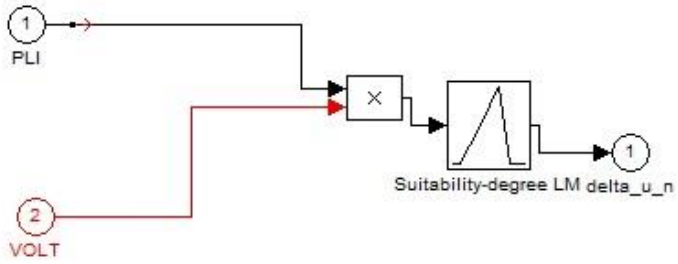


**Figure C.5**: Inner Snapshot of 1/25 Rules,SIMULINK.

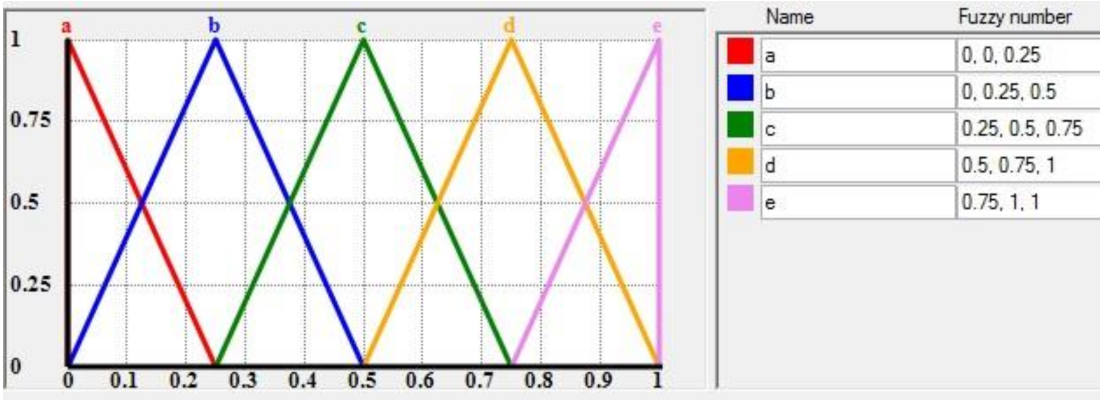


**Figure C.6**: Membership Functions Defining and Editing, FUZZME.

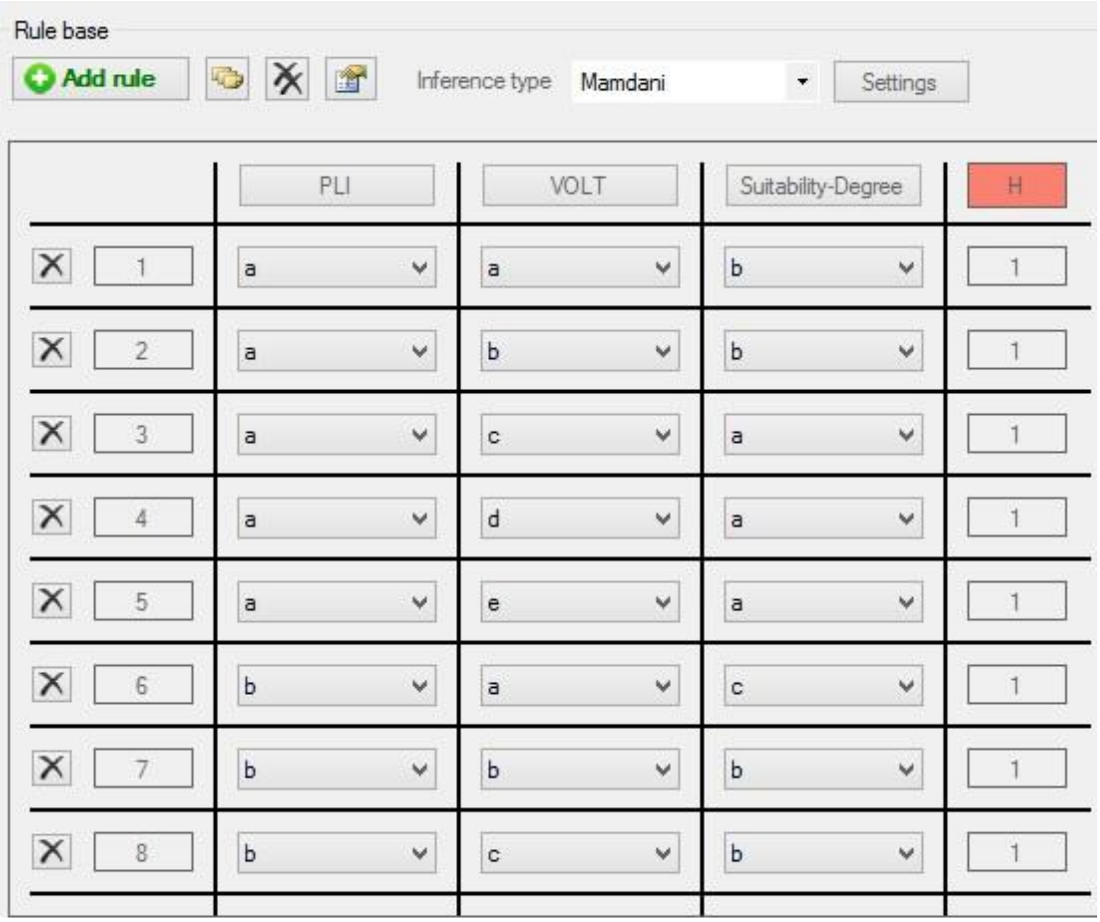


**Figure C.7**: Defining and Editing Rules, FUZZME

**CURRICULUM VITAE**

**Name Surname:** Mahmod  Abusall

**Place and Date of Birth:** Gaza – Palestine. 10/07/1986

**Address:** Turkey, Istanbul, Sariyer,

**E-Mail:** abusall@itu.edu.tr

**B.Sc.:** Electrical and Communication Engineering 2009, Islamic Univeristy of Gaza, Palestine.