Planning of Distribution Networks in Baghdad City

Dr. Thamir M. Abdul-Wahhab
Lecturer
Department of Electrical Engineering
University of Technology
E-mail: thamir62@yahoo.com

Adeeb Nasser Hussein
M. Sc. Student
Department of Electrical Engineering
University of Technology
E-mail: adeeb.nasser@yahoo.com

ABSTRACT

Planning of electrical distribution networks is considered of highest priority at the present time in Iraq, due to the huge increase in electrical demand and expansions imposed on distribution networks as a result of the great and rapid urban development.

Distribution system planning simulates and studies the behavior of electrical distribution networks under different operating conditions. The study provide understanding of the existing system and to prepare a short term development plan or a long term plan used to guide system expansion and future investments needed for improved network performance.

The objective of this research is the planning of Al_Bayaa 11 kV distribution network in Baghdad city based on the powerful and efficient CYMDist software as a tool for the simulation and analysis of the network.

The planning method proposed in this thesis is to reach the optimum operating conditions of the network by combining the network reconfiguration in sequence with the insertion of capacitors with optimal sizing and locations. The optimum performance of the network is achieved by reducing losses, improving voltage profile and alleviating overload for transformers and cables.

Key words: Distribution network planning, CYMDist software, network reconfiguration, capacitor placement, loss minimization.

تخطيط شبكات التوزيع في مدينة بغداد

د. ثامر محمد عبد الوهاب
مدرس
قسم الهندسة الكهربائية
الجامعة التكنلوجية

أديب ناصر حسين
طالب ماجستير
قسم الهندسة الكهربائية
الجامعة التكنلوجية

الخلاصة

يعد تخطيط شبكات التوزيع الكهربائية من الأولويات في الوقت الحاضر في العراق نظراً للزيادة الهائلة في الأحمال الكهربائية و التوسعات المفروضة على الشبكات نتيجة التطور العمراني الكبير والسريع.

تخطيط منظومة التوزيع يحاكي ويدرس سلوك شبكات التوزيع الكهربائية في ظل ظروف تشغيل مختلفة. الدراسة توفر فهم المنظومة القائمة وإعداد خطة تنموية قصيرة الأجل أو خطة طويلة المدى تستخدم لتوجيه التوسع في المنظومة والاستثمارات المستقبلية اللازمة لتحسين أداء الشبكة.

الهدف من البحث هو تخطيط شبكة توزيع كهرباء البياع 11 kV في مدينة بغداد استناداً الى برمجيات CYMDist ذات القدرة والكفاءة العالية كأداة لتمثيلها حاسوبياً و اجراء التحليلات عليها.

ان طريقة التخطيط المقترحة في هذه الأطروحة للوصول الى حالة الأداء الأمثل للشبكة هي بأجراء عملية تغيير طوبوغرافية الشبكة بالتعاقب مع ادخال متسعات بسعات محسوبة وفي اماكن مثالية في منظومة التوزيع. ويتحقق الأداء الأمثل للشبكة بتقليل المفاقيد, وتحسين الجهد (voltage profile) ومعالجة مشكلة الحمل الزائد للمحولات والمغذيات.

الكلمات الرئيسية: تخطيط شبكات التوزيع, برنامج CYMDist, تغيير طوبوغرافية الشبكة, ادخال متسعات, تقليل المفاقيد.

1. INTRODUCTION

The objective of distribution network planning is to satisfy the annual load growth for the planning period, reduce line losses, improve voltage profile and increase reliability of the network. The power loss is significantly high in distribution networks because of lower voltage levels and higher currents, these losses cannot be eliminated but can be reduced, **,Satish, 2012.** Power loss minimization by reconfiguring the network and installing shunt capacitors are two main means for loss reduction. Network reconfiguration is defined as altering the topological structure of distribution networks by changing the open/closed status of the normally closed (sectionalizing) and normally open (tie) switches. If shunt capacitors are installed in the correct position and size it can significantly improve the performance of distribution circuits. **Literature Review: ,Baran, and Wu, 1989.** proposed a new solution method for network reconfiguration based on a branch-exchange for both loss reduction and load balancing between feeders. Two approximate load flow methods for radial systems have been developed, these are the simple Dist flow and Backward/Forward methods.

,Thiruvenkadam, et al., 2008. presented a feeder reconfiguration algorithm for loss reduction and load balancing at the same time. The proposed algorithm efficiently utilizes a heuristic based fuzzy strategy and constrained fuzzy operation along with back propagation neural network.

,Dong Zhang, et al., 2008. proposed a joint optimization algorithm of combining network reconfiguration and capacitor control for loss reduction in distribution systems. An improved adaptive genetic algorithm (IAGA) is developed to optimize capacitor switching, and a simplified branch exchange algorithm is developed to find the optimal network structure.**,Gupta et al., 2011.** presented a fast and efficient heuristic algorithm to explore the optimal number, locations and sizing of shunt capacitors in radial distribution systems under varying load conditions. A new constraint objective cost function (COCF) has been formulated to maximize the net annual saving by minimizing the real power losses and optimizing the annual investment on shunt capacitors while improving the system node voltage profile.

,Prasanna et al., 2012. proposed a new method of Second order PSO for a more effective capacitor sizing in radial distribution feeders to reduce the real power loss and to improve the voltage profile. The location of the nodes where the capacitors should be placed is decided by a set of rules given by the fuzzy expert system and the sizing of the capacitors is modeled by the objective function to obtain maximum savings using Particle Swarm Optimization (PSO).

2. THE PROPOSED METHOD

The proposed planning approach consists of:

1. Load allocation.
2. Reconfiguration of the network by changing switch status.
3. In case of operational constraints are violated in the reconfigured network, reactive power compensation is applied for candidate buses.

a. Load Allocation: In this work the connected kVA load allocation technique provided by CYMDist software is used which distributes the substation load demand (entered by the user in amps for each phase) along the feeder according to the connected kVA of the distribution transformers.

b. Network Reconfiguration: In the problem of system reconfiguration, the control variables are switching statuses. To get different choices of topologies, the switching statuses are randomly altered in between two values such as 1 for close or 0 for open. The objective function of the network reconfiguration problem is the minimization of power loss which can be expressed mathematically as follows **,Manju, et al., 2012.**

$$min.f = \sum_{i=1}^{n} k_i \, r_i \frac{P_i^2 + Q_i^2}{V_i^2} \tag{1}$$

Where: f the objective function, n total number of branches, r_i resistance of branch i, Q_i reactive power of branch i, P_i active power of branch i, V_i voltage on head node of branch i, k_i switch status on branch i (k_i =1 equal to closed, k_i= 0 equal to open).

2.1 Subject to the following constraints

Voltage Constraint: Voltage magnitude at each node must lie within its permissible range:

$$V_{min.} \le V_{load} \le V_{max.} \tag{2}$$

Where: $V_{min.}$ and $V_{max.}$ are the lower and upper voltage limits, respectively.
Radiality Constraints: each load node should be fed by only one substation (no loops are allowed in the network).
Power Source Limit Constraint: The total loads of a certain partial network cannot exceed the capacity limit of the corresponding power source:

$$P_t \le P_s^{max.} \tag{3}$$
$$Q_t \le Q_s^{max.} \tag{4}$$

Power factor constraint, harmonics constraint, and voltage angle constraint has not been taken into consideration to avoid the complexity of the problem.

2.2 The reconfiguration method

starts with a meshed distribution network obtained by considering all switches closed. Then, the switches are opened successively to eliminate the loops. The opening criterion is based on minimum total power loss increase, and this is determined using the power-flow program in CYMDist. The two procedures of this method are illustrated in **,Flávio, et al., 2005.**

2.3 Optimal capacitor placement and sizing

The problem is formulated to determine the optimal shunt capacitor size and location in a radial distribution network by minimizing the ohmic losses, taking into account cost of the capacitor. At the same time, the choice is restricted by electric network constraints. The sizes of capacitor banks are given by standard size, which makes the set of solutions to be discrete, **,Héctor, 2013.**
For simplicity, the operation and maintenance cost of the capacitor placed in the distribution system is not taken into consideration.
Capacitor placement routine exists in CYMDist module, the routine performs single objective optimization (either P_{loss} or ΔV).

Subject to The Following Constraints:
Bus Voltage Limits: The bus voltage magnitudes are to be kept within acceptable operating limits throughout the optimization process:

$$V_{min.} \le |V_i| \le V_{max.} \tag{5}$$

Where: $V_{min.}$ Lower bus voltage limit; $V_{max.}$ Upper bus voltage limit; $|V_i|$ rms value of the i_{th} bus voltage.

The Line Current (I), should be less than the line rated current (I_{rated}).

$$I \le I_{rated} \tag{6}$$

Power-Conservation Limit: The algebraic sum of all incoming and outgoing power including line losses over the whole distribution network should be equal to zero:

$$P_G - \sum_{i=1}^{n} P_D - P_{lt} = 0 \tag{7}$$

Where: P_G power generation, P_D power demand; P_{lt} total power losses

The Number and Sizes of Permissible Capacitor Banks Constraint:

The number of capacitor banks can be expressed to satisfy the following expression:

$$\sum_{i=1}^{m} Q_c \le Q_t \tag{8}$$

Where: Q_c kVAr obtained from the capacitor bank; Q_t total reactive power flow required; *m* total number of capacitor banks.

The capacitor placement method determines the optimal sizes and placements of the capacitors that minimize the objective function and satisfy constraints.

3. FORWARD/BACKWARD SWEEP LOAD FLOW OF DISTRIBUTION SYSTEMS (Ladder Iterative Technique)

The backward-forward sweep method is an iterative means to solve the load flow equations of radial distribution networks which has two steps. The backward sweep, which updates currents using Kirchoff's Current Law (KCL), and the forward sweep, which updates voltage using voltage drop calculations, **,William, 2002.** The voltage magnitude and phase angle of the source should to be specified. Also the complex values of load demands at each node along the feeder should be known, **,Manas, 2014.**

4. COST OF ENERGY LOSSES

To calculate the annual cost of system losses, the built-in loss factor formula in CYMDist is used (eq. 9). The loss factor (L_{fls}) is an expression of the real power loss over a given period of time at a given loading condition.

$$Loss\ Factor = A \times LDF + (1 - A) \times LDF^2 \tag{9}$$

Where, A is a constant for distribution network and taken occasionally as 0.15 for distribution system **,Meghana, 2011.**, LDF is the load factor.

The following empirical formula is used to estimate the annual cost of active power losses after a load flow simulation, **,Sarwar, et al., 2012.**

$$Annual\ cost = P_{loss\ max.} \times L_{fls} \times T \times C \tag{10}$$

Where:

$P_{loss\ max}$: power loss at the peak load power (kW); L_{fls}: loss factor

T: time interval (h); C: tariff cost ($)

For reactive power compensation, the cost includes the cost of power loss and the investment cost of capacitor placement. The maximum capacitor size Q_{max} should not exceed the total reactive loads. The annual cost equation will be, **,Divya,** and **Siva, 2013.**

$$annual\ cost = P_{\underset{max.}{loss}} \times L_{fls} \times T \times C + \sum_{j=1}^{k} K_j Q_j \tag{11}$$

Where: Q: Capacitor size (kVAr); K: Cost of capacitor size ($/kVAr)
j=1, 2… k represents the selected buses.

5. CYMDist SOFTWARE

CYMDist is a windows-based primary distribution analysis software available from CYME Inc, Canada. It is an advanced engineering tool that used for planning studies and simulating the behavior of electrical distribution networks in its present or future state under different operating conditions and scenarios. Analytical capabilities of the CYME software fully support any type of simulation, the graphical representation of network components can represented schematically or geographically, **,CYME Reference, Manual.**

a. Types of Loads Identified by CYMDist

Distributed loads are the “normal” loads in the system, while Spot loads are often representing predictable and substantially large loads, such as industrial customers.
In Iraq, loads are usually represented by spot load type, which often placed at the center of sections [MOE].

b. Network Modeling

The modeling process begins with acquiring all the input data required for the modeling, and the combined processed data are entered or imported from GIS software into CYMDist to create the distribution system model, with the single line diagram automatically generated.

c. Types of Analysis Features in CYMDist

The voltage drop calculation technique in CYMDist is an iterative technique that is specifically designed and optimized for radial or weakly meshed networks.
In this thesis, the studied networks are analyzed based on voltage drop analysis.

i. Load Allocation Methods

CYMDist provides four load allocation methods among these methods the connected kVA load allocation method is the one used in this work.

ii. Load Flow Analysis in CYME:

The backward-forward sweep method, also known as the ladder methodology, is used by the iterative software in CYMDist to compute the branch currents.

iii. CYMDist_SOM (Switching Optimization)

The module can determine the optimal location of the tie points by suggesting new locations or recommending new switching schemes for existing devices to achieve optimal network topologies.

6. THE PROPOSED PLANNING METHOD

The proposed planning method in this work is illustrated by the flow chart in **Fig.1**.

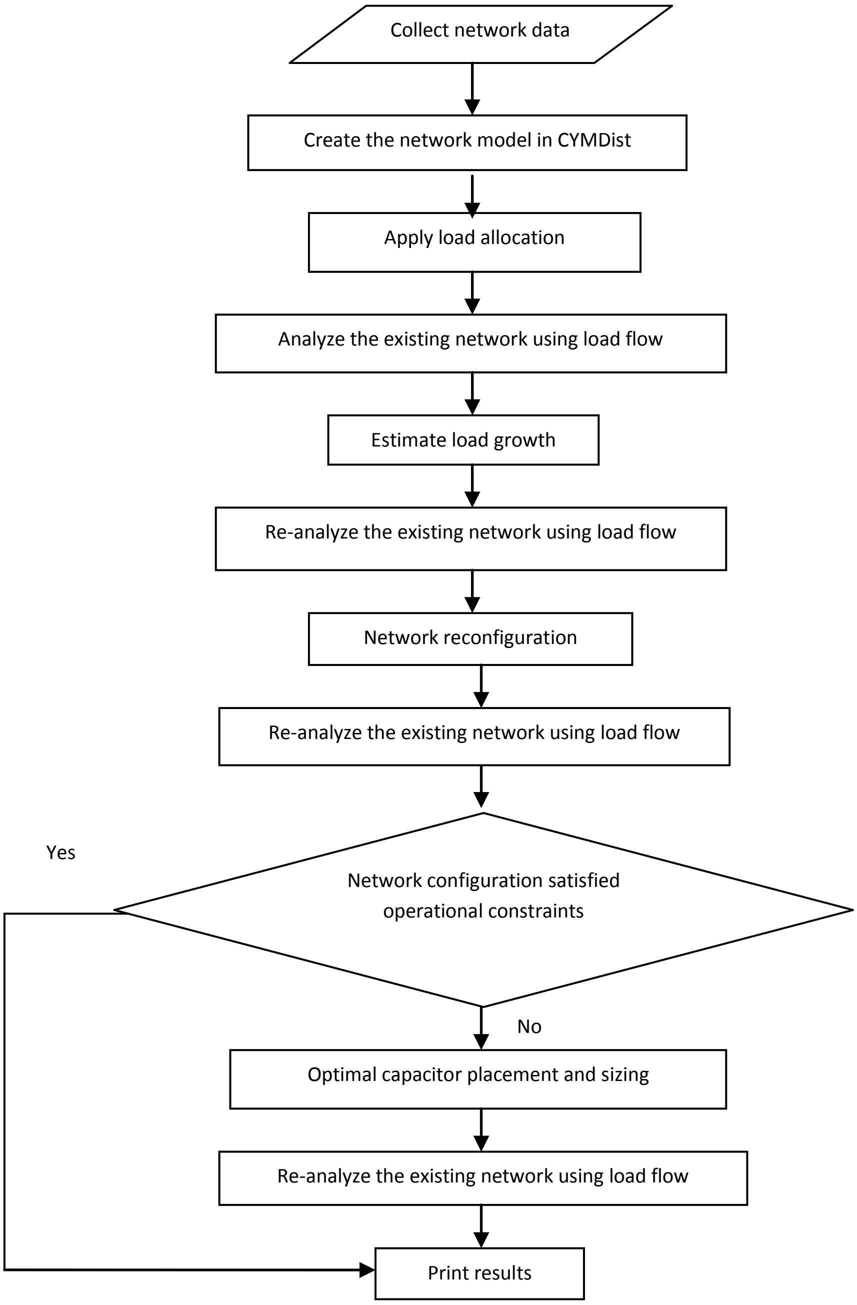


Figure 1. Flow chart representing the proposed planning method using CYMDist software.

7. CASE STUDY and RESULTS

The proposed analysis is implemented, using the CYMDist 4.5 (Rev.6) software, on Al_Bayaa distribution network in Baghdad city. The capacity of Al_Bayaa (33/11 kV) substation is (2*31.5 MVA), which is fed by two 33kV feeders from Al-Jazayr and Al-Dora expansion substations (132/33/11 kV). There are Fourteen (11 kV) feeders outgoing from Al_Bayaa substation serving a large area of mixed residential, commercial, and industrial loads. Only four feeders are considered in this work.

a. Al_Bayaa Distribution Network

Al_Bayaa network is rated at 11 kV, base MVA =100, and frequency of 50 Hz with (151) line sections, (145) buses, and six tie switches. The schematic diagram of Al_Bayaa system by CYMDist is shown in **Fig.2**. The load for Al_Bayaa feeders is mixed, approximately 94% residential and 6% commercial.

The load duration curve for the years of planning horizon is divided to three load levels (high, medium and low) as shown in **Table 1.**

Table 1. Load duration curve of Al_Bayaa substation [MOE].

Load (%)	100	70	40
Time of loading (%)	33	52	15
Duration (h)	2891	4555	1314

The modeling of Al_Bayaa network is based on the actual coordination's of the secondary distribution transformers. This coordination's are taken from Iraqi ministry of electricity depending on the global positioning system (GPS). The coordinates are entered to the CYMDist module as x and y coordinates for the nodes (buses) to build the model and specify the actual length of the network sections.

Before starting, some assumptions are made in this work:

- Balance voltage drop iterative method is used, the maximum number of iterations are 40 for load flow and the convergence error (dv) to be 0.01%.
- Tariff cost (cost of electrical energy) is 0.1 $/kWh according to Iraqi ministry of electricity.
- Voltage limitation is set to 5% over the voltage rating, or 5% under voltage rating.
- The objective functions of the switching optimization and capacitor placement are to minimize kW losses, for the average peak demand for the last year of planning horizon.
- The entire feeders load factor for the selected networks in this thesis is equal to 65%.
- The effect of harmonics is ignored.
- All the loads have the same power factor.
- The Stability is ignored.
- The basic distribution infrastructure and characteristics will remain as they are today.

By using the connected kVA method with (dv= 0.01%) tolerance for accuracy, loads are distributed in all sections for each phase depending on the current values at the head of each feeder and the secondary (11/0.4 kV) (Delta- Grounded wye) transformer capacities are as shown in **Table 2a. and Table 2b.**

Table 2a. The current at the top head of each feeder of Al_Bayaa network.

Top head feeder	Current / phase (A)	P.F (%)
Bayaa_7	240	80
Bayaa_8	200	80
Bayaa_11	220	80
Bayaa_12	170	80

Table 2b. Secondary transformer capacities of Al_Bayaa network.

Spot load number	Transformer capacity (kVA)
2, 3, 6, 11, 26, 27, 30, 31, 32, 34, 36, 37, 40, 41, 43, 46, 48, 49, 50, 56, 59, 63, 64, 68, 69, 71, 78, 82, 85, 88, 89, 91, 94, 95, 96, 97, 107, 111, 112, 113, 115, 117, 118, 120, 121, 125, 128, 130, 132, 134, 149.	250
4, 7, 8, 9, 12, 13, 14, 18, 19, 20, 21, 22, 23, 25, 29, 35, 38, 54, 58, 60, 67, 73, 84, 87, 90, 92, 98, 101, 102, 105, 109, 110, 123, 126, 138, 142, 144, 150.	400

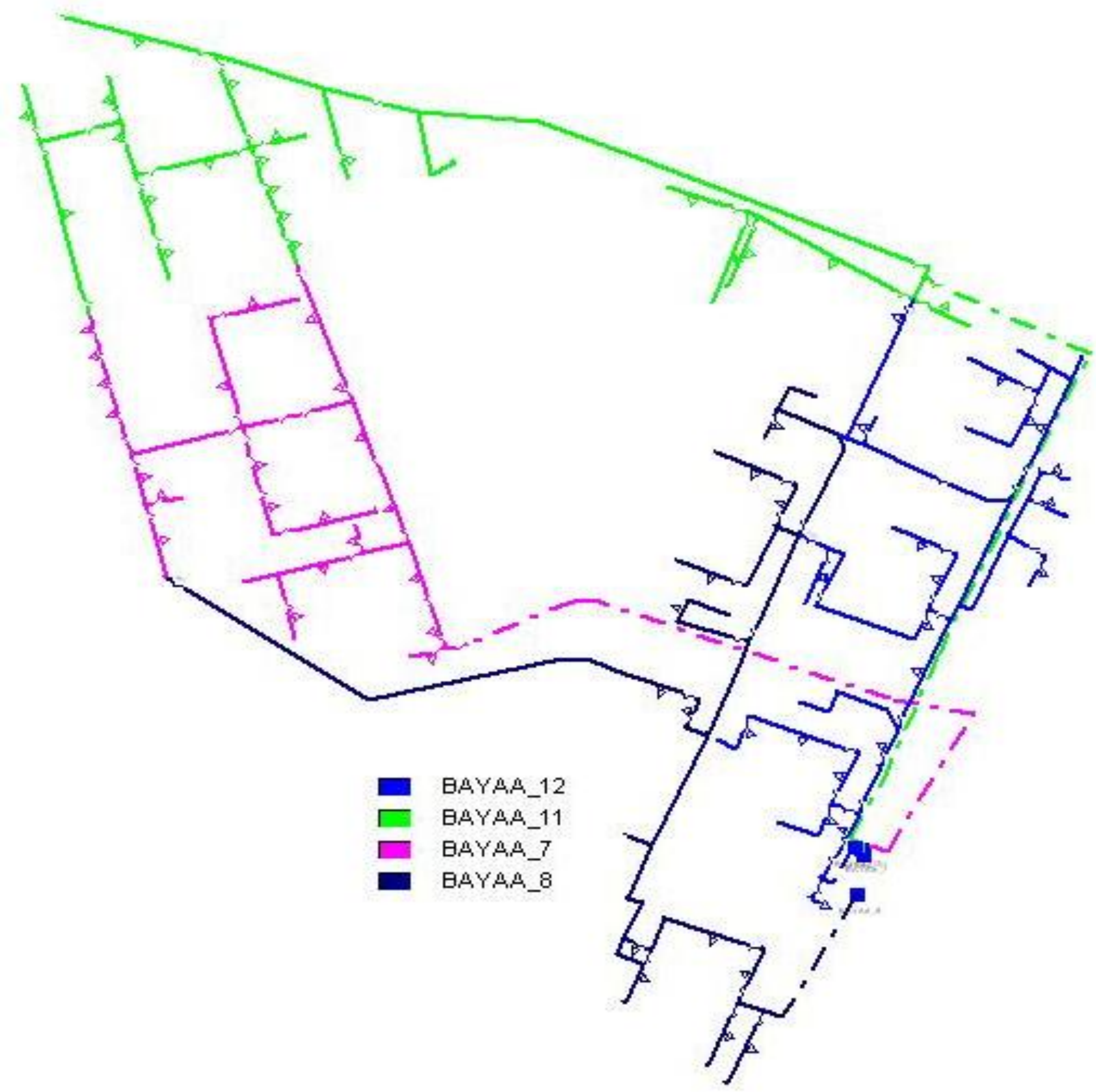


Figure 2. Initial configuration of Al_Bayaa network.

Before applying the short term planning to the existing network, it must be analyzed using load flow. Load growth analysis should be applied to the network in order to examine its consolidation and efficiency to yearly load growth. The network is assessed with the percentage annual load growth rate for the next 5 years (2013-2017) as shown in **Fig. 3**.

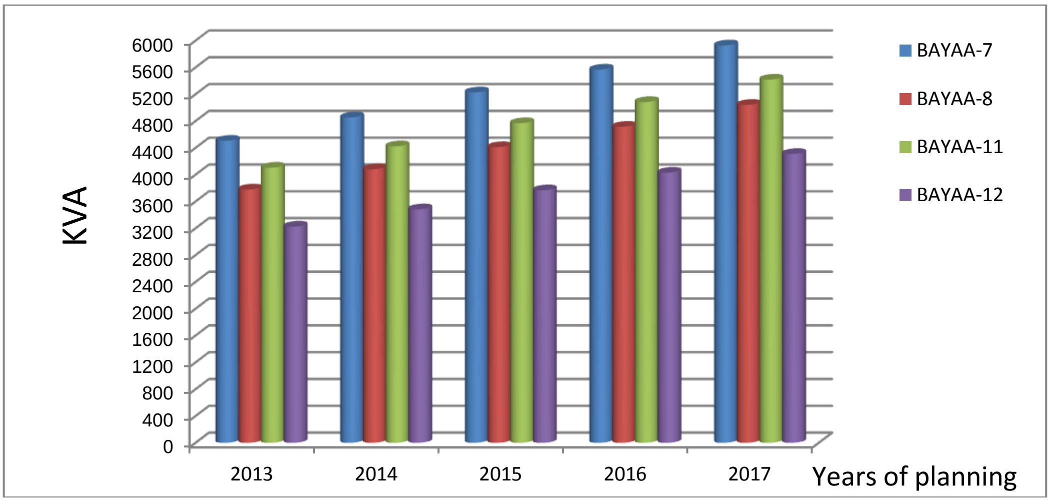
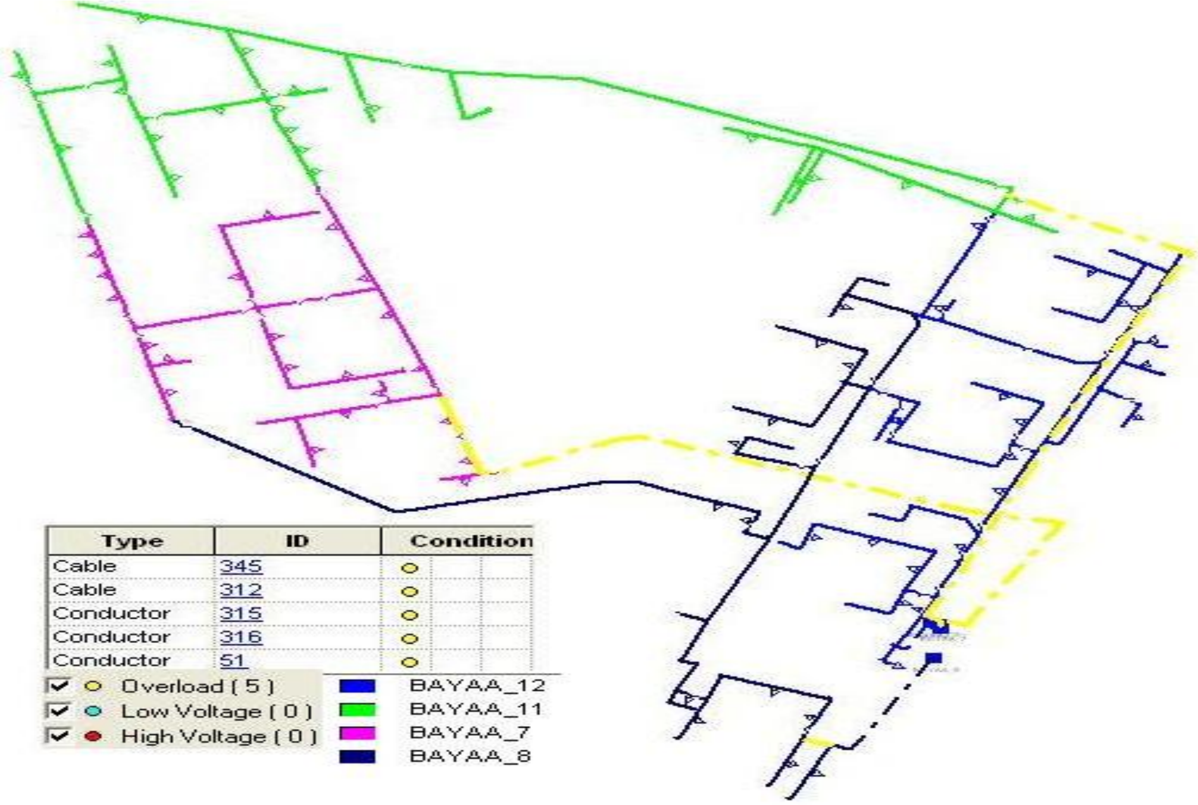


Figure 3. Load growth of the feeders of Al_Bayaa network.

There are 5 sections that operate in overloaded condition as shown in **Fig.4**. (All calculations are done for the last year of the planning horizon and for peak load only).



Type	ID	Condition
Cable	345	○
Cable	312	○
Conductor	315	○
Conductor	316	○
Conductor	51	○

☑ ○ Overload (5)
☑ ○ Low Voltage (0)
☑ ● High Voltage (0)

Figure 4. Abnormal conditions after load growth for Al_Bayaa network.

The simulation results listed in **Table 3.** shows that the initial system real power losses after load growth for all feeders were 269.36 kW. Applying the switching optimization technique to minimize losses and to distribute loads on a regular basis among feeders, the final power loss after reconfiguration became 229.29 kW, so the total reduction in power losses after reconfiguration became 40.07 kW (14.87 % of its initial value). The optimal configuration is shown in **Fig.5**. **Table 4.** shows the switching operation modes during system reconfiguration.

After applying the load flow, it is obvious that the network is still operating under abnormal conditions (5 sections are operating under overloaded conditions as shown in **Fig. 6**. Therefore, reactive power compensation can be the solution to this problem by increasing the capacity of these feeders. Optimal locations of capacitors are shown in **Fig.7** and **Table 5.** gives the optimal of capacitor placement and sizing. **Table 3.** gives the voltage drop before and after load growth, switching optimization and kVAr compensation. **Table 6.** gives the voltage drop summary for all feeders, the total system kW losses for all feeders are shown in **Fig.8**.

Table 3. Voltage drop before and after load growth, after switching optimization and kVAr compensation of Al_Bayaa network at peak load.

Bayaa_7		Total load used	Total adjusted shunt capacitor + total conductor capacitances	Total losses	Total source power
Before load growth	kW	3605.97	---	51.84	3657.81
	kVAr	2702.52	0+5.69	46.49	2743.32
	kVA	4506.29	---	69.64	4572.24
	P.F.	0.8	---	0.74	0.8
After load growth	kW	4744.08	---	90.68	4834.76
	kVAr	3555.49	0+5.67	81.32	3631.14
	kVA	5928.56	---	121.8	6046.49
	P.F.	0.8	---	0.74	0.8
After switching optimization	kW	4291.55	---	69.89	4361.44
	kVAr	3215.07	0+5.47	61.91	3271.51
	kVA	5362.28	---	93.36	5452.05
	P.F.	0.8	---	0.74	0.8
After kVAr compensation	kW	4291.55	---	44.9	4336.45
	kVAr	3215.07	3086.01+5.49	39.9	163.47
	kVA	5362.28	---	60.07	4339.53
	P.F.	0.8	---	0.74	0.99
Bayaa_8		Total load used	Total adjusted shunt capacitor + total conductor capacitances	Total losses	Total source power
Before load growth	kW	3025.22	---	23.16	3048.38
	kVAr	2265.19	0 + 2.69	23.78	2286.27
	kVA	3779.29	---	33.19	3810.47
	P.F.	0.8	---	0.69	0.8
After load growth	kW	4035.19	---	42.07	4077.26
	kVAr	3021.43	0 + 2.68	43.23	3061.98
	kVA	5041.01	---	60.32	5099
	P.F.	0.8	---	0.69	0.8
After switching optimization	kW	4117.04	---	52.52	4169.57
	kVAr	3083.26	0 + 2.63	54.56	3135.19
	kVA	5143.59	---	75.73	5216.77
	P.F.	0.8	---	0.69	0.8
After kVAr compensation	kW	4117.04	---	34.25	4151.29
	kVAr	3083.26	2204.31 + 2.65	35.54	911.84
	kVA	5143.59	---	49.36	4250.26
	P.F.	0.8	---	0.69	0.97

Table 3 continued

Bayaa_11		Total load used	Total adjusted shunt capacitor + total conductor capacitances	Total losses	Total source power
Before load growth	kW	3286.84	---	66.43	3353.27
	kVAr	2457.61	0 + 6.46	63.81	2514.96
	kVA	4104.04	---	92.11	4191.59
	P.F.	0.8	---	0.72	0.8
After load growth	kW	4339.6	---	117.22	4456.82
	kVAr	3244.77	0 + 6.43	112.55	3350.9
	kVA	5418.55	---	162.5	5576
	P.F.	0.8	---	0.72	0.8
After switching optimization	kW	4122.84	---	76.11	4198.95
	kVAr	3083.83	0 + 6.63	69.29	3146.5
	kVA	5148.58	---	102.93	5247.06
	P.F.	0.8	---	0.73	0.8
After kVAr compensation	kW	4125.43	---	50.02	4175.45
	kVAr	3085.77	2635.49 + 6.66	45.76	489.38
	kVA	5151.81	---	67.8	4204.03
	P.F.	0.8	---	0.73	0.99
Bayaa_12		Total load used	Total adjusted shunt capacitor + total conductor capacitances	Total losses	Total source power
Before load growth	kW	2580.34	---	10.8	2591.14
	kVAr	1934.26	0 + 2.32	11.41	1943.35
	kVA	3224.83	---	15.71	3238.92
	P.F.	0.8	---	0.68	0.8
After load growth	kW	3447.68	---	19.39	3467.07
	kVAr	2584.43	0 + 2.32	20.5	2602.61
	kVA	4308.8	---	28.21	4335.22
	P.F.	0.8	---	0.68	0.8
After switching optimization	kW	4038.62	---	30.77	4069.4
	kVAr	3026.58	0 + 2.4	32.7	3056.87
	kVA	5046.84	---	44.9	5089.64
	P.F.	0.8	---	0.68	0.8
After kVAr compensation	kW	4043.62	---	20.8	4064.42
	kVAr	3030.32	2224.38 + 2.41	22.12	825.64
	kVA	5053.08	---	30.36	4147.43
	P.F.	0.8	---	0.68	0.98

Table 4. Switching operations of Al_Bayaa network.

Section Id	142	14	103	124	140	51	55	136	61	24	88	102
Action	Close	Close	Close	Close	Close	Close	Open	Open	Open	Open	Open	Open
Switch Id	S142	S14	S103	S124	S140	S51	S55	S136	S61	S24	S88	S102

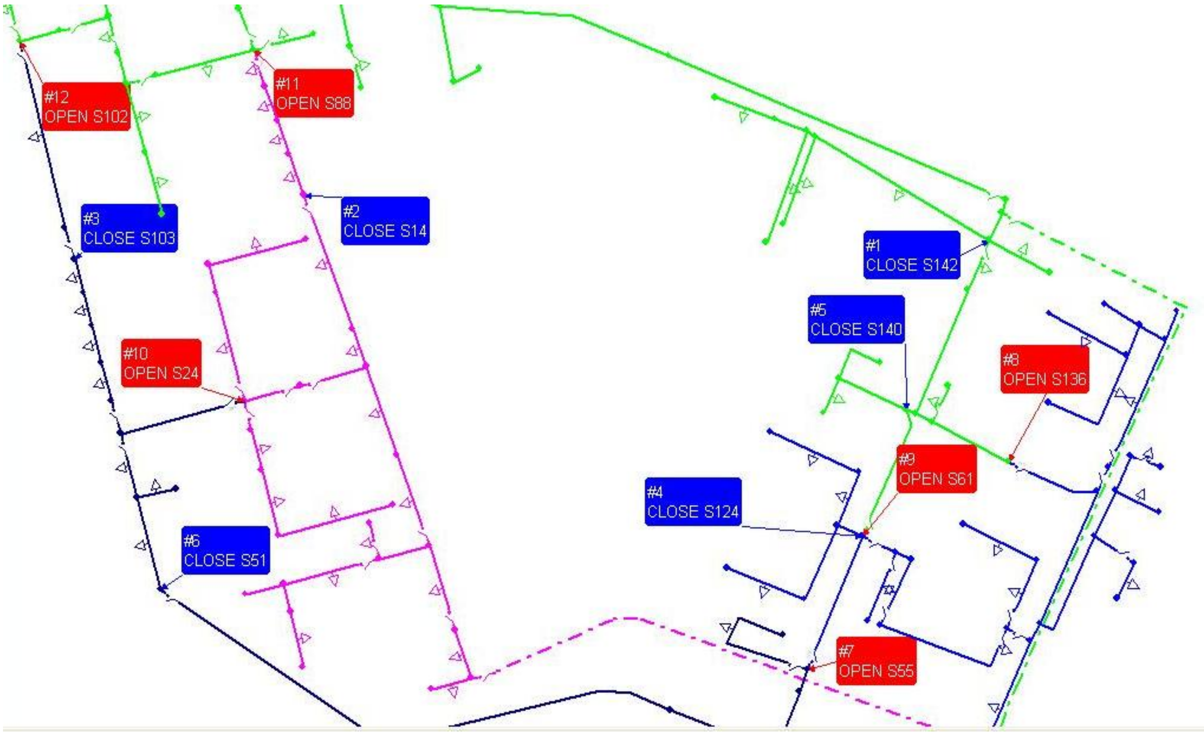
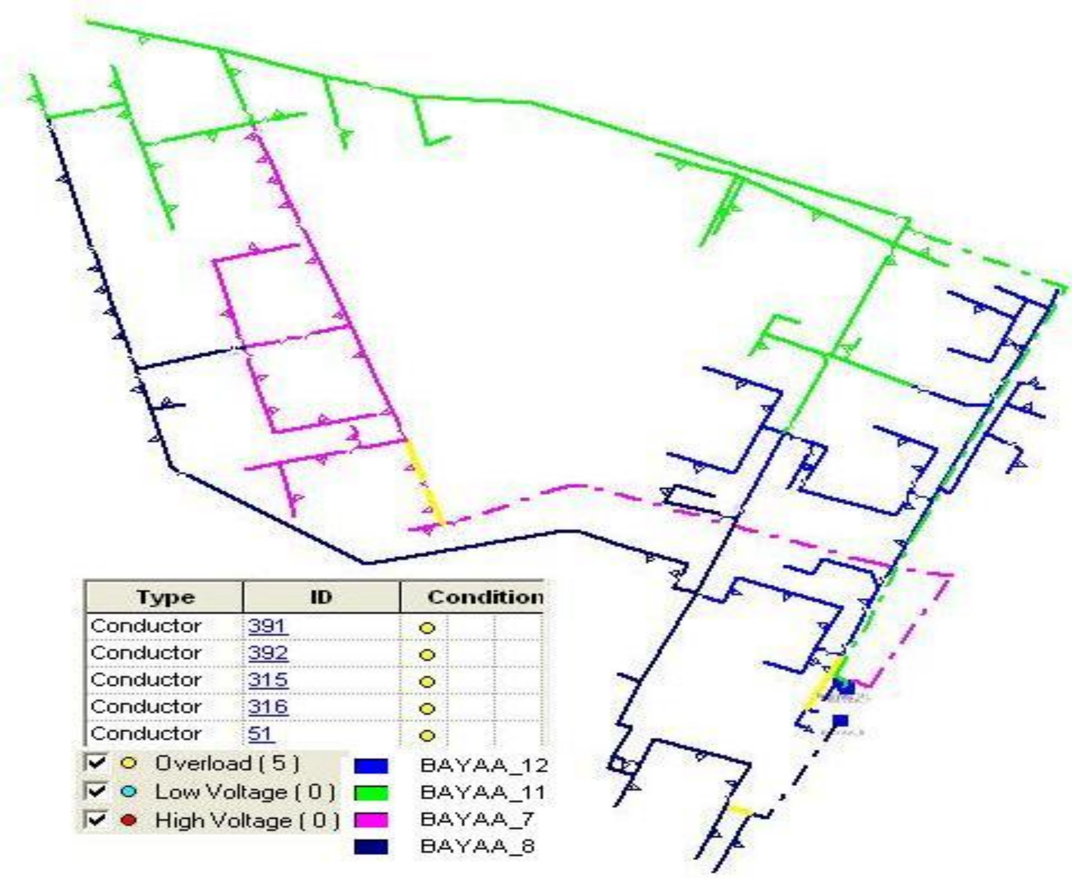


Figure 5. Optimal configuration of Al_Bayaa network.



Type	ID	Condition
Conductor	391	○
Conductor	392	○
Conductor	315	○
Conductor	316	○
Conductor	51	○

Figure 6. Abnormal conditions after applying switching optimization technique of Al_Bayaa network.

Table 5. Optimal location and size of capacitors for Al_Bayaa network at peak load conditions (100% loading).

Bayaa_7 : P.F corrected to 0.99			
Node Id	Cap. kV (L-L)	Total capacitors (kVAr)	Loss reduction (kW)
16	11	900	11.3
14	11	900	7.7
4	11	1350	0.58
Total		3150	23.9
Bayaa_8 : P.F corrected to 0.97			
29	11	900	10.9
49	11	450	4
39	11	900	3.1
Total		2250	18
Bayaa_11 : P.F corrected to 0.99			
96	11	450	9.5
85	11	900	10.3
66	11	1350	5.7
Total		2700	25.5
Bayaa_12 : P.F corrected to 0.98			
56	11	900	5.5
119	11	450	2.4
115	11	900	1.8
Total		2250	9.7

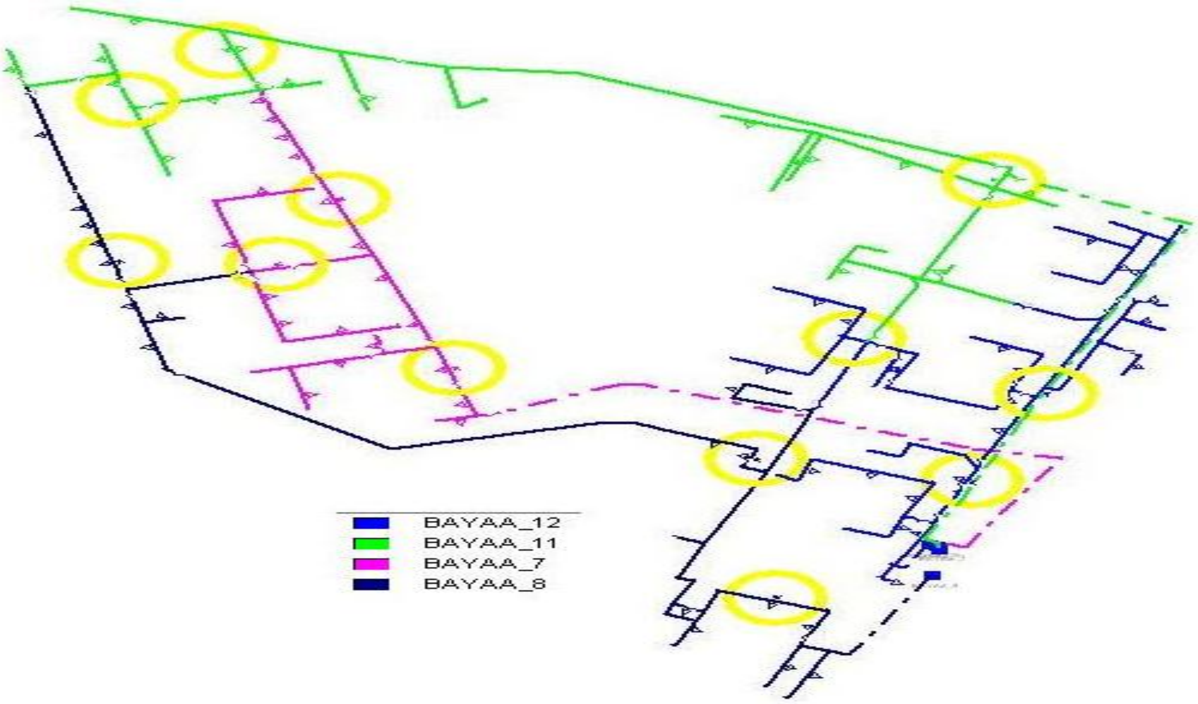


Figure 7. Optimal capacitor allocations for Al_Bayaa network.

Table 6. Summary of results of Al_Bayaa network using CYMDist

Bayaa_7	Before load growth	After load growth	After switching optimization	After kVAr compensation
Maximum voltage (p.u.)	1	1	1	1
Minimum voltage (p.u.)	0.982	0.976	0.98	0.987
Total Active power loss (kW)/phase	17.28	30.23	23.3	14.97
Total Reactive power loss (kVAr)/ phase	15.5	27.11	20.64	13.3
Total kW load/phase	1202	1581.4	1430.5	1430.5
Total kVAr load/phase	901	1185	1072	1072
Total actual kVA load/phase	1502	1976	1787	1787
Bayaa_8	Before load growth	After load growth	After switching optimization	After kVAr compensation
Maximum voltage (p.u.)	1	1	1	1
Minimum voltage (p.u.)	0.987	0.983	0.975	0.985
Total active power loss (kW)/phase	7.72	14.02	17.51	11.42
Total reactive power loss (kVAr)/ phase	7.93	14.41	18.19	11.85
Total kW load/phase	1011.5	1350.8	1372.3	1372.3
Total kVAr load/phase	757	1011	1028	1028
Total actual kVA load/phase	1264	1688	1715	1715
Bayaa_11	Before load growth	After load growth	After switching optimization	After kVAr compensation
Maximum voltage (p.u.)	1	1	1	1
Minimum voltage (p.u)	0.972	0.963	0.972	0.981
Total active power loss (kW/phase)	22.14	39.07	25.37	16.67
Total reactive power loss (kVAr/ phase)	21.27	37.52	23.1	15.25
Total kW load/phase	1096.1	1447.5	1377.2	1377.2
Total kVAr load/phase	820	1082	1030	1030
Total actual kVA load/phase	1369	1807	1720	1720

Table 6. continued

Bayaa_12	Before load growth	After load growth	After switching optimization	After kVAr compensation
Maximum voltage (p.u.)	1	1	1	1
Minimum voltage (p.u.)	0.993	0.991	0.987	0.992
Total active power loss (kW)/ phase	3.6	6.46	10.26	6.93
Total reactive power loss (kVAr)/ phase	3.8	6.83	10.9	7.37
Total kW load/phase	861.2	1151.3	1350.9	1350.9
Total kVAr load/phase	646	863	1012	1012
Total actual kVA load/phase	1076	1439	1688	1688

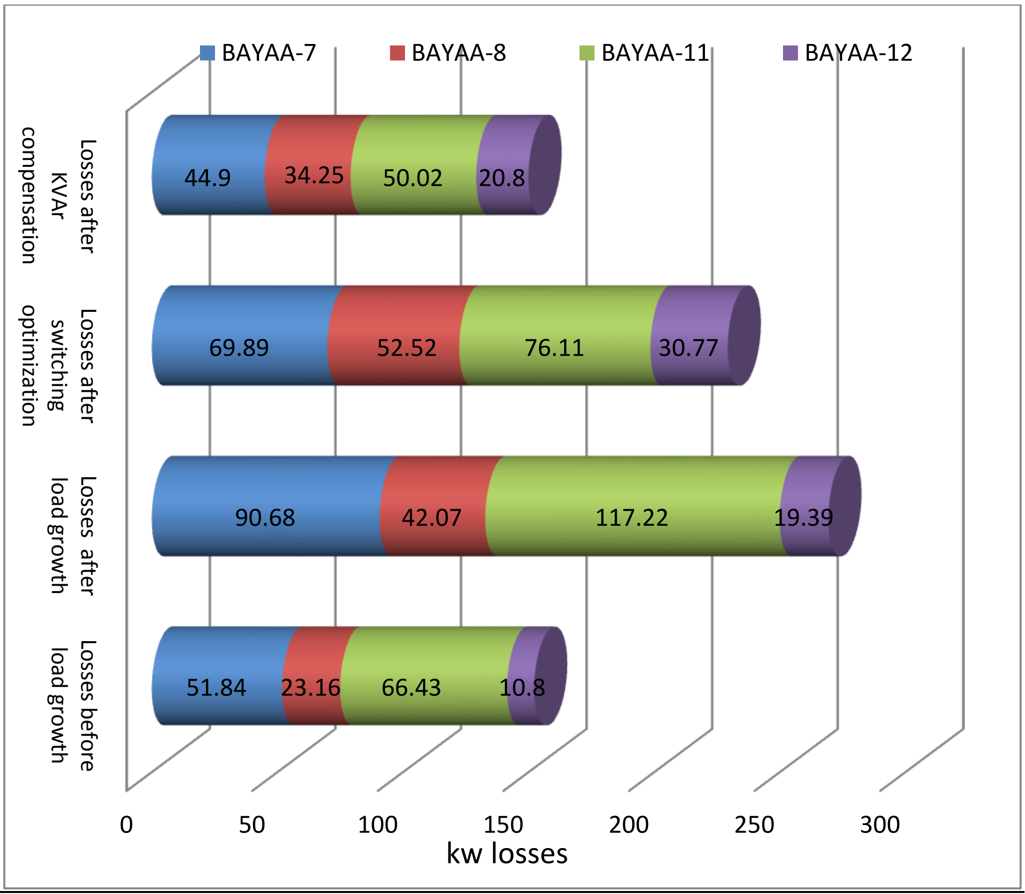


Figure 8. Al_Bayaa system kW losses.

From **Table 3.** the total system power losses before, after load growth, after switching optimization, and after kVAr compensation are 152.23, 269.36, 229.29 and 149.97 kW respectively. So the kW saving between the case after load growth and after kVAr compensation is 119.39 kW.

By using equation (10) and (11), the annual costs of the system losses are shown in **Table 7.** and the total net saving cost of the peak load is 13.7 k$/year.

Table 7. Annual cost of Al_Bayaa system losses (k$/year).

Feeder name	Feeder load factor (%)	Before load growth	After load growth	After switching optimization	After kVAr compensation
Bayaa_7	65	6.84	11.97	9.23	6.54
Bayaa_8	65	3.06	5.55	6.93	4.96
Bayaa_11	65	8.77	15.47	10.05	7.16
Bayaa_12	65	1.43	2.56	4.06	3.19
Total loss cost (k$)		20.1	35.55	30.27	21.85

Discussion of the results:

Fig. (9a, b, c, and d) show the bus voltage profile for Al_Bayaa selected feeders before and after load growth, after switching optimization and after capacitor placement. It is shown that after applying load growth, the overall voltage magnitudes will drop significantly within the specified limits. These values are improved after applying switching optimization technique and improved more after allocation of capacitors in these feeders so they became closer to 1 p.u.

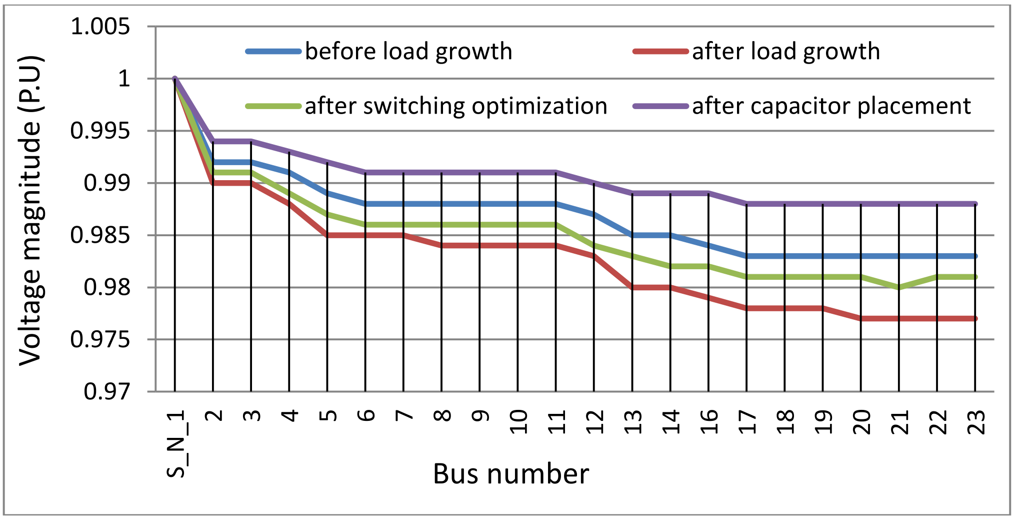


Figure 9a. Voltage profile of feeder Al_Bayaa_7.

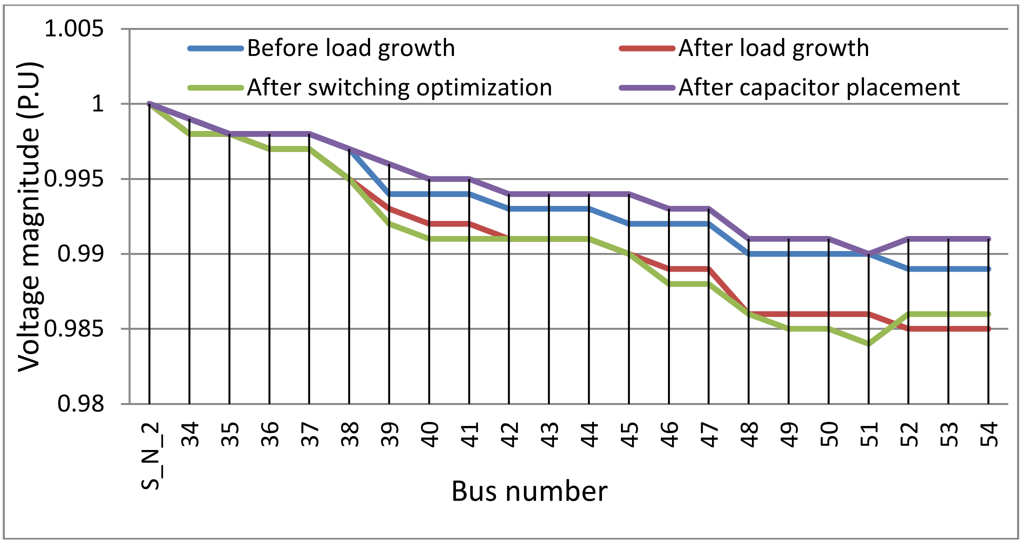


Figure 9b. Voltage profile of feeder Al_Bayaa_8.

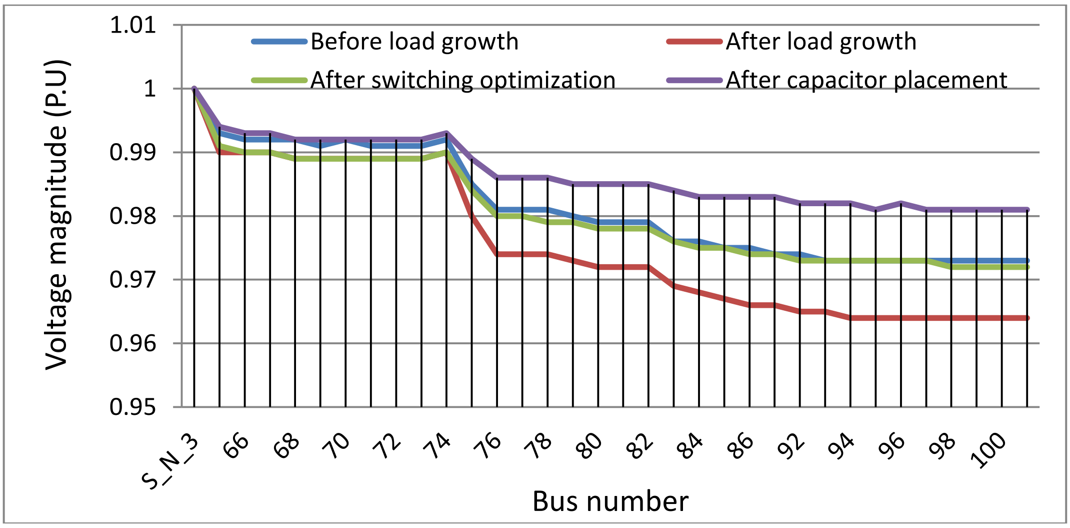


Figure 9c. Voltage profile of feeder Al_Bayaa_11.

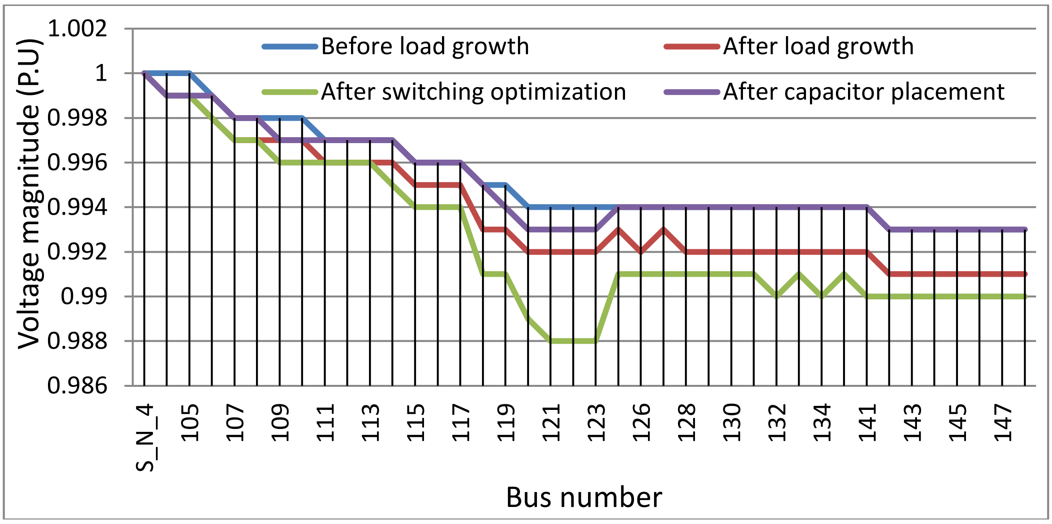


Figure 9d. Voltage profile of feeder Al_Bayaa_12.

Fig.10 shows the behavior of the total downstream reactive power profile with respect to distances for Al_Bayaa_7 feeder of each section for the longest path from the substation that feed this network to node 21. **Fig.10a** considers the behavior before load growth, **Fig.10b** considers the behavior after load growth, **Fig.10c** considers the behavior after switching optimization, and **Fig.10d** considers the behavior after kVAr compensation.

Section 1 (1321 m length) has 914.4 downstream kVAr/phase before compensation; this value is increased to 1210 kVAr/phase after load growth (above the maximum value). Then the kVAr/phase is reduced to 1091 after applying switching optimization. At the final step of the planning after placement of capacitors the kVAr/phase became 54.5 and so on for the other sections. The sections that have capacitors become a source of reactive power, the overall active and reactive power losses will be reduced. The overall P.F. of each feeder is improved as shown in **Table 3**.

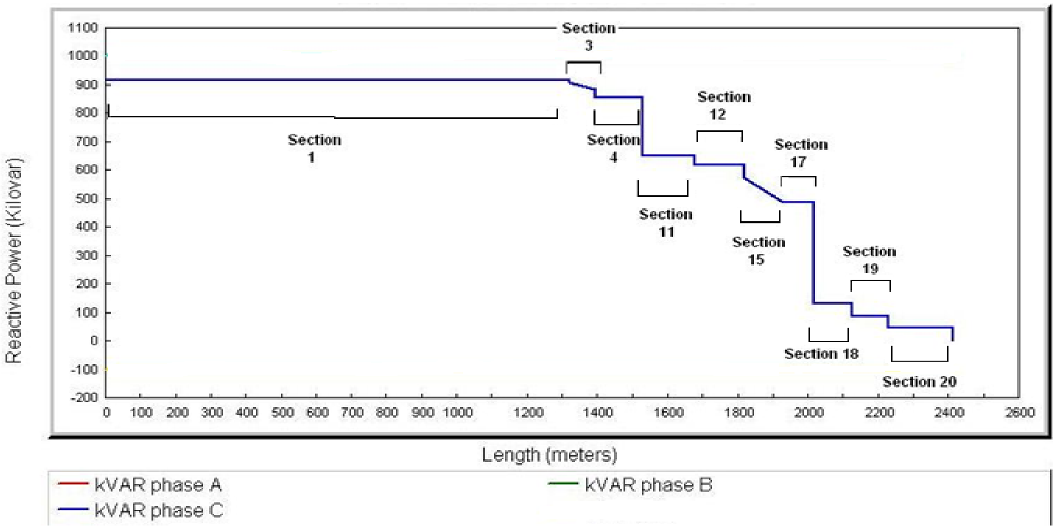


Figure 10a. kVAr profile of Al_Bayaa_7 before load growth.

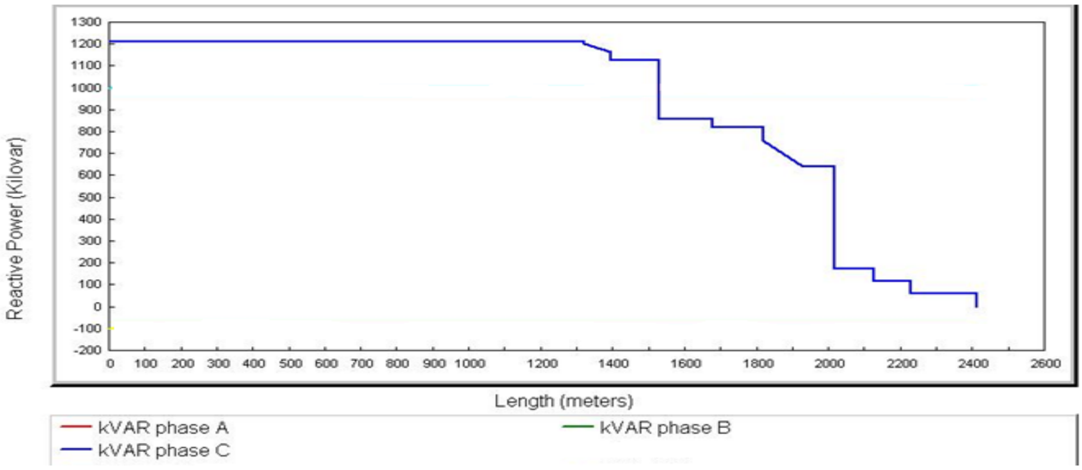


Figure 10b. kVAr profile of Al_Bayaa_7 after load growth.

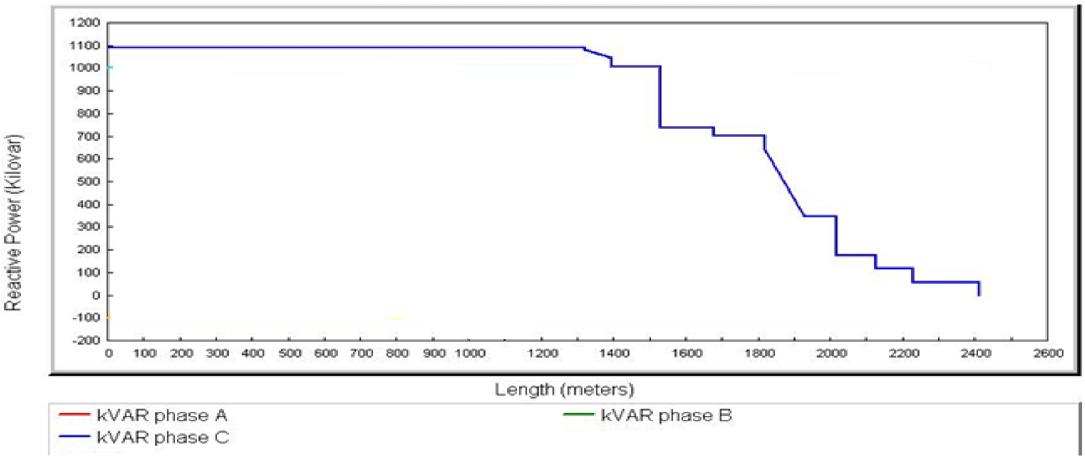


Figure 10c. kVAr profile of Al_Bayaa_7 after switching optimization.

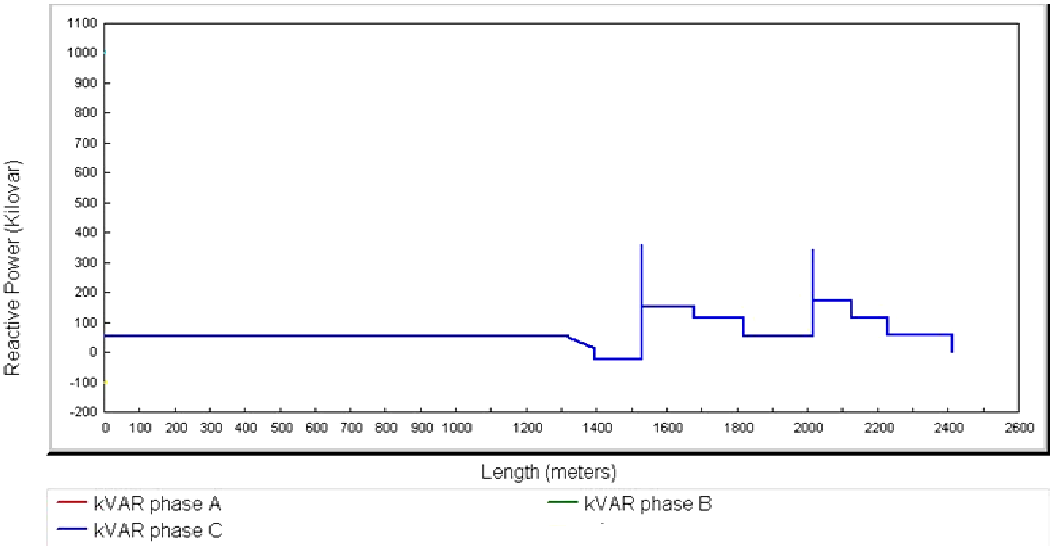


Figure 10d. kVAr profile of Al_Bayaa_7 after capacitor placement.

8. CONCLUSIONS

The results of planning Al_Bayaa distribution network by using CYMDist software show clearly the power loss reduction after applying the proposed method by using network reconfiguration in sequence with optimal capacitor placement.

The network model only needs to be created once; this may satisfy various types of simulation analysis required for the distribution network planning. Three simulation functions are achieved; load flow, switching optimization and capacitance optimal allocation.
Although, computational time increases with increasing system size, CYMDist module gives a very fast execution time even for large scale networks as compared to other methods documented in the literature, so it can be used in online distribution automation. Also, it gives accurate results depending on the accuracy of the input data.

REFERENCES

- Sarwar, M., Jaffery, Z. A., Siddiqui, A. S., and Quadri, I. A., 2012, *Techno-Economic Feasibility of HVDS Concept for Distribution Feeder Power Loss Minimisation*, IEEE 5th India International Conference on Power Electronics (IICPE).

- *CYME Reference Manual*, www.scribd.com/doc/136501684/CYME-502-Ref-EN-V1-2

- Divya, P., and Siva, K. R., 2013, *Proposed Strategy for Capacitor Allocation in Radial Distribution Feeders*, International Journal of Research in Engineering & Technology, Vol. 1, Issue 3, P.P. 85-92.

- Flávio, V. G., Sandoval, C. J., Jose, L. R., Marcio, P. V., Paulo, A. N., and Leandro, R. A., 2005, *A New Heuristic Reconfiguration Algorithm for Large Distribution Systems*, IEEE Transactions on Power Systems, Vol. 20, No. 3, P.P. 1373-1378.

- Héctor, M. L., 2013, *Optimization of Capacitor Banks in the Skagerak Networks Transmission Grid*, M. Sc. Thesis, University of Agder.

- William, H. K., 2002, *Distribution System Modeling and Analysis*, CRC Press LLC Book, New York Washington.

- Manas, R. N., 2014, *Optimal Feeder Reconfiguration of Distribution System with Distributed Generation Units using HC-ACO*, International Journal on Electrical Engineering and Informatics - Volume 6, Number 1.

- Manju, M., Sandeep S., Leena G., and Saxena, N. S., 2013, *Minimizing Distribution Losses by System Reconfiguration*, International Journal of Electrical, Electronics and Data Communication, Vol.1, Issue 10.

- Meghana, M., 2011, *Optimal Sitting and Sizing of Solar Photovoltaic Distributed Generation to Minimize Loss, Present Value of Future Asset Upgrades and Peak Demand Costs on a Real Distribution Feeder*, M. Sc. Thesis, University of Waterloo, Ontario, Canada.

- Satish, K. I., and Navuri, P. K., 2012, *Planning and Operation of Active Radial Distribution Networks for Improved Voltage Stability and Loss*

Reduction, World Journal of Modeling and Simulation, England, UK, Vol. 8, No. 3, P.P. 211-222.

- Baran, M. E. and Wu, F. F., *Network Reconfiguration in Distribution Systems for Loss Reduction and Load Balancing*, IEEE Transactions on Power Delivery, Vol. 4, No. 2, April, 1989.

- Thiruvenkadam, S., Nirmalkumar, A. Sakthivel, A., *MVC Architecture Based Neuro-Fuzzy Approach for Distribution Feeder Reconfiguration for Loss Reduction and Load Balancing*, IEEE Student’s Conference on Electrical, Electronics and Computer Science, 2008.

- Dong Zhang, Zhengcai Fu, and Liuchun Zhang, *Joint Optimization for Power Loss Reduction in Distribution Systems*, IEEE Transactions on Power Systems, Vol. 23, No. 1, P.P. 161-169, February, 2008.

- Gupta, N., Swarnkar, A., and Niazi, K. R., *An Efficient Greedy Approach for Reactive Compensation on Large-Scale Distribution Systems*, IEEE Power and Energy Society General Meeting, 2011.

- Prasanna, M. Y. B., Balaji, T. R. N., and Kannan, S. M., *Maximization of Annual Savings by using Fuzzy-Second Order PSO based Optimal Capacitor Placement in RDF for Constant Load*, IEEE Student's Conference on Electrical, Electronics and Computer Science, 2012.

NOMENCLATURE

r_i= resistance of branch i, ohm.
P_i= active power of branch i, kW.
Q_i= reactive power of branch i, kVAr.
k_i= switch status of branch i, dimensionless.
$V_{min.}$= lower bus voltage limit, kV.
$V_{max.}$= upper bus voltage limit, kV.
$|V_i|$ = rms value of the i_{th} bus voltage, kV.
$P_t =$ total active power load, kW.
$P_s^{max.}$= maximum active power source, kW.
Q_t = total reactive power load, kVAr.
$Q_s^{max.}$ = maximum reactive power source, kVAr.
$I_{rated} = line\ rated\ current, amp.$
P_G = power generation, kW.
P_D = power demand, kW.
P_{lt} = total power losses, kW.
Q_c = reactive power obtained from the capacitor bank, kVAr.
m = total number of capacitor banks, dimensionless.
LDF= load factor, dimensionless.
$P_{loss\ max}$ = power loss at the peak load power, kW.
L_{fls} = loss factor, dimensionless.
T= time interval, hours.
C= tariff cost, $.
K= cost of capacitor size, $/kVAr.