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Load Factor Improvement of Distribution Feeders by Feeder Reconfiguration Using Binary Particle Swarm Optimization

by

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A THESIS

SUBMITTED TO THE DEPARTMENT OF ELECTRICAL ENGINEERING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN POWER SYSTEM ENGINEERING

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The undersigned certify that they have read and recommended to the Institute of Engineering for acceptance, a thesis entitled "**Load Factor Improvement of Distribution Feeders by Feeder Reconfiguration Using Binary Particle Swarm Optimization**" submitted by **Ram Prasad Jnawali** in partial fulfilment of the requirements for the degree of Master of Science in Power System Engineering.

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ABSTRACT

The power industry restructuring has created many opportunities for customers to reduce their electricity bills. In liberal power market, the selling and buying of energy is now becoming like that of other commodities. Introduction of private players and various companies in the energy market has created more competition in the market and hence assuring the reliability and quality of energy supplied to consumers and thus ending the monopolistic behavior of vertically integrated utilities. In such liberal market, there are various options for consumers, the bargaining power of the consumers has now increased. There is continuous flow and exchange of information between the buyers of energy, suppliers of energy and the market. The various participants in the market can make their decisions independently. The consumers of energy take time to time information from the market and make their strategies to get more and more benefit from the market. The group of consumers can adjust their loads based on price signals in the market.

To maximize the benefit from the market, load aggregation is a strategy in which different types of consumers make an alliance to secure more competitive price by negotiating with the energy suppliers. In some contracts between group of consumers and the energy suppliers, the load factor is being considered as one critical aspect of load aggregation. If the load factor for a group of consumers is higher, the more flatter is the load profile and in such type of load profile the attraction of energy suppliers is more and so the negotiating power of consumers increases.

In order to aggregate the diversified customers in the distribution system and hence to meet the load factor requirement in the power purchasing contract, feeder reconfiguration for load factor improvement is presented in this thesis. Also the losses before and after the reconfiguration are calculated and finally total cost of energy supplied is calculated. Since feeder reconfiguration is a binary type of optimization problem, discrete version of Particle Swarm Optimization is used.

A sample three feeder network and a three feeder network from Patan substation of Nepal Electricity Authority is considered and feeder reconfiguration problem is solved. The load factor of the feeders is increased by 1.495%, 15.59%, 7.44% and 17.95%, 5.90%, 6.44% for respective networks. Due to this improvement in load factor, the daily cost of energy supply is decreased from Nrs. 56638.15 to Nrs. 55895.82 and Nrs. 781264.99 to Nrs. 780827.46 respectively although the power loss increased from 1.54 kW to 2.22 kW and 24.29 kW to 42.78 kW.

ACKNOWLEDGEMENT

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LIST OF ARRONYMS AND ABBREVIATION

Genco	Generating Company
Transco	Transmission Company
Disco	Distribution Company
Resco	Retail Energy Service Company
PPA	Power Purchase Agreement
IPP	Independent Power Producer
NC	Normally Closed
MATLAB	Matrix Laboratory
NO	Normally Open
PSO	Particle Swarm Optimization
BPSO	Binary Particle Swarm Optimization
kW	Kilo Watt
kWh	Kilo Watt Hour
P_{best}	Particle Best
G_{best}	Global Best

LIST OF PUBLICATIONS

Paper 1

R. P. Jnawali, K. B. Thapa, and N. R. Karki, “Load Factor Improvement of Distribution Feeders by Feeder Reconfiguration Using Modified BPSO Considering Losses, ” in International Conference on Sustainable Energy and Future Electric Transportation, Jan 2021. *Manuscript.*

INTRODUCTION

1.1 Background

Deregulation of power industry has now become a global trend as a method of best practice, reforming power sector towards more competitive market adopted after the success of markets in leading countries like Chile, Norway, Sweden, UK, parts of United States, parts of Canada and Australia. The motivation towards restructuring of the power system after global economic liberalization is to remove the monopolistic behavior of vertically integrated utility and thereby promoting competitive trade of energy. The vertically integrated electric utilities did not provide any incentive to users for its efficient operation in past. Also, the change in power generation technologies and various possibilities of building the power plants near load centers generating cost effective power helped for the private players i.e. independent power producers. High tariffs, managerial inefficiency, rise of environmental concerns, global economic scenarios and the shortage of public resources for investment also contributed for restructuring of the power industry [1]-[3].

In deregulated environment, the participants can take their decisions independently. They receive time to time information from the market and make and prepare for the strategies to maximize their benefit. The consumers can adjust their loads according to the price signals from the market. There are numbers of choices for the customers to purchase the energy based on their bidding price, reliability, power quality and mutual agreement and every customer wants to buy the energy as cheap as possible. To obtain this benefit, one approach is to aggregate the loads which involves consolidation and profiling of the various types loads supplied to various types of customers. In some contracts, load factor is considered as one critical aspect of aggregation [4].

Load aggregation is a mechanism where different types of energy consumers band together in an alliance to secure more competitive price by negotiating with the energy suppliers. Aggregation of load allows smaller customers to increase their purchasing power in the market and hence negotiating attractive rates for energy. Proper aggregation of load can produce savings for customers and reduce generation cost for producers. By load aggregation, the load factor of the distribution feeders can be increased and due to this the price of energy to the customers will decrease. The load aggregation in an area with different types of customers, fed by numbers of distribution feeders can be done with feeder reconfiguration technique which leads to better values of load factors for the individual feeders [4][12].

The load factor of a feeder is the ratio of average load supplied by the feeder to peak load supplied under period of study. In any area there are diversified customers getting energy from different feeders. As all the customers in any area cannot be supplied with a single feeder due to power loss and voltage drop issues, numbers of feeders are required to cover the whole area. If individual feeders are supplying more similar types of loads, the load factor of the feeder will be poor, leading to less smooth and less predictable load profile of the feeder due to low diversity, effect of this is reflected in the unit price of the energy.

It is better to supply more dissimilar types of loads by the individual feeders. The more dissimilar types of loads means that the load profiles are less overlapped. On doing so, the load factor of the individual feeders will be improved and hence more smooth and more predictable load profile of the individual feeders will be achieved due to high diversity. So, betterment of load factor for individual distribution feeders by feeder reconfiguration through load aggregation is significant.

1.2 Problem Statement

Load factor is very important aspect regarding electric power distribution system. Every electric power distribution system supplies energy to variety of consumers having different behavior or profiles viz. residential, commercial, industrial and others. The energy requirement of a particular area is nearly fixed for a time period but the smoothness and predictability of load profile of every feeder depends upon the value of load factor. Higher the value of load factor, more smooth and predictable the load profile of the feeder and vice-versa. So, if we are able to get high value of load factor, it is beneficial and attractive to the energy suppliers and hence there is a chance to capture sufficient purchasing power negotiating attractive rates based on price signals from the market by end users.

In restructured power industry, there are many opportunities for the customers to reduce the energy bill. Some power retailers may specialize in one or few types of customer. Any typical energy supplier may have only base load generation to sell, then such supplier tries to focus on finding customers with flat daily load curves, this means finding customers whose needs best match the profile of the company's particular products and services. In some cases there may be a type of customers having very uncertain and unpredictable power demand and hence having very poor load factor. If such type of customers make an alliance with other types of customers through aggregation, all of them will get the power and at reasonable and competitive price by negotiating with the energy supplier by making more comfortable and practical to the supplier too.

The energy suppliers can make price signals based on the value of load factor of the end users or in some cases they may fix the threshold value of the load factor as requirement of the users. If different types of diversified loads are aggregated, this requirement may meet and they can bargain with the supplier allowing the customers to buy electricity at lower price. So, in every area supplied by numbers of feeders, it is very good to have high value of load factor for each distribution feeders.

There are various methods for load factor improvement. Demand side management is one method in which the consumers try to make the load profile as flat as possible by reduction in simultaneous use of multiple load as possible. Feeder reconfiguration is an approach in which the different types of the loads in an area fed with numbers of distribution feeders are aggregated so as to improve the load factor of individual feeders getting advantage of diversity of different types of consumers.

The power and energy losses change after reconfiguration. The calculation of cost of energy supplied considering those losses is necessary to compare cost of energy before and after reconfiguration.

In feeder reconfiguration, to meet the objective with numbers of network constraints, the optimization is done to have best opening and/or closing of sectionalizing switches and tie switches. Being a binary type of optimization problem, corresponding optimization technique can be used.

1.3 Objective and Scope of the thesis

The main objective of this research work is to improve the load factors of the individual distribution feeders feeding a particular area taking a sample case and practical case through feeder reconfiguration technique using MATLAB considering all the possible constraints.

In order to achieve the main objective, the following sub-objectives are set.

1. To derive the load pattern of different types of energy consumers in the corresponding distribution system.
2. Mathematical modeling i.e. defining objective function and constraints for optimization.

3. Review of different papers, analysis and comparison of different methods/approaches to solve the optimization problem and select the best one.

4. Development of algorithm and hence MATLAB program to realize the selected approach of optimization.

5. Checking the validity and performance of the developed model through statistical analysis if necessary and comparison with other methods if possible.

6. Finally comparing the load factors, losses and cost of energy supplied before and after reconfiguration to draw conclusions.

1.4 Outline of this thesis

This thesis has been organized into following chapters.

Chapter 1 gives brief introduction regarding restructuring of power system, importance of deregulated power market over monopolistic power market, buying/selling of energy in such market, relationship of load factor with price signal in the market along with objective and scope of this thesis.

Chapter 2 gives the overview of literature review on restructuring of power system, market behavior and factors affecting the market, market models, cost of electrical energy, load aggregation, methodologies for load pattern determination, load factor and importance, network reconfiguration, optimization techniques, their limitation and modification made.

Chapter 3 presents the methodology used for modeling and simulation for the feeder reconfiguration purpose.

Chapter 4 includes the test system under consideration, tools and software used.

Chapter 5 describes MATLAB simulation, output analysis i.e. calculation and comparison of load factors, losses and cost of energy before and after reconfiguration.

Chapter 6 summarizes this thesis and highlights the contribution of the thesis.

Finally this thesis ends with list of reference papers used for this research work.

LITERATURE REVIEW

2.1 Restructuring of the power system

The power industry across the world is experiencing radical changes in its business as well as operational model. Earlier, the activities of power generation, transmission and distribution used to own, operate and manage by a single utility in a given area of operation i.e. the vertically integrated utilities. But these days, such vertically integrated utilities are being unbundled and opened up for competition with the private players, enabling the end of monopoly of those vertically integrated utilities and developing the electric power as a commodity.

2.1.1 Regulated electricity market

Regulated electricity market may be owned by private or government entity (utility) with monopolistic business and bundled structure (generation, transmission and distribution owned by same) in which government has set down laws that put limits on how a particular company can operated. Moreover, in regulated electricity market economy of the market is restricted by predefine laws or by laws or rule which may not be beneficial to buyer or seller choice to get electricity at competitive price.

Structure of regulated electricity market

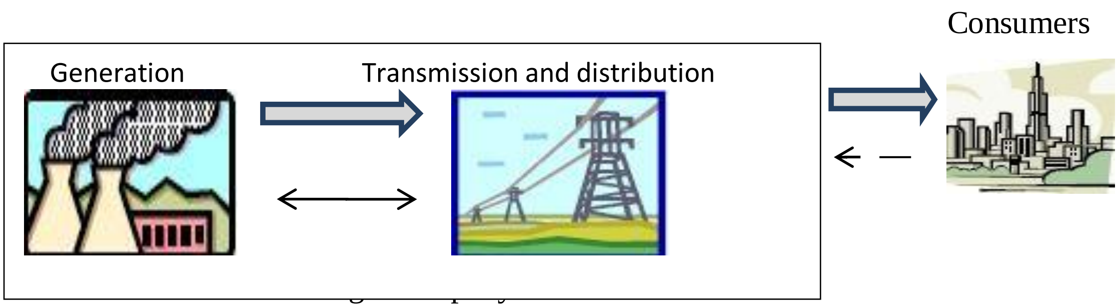


Figure 2.1 Structure of regulated electricity market

Symbols: Energy flow Information flow Money flow

The above figure shows the structure of regulated electricity market where the direction of energy flow, information flow and money flow are indicated. The flow of money is unidirectional and the information flow is only between the generators and transmission systems.

Characteristics of regulated electricity market

1. No competition

Since the generation, transmission and distribution system owned, operated and managed by single entity/utility, there is no chance of competition as in case of other commodities. Due to this reason the price of energy will high and there may be lack of quality too, as in case of competitive market the consumers can buy commodity at lower price and of acceptable quality.

2. Universal supply obligation

The utility must provide electricity service to all the types of consumers in all possible places and not only to those where the profit is more.

3. Regulated framework

The rates are set in accordance with government rules, regulations and guidelines and all the utility's business and operating practices must be in accordance with those rules, regulations and guidelines.

Drawbacks of regulated electricity market

1. Lack of competition.
2. Lack of focus to consumer's requirements.
3. Lack of innovation, no optimization and less efficient operation.

2.1.2 Deregulated electricity market

The meaning of deregulation is regulation after unbundling. The deregulation is also known as re-regulation, restructuring, reform, liberalization etc., which involves separating the business of transmission from business of generation and business of distribution from business of transmission. Thus these three mutually exclusive functions are created and there are separate entities or companies that control these functions. The competition is introduced in generation activity by allowing other private participants. Now there is a scope for private players to sell their generated energy at competitive prices. The generator owned by earlier vertically integrated utilities will then compete with those private players. There is open access of transmission line and multiple distribution companies. The wheeling charge for transmission of energy is fixed by independent regulatory authority. The customers can buy the required amount of energy through the generating companies directly or from the local distribution companies at competitive prices by good negotiation. The consumers can make the strategies based on market information which may change time to time and also based on price signal on market.

Structure of deregulated electricity market

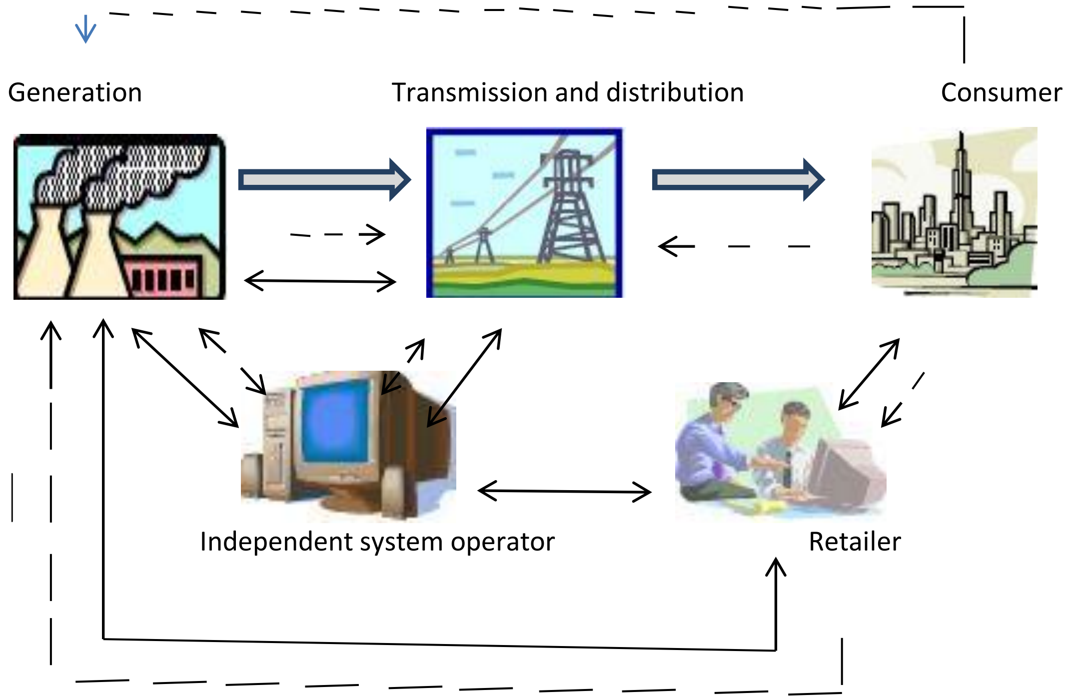
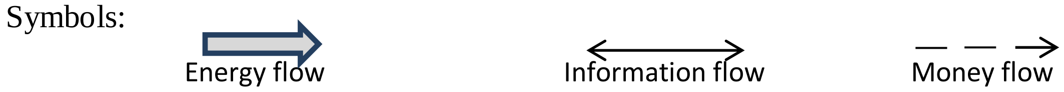


Figure 2.2 Structure of deregulated electricity market



The above figure shows a typical structure of deregulated electricity market where the flow of energy, information and money is as indicated. There are various models of such deregulated electricity market but the objective of all those models is same. As shown in above figure, the consumers receive time to time information from the market and make and prepare for the strategies to maximize their benefit. The consumers can adjust their loads according to the price signals from the market. There are numbers of choices for the customers to purchase the energy based on their bidding price, reliability, power quality and mutual agreement.

Various entities involved in deregulated environment

1. Genco (Generating Company) : These are the entities who are responsible to generate electricity using different technologies. These companies may be the generators of earlier vertically integrated utility or other independent power producers i.e. private players. Those generating companies can sell their energy directly to the customer or through the local distribution companies or from retail energy service

company. Genco sells energy at its sites in the same manner that a fuel mining company might sell fuel in bulk amount at its mine. These companies may build the power generation plant near area using different technology and sell directly to the consumers or to the local distribution company.

2. Transco (Transmission Company) : The transmission company owns and develop physical infrastructure to transmit the bulk amount of power from generation location to consumption location. The wheeling charge for the transmission of the power is fixed by independent regulatory authority. They have to perform regular management and various engineering functions for regular and smooth running of the system considering various internal and external disturbances and constraints imposed.

3. Disco (Distribution Company) : This company owns, operate and manage its local distribution network. This may or may not sell the energy directly to the end users. It may directly sell the energy to the individual consumers or it may combine its function with retail function or in some cases the distribution company only owns and operate the local distribution network and obtains its revenue by wheeling the energy through its network.

4. Resco (Retail Energy Service Company) : These companies don't have their own physical network as an asset. They may work as a mediator between seller and buyer of energy. They may buy energy from Genco and sell the energy directly to the consumers or they may work along with the local distribution companies.

5. Market Operator : They provide a platform for buying and selling of energy between generator and consumers. In the market the energy generator/seller may put types of offers and based on market situation and price signals, the consumers may make their strategies. So, the Market Operator runs the computer program that matches the various offers made by sellers and buyers and hence settling the market.

6. System Operator : It is an independent regulatory authority carrying the responsibility of ensuring reliability, security and quality in the market and not participating in the electricity market trade. It makes various rules, regulations and guidelines for the trade of electricity, fixing the wheeling charge of electricity, fixing and regulating the rate of energy in the market and so on.

7. Customers : In a completely deregulated market, the customers can buy the energy like other commodities in competitive price according to their choice. They can directly buy the energy from the generators or from the local distribution companies or from the retail energy service company wherever possible. Based on market

behavior, the seller of energy can make and change their offers time to time. The customers getting the information of market time to time can set up their strategies. Different types of customers can make an alliance based on the offers on the market to take advantage of their diversity and can negotiate with the sellers to get the energy in competitive prices.

2.1.3 Market models

The objective of restructuring in electricity market is to make the buying and selling of electrical energy similar to other commodities, which we use in our everyday life. The classification of market models gives the idea of how buying and selling of energy can be done in market, which arrangement of energy trade is more unbundled and which is less unbundled and so on.

Market models based on extent of deregulation

The meaning of deregulation is regulation after unbundling. So, the first task is to unbundle the vertically integrated nature of utilities. Then after unbundling, there is an independent regulatory authority which should not be an arm of the government, to regulate the various companies that came after unbundling and hence to regulate the trade of electrical energy. The various models based on extent of competition or extent of choice for consumers are as follows.

Monopoly model

The monopoly model is such model in which the generation, transmission and distribution of electrical energy is owned and done by a single entity, normally the government owned utility. In Nepal, the task of generation, transmission and distribution of electrical energy is done by Nepal Electricity Authority, which is government owned utility, but in generation side some private parties are also engaged. These utilities are also known as vertically integrated utilities. Since, the generation, transmission and distribution of electrical energy is done by single entity, there is no competition and there are no choices for end users. These days the government of Nepal is making forward steps for restructuring of power industry. Separate transmission company has established for infrastructure development for transmission of electrical energy within the country from generation sites to consumer sites as well as for cross-border transmission of energy. An independent regulatory authority has established and started its function to regulate the electricity market regarding various aspects. Also, the annual budget of fiscal year 2077-78 has emphasized on the restructuring of this vertically integrated nature of electricity market. The monopoly market nature is as shown is following block diagram.

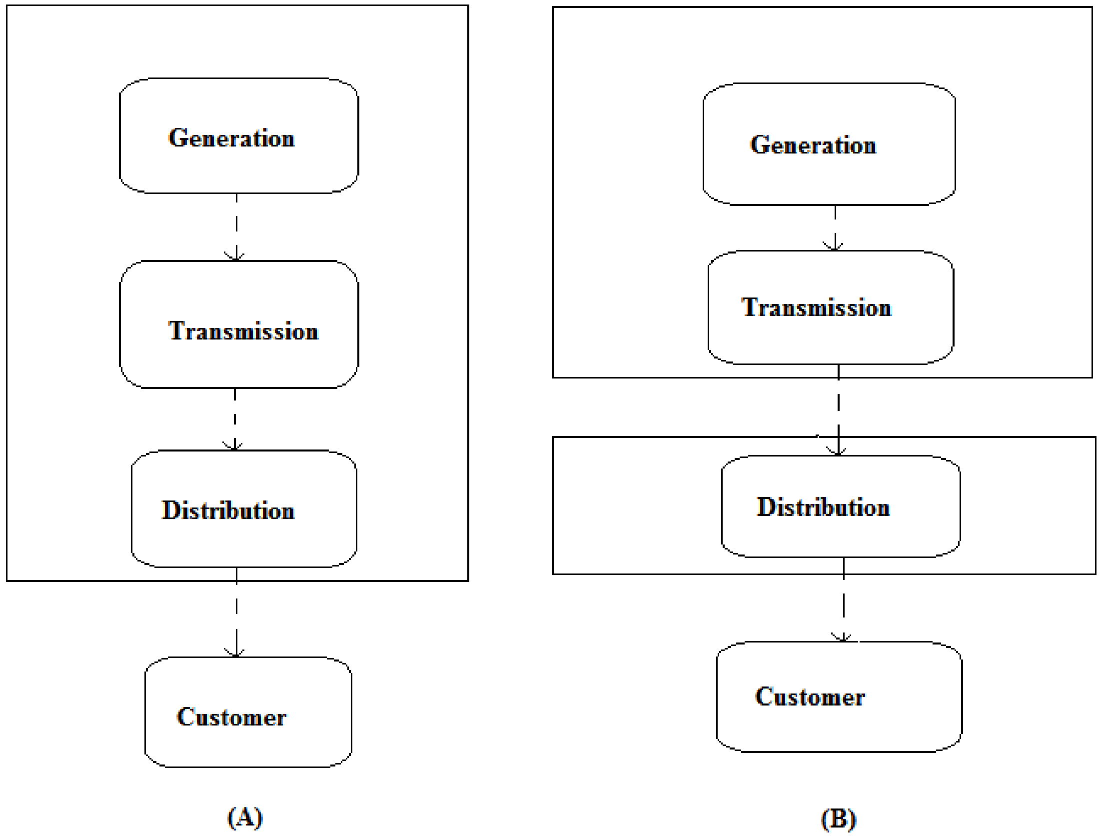


Figure 2.3 Two cases of monopoly models

In case (A), entire task of generation, transmission and distribution is owned and done by single entity where as in case (B), generation and transmission is done by one entity and distribution is done by another entity. In both the cases there are no choice for end users.

<u>Single buyer model</u>

The objective of liberalization of economy is to engage and introduce more and more private investors and participants in the market so that the consumers could get the required commodities at relatively cheaper price and of better quality. In this single buyer model, though there is no choices for end users, the private electricity generators i.e. independent power producers (IPP) can take participation in the market. Here, a single entity buys energy generated by independent power producers in addition to its own generation. There exists a long term contract between those independent power producers and the single buyer entity regarding buying and selling of energy between them which is also known as power purchase agreement (PPA).

Since the terms and conditions are similar for all the independent power producers, there exists little competition in generation side though there are no choices for end users. This model seems good for increasing interest on participation of private players in the market in developing countries.

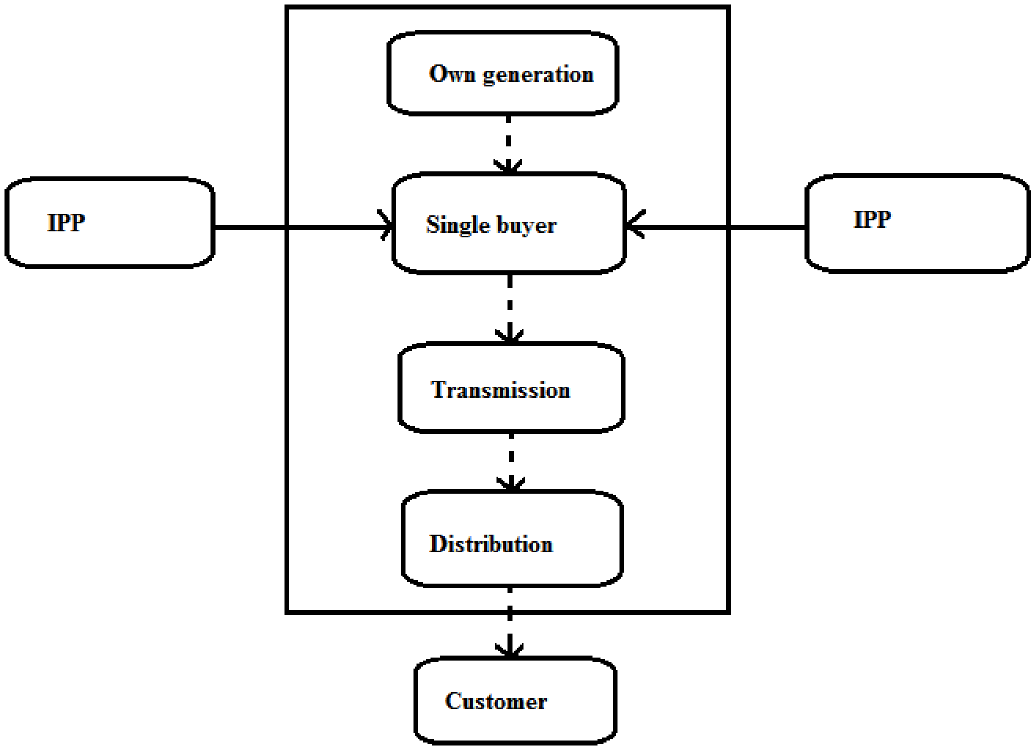


Figure 2.4 The single buyer model

In another version of single buyer model as shown in figure 2.5, the buyer does not owns its own generation, the electricity is generated by independent power producers and sold to the single buyer through long term contracts. Then the buyer supplies energy to its consumers through one or more distribution companies.

Advantages of Single buyer model

a. Involvement of private parties in generating market helps for utilization of available resources in the country and hence increasing the GDP.

b. A little competition in generation side with little investments.

Disadvantages of Single buyer model

a. No perfect competition.

b. No choices for end users.

c. Prices to the end users are commanded.

d. Doing power purchase agreement with single buyer is complex.

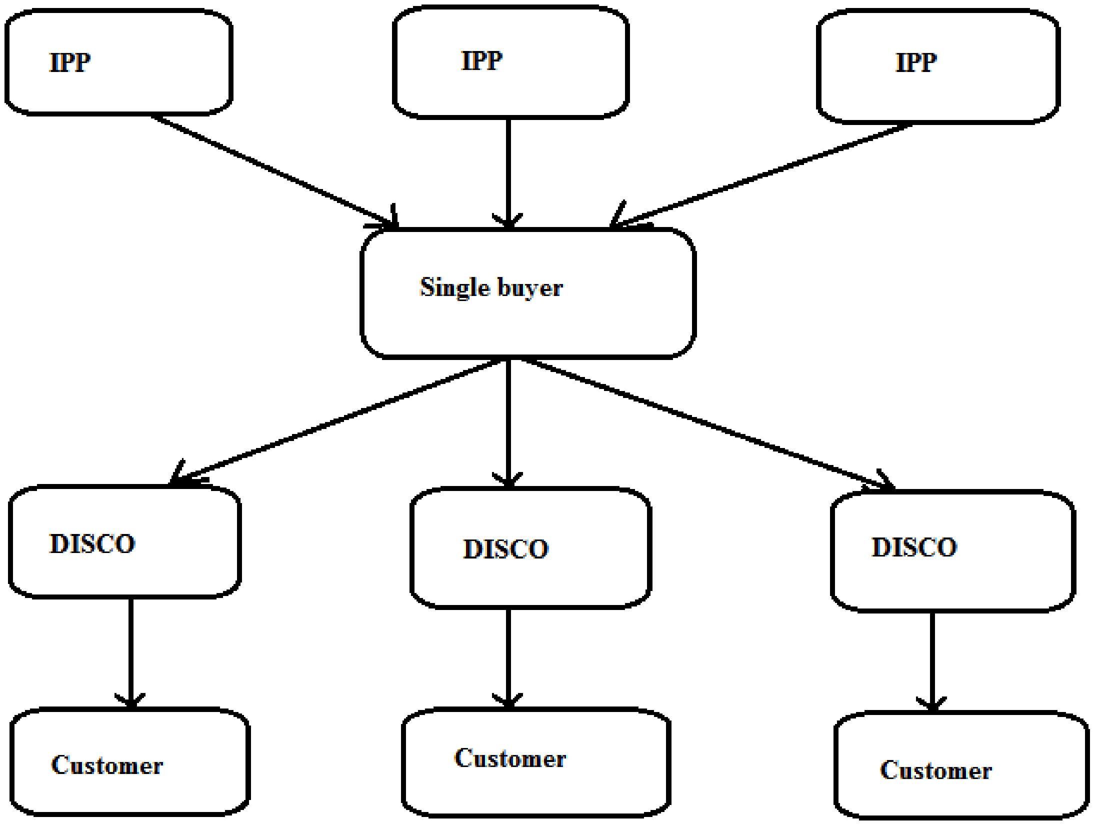


Figure 2.5 Single buyer model with only IPPs

<u>Wholesale competition model</u>

Here, there are multiple generating companies and multiple distribution companies. There is competition at generation level and multiple distribution companies can buy energy from the wholesale market place in competitive prices and sell to their consumers. Some big consumers can directly buy energy from the wholesale market place through competition. The energy retailers can also buy energy from wholesale market place and sell their consumers. The important thing is that still there is no choice at small end consumers levels because they have to buy energy from the single distribution company or energy retail company in that particular area. There is open access of transmission line where as the distribution companies in particular area own and operate the distribution system in their own and hence those distribution companies have monopoly over the customers. This model is more close to fully deregulated model.

Advantages of Wholesale competition model

1. This is the model which is more close to 100% deregulated model.

2. Competition at generation level.

3. The distribution companies, bulk consumers and retail companies can buy energy from wholesale market place with competition.

4. Open access of transmission lines.

Disadvantages of Wholesale competition model

1. Still no choices for end users.

2. In small consumer level, the rate is not determined by interaction of demand and supply.

The block diagram for wholesale competition model is as shown in figure 2.6 as below.

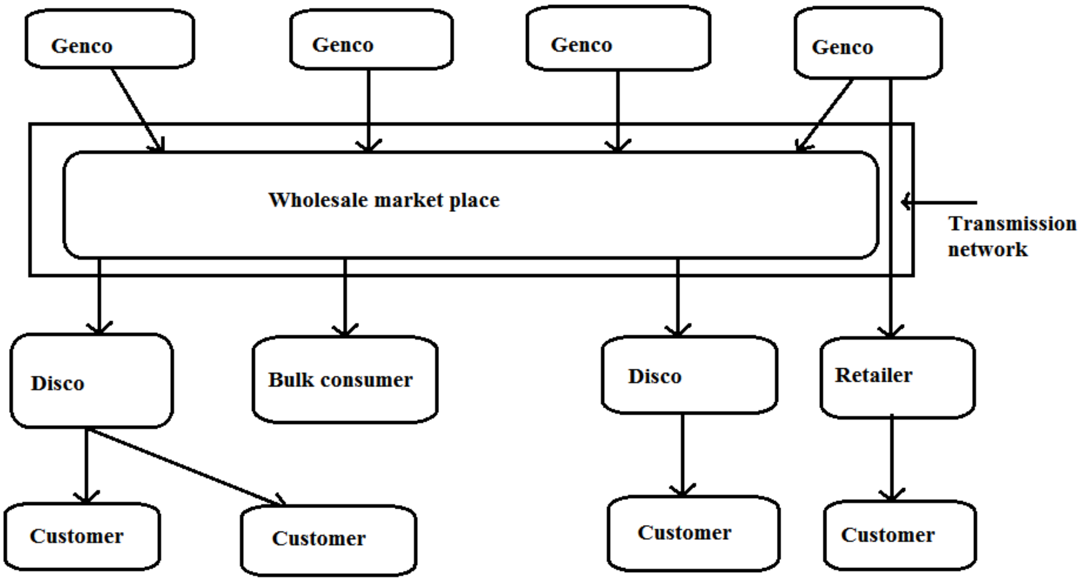


Figure 2.6 Wholesale competition model

Retail competition model

The retail competition model is supposed to be 100% deregulated model. In this model, there is competition is generation as well as distribution. There is open access of transmission and distribution lines. The end users have multiple choices. There are two markets namely wholesale market and retail market. Both the big consumers as well as small consumers can buy energy from either wholesale market or retail market. The consumers can buy energy directly from generating companies or from distribution companies or from retailers. The retail energy market is similar to the market where we buy vegetables in everyday life.

Advantage of retail competition model

1. Every individual consumer has choice to buy power.

2. This model is supposed to fully deregulated model.

3. This model supports the concept of liberal economy.

4. This model is in accordance with mixed economy i.e. mixing of command economy and market based economy.

5. The price of energy is depending upon interaction of demand and supply, and hence true competition occurs.

6. Effective load aggregation increases the bargaining power of consumers.

Disadvantage of retail competition model

1. The management is complex due to large number of participants.

2. Huge infrastructure development is required.

The following block diagram realizes the concept of retail competition model.

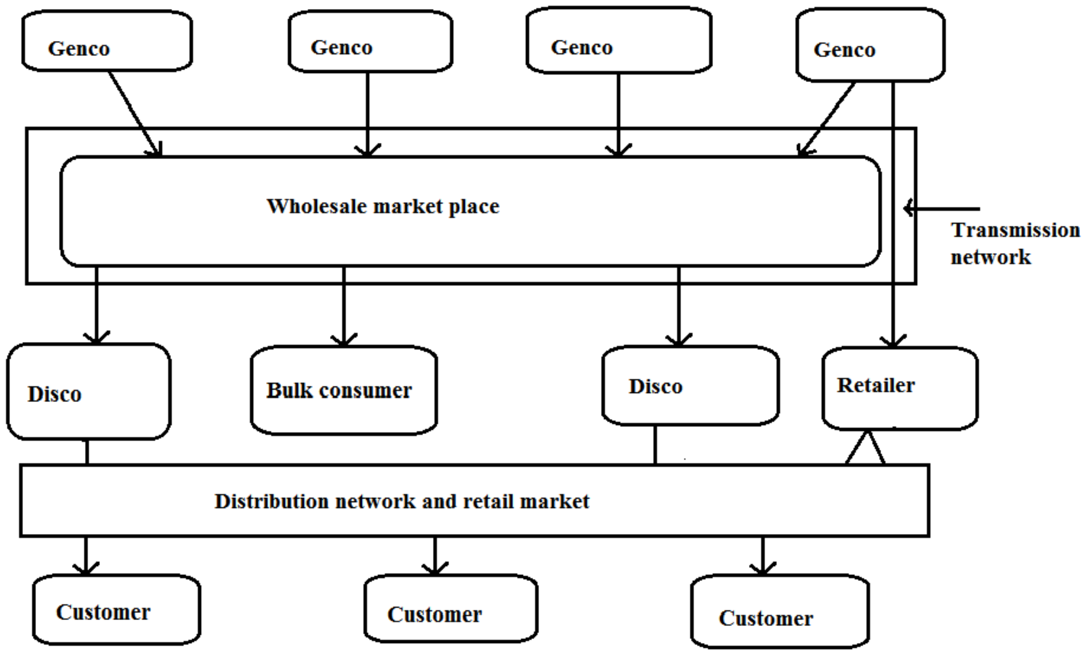


Figure 2.7 The retail competition model

2.2 Cost of electrical energy

There are various sources of energy in the world. Some are renewable sources of energy and some are non-renewable source of energy. Whether the source is renewable or non-renewable, to generate and use the energy as electrical energy at consumer end, we have to make investment on it. The amount and nature of investment of resources depend upon the type of source from which we want to extract required energy to us.

The per unit cost of electrical energy generated depends on the initial investment made for physical infrastructure, land, equipment etc. and operating and maintenance costs, the latter is required throughout the life of the system. If we need more reliability, then we should make additional investments on the system for redundancy and for reserve capacity requirements. The per unit cost of electrical energy generated depends on the type of load profile to which the system is feeding the energy. If the load profile is more smooth and flatter, the per unit cost of electrical energy generated will be lower.

The cost of electrical energy composed of two parts. The first is the capital cost which depends upon the installed capacity of the plant and is independent of the amount of energy produced. The second is the operating and maintenance cost which depends upon the amount of energy produced and is independent of the installed capacity of the plant. The combination of these two parts gives the overall per unit cost of electrical energy generated from any sources. Out of various sources of energy production available to us, the renewable sources of energy are dominated by capital cost where the operating and maintenance costs are negligible in comparison to capital cost and the non-renewable sources are dominated by the operating and maintenance cost throughout its total operation in comparison to the capital cost [15].

Capital cost

The capital cost includes the cost for land, equipment and other physical infrastructures required. The amount that need to be invested in the capital cost depends on the type of energy generation sources and conversion process. For example, the cost per kW in case of diesel power plant and steam power plant may be less than in case of large hydroelectric power plants. This cost may also vary with the site and location of the power plant. The cost of transmission lines, right of way and substations is also included in this part.

In addition to this payment for the interest of loans, taxes for the property and other similar things are also added to the capital cost.

Operating cost

These are the cost which are proportional to the amount of energy generated. In renewable energy sources like photovoltaic, hydroelectricity and wind energy, the operating cost are negligible because the fuel for those are sunlight, water and wind which are available free of cost by nature to us but the capital investment in these cases are large at initial phase. In case of non-renewable sources based plant like diesel, thermal and nuclear, the cost of fuel sources like diesel, coal, uranium etc. is significant and these cost are proportional to the amount of electrical energy generated. The cost of fuel varies with the types of fuel depending upon their availability, calorific value, transportation costs etc.

The regular maintenance is required in all type of energy generation and conversion system. The much more maintenance is required where there is more rotating parts. In case of diesel power plant, thermal power plant, nuclear power plant etc. the regular maintenance is required to keep the operation efficient and continuous. The lubrication system and the cooling system are very important part of maintenance. The cost of lubricating oil and the cost of cooling mechanism is significant.

Effect of load factor on cost of electrical energy

The total cost for energy generation consists of capital cost and operating cost as described above. If the load factor of the load fed by the power plant is higher, the per unit cost of electrical energy generation will be lower and vice-versa.

Example:

Let us consider a thermal power plant for which the capital cost is Rs. 4.00 per kW of installed capacity per hour and the fuel and other operating cost is Rs. 4.00 per kWh generated. If the plant feeds the load having load factor of 100%, 75%, 50% and 25% then the per unit cost of generated energy can be calculated as follows.

Capital cost per hour (Rs.)	Load factor	Energy produced in 1 hour with 1 kW plant (kWh)	Fuel and operating cost per hour(Rs.)	Total cost(Rs.)	Per unit cost(Rs.)
4	0.25	0.25	1	5	20.00
4	0.50	0.50	2	6	12.00
4	0.75	0.75	3	7	9.33
4	1.00	1.00	4	8	8.00

From the above calculation table it is clear that the per unit cost of electrical energy generated is inversely proportional to the load factor of the load fed by the plant, which is because of the fact that the amount of energy generated for given amount of peak power in kW increases with increase in load factor. From these data, a curve is plotted showing the relationship between the load factor and per unit cost of electrical energy generated which is shown in figure 2.8. In case of renewable sources of energy like hydroelectricity, photovoltaic, wind energy etc. the capital cost form large proportion of the total costs and in such case the inverse relationship between the load factor and per unit cost of electrical energy generated will be more pronounced. This means that feeding the load group of higher load factor by hydroelectric power plant, solar power plant, wind energy based power plant seems more effective than in case of diesel power plant, thermal power plant, nuclear power plant regarding the per unit cost of electrical energy generated.

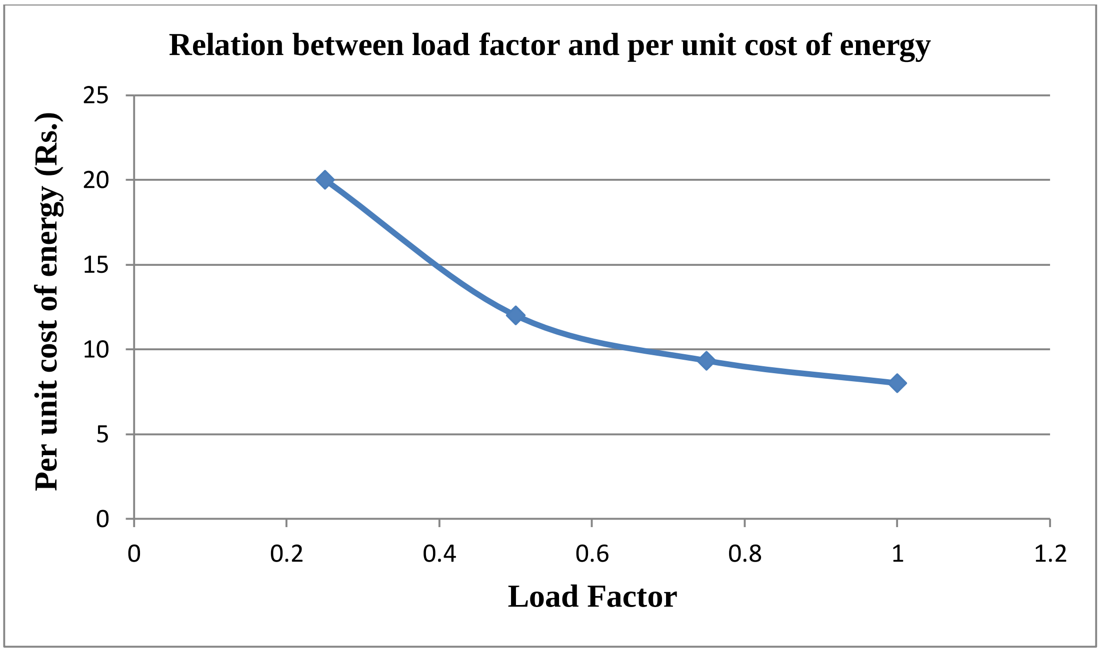


Figure 2.8 The effect of load factor on per unit cost of energy

The relationship between the per unit cost of electrical energy and load factor based on above calculation is in general case. But if we have a numbers of feeders in considered system and the feeder reconfiguration problem is solved to improve the load factors of individual feeders, then the numbers and locations of the loads supplied by the feeders before and after the reconfiguration will not be same. Due to this reason, the active power loss and energy loss in the individual feeders will be changed and hence the total power loss and the energy loss of the system will be changed.

The power and energy loss after reconfiguration may increase or decrease depending upon the new topology of the system after reconfiguration. So, due to this reason we have to consider the power and energy loss before and after the reconfiguration during calculation of per unit cost of electrical energy.

2.3 Electric load aggregation and its advantages

Electric load aggregation is the process in which individual energy users band together in an alliance to secure more competitive prices than they might otherwise receive buying independently. Aggregation can be accomplished through a simple pooling arrangements or through the formation of clusters where individual contracts are negotiated between the suppliers and each member of the aggregate group. It is one of the most effective means of maximizing saving in today's emerging deregulated power environment.

Increased Buying Power : The big industries with large sizable electric loads have greater purchasing power than that of smaller companies. It is normal thing that if we buy any type of commodity from the market then we are more likely to secure a significant discount and getting the commodity at lower unit price. When buying energy from the retail energy service company, bulk discounts are possible when the purchaser's ability is to buy bulk of power. Since very few consumers demand energy in such bulk quantities, companies have begun to aggregate the loads of several types or forming purchasing alliance with other local business to purchase large blocks of power, which tends to attract more supplier to the market and thus creating a more competitive bidding and pricing situation.

Load factor improvement : Load factor is the ratio of average load to peak load. For a time period considered, if the load profile or load pattern of any customer or group of customer or a feeder is more flatter then the load factor is higher than it will be in case of irregular or non smooth load profile. Through load aggregation, customers can increase their purchasing power by taking advantage of load diversity among various types of load pattern out of them as a means of improving the overall load factor for the group.

The independent regulatory authority allows every energy supplier to charge in two ways i.e. based on energy consumed and peak power requirement. This means the consumer need to pay peak demand charge as well as energy charge to the energy suppliers. The peak demand charge is fixed and that does not depend upon the amount the energy consumption. If the customer's load factor is relatively high, meaning that the load runs consistently at or near their peak demand so that the peak demand charge will represent smaller percentage of the overall cost of energy consumed.

When the load of various types of customers are aggregated, non-coincident peaks and valleys in the load profiles of individual customers tends to offset one another. This effect results in a flatter overall load profile, a higher load factor and so lower per unit cost of energy to the individual customers.

Example : Consider two groups of consumers in a locality. Both the group have equal peak power requirement but different load factor values. Then the supplier will now more attracted towards the group having higher load factor because the supplier can generate more revenue by supplying this group due to higher value of units of energy consumed for the same peak power requirement and so this group can also negotiate for price of energy.

In another case suppose that these two groups have equal energy requirements but different values of load factor. The supplier will now attracted towards the group having higher load factor again because for the group having higher load factor, the value of peak power requirement will be lower, meaning that lowering the investment in generation or selling the remaining part of the generation to another customer and hence generating more revenue. So, it is beneficial and attractive to the supplier to supply the customers having higher load factor regardless of value of peak power demand or amount of energy requirement.

2.4 Network reconfiguration in distribution system

Distribution system is one of the most important part of entire power system which provides final link between the transmission system and the end users. The distribution network consists of numbers of radial or loop feeders fitted with number of switches. Whatever may be the type of distribution system i.e. radial , parallel, loop or network structure, ultimately on feeding every load in the system, each feeder must operate in radial mode and this is done by properly regulating the status of those switches installed at various locations. The switches are of two types, sectionalizing switches which are normally closed NC and the tie switches which are normally opened NO. By changing the status of these switches, loads in the distribution system can be transferred from one feeder to another feeder depending upon the requirements and objectives taking into account the various constraints imposed and this process is known as reconfiguration.

The feeder can be reconfigured by opening/closing of sectionalizing switches and the tie switches on distribution system. On doing so, some of the constraints must be considered.

1. The radial structure of the distribution feeder must be retained.
2. All the load zones must be served during normal operation.
3. The feeder, transformer and other equipment capacities should not be exceeded.
4. The voltage profile of the feeder should be maintained.

Distribution network reconfiguration is necessary operation to improve system security, to reduce power losses, for making balancing of loads, for service restoration, to relieve network overload, enhance voltage stability, improve reliability and minimize financial losses due to deficiency of power quality. Regarding the concept of smart grid, reconfiguration is an essential automation task to improve the efficiency, reliability and sustainability of the distribution system [5][6][7][13].

Regarding the reconfiguration of the distribution network for improvement of load factor of the individual distribution feeders through load aggregation technique, to maximize the objective of load factor, there are multiple options for opening/closing of the sectionalizing and tie switches considering all the constraints imposed. So, the reconfiguration problem is constrained optimization problem and if we are going to include more than one objective at a time then the problem becomes multi objective constrained optimization problem to solve.

There are different types of consumers in every distribution system having different behavior i.e. load profile. In fact, load of every end user in distribution system is changing hour to hour, day to day and season to season. Based on this feature of loads, the reconfiguration problem is divided into two classes i.e. short term reconfiguration problem and long term reconfiguration problem.

In short term reconfiguration problem, the hourly changes in the load profile in considered. The reconfiguration problem considering the daily load profile, which shows the variation of loads hour to hour is known as short term reconfiguration problem. This means the optimized solution from short term reconfiguration is for a day. This type of dynamic network reconfiguration is possible in the context of smart grids where all the manual switches are substituted with automatic switches.

The long term reconfiguration problem represents seasonal and daily behavior of the system. The reconfiguration is done by considering mean or maximum of the load profile for a time period considered. In this type of operation schedule, the switching operation is executed only with seasonal changes. This type of network reconfiguration schedule is suitable for the distribution systems with manually controlled switches and the operation centers of the utility companies usually avoid high frequency switching.

2.5 Determination of load profile

To meet the objective by feeder reconfiguration technique, the determination of approximate load profiles/ load pattern of various types of the consumers in the distribution system under consideration is necessary. The methods to determine the load profile are followings.

2.5.1 By measurement

In every distribution center, there are variety of customer and all the customers are somehow different regarding their electricity uses pattern. There is no even two electrical consumers who uses electrical energy of identical characteristics even for a very small fraction of time. But for simplicity of study and analysis the electric utilities classify the customers into classes like residential, commercial, non-commercial, industrial, irrigation and so on. These type of customer also further classified based on voltage level, rural/urban etc. We need to determine the pattern of load for these type of consumers. In this method of load pattern determination, a numbers of customers over various customer classes are selected by the sampling and installation of intelligent meters to record the power consumption of those test customers within a fixed time interval say 15 minutes or 30 minutes etc. Thus recorded load data of the test customers is collected and typical load pattern of the customers classes can be derived. The observation may be repeated for different geographical locations, urban and rural, other possible variations too. Regarding the sampling time, high sampling rate is needed when studying the non-coincident load behavior of small group of customers but this may not be needed for large consumers group.

2.5.2 Simulation method

Consider an area where there are different types of consumers and all consumers are classified into k number of types and there are n numbers of distribution feeders. The total numbers of each class of consumer in each feeder can be evaluated and the load on the each feeder for a given interval of time is recorded. Then for a single instant of time,

$$P(t)= D_1N_1+D_2N_2+D_3N_4+\dots\dots+D_kN_k$$

Where, P(t) = load on the feeder for instant 't'

D_k = average demand per consumer for k^{th} class

N_k = number of consumers for k^{th} class in that feeder

Since we have the similar data for n numbers of feeders at that particular instant then,

$$\begin{aligned}
S_1 &= D_1N_{11} + D_2N_{21} + D_3N_{31} + \dots\dots + D_kN_{k1} \\
S_2 &= D_1N_{12} + D_2N_{22} + D_3N_{32} + \dots\dots + D_kN_{k2} \\
S_3 &= D_1N_{13} + D_2N_{23} + D_3N_{33} + \dots\dots + D_kN_{k3} \quad \dots\dots\dots\dots(1) \\
&\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\
S_n &= D_1N_{1n} + D_2N_{2n} + D_3N_{3n} + \dots\dots + D_kN_{kn}
\end{aligned}$$

The above set of equations can be written in matrix from as:

$$\begin{bmatrix} N_{11} & N_{21} & & N_{k1} \\ N_{12} & N_{22} & & N_{k2} \\ \dots & \dots. & \dots & \dots. \\ N_{1n} & N_{2n} & & N_{kn} \end{bmatrix} \begin{bmatrix} D_1 \\ D_2 \\ \\ D_k \end{bmatrix} = \begin{bmatrix} S_1 \\ S_2 \\ \\ S_n \end{bmatrix}$$

So, $ND = S$ and $D = N^{-1}S$

If N is not a square matrix then,

$N'ND = N'S$

$D = (N'N)^{-1}N'S$

In this way the matrix D can be determined. The matrix D gives the average demand per consumer of k number of consumer classes for a particular instant.

The above process can be repeated for all the sample data for the load of feeder at a appropriate time interval. On doing so we can get the average load curve per consumer for all classes.

The important thing is that above obtained load curve is not the load curve of a particular consumer but it is the average load curve of all the consumers of similar class. So, by dividing the above average load curves of different classes by their corresponding peak values, the load pattern of the consumer classes can be determined.

Thus obtained load pattern can be used for the determination of load factor of the corresponding class. If we have data of energy consumption for those classes at any bus in the distribution system then peak value of power for that class can be determined as :

peak load = daily energy consumption / (24 * load factor)

The multiplication of this class peak load with the class load pattern gives the actual load profile of each classes.

And finally addition of such obtained actual load profiles of different classes at a particular bus gives the actual load profile at that bus.

2.6 Particle Swarm Optimization

Particle Swarm Optimization(PSO) was originally designed and introduced by Eberhart and Kennedy in 1995 [8]. This is a population based stochastic search algorithm based on simulation of social behavior of birds, bees or fishes. This algorithm originally intends to graphically simulate the graceful and unpredictable choreography of a bird folk. Each individual within the swarm is represented by a vector in multidimensional search space. This vector has also one assigned vector which determines the next movement of the particle and is called the velocity vector. Each particle in the swarm update their velocity based on current velocity, the best position it has explored so far i.e. personal pest position and the global best position explored by the swarm. This process is then iterated for considering some convergence criteria based on desired performance index to achieve.

2.6.1 Continuous Particle Swarm Optimization

The PSO was originally developed for continuous valued spaces. In the PSO method, i-th particle of the swarm can be represented by a d-dimensional position vector $X_i = (x_{i1}, x_{i2}, x_{i3}, ..., x_{id})$. The velocity of the particle is denoted by $V_i = \left(v_{i1}, v_{i2}, v_{i3}, ..., v_{id}\right)$. Also consider best visited position for the particle is $P_{ibest} = (p_{i1}, p_{i2}, p_{i3}, ..., p_{id})$ and also the best position explored so far is $P_{gbest} = \left(p_{g1}, p_{g2}, p_{g3}, ..., p_{gd}\right)$. So the position of the particle and its velocity is updated using following equations.

$$v_{id} = w * v_{id} + c_1 * r_1 * (p_{id} - x_{id}) + c_2 * r_2 * \left(p_{gd} - x_{id}\right) \text{.....................(2)}$$

and

$$x_{id} = x_{id} + v_{id} \text{ ....(3)}$$

In the velocity update equation (2), first term, the inertia part represents the particle trusts its own status at present location and provides a basic momentum. The second term, the cognition part, represents the attraction of its previous best position and the third term, the social term represents the attraction of the best position so far in the population. Inside those three parts, W is the inertia weight showing the effect of previous velocity vector on the new vector. Also c_1 and c_2 are positive constants also called as acceleration coefficients and r_1 and r_2 are two random variables with uniform distribution between 0 and 1. The purpose of this updating formula is to lead the particles moving towards the compound vector of inertia part, cognition part and social part. On doing so, the opportunity for particles to reach the particles will be increased. The equation (2 and 3) can be represented in diagram as follows.

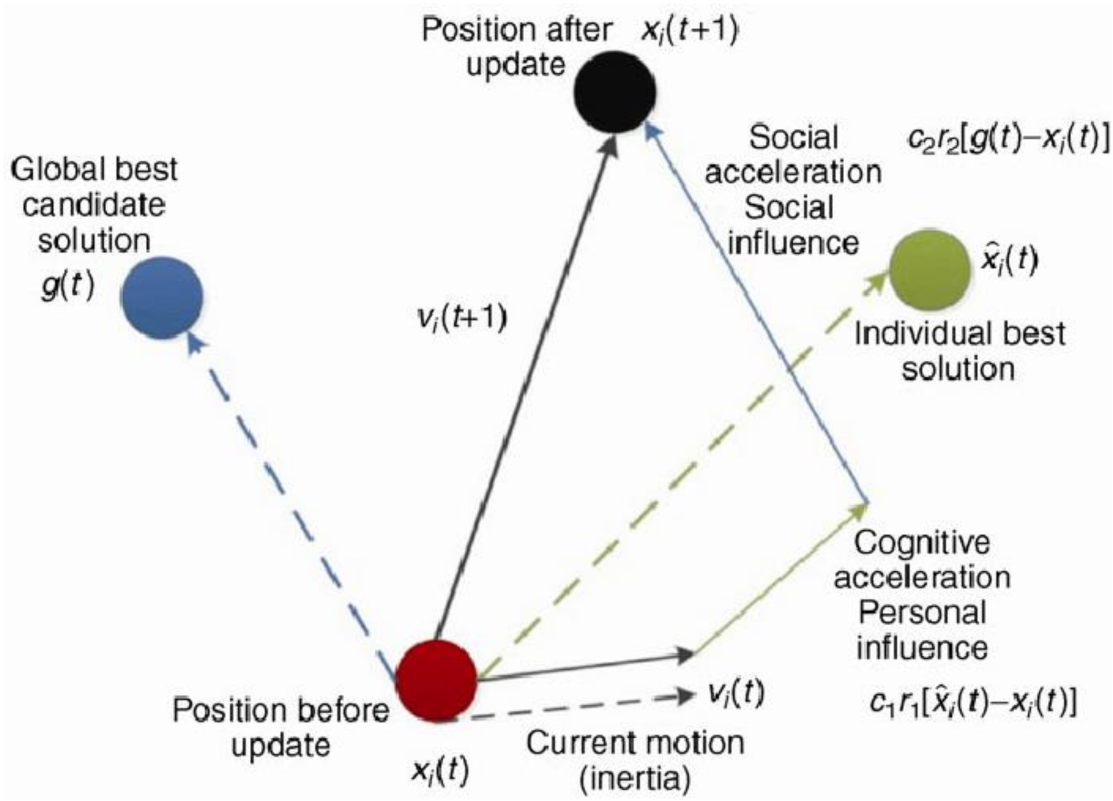


Figure 2.9 Searching diagram of PSO

The acceleration coefficients control the distance moved by a particle in the iteration. The inertia weight controls the convergence behavior of PSO. A large inertia weight facilitates the global search and a small inertia weight facilitates the local search. Sometimes, the value of inertia weight is considered as a constant value for all iterations. However, experimental results indicated that it is better to initially set the inertia weight to larger value and gradually reduce it to get refined solutions. The time varying inertia weight can be evaluated as follows

$$w = w_{\max} - \frac{iter}{\max iter} * (w_{\max} - w_{\min}) \quad \text{....................(4)}$$

In equation (4), $w_{\max}$ and $w_{\min}$ are the maximum and minimum value of inertia weight supposed and the equation shows that the value of inertia weight is going decreasing with increasing number of iterations.

Now, the algorithm for PSO can be summarized as follows.

1. Initialize the position and velocity of particles.

2. Evaluate the performance of each particle i.e. evaluation of objective function to optimize, using its current position.

3. Compare the performance of each individual to its best performance so far and do update the personal best position.

4. Compare the performance of each particle to the global best particle the do update the global best position.

5. Change the velocity of the particle according to equation (2).

6. Move each particle to the new position using equation (3).

7. Go to step 2 and repeat the steps until convergence criteria is satisfied.

The above algorithm can be represented in flowchart as follows.

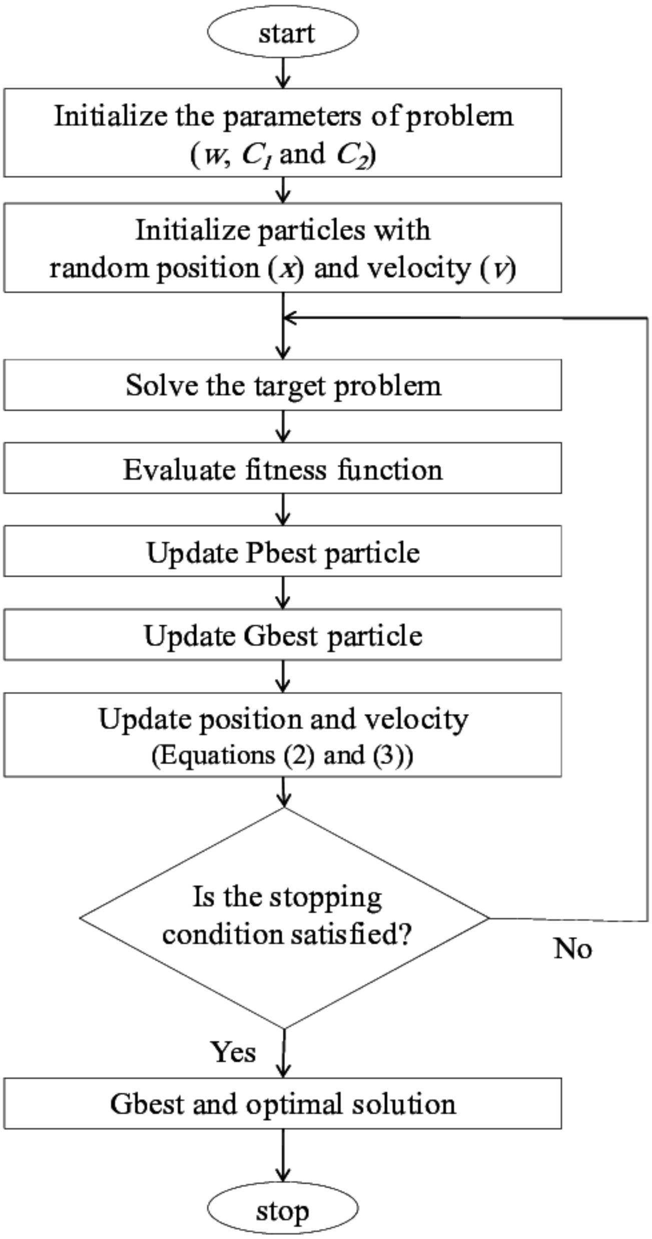


Figure 2.10 Flowchart for PSO

2.6.2 Binary Particle Swarm Optimization

Kennedy and Eberhart proposed a discrete binary version of PSO for binary type of problems in 1997 [9]. In the binary PSO, the particle's personal best and global best is updated as in continuous version. The major difference between binary PSO and continuous version of PSO is that velocities of the particles are rather defined in terms of probabilities that a bit will change to one. Using this definition, a velocity is restricted within the range [0,1]. So, a map is introduced to map all the real valued numbers of velocities to the above range of probabilities. To do this, the sigmoid function as normalization function is used as follows.

$$v'_{id} = sig(v_{id}) = \frac{1}{1+e^{-v_{id}}} \quad \text{.............................(5)}$$

The equation (5), known as sigmoid function maps all the real values of v_{id} obtained from equation (2) in the range [0,1]. The sigmoid function $y = \frac{1}{1+e^{-x}}$ is shown in following diagram.

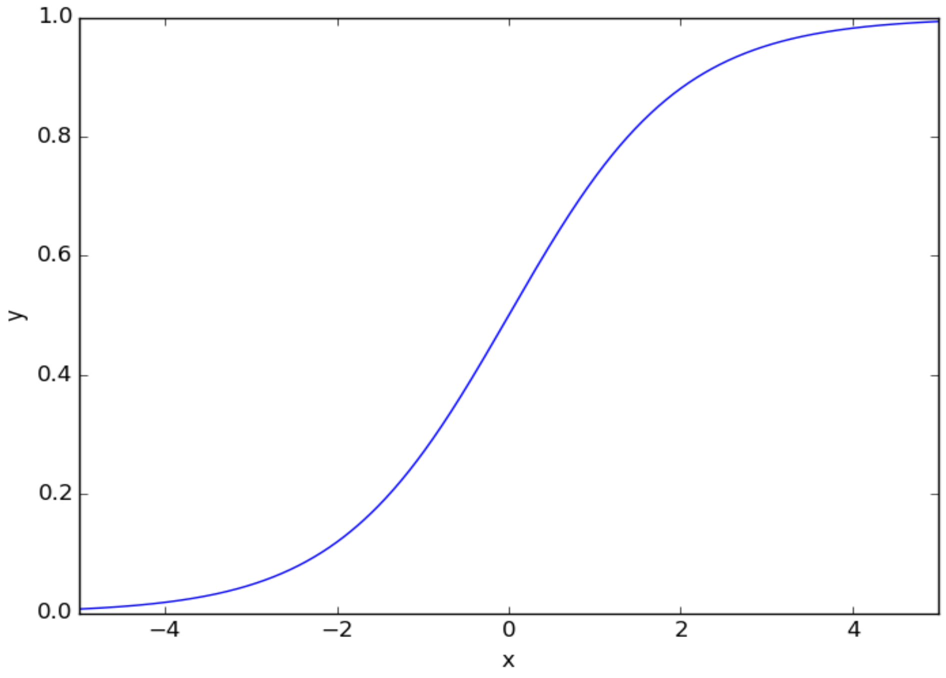


Figure 2.11 The Sigmoid transformation

After this normalization, the new position of the particle is obtained using the following equation.

$$x_{id} = \begin{cases} 1 \text{ if } r_1 < \text{sig}(v_{id}) \\ 0 \text{ otherwise} \end{cases} \quad \text{..........................(6)}$$

Where, r_1 is a uniform random number in the range of [0,1].

2.6.3 Limitations of BPSO

As mentioned in section 2.5.1, continuous PSO are defined by x_{id} and v_{id} in which x_{id} is the position of the particle for a candidate solution to the problem and v_{id} is the velocity. A large value of v_{id} (either positive or negative) indicates that the current position is not proper and is far from the optimal solution and so large movement is necessary in corresponding direction. And small value of v_{id} (either positive or negative) indicates that the current position is close to the optimal solution and so smaller movement is necessary in corresponding direction.

But in case of BPSO as explained in section 2.5.2, regarding the Sigmoid transformation, a large positive value of v_{id} maps to 1 and so for large positive value of v_{id}, the corresponding value of bit will be one regardless of the previous value of the bit. Also, a large negative value of v_{id} maps to 0 and so for large negative value of v_{id}, the corresponding value of bit will be zero regardless of the previous value of that bit. In the same way, a very small number tending to zero maps to 0.5 meaning that there is a probability of 0.5 of changing the corresponding bit to one.

So, based on above descriptions, the following limitations of the BPSO can be pointed out.

1. The first drawback is related with the sigmoid function. In the original continuous PSO, there is no difference between the large value of v_{id} either in positive or in negative direction and it just shows that current position is not satisfactory and a large movement is necessary to meet the optimum solution based on previous position. But in case of binary PSO, there is the different meaning of large positive value of v_{id} and large negative value of v_{id}. The large positive value of v_{id} indicates that the corresponding bit is going to one where as large negative value of v_{id} indicates that the corresponding bit is going to zero. Also in continuous PSO, the very small value of v_{id} tending to zero indicates that current position is good enough and movement is not necessary where as in BPSO, the sigmoid transformation of very small value tending to zero is 0.5 and so in this case the corresponding bit goes to either 0 or 1 with a probability of 0.5 which does not make good sense.

2. The second limitation is related with the memory of binary PSO. Regarding position update equation (6), the new position is being updated without considering the previous position [10].

The experiences of obtained results in solving various problems show that the objective function is improving for the first few iterations meaning that the algorithm is getting close to the optimal solution but as the algorithm continues the particle diverge from the optimal solution and may trapped in local optimum. The reason of divergence is as explained in above first limitation. Whenever the algorithm goes very close to optimal solution, the probability of changing the position of particle must be close to zero but according to the sigmoid transformation the position will change by taking the value of 0 or 1 with a probability of 0.5. This causes the algorithm not to converge well.

2.6.4 Modifications on BPSO

To overcome the first limitation of BPSO, a proper probability function can be defined as follows replacing the equation (5).

$$v'_{id} = 2 \times \left| sigmoid(v_{id}) - 0.5 \right| \quad \text{...(7)}$$

In equation (7), there is no difference between the large negative and large positive values of v_{id}. Whenever v_{id} has a large value regardless of its polarity, the v'_{id} will have a large value and for v_{id} close to zero regardless of polarity, the probability of bit changing to one is close to zero. The equation (7) is represented in following diagram.

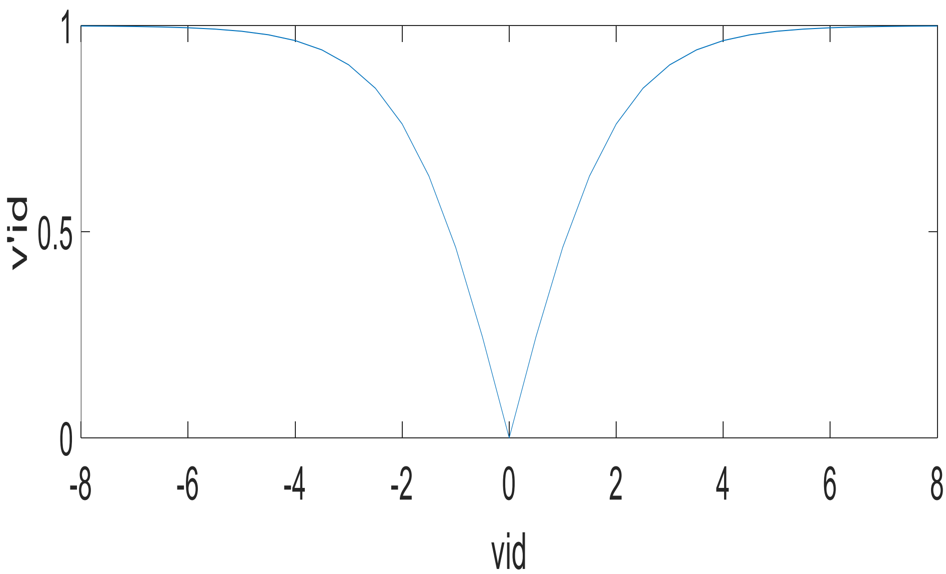


Figure 2.12 The modified transformation

To overcome the second limitation of BPSO, the equation (6) can be replaced by following equation (8) in which if the value of v_{id} is larger (either positive or negative), the corresponding bit value changes from 1 to 0 or 0 to 1 indicating that the current position is the good. And at the same time for smaller value of v_{id} (either positive or negative), the corresponding bit value does not change indicating that the current position is satisfactory.

$$\text{if } r_1 < v'_{id} \quad \text{then } x_{id} = exchange(x_{id}) \quad \text{else } x_{id} = x_{id} \qquad (8)$$

METHODOLOGY

In this thesis, feeder reconfiguration technique is used for load factor improvement of the individual distribution feeders. Since every distribution system consists of set of sectionalizing and tie switches, feeder reconfiguration means altering the position of those sectionalizing and tie switches to meet the objective. On doing so, the various network constraints imposed must be satisfied.

The problem is mathematically modeled with objective function and the constraints as in section 3.1 as constrained optimization problem. The feeder reconfiguration being a binary type of optimization problem, binary particle swarm optimization (BPSO) is used to solve the problem. The overall algorithm to solve the problem using BPSO as in section 3.2 is developed in MATLAB. The power losses, line flows and voltage profile of the buses are evaluated through load flow since the line flows and voltage profile are the constraints for the problem. Finally the developed algorithm in MATLAB is run for a number of iterations to get the results.

3.1 Problem Formulation

The feeder reconfiguration problem for feeder load factor improvement can be formulated as follows [4].

$$\text{Maximize} \quad \sum_{k=1}^{N} LF_k^{\,2} \quad \text{..............................(9)}$$

Subject to

1. Maximum load in each feeder should be less than or equal to feeder capacity.
2. No feeder section can be left out of service.
3. The radial network structure must be retained.
4. Each bus bar voltage magnitude should not exceed the upper and lower limit.

Where,

$$LF_k = \frac{\sum_{t=1}^{24} kW_k(t)}{24 \times \max(kW_k(t))}$$

$$kW_k(t) = \sum_{j=1}^{C} kW_j(t)$$

$$kW_j(t) = \frac{LP_{tj} \times kWh_{kj}}{24 \times LF(j)}$$

$$LF(j) = \frac{\sum_{t=1}^{24} LP_{tj}}{24 \times \max(LP_{tj})}$$

$$kWh_{kj} = \sum_{s=1}^{n_k} kWh_{sj}$$

LF_k = Load factor of feeder k

N = Number of feeders

$kW_k(t)$ = kW of feeder k at any time 't'

$kW_j(t)$ = kW of consumer class 'j' in feeder k at any time 't'

C = total number of consumer classes

LP_{tj} = value representing load pattern of consumer class 'j' at time 't'

kWh_{kj} = total kWh of consumer class 'j' in feeder 'k'

$LF(j)$ = load factor of consumer class 'j'

kWh_{sj} = kWh of consumer class 'j' in section 's'

n_k = number of sections in feeder 'k'

So, the feeder reconfiguration problem is the constrained optimization problem and some optimization technique must be applied to get the solution.

3.2 Optimization technique and overall algorithm

In this thesis, Particle Swarm Optimization technique is used to solve the constrained optimization problem. Since feeder reconfiguration is a binary type of optimization problem, binary particle swarm optimization technique is used here.

The binary particle swarm optimization is described in section 2.6.2 and based on the theory, the algorithm for solving the feeder reconfiguration problem can be summarized as follows.

1. Set population size and the stopping criteria.
2. Initialize the initial position and velocities of the swarm.
3. Initialize the P_{best} and G_{best} matrices.
4. Update velocities of the particles using velocity update equation.
5. Update position of particles using position update equation.
6. Calculate feeder load factors and hence the objective function.
7. Based on the value of objective function, update P_{best} and G_{best} matrices.
8. If stop criteria is satisfied, then set the solution as G_{best} otherwise go to step (4).

SYSTEM UNDER CONSIDERATION, TOOLS AND SOFTWARE

4.1 System under consideration

For the purpose of study and analysis, two systems are considered.

4.1.1 A sample three feeder system

A sample three feeder system as shown in figure 4.1 consists of thirteen closed sectionalizing switches and three normally opened tie switches.

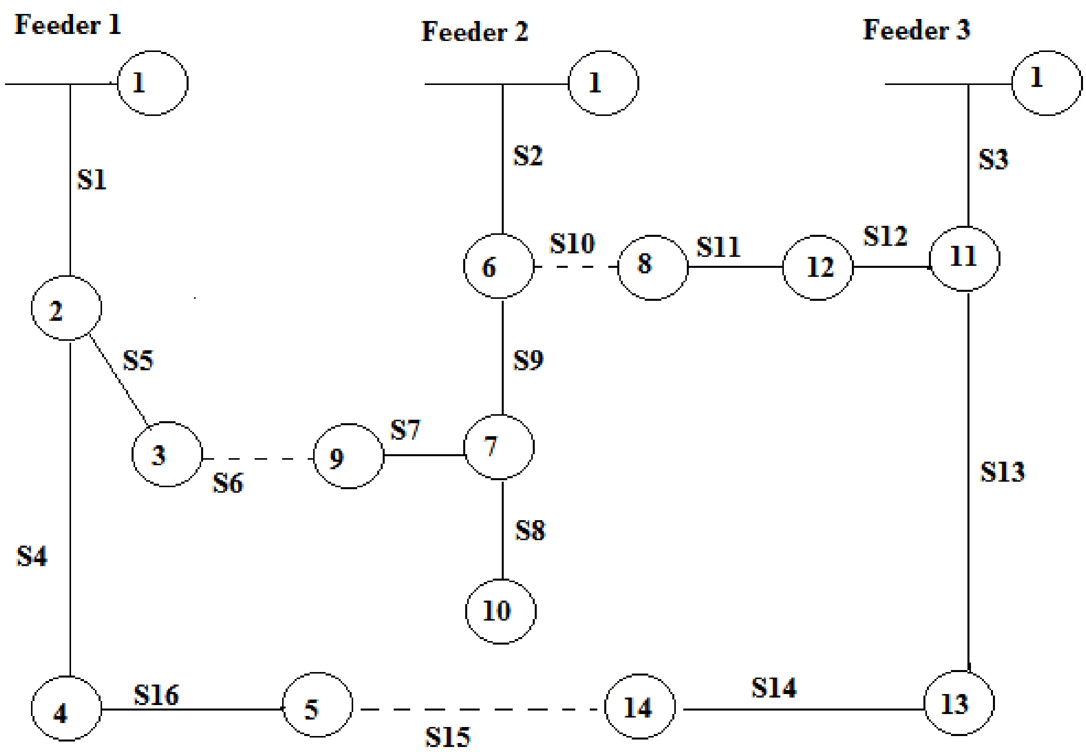


Figure 4.1 A three feeder sample network

There are sixteen branches in the sample three feeder network as shown above and sixteen load buses.

Regarding the feeder reconfiguration problem to solve, some techniques are applied to limit the problem's searching space or solution space. This also improves the computational efficiency of the search technique.

1. All switches which do not belong to any loop have to be closed to keep all the loads to be served.

2. All switches connected to the sources have to be closed.

In this particular three feeder sample network, the sectionalizing switch **S8** does not belong to any loop and so the sectionalizing switch **S8** is always closed and hence it does not belong to the searching space.

Similarly, in this sample network considered, the three sectionalizing switches **S1**, **S2** and **S3** are connected to the source and hence these three sectionalizing switches are always closed.

The different types of loads served by the above system is classified into residential, industrial, commercial and non-commercial. Based on data of Taiwan Power Company, the hourly load in pu of these classes are tabulated as following.

Table I

Loads in per unit of different class of consumer-1

Time of a day	Industrial	Domestic	Commercial	Non-commercial
1	0.63	0.548	0.23	0.11
2	0.61	0.49	0.2	0.11
3	0.6	0.458	0.19	0.11
4	0.585	0.45	0.19	0.11
5	0.58	0.44	0.19	0.11
6	0.579	0.39	0.187	0.11
7	0.608	0.389	0.22	0.14
8	0.663	0.37	0.31	0.38
9	0.741	0.38	0.475	0.835
10	0.774	0.39	0.59	0.885
11	0.795	0.39	0.63	0.887
12	0.8	0.418	0.65	0.82
13	0.77	0.456	0.59	0.67
14	0.8	0.464	0.64	0.845
15	0.8	0.462	0.67	0.86
16	0.805	0.45	0.67	0.83
17	0.795	0.456	0.66	0.7
18	0.782	0.475	0.63	0.41
19	0.793	0.575	0.69	0.305
20	0.793	0.647	0.7	0.26
21	0.776	0.678	0.6	0.21

22	0.745	0.73	0.44	0.16
23	0.721	0.71	0.33	0.14
24	0.68	0.64	0.27	0.13

Based on table I, the load pattern for these four classes of consumer is represented in figure 4.2 below.

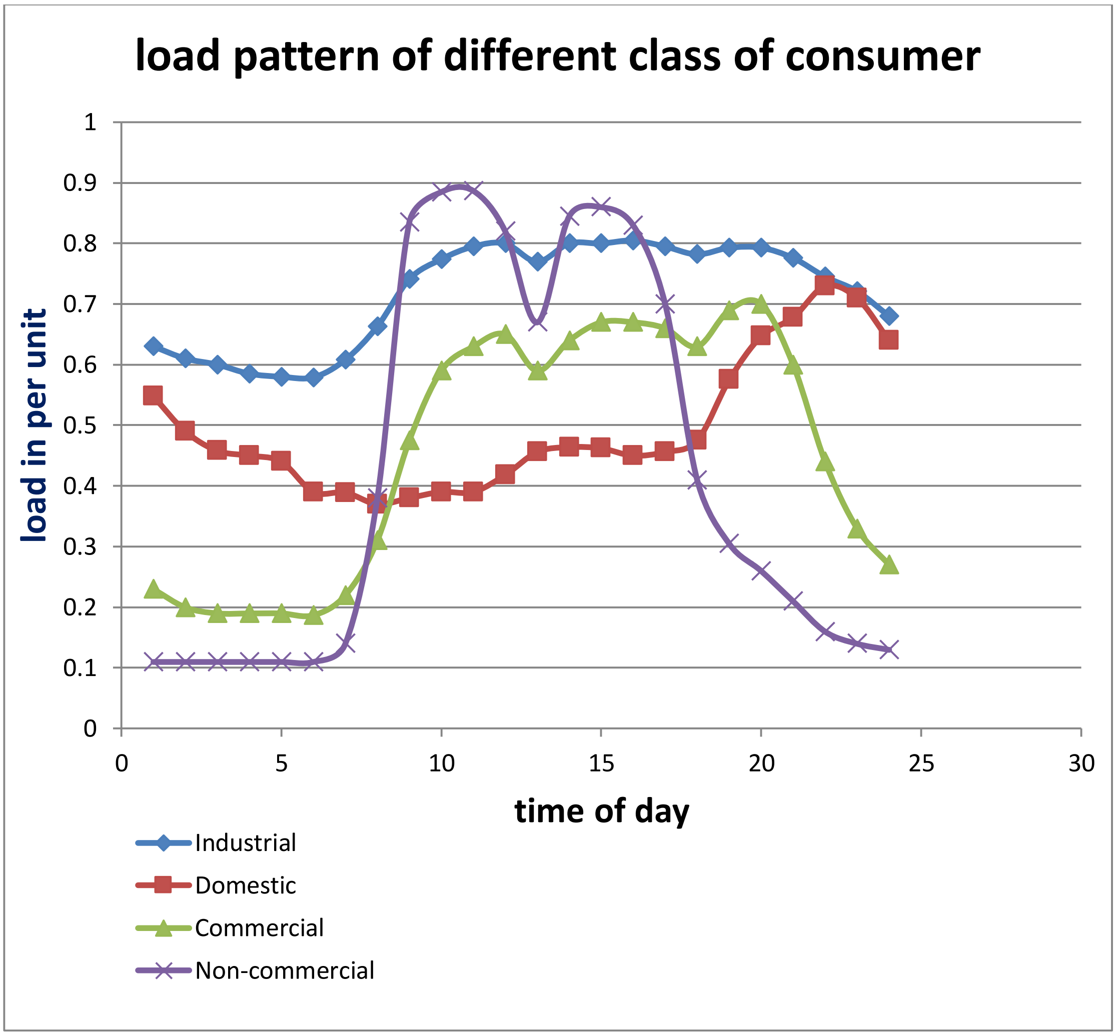


Figure 4.2 Load pattern of different classes of consumer-1

Also, the bus energy requirement per day is tabulated as below.

Table II

Bus energy requirements of various classes in KWH per day

Bus No.	Industrial	Domestic	Commercial	Non-commercial
2	0	380	0	200

3	0	620	20	160
4	0	470	0	200
5	0	310	60	260
6	20	40	280	220
7	0	30	190	300
8	30	220	480	0
9	20	80	200	250
10	20	80	340	240
11	320	130	0	0
12	210	280	30	0
13	380	140	20	20
14	500	160	0	0

Also, based on the load pattern and the bus energy requirement of each buses, the peak load requirement of each bus can be derived as below.

Table III

Daily peak load at buses in kW

Bus No.	Daily peak load in kW
2	31.792
3	41.5062
4	35.2991
5	37.8301
6	38.2996
7	38.2689
8	44.0662
9	37.5119
10	45.2273
11	21.8505
12	27.5282
13	26.9261
14	31.7503

4.1.2 Network of Patan substation

A practical distribution network of Nepal Electricity Authority is taken. In Patan substation there are numbers of 11 kV feeders. Out of them following three feeders are considered for reconfiguration problem for this thesis work.

a. Jawalakhel feeder

b. Ring road feeder

c. Local Patan feeder

The GIS view of distribution network consisting of these three feeders is shown in figure 4.3 as below.

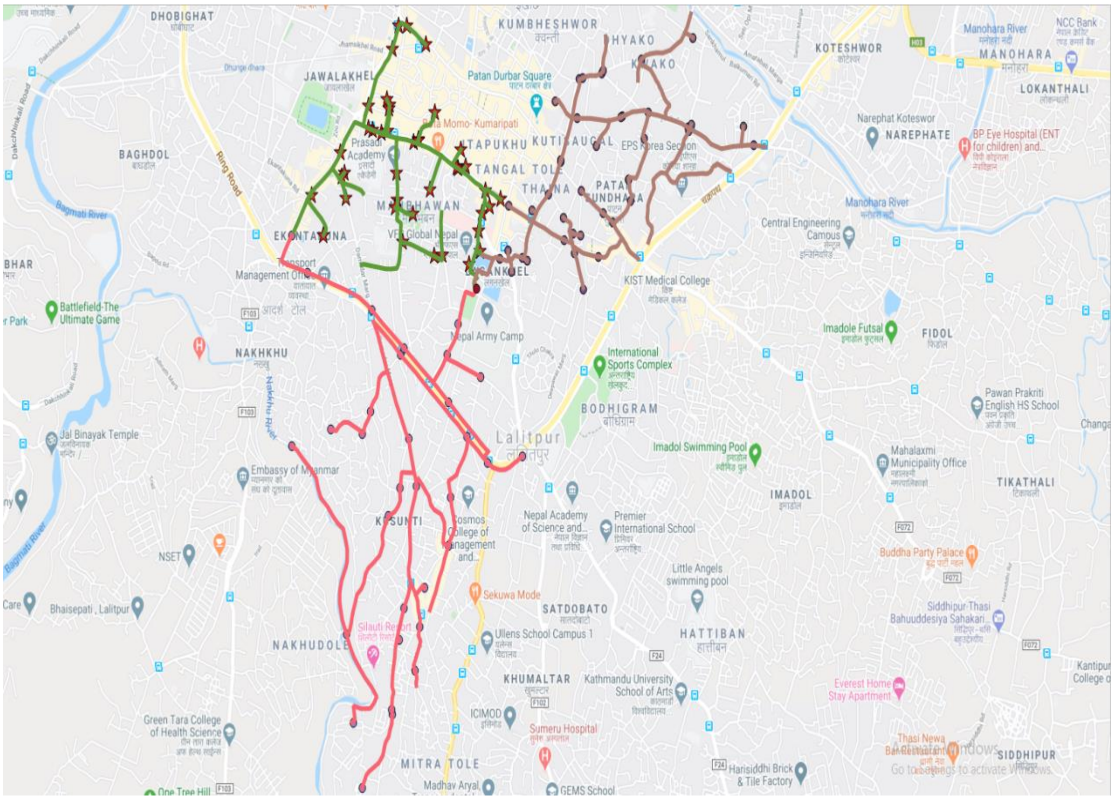


Figure 4.3 GIS view of three feeders under consideration

The three feeders under consideration are originated from Patan substation bus, which is considered as the reference bus and the three feeders are independently operating in radial mode. The total number of buses, no of branches and the capacity of feeder for each of these three feeders are as following.

Name of the feeder	Number of buses	Number of branches	Capacity of feeder
Jawalakhel feeder	63	62	300A
Ring road feeder	43	42	300A
Local Patan feeder	54	53	300A

The consumers in the area under consideration are classified into domestic, industrial, commercial and non-commercial. The load pattern for these classes of consumers are collected, derived and tabulated as following.

Table IV

Loads in per unit of different class of consumer-2

Time of a day	Industrial	Domestic	Commercial	Non-commercial
1	0.166	0.179	0.314	0.124
2	0.165	0.193	0.442	0.124
3	0.146	0.237	0.678	0.157
4	0.175	0.252	0.842	0.428
5	0.392	0.201	0.900	0.941
6	0.965	0.164	0.928	0.997
7	1.000	0.164	0.842	1.000
8	0.999	0.164	0.914	0.924
9	0.470	0.172	0.957	0.755
10	0.938	0.285	0.957	0.952
11	0.302	0.563	0.942	0.969
12	0.277	0.900	0.900	0.935
13	0.165	1.000	0.985	0.789
14	0.156	0.868	1.000	0.462
15	0.169	0.629	0.857	0.343
16	0.226	0.406	0.628	0.293
17	0.165	0.307	0.471	0.236
18	0.139	0.219	0.385	0.180
19	0.137	0.197	0.328	0.157
20	0.150	0.267	0.285	0.146
21	0.161	0.406	0.271	0.124
22	0.146	0.498	0.271	0.124
23	0.142	0.432	0.271	0.124
24	0.145	0.267	0.267	0.124

Based on table IV, the load pattern for these four classes of consumer is represented in figure 4.4 below.

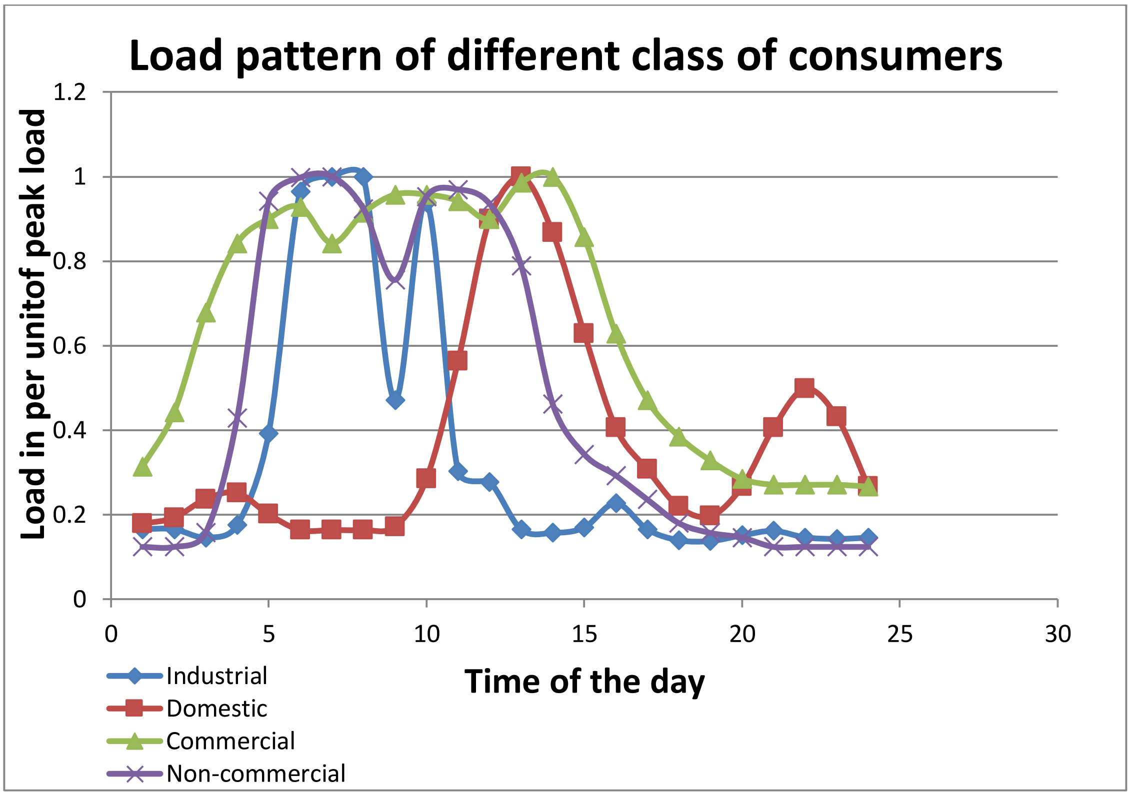


Figure 4.4 Load pattern of different classes of consumer-2

All other network data, load data and energy data for this network of Patan substation are collected in appendix.

4.2 Software tool

In earlier times, the modeling and analysis of power system was tough, time consuming and inaccurate. But these days, due to technological advancement in computer architecture, software and programming tools the task is becoming easy, accurate and efficient. We can mathematically model individual power system components and integrate them using various software tools, develop necessary algorithm and simulate to get the results. There are various software tools available to model and simulate the power system like MATLAB, Power World Simulator, DIgSILENT, ETAP, PSCAD, PAST and so on.

MATLAB is powerful, user friendly and highly interactive programming and simulation software designed for large numbers of engineering analysis developed by MathWorks. It is the largest tool available till now among all the tools. So, in this thesis MATLAB is used for algorithm development for binary particle swarm optimization.

SIMULATION RESULTS AND DISCUSSION

The algorithm to solve the feeder reconfiguration problem is developed in MATLAB.

<u>Sample three feeder system</u>:

Regarding the figure 4.1, initially the configuration is such that the switches S6, S10 and S15 are working as tie switches so that radial behavior is observed.

The developed program is run in MATLAB for 30 number of iterations taking the parameters as follows.

Population size	10
Dimension size	3
Wmax, Wmin	0.9, 0.4
C1	2*rand(1)
C2	2*rand(1)
R1	Matrix of random numbers
R2	Matrix of random numbers

The following table shows the solution of reconfiguration problem comparing the objective function, individual load factors of the feeders, various switches status before and after the reconfiguration.

	Load factor			Objective function
	Feeder 1	Feeder 2	Feeder 3	
Initial case Tie switch: S6, S10, S15	0.776	0.6042	0.8034	1.6128
Final solution Tie switch: S5, S12, S14	0.7876	0.6984	0.8632	1.8532
Increase %	1.495	15.59	7.44	14.91

The result shows that the overall objective function is increased by 14.91% and the individual feeder load factors are increased by 1.495%, 15.59% and 7.44% respectively.

The load profiles of three feeders before and after the reconfiguration problem is shown below.

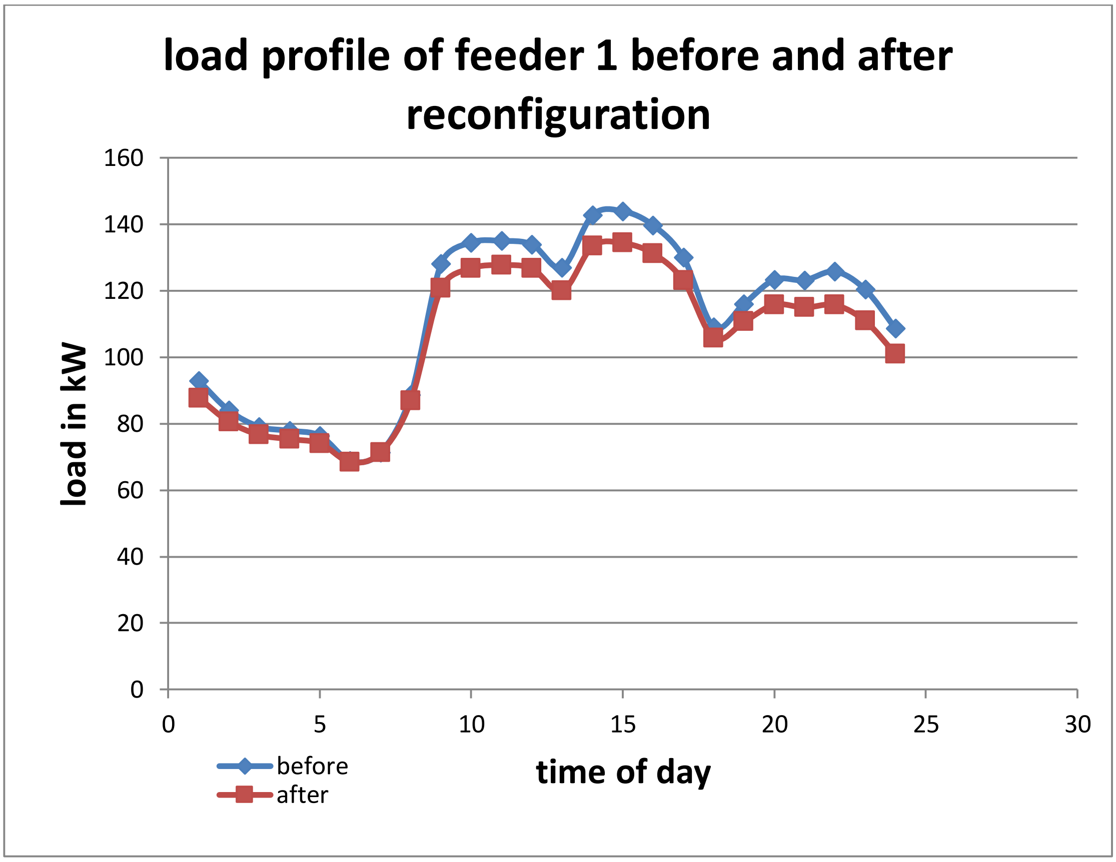


Figure 5.1 Load profile of feeder 1 before and after reconfiguration

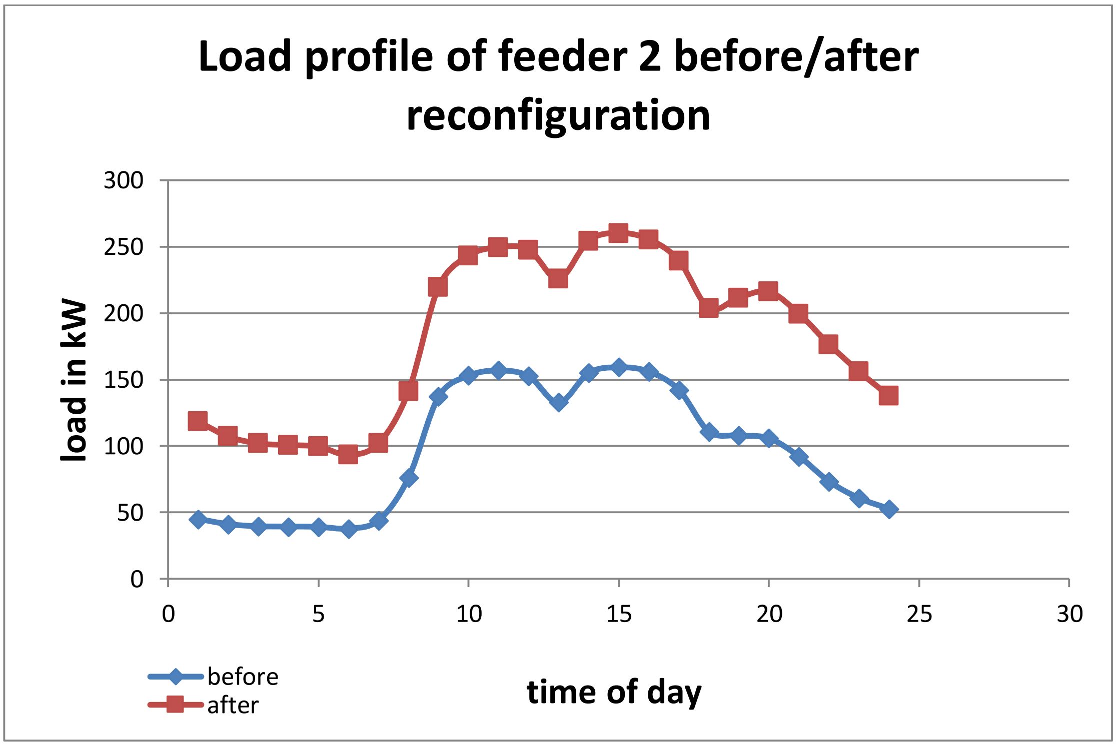


Figure 5.2 Load profile of feeder 2 before and after reconfiguration

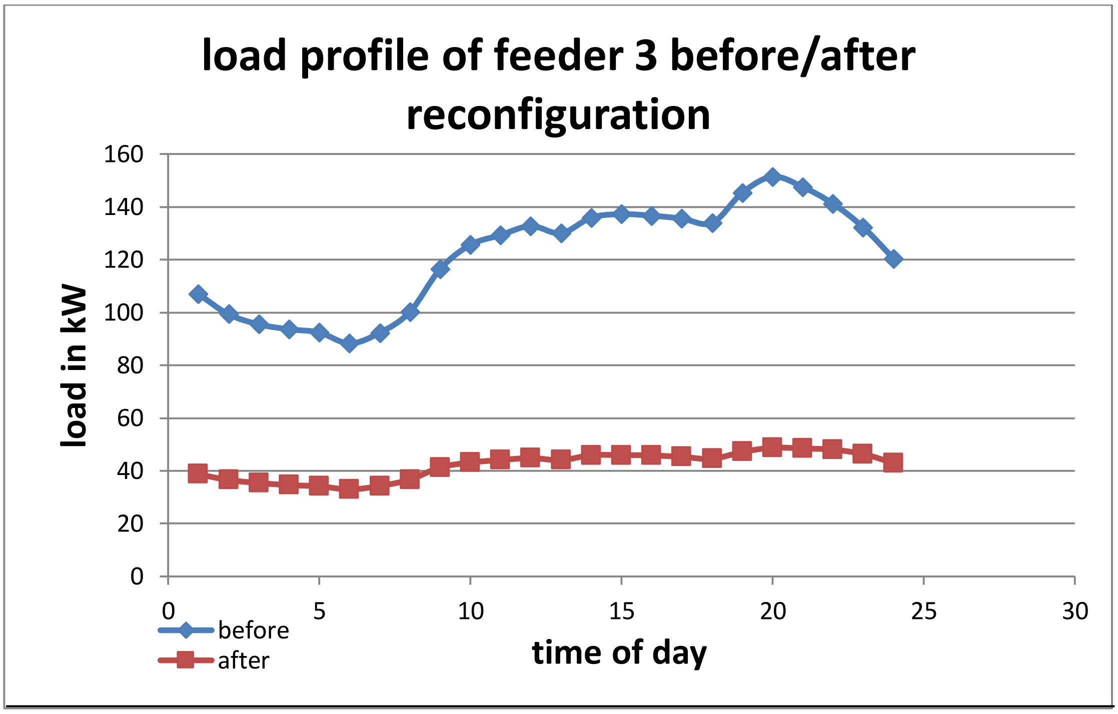


Figure 5.3 Load profile of feeder 3 before and after reconfiguration

The voltage profile of various buses before and after reconfiguration are shown in figure 5.4 as shown below.

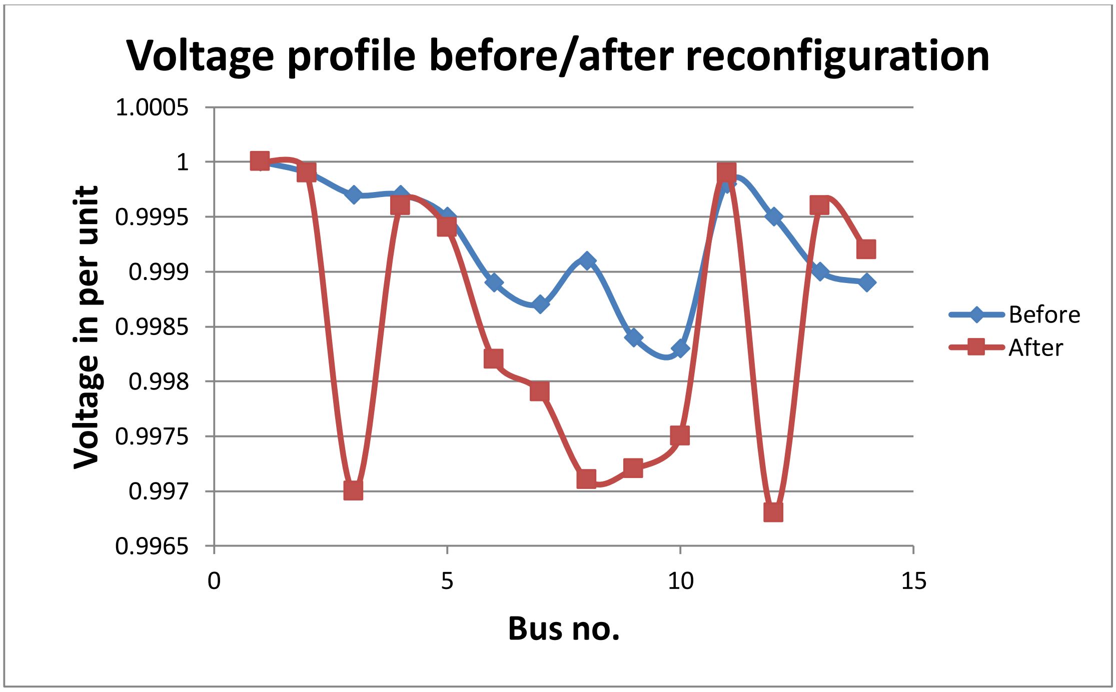


Figure 5.4 Bus voltages before and after reconfiguration in pu-1

The hourly load in kW and bus voltages for the feeders before and after reconfiguration are collected in appendix.

Comparison of losses:

Considering fixed cost of a thermal station Rs. 26280.00 per kW of installed capacity per year and fuel and operating cost as Rs. 3.00 per kWh generated, the peak power loss in kW, daily energy loss in kWh and Total daily cost (Nrs.) are calculated as follows.

	Power loss(kW)	Daily energy loss(kWh)	Daily total cost(Nrs.)
Before reconfiguration	1.539	21.3931711	56638.15
After reconfiguration	2.2189	31.0367986	55895.82

The detail calculations are collected in appendix.

Network of Patan substation:

For this network, five tie switches are selected for reconfiguration purpose as specified in Table A2 of appendix.

The developed program is run in MATLAB for 500 number of iterations taking the parameters as follows.

Population size	30
Dimension size	5
Wmax, Wmin	0.9, 0.4
C1	2*rand(1)
C2	2*rand(1)
R1	Matrix of random numbers
R2	Matrix of random numbers

The following table shows the solution of reconfiguration problem comparing the objective function, individual load factors of the feeders, various switches status before and after the reconfiguration.

	Load factor			Objective function
	Jawalakhel feeder	Ring road feeder	Local Patan feeder	
Initial case Tie switch:	0.5469	0.5011	0.4499	0.7526

158,159,160,161,162				
Final solution Tie switch: 6,116,36,72,20	0.6451	0.5307	0.4789	0.9271
Increase %	17.95	5.90	6.44	23.18

The result shows that the overall objective function is increased by 23.18% and the individual feeder load factors are increased by 17.95%, 5.90% and 6.44% respectively.

The load profiles of three feeders before and after the reconfiguration problem is shown below.

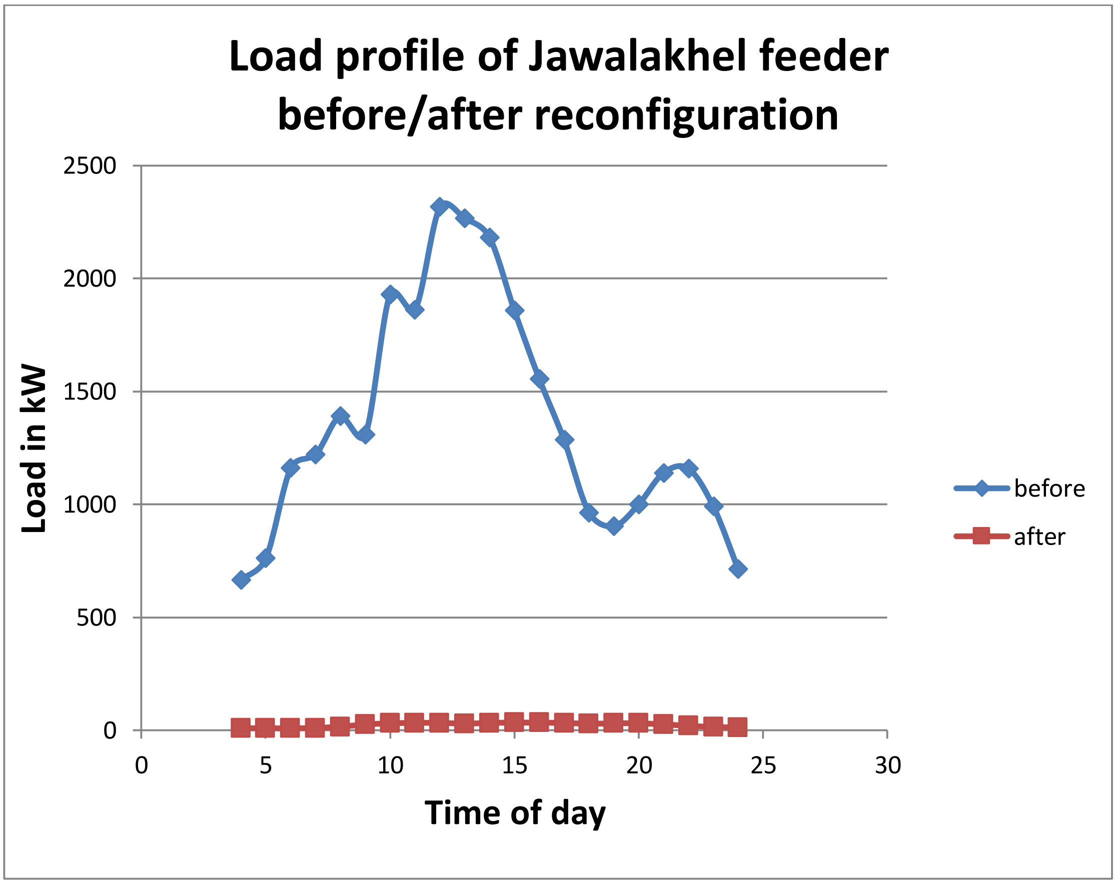


Figure 5.5 Load profile of Jawalakhel feeder before and after reconfiguration

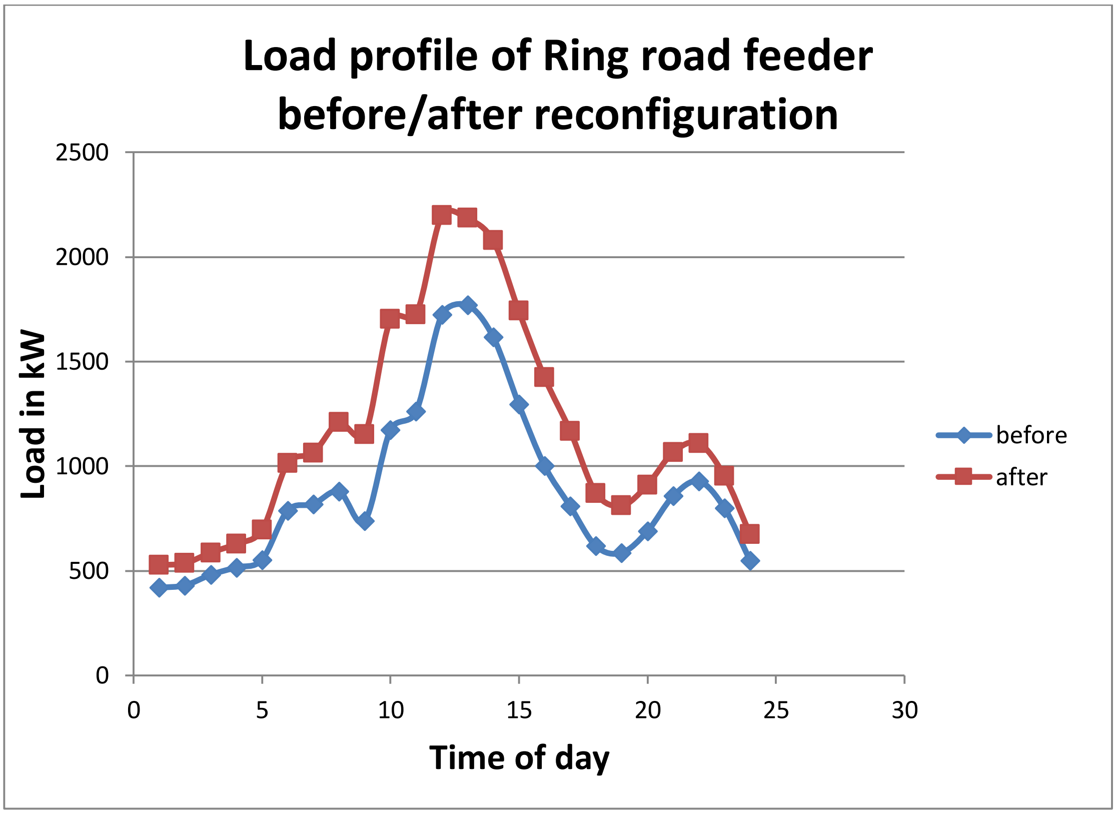


Figure 5.6 Load profile of Ring road feeder before and after reconfiguration

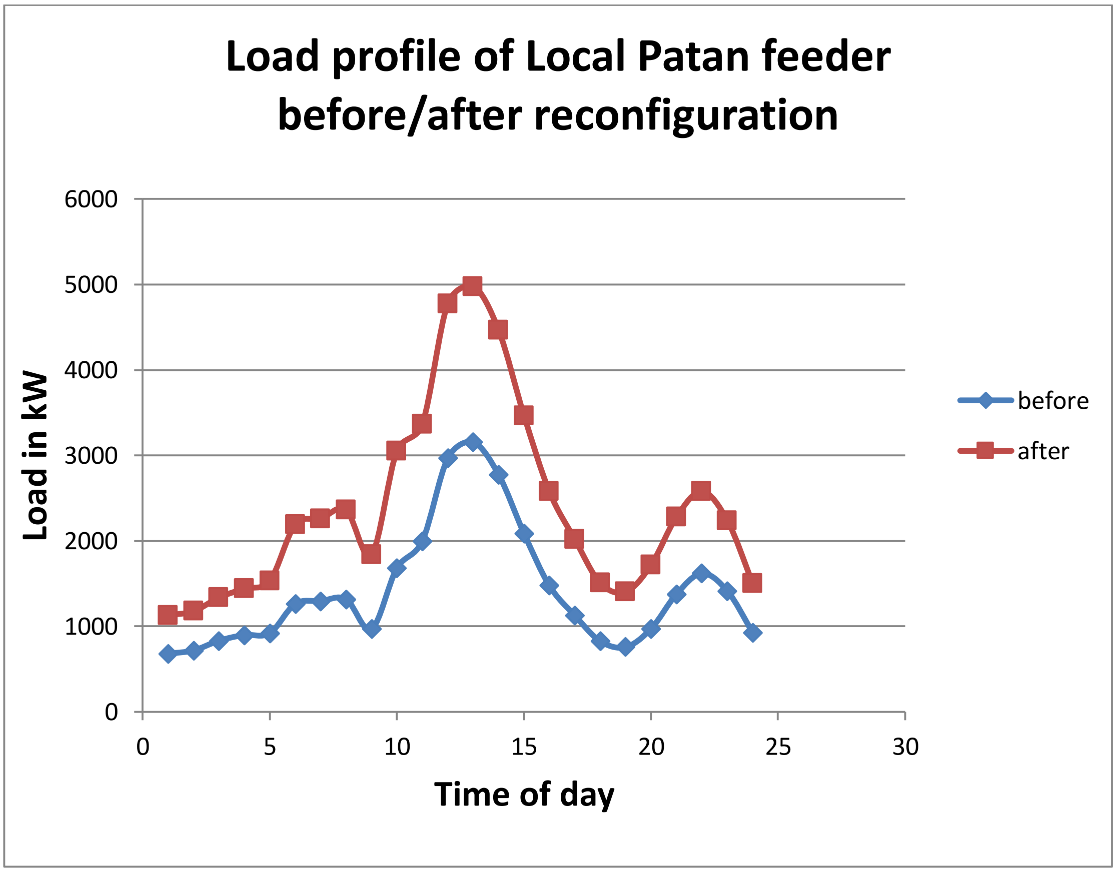


Figure 5.7 Load profile of Local Patan feeder before and after reconfiguration

The bus voltages in per unit before and after reconfiguration are shown in figure 5.8 as shown below.

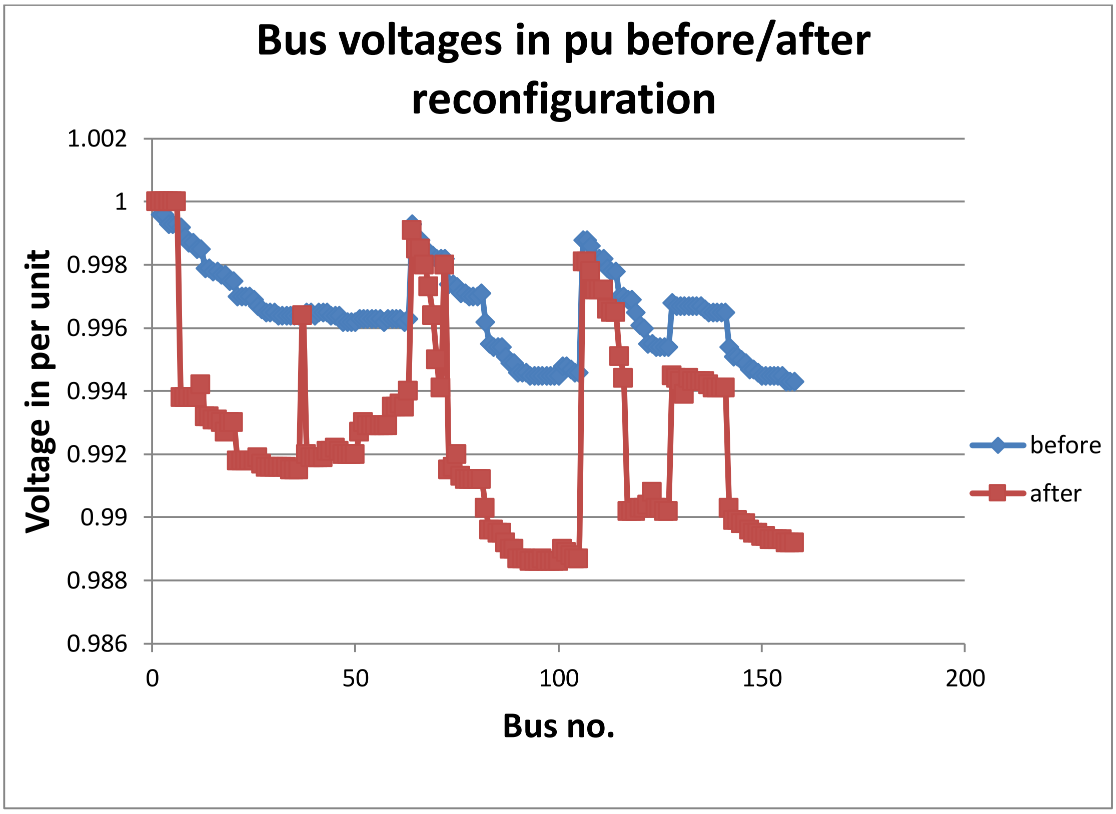


Figure 5.8 Bus voltages in per unit before and after reconfiguration-2

The hourly load in kW and bus voltages for the feeders before and after reconfiguration are collected in appendix.

Comparison of losses:

Considering fixed cost of a thermal station Rs. 26280.00 per kW of installed capacity per year and fuel and operating cost as Rs. 3.00 per kWh generated, the peak power loss in kW, daily energy loss in kWh and Total daily cost (Nrs.) are calculated as follows.

	Power loss(kW)	Daily energy loss(kWh)	Daily total cost(Nrs.)
Before reconfiguration	24.2889	183.750758	781264.9873
After reconfiguration	42.78197	323.72264	780827.464

The detail calculations are collected in appendix.

CONCLUSION

The load factor improvement of individual distribution feeders has various advantages both qualitative and quantitative advantages which give solution to the issues put on problem statement. The load factors of individual distribution feeders can be improved through load aggregation taking the advantage of diversity of loads using feeder reconfiguration technique. Feeder reconfiguration being a binary type of constrained optimization problem, binary particle swarm optimization technique is used here to solve the problem. Two different three feeder networks are considered and reconfiguration problem is solved. The load factor of the feeders is increased by 1.495%, 15.59%, 7.44% and 17.95%, 5.90%, 6.44% for respective networks. Due to this improvement in load factor, the daily cost of energy supply is decreased from Nrs. 56638.15 to Nrs. 55895.82 and Nrs. 781264.99 to Nrs. 780827.46 respectively although the power loss increased from 1.54 kW to 2.22 kW and 24.29 kW to 42.78 kW. This signifies the importance of higher load factor of the feeders in deregulated energy market. Therefore, in distribution system, reconfiguration with objective of minimization of losses may not always efficient. In vertically integrated nature of market, loss minimization may be important but in deregulated environment, loss minimization or loss reduction may not always ensure the most economic operation of the system.

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Appendix A

Table A1

Bus load data for network of Patan substation

Bus No.	Peak load(kW)	Bus No.	Peak load(kW)
2	0	45	0
3	6.58	46	86.96
4	0	47	86.96
5	28.88	48	86.96
6	0	49	43.48
7	43.48	50	43.48
8	12.17	51	86.96
9	0	52	0
10	26.14	53	0
11	43.48	54	36.35
12	117.88	55	30.85
13	0	56	0
14	86.96	57	86.96
15	108.7	58	0
16	86.96	59	0
17	0	60	7.82
18	26.42	61	0
19	0	62	43.48
20	31.47	63	0
21	0	64	45.66
22	86.96	65	45.66
23	43.48	66	45.66
24	86.96	67	0
25	86.96	68	45.66
26	0	69	45.66
27	11.65	70	45.66
28	43.48	71	91.33
29	0	72	45.66
30	6.96	73	0
31	229.15	74	11.41
32	0	75	137
33	86.96	76	0
34	43.48	77	45.66
35	43.48	78	91.33
36	0	79	0
37	0	80	0
38	86.96	81	45.66
39	43.48	82	45.66
40	130.44	83	0
41	130.44	84	45.66
42	16.29	85	91.33
43	0	86	45.66
44	44.08	87	91.33

Bus No.	Peak load(kW)	Bus No.	Peak load(kW)
88	0	124	104.84
89	45.66	125	104.84
90	0	126	52.42
91	0	127	104.84
92	3.27	128	104.84
93	114.16	129	0
94	91.33	130	52.42
95	0	131	104.84
96	91.33	132	0
97	3.73	133	104.84
98	45.66	134	52.42
99	21.39	135	52.42
100	22.83	136	78.63
101	45.66	137	52.42
102	114.16	138	52.42
103	0	139	52.42
104	68.5	140	52.42
105	45.66	141	104.84
106	0	142	104.84
107	0	143	0
108	104.84	144	104.84
109	0	145	52.42
110	104.84	146	104.84
111	104.84	147	157.26
112	104.84	148	104.84
113	0	149	0
114	10.26	150	104.84
115	0	151	14.41
116	52.42	152	157.26
117	52.42	153	0
118	0	154	3.17
119	104.84	155	104.84
120	52.42	156	0
121	52.42	157	158.01
122	0	158	104.84
123	52.42		

Table A2

Line data for network of Patan substation

Line No.	From bus	To bus	Resistance(ohm)	Reactance(ohm)	Remarks
1	1	2	0.014464	0.012544	
2	2	3	0.00226	0.00196	
3	2	4	0.009718	0.008428	
4	4	5	0.003164	0.002744	

5	4	6	0.006102	0.005292	
6	4	7	0.0038	0.003296	
7	7	8	0.011187	0.009702	
8	8	9	0.006893	0.005978	
9	9	10	0.004859	0.004214	
10	9	11	0.007119	0.006174	
11	11	12	0.014238	0.012348	
12	11	13	0.022148	0.019208	
13	13	14	0.003729	0.003234	
14	13	15	0.004181	0.003626	
15	15	16	0.001243	0.001078	
16	16	17	0.004181	0.003626	
17	17	18	0.011639	0.010094	
18	17	19	0.010509	0.009114	
19	19	20	0.020679	0.017934	
20	19	21	0.021244	0.018424	
21	21	22	0.002232	0.001936	
22	22	23	0.000235	0.000204	
23	23	24	0.023098	0.020032	
24	21	25	0.003503	0.003038	
25	25	26	0.014012	0.012152	
26	26	27	0.021131	0.018326	
27	27	28	0.01695	0.0147	
28	28	29	0.005255	0.004557	
29	29	30	0.001808	0.001568	
30	29	31	0.013899	0.012054	
31	29	32	0.022035	0.01911	
32	32	33	0.001582	0.001372	
33	33	34	0.027572	0.023912	
34	34	35	0.010848	0.009408	
35	35	36	0.02599	0.02254	
36	32	37	0.045878	0.039788	
37	26	38	0.012882	0.011172	
38	38	39	0.017402	0.015092	
39	39	40	0.014351	0.012446	
40	39	41	0.001808	0.001568	
41	41	42	0.004294	0.003724	
42	38	43	0.007797	0.006762	
43	43	44	0.003729	0.003234	
44	44	45	0.004294	0.003724	
45	45	46	0.011639	0.010094	
46	46	47	0.040567	0.035182	
47	47	48	0.014803	0.012838	
48	48	49	0.007797	0.006762	
49	49	50	0.019436	0.016856	
50	45	51	0.029154	0.025284	
51	51	52	0.012091	0.010486	
52	52	53	0.00904	0.00784	

53	53	54	0.002486	0.002156	
54	54	55	0.003051	0.002646	
55	53	56	0.002034	0.001764	
56	56	57	0.010961	0.009506	
57	56	58	0.019662	0.017052	
58	52	59	0.023504	0.020384	
59	59	60	0.001582	0.001372	
60	59	61	0.00452	0.00392	
61	61	62	0.026216	0.022736	
62	61	63	0.0226	0.0196	
63	1	64	0.03503	0.03038	
64	64	65	0.020792	0.018032	
65	65	66	0.033561	0.029106	
66	65	67	0.020679	0.017934	
67	67	68	0.031075	0.02695	
68	68	69	0.035143	0.030478	
69	69	70	0.058195	0.05047	
70	70	71	0.041019	0.035574	
71	67	72	0.017628	0.015288	
72	72	73	0.049607	0.043022	
73	73	74	0.004294	0.003724	
74	74	75	0.032092	0.027832	
75	73	76	0.017741	0.015386	
76	76	77	0.042262	0.036652	
77	77	78	0.031527	0.027342	
78	78	79	0.040567	0.035182	
79	78	80	0.052432	0.045472	
80	76	81	0.001017	0.000882	
81	81	82	0.073902	0.064092	
82	82	83	0.062376	0.054096	
83	83	84	0.029945	0.02597	
84	84	85	0.015481	0.013426	
85	85	86	0.03051	0.02646	
86	83	87	0.044861	0.038906	
87	87	88	0.021018	0.018228	
88	88	101	0.02034	0.01764	
89	101	102	0.021696	0.018816	
90	102	103	0.082942	0.071932	
91	103	104	0.133792	0.116032	
92	103	105	0.080908	0.070168	
93	88	89	0.008588	0.007448	
94	89	90	0.059664	0.051744	
95	90	91	0.008588	0.007448	
96	91	92	0.010396	0.009016	
97	91	93	0.020114	0.017444	
98	93	94	0.028476	0.024696	
99	94	95	0.009492	0.008232	
100	90	96	0.016611	0.014406	

101	96	97	0.021244	0.018424	
102	97	98	0.044296	0.038416	
103	98	99	0.003051	0.002646	
104	99	100	0.053223	0.046158	
105	1	106	0.030284	0.026264	
106	106	107	0.008701	0.007546	
107	106	108	0.006102	0.005292	
108	108	109	0.009266	0.008036	
109	109	110	0.007006	0.006076	
110	109	111	0.006893	0.005978	
111	109	112	0.010735	0.00931	
112	112	113	0.001582	0.001372	
113	113	114	0.002712	0.002352	
114	113	115	0.023956	0.020776	
115	115	116	0.022261	0.019306	
116	115	118	0.006102	0.005292	
117	117	118	0.003955	0.00343	
118	118	119	0.014803	0.012838	
119	119	120	0.022035	0.01911	
120	120	121	0.001469	0.001274	
121	121	122	0.026894	0.023324	
122	122	123	0.01808	0.01568	
123	122	124	0.02486	0.02156	
124	124	125	0.002712	0.002352	
125	125	126	0.016385	0.01421	
126	126	127	0.002034	0.001764	
127	122	142	0.004294	0.003724	
128	142	143	0.026781	0.023226	
129	143	144	0.01921	0.01666	
130	143	145	0.009831	0.008526	
131	145	146	0.00113	0.00098	
132	146	147	0.021809	0.018914	
133	147	148	0.017176	0.014896	
134	147	149	0.015142	0.013132	
135	149	150	0.048138	0.041748	
136	150	151	0.048703	0.042238	
137	149	152	0.01921	0.01666	
138	152	153	0.001582	0.001372	
139	153	154	0.002938	0.002548	
140	153	155	0.001582	0.001372	
141	153	156	0.045878	0.039788	
142	156	157	0.010283	0.008918	
143	156	158	0.010283	0.008918	
144	115	128	0.0226	0.0196	
145	128	129	0.006554	0.005684	
146	129	130	0.006328	0.005488	
147	130	131	0.023504	0.020384	
148	129	132	0.007797	0.006762	

149	132	133	0.012091	0.010486	
150	132	134	0.003616	0.003136	
151	134	135	0.006328	0.005488	
152	129	136	0.022487	0.019502	
153	136	137	0.030962	0.026852	
154	137	138	0.020114	0.017444	
155	138	139	0.013899	0.012054	
156	137	140	0.009153	0.007938	
157	140	141	0.022713	0.019698	
158	63	71	0.002938	0.002548	Tie switch
159	37	69	0.028815	0.02499	Tie switch
160	12	116	0.007571	0.006566	Tie switch
161	18	123	0.08362	0.07252	Tie switch
162	75	131	0.113565	0.09849	Tie switch

Table A3

Daily energy consumption at various buses (kWh) for network of Patan substation

Bus No.	Industrial	Domestic	Commercial	Non-commercial
2	0	0	0	0
3	0	0	0	75.13333333
4	0	0	0	0
5	0	0	451.6	0
6	0	0	0	0
7	125.81	311.79	92.99	16.41
8	0	0	0	138.8666667
9	0	0	0	0
10	0	0	408.8	0
11	125.81	311.79	92.99	16.41
12	931.9333333	0	0	0
13	0	0	0	0
14	251.62	623.58	185.98	32.82
15	314.525	779.475	232.475	41.025
16	251.62	623.58	185.98	32.82
17	0	0	0	0
18	0	0	0	301.4666667
19	0	0	0	0
20	0	0	0	359.0666667
21	0	0	0	0
22	251.62	623.58	185.98	32.82
23	125.81	311.79	92.99	16.41
24	251.62	623.58	185.98	32.82
25	251.62	623.58	185.98	32.82
26	0	0	0	0
27	0	104.5333333	0	0
28	125.81	311.79	92.99	16.41
29	0	0	0	0

30	0	0	0	79.4
31	0	0	0	2614.2
32	0	0	0	0
33	251.62	623.58	185.98	32.82
34	125.81	311.79	92.99	16.41
35	125.81	311.79	92.99	16.41
36	0	0	0	0
37	0	0	0	0
38	251.62	623.58	185.98	32.82
39	125.81	311.79	92.99	16.41
40	377.43	935.37	278.97	49.23
41	377.43	935.37	278.97	49.23
42	0	0	0	185.9
43	0	0	0	0
44	0	0	0	502.9333333
45	0	0	0	0
46	251.62	623.58	185.98	32.82
47	251.62	623.58	185.98	32.82
48	251.62	623.58	185.98	32.82
49	125.81	311.79	92.99	16.41
50	125.81	311.79	92.99	16.41
51	251.62	623.58	185.98	32.82
52	0	0	0	0
53	0	0	0	0
54	0	0	568.3666667	0
55	0	0	0	351.9666667
56	0	0	0	0
57	251.62	623.58	185.98	32.82
58	0	0	0	0
59	0	0	0	0
60	0	0	0	89.23333333
61	0	0	0	0
62	125.81	311.79	92.99	16.41
63	0	0	0	0
64	103.93	333.67	76.58	32.82
65	103.93	333.67	76.58	32.82
66	103.93	333.67	76.58	32.82
67	0	0	0	0
68	103.93	333.67	76.58	32.82
69	103.93	333.67	76.58	32.82
70	103.93	333.67	76.58	32.82
71	207.86	667.34	153.16	65.64
72	103.93	333.67	76.58	32.82
73	0	0	0	0
74	25.9825	83.4175	19.145	8.205
75	311.79	1001.01	229.74	98.46
76	0	0	0	0
77	103.93	333.67	76.58	32.82
78	207.86	667.34	153.16	65.64
79	0	0	0	0

80	0	0	0	0
81	103.93	333.67	76.58	32.82
82	103.93	333.67	76.58	32.82
83	0	0	0	0
84	103.93	333.67	76.58	32.82
85	207.86	667.34	153.16	65.64
86	103.93	333.67	76.58	32.82
87	207.86	667.34	153.16	65.64
88	0	0	0	0
89	103.93	333.67	76.58	32.82
90	0	0	0	0
91	0	0	0	0
92	0	0	51.2	0
93	259.825	834.175	191.45	82.05
94	207.86	667.34	153.16	65.64
95	0	0	0	0
96	207.86	667.34	153.16	65.64
97	0	0	38.29	16.41
98	103.93	333.67	76.58	32.82
99	0	0	0	244.0666667
100	51.965	166.835	38.29	16.41
101	103.93	333.67	76.58	32.82
102	259.825	834.175	191.45	82.05
103	0	0	0	0
104	155.895	500.505	114.87	49.23
105	103.93	333.67	76.58	32.82
106	0	0	0	0
107	0	0	0	0
108	164.1	886.14	21.88	21.88
109	0	0	0	0
110	164.1	886.14	21.88	21.88
111	164.1	886.14	21.88	21.88
112	164.1	886.14	21.88	21.88
113	0	0	0	0
114	0	0	160.5666667	0
115	0	0	0	0
116	82.05	443.07	10.94	10.94
117	82.05	443.07	10.94	10.94
118	0	0	0	0
119	164.1	886.14	21.88	21.88
120	82.05	443.07	10.94	10.94
121	82.05	443.07	10.94	10.94
122	0	0	0	0
123	82.05	443.07	10.94	10.94
124	164.1	886.14	21.88	21.88
125	164.1	886.14	21.88	21.88
126	82.05	443.07	10.94	10.94
127	164.1	886.14	21.88	21.88
128	164.1	886.14	21.88	21.88
129	0	0	0	0

130	82.05	443.07	10.94	10.94
131	164.1	886.14	21.88	21.88
132	0	0	0	0
133	164.1	886.14	21.88	21.88
134	82.05	443.07	10.94	10.94
135	82.05	443.07	10.94	10.94
136	123.075	664.605	16.41	16.41
137	82.05	443.07	10.94	10.94
138	82.05	443.07	10.94	10.94
139	82.05	443.07	10.94	10.94
140	82.05	443.07	10.94	10.94
141	164.1	886.14	21.88	21.88
142	164.1	886.14	21.88	21.88
143	0	0	0	0
144	164.1	886.14	21.88	21.88
145	82.05	443.07	10.94	10.94
146	164.1	886.14	21.88	21.88
147	246.15	1329.21	32.82	32.82
148	164.1	886.14	21.88	21.88
149	0	0	0	0
150	164.1	886.14	21.88	21.88
151	113.9333333	0	0	0
152	246.15	1329.21	32.82	32.82
153	0	0	0	0
154	0	0	0	36.2
155	164.1	886.14	21.88	21.88
156	0	0	0	0
157	1249.2	0	0	0
158	164.1	886.14	21.88	21.88

Appendix B

Table B1

Hourly load of feeders before and after reconfiguration for sample network

Time of day	Feeder 1 Load in kW		Feeder 2 Load in kW		Feeder 3 Load in kW	
	Before	After	Before	After	Before	After
1	92.8609	87.7285	45.0068	118.4209	107.0011	38.7193
2	83.9339	80.5261	41.0453	107.2499	99.3277	36.5309
3	79.0566	76.6183	39.4675	102.0259	95.4977	35.3775
4	77.8555	75.2922	39.2601	100.8537	93.6162	34.5858
5	76.3541	74.0337	39.0487	99.628	92.4137	34.1548
6	68.8255	68.4214	37.7985	93.4954	88.2629	32.9701
7	71.3455	71.2879	43.9154	101.9929	92.2651	34.2453
8	88.5836	86.9034	75.9743	141.1704	100.202	36.6861
9	128.1323	120.8383	137.0351	219.4362	116.3906	41.2835
10	134.5223	126.7982	152.9361	243.0968	125.5977	43.1611
11	134.9764	127.7572	156.8975	249.3181	129.293	44.0915
12	133.9012	126.7628	152.6204	247.6651	132.7429	44.8365
13	127.0223	120.0182	132.7598	225.7028	130.0158	44.077
14	142.7586	133.4588	155.0839	254.3851	135.9166	45.9152
15	143.8921	134.3781	159.3077	260.1088	137.2411	45.9541
16	139.6613	131.232	156.1003	255.3635	136.6586	45.8248
17	129.9627	123.0825	142.2944	239.4471	135.5526	45.28
18	109.1144	105.7563	110.9284	203.6613	133.9317	44.5569
19	116.0641	110.6948	107.9678	211.5454	145.3916	47.1834
20	123.3032	115.833	105.7988	215.9509	151.4344	48.7525
21	123.1783	114.9845	92.1323	199.3467	147.5069	48.4863
22	125.768	115.7389	73.2911	176.453	141.1526	48.0197
23	120.3424	110.9095	60.6806	155.9795	132.2147	46.3486
24	108.5849	100.9454	52.6492	137.7027	120.3729	42.959

Table B2

Bus voltage in pu before and after reconfiguration for sample network

Bus no.	Voltage in pu		Bus no.	Voltage in pu	
	Before	After		Before	After
1	1	1	8	0.9991	0.9971
2	0.9999	0.9999	9	0.9984	0.9972
3	0.9997	0.997	10	0.9983	0.9975
4	0.9997	0.9996	11	0.9998	0.9999
5	0.9995	0.9994	12	0.9995	0.9968
6	0.9989	0.9982	13	0.999	0.9996
7	0.9987	0.9979	14	0.9989	0.9992

Table B3

Hourly load of feeders before and after reconfiguration for network of Patan substation

Time of day	Jawalakhel feeder Load in kW		Ring road feeder 2 Load in kW		Local Patan feeder 3 Load in kW	
	Before	After	Before	After	Before	After
1	569.8	10.29	417.9	526.5	681.7	1132.6
2	575.5	9.048	429.3	535.5	720.2	1180.5
3	620.8	8.64	479.5	585.9	833.5	1339.1
4	666.3	8.64	515.4	628.1	900.5	1445.5
5	762.7	8.64	552	693.2	922.1	1534.9
6	1161	8.52	786.6	1013.2	1265.5	2191.4
7	1220.7	10.1	817.7	1063.1	1297.7	2262.9
8	1392.2	15.58	877.9	1209.8	1319.9	2364.7
9	1308.6	25.78	737.5	1150.8	969.4	1838.9
10	1931.2	30.88	1172.6	1701.3	1682.9	3054.6
11	1861.4	32.58	1259.9	1724.4	2000.7	3365.1
12	2316.9	32.88	1722.1	2199.6	2968.2	4774.6
13	2267	29.29	1768.8	2184.7	3158.7	4980.5
14	2181.8	32.66	1616.9	2078.6	2779.8	4467.2
15	1858.7	34.02	1293.7	1740.7	2090.5	3468.1
16	1556.3	33.79	1000.8	1423.9	1478.5	2577.9
17	1285.5	32.4	806.5	1167.7	1129	2020.9
18	965	29.03	616.8	870.4	828.3	1510.7
19	903.7	30.7	585.2	810.8	759.4	1406.9
20	1000.1	30.81	687.8	910.3	973.5	1720.3
21	1139.4	26.3	855.7	1066	1379.5	2282.3
22	1158.7	19.32	927.2	1108.7	1622.4	2580.4
23	992.8	14.63	798.2	951.7	1416.2	2240.8
24	714.5	12.08	546.7	672.6	928.3	1504.9

Table B4

Bus voltage in pu before and after reconfiguration for network of Patan substation

Bus no.	Voltage in pu		Bus no.	Voltage in pu	
	Before	After		Before	After
1	1	1	80	0.997	0.9912
2	0.9996	1	81	0.9971	0.9912
3	0.9996	1	82	0.9962	0.9903
4	0.9993	1	83	0.9955	0.9896
5	0.9993	1	84	0.9954	0.9896
6	0.9993	1	85	0.9954	0.9895
7	0.9992	0.9938	86	0.9954	0.9895
8	0.9989	0.9938	87	0.9951	0.9892
9	0.9987	0.9938	88	0.9949	0.989
10	0.9987	0.9938	89	0.9949	0.989

11	0.9985	0.9938	90	0.9946	0.9887
12	0.9985	0.9942	91	0.9946	0.9887
13	0.9979	0.9932	92	0.9946	0.9887
14	0.9979	0.9932	93	0.9945	0.9886
15	0.9978	0.9931	94	0.9945	0.9886
16	0.9978	0.9931	95	0.9945	0.9886
17	0.9977	0.993	96	0.9945	0.9887
18	0.9977	0.9927	97	0.9945	0.9886
19	0.9975	0.993	98	0.9945	0.9886
20	0.9975	0.993	99	0.9945	0.9886
21	0.997	0.9918	100	0.9945	0.9886
22	0.997	0.9918	101	0.9948	0.989
23	0.997	0.9918	102	0.9948	0.9889
24	0.997	0.9918	103	0.9947	0.9888
25	0.9969	0.9918	104	0.9946	0.9887
26	0.9967	0.9919	105	0.9946	0.9887
27	0.9966	0.9917	106	0.9988	0.9981
28	0.9965	0.9916	107	0.9988	0.9981
29	0.9965	0.9916	108	0.9986	0.9978
30	0.9965	0.9916	109	0.9982	0.9972
31	0.9964	0.9916	110	0.9982	0.9972
32	0.9964	0.9916	111	0.9982	0.9972
33	0.9964	0.9916	112	0.9979	0.9966
34	0.9964	0.9915	113	0.9978	0.9965
35	0.9964	0.9915	114	0.9978	0.9965
36	0.9964	0.9915	115	0.997	0.9951
37	0.9964	0.9964	116	0.997	0.9944
38	0.9965	0.992	117	0.9969	0.9902
39	0.9965	0.9919	118	0.9969	0.9902
40	0.9964	0.9919	119	0.9965	0.9902
41	0.9965	0.9919	120	0.9961	0.9903
42	0.9965	0.9919	121	0.996	0.9903
43	0.9965	0.9921	122	0.9955	0.9904
44	0.9964	0.9921	123	0.9955	0.9908
45	0.9964	0.9922	124	0.9954	0.9903
46	0.9964	0.9921	125	0.9954	0.9903
47	0.9962	0.992	126	0.9954	0.9902
48	0.9962	0.992	127	0.9954	0.9902
49	0.9962	0.992	128	0.9968	0.9945
50	0.9962	0.992	129	0.9967	0.9944
51	0.9963	0.9927	130	0.9967	0.9943
52	0.9963	0.993	131	0.9967	0.9939
53	0.9963	0.9929	132	0.9967	0.9944
54	0.9963	0.9929	133	0.9967	0.9943
55	0.9963	0.9929	134	0.9967	0.9943
56	0.9963	0.9929	135	0.9967	0.9943
57	0.9962	0.9929	136	0.9966	0.9943
58	0.9963	0.9929	137	0.9965	0.9942
59	0.9963	0.9935	138	0.9965	0.9941
60	0.9963	0.9935	139	0.9965	0.9941

61	0.9963	0.9936	140	0.9965	0.9941
62	0.9962	0.9935	141	0.9965	0.9941
63	0.9963	0.994	142	0.9954	0.9903
64	0.9993	0.9991	143	0.9951	0.9899
65	0.9989	0.9985	144	0.9951	0.9899
66	0.9988	0.9985	145	0.995	0.9898
67	0.9985	0.998	146	0.9949	0.9898
68	0.9984	0.9973	147	0.9947	0.9896
69	0.9983	0.9964	148	0.9947	0.9895
70	0.9982	0.995	149	0.9946	0.9895
71	0.9982	0.9941	150	0.9945	0.9894
72	0.9982	0.998	151	0.9945	0.9894
73	0.9974	0.9915	152	0.9945	0.9893
74	0.9974	0.9916	153	0.9945	0.9893
75	0.9973	0.992	154	0.9945	0.9893
76	0.9971	0.9913	155	0.9945	0.9893
77	0.9971	0.9912	156	0.9943	0.9892
78	0.997	0.9912	157	0.9943	0.9892
79	0.997	0.9912	158	0.9943	0.9892

Table B5

Cost comparison before and after reconfiguration for sample network

Feeder 1	Daily peak load(kW)	Peak power loss(kW)	Daily peak power generation (kW)	Daily energy sell(kWh)	LF	LLF	Daily energy loss (kWh)	Daily total energy generation (kWh)	Daily fixed cost(Nrs)	Daily operating cost(Nrs)	Daily total cost(Nrs)	Per unit cost(Nrs)
Before Reconfiguration	143.8921	0.426	144.3181	2679.846	0.776	0.654	6.6898	2686.5363	10390.903	8059.609	18450.5	6.88491
After Reconfiguration	134.3781	0.507	134.8851	2540.069	0.788	0.67	8.15864	2548.2272	9711.7272	7644.682	17356.4	6.83305
Feeder 2												
Before Reconfiguration	159.3077	0.619	159.9267	2310.089	0.604	0.437	6.48911	2316.5782	11514.722	6949.735	18464.5	7.99296
After Reconfiguration	260.1088	1.668	261.7768	4359.84	0.698	0.551	22.0558	4381.8954	18847.93	13145.69	31993.6	7.33826
Feeder 3												
Before Reconfiguration	151.4344	0.494	151.9284	2919.898	0.803	0.693	8.21426	2928.1118	10938.845	8784.335	19723.2	6.75475
After Reconfiguration	48.7525	0.0439	48.7964	1009.996	0.863	0.781	0.82238	1010.8182	3513.3408	3032.455	6545.8	6.48101

Table B6

Cost comparison before and after reconfiguration for network of Patan substation

Jawalakhel feeder	Daily peak load (kW)	Peak power loss(kW)	Daily peak power generation (kW)	Daily energy sell(kWh)	LF	LLF	Daily energy loss(kWh)	Daily total energy generation (kWh)	Daily fixed cost(Nrs)	Daily operating cost(Nrs)	Daily total cost(Nrs)	Per unit cost(Nrs)
Before Reconfiguration	2316.9	6.6417	2323.542	30410.7	0.547	0.373	59.52659	30470.229	167295	91410.69	258705.69	8.50706
After Reconfiguration	34.02	0.00047	34.02047	526.7112	0.645	0.485	0.005516	526.71676	2449.4741	1580.15	4029.6244	7.65054
Ring road feeder												
Before Reconfiguration	1768.8	5.9418	1774.742	21272.3	0.501	0.326	46.50302	21318.799	127781.41	63956.4	191737.81	9.0135
After Reconfiguration	2199.6	9.0815	2208.682	28015.87	0.531	0.356	77.67074	28093.536	159025.07	84280.61	243305.68	8.68457
Local Patan feeder												
Before Reconfiguration	3158.7	11.7054	3170.405	34106.38	0.45	0.277	77.72114	34184.1	228269.19	102552.3	330821.49	9.6997
After Reconfiguration	4980.5	33.7	5014.2	57243.87	0.479	0.304	246.0464	57489.921	361022.4	172469.8	533492.16	9.31964

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