Comparison of different methods to face the huge increase in future load in power distribution network

Salam Bnyan Abood[1,2], Thamir M. Abdul Wahhab[3]
[1]Ministry of Electricity, Basra, Iraq
[2]Department of Electrical Engineering, Engineering Collage, University of Basra, Basra, Iraq
[3]Department of Electrical Engineering, University of Technology, Baghdad, Iraq

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ABSTRACT

The main challenge of present distribution networks is the huge increase in demand for electricity especially in city center where the demand is increasing vertically for the same geographical area. This work presents the analyses of 5-Mail distribution network in Basra City/Iraq with conventional system 33/11/0.416 kV, at future load by estimating the increase in load 10 years later. The network is analyzed in terms of voltage drop, power losses, and the feeder loading. To improve the network the 33/11/0.416 kV system is re-analyzed at the expected future load using the optimal reconfiguration of the network or adding capacitor placement to reduce losses and voltage drop. The results of these methods are compared with the results of the network re-analyzed using the proposed 33/0.416 kV system at future load. The results show that the proposed method of upgrading the voltage level of distribution network is the best solution. The GIS software is used to locate the distribution transformers and lying of the underground cables. CYME software is used to simulate the electric distribution system and conduct the load flow and other analyses.

Corresponding Author:

Salam Bnyan Abood
Ministry of Electricity, Basra, Iraq
Email: eee.20.39@grad.uotechnology.edu.iq

1. INTRODUCTION

The power distribution networks are subject to future increase in load. This increase in load may be fast and huge especially for networks that are in center of high load density [1], [2]. When that increase in load demand is so large that it cannot be faced with traditional solutions such as reconfiguration of the network to balance the loads or adding capacitors placement to reduce losses and reduce voltage drop [3], [4]. This requires adding new feeders and new distribution substations [5], [6]. As a result of the fact that the distribution networks are close to consumers and thus are governed by the nature of the urban design of the residential areas, and therefore it is not possible to provide new paths for new feeders or distributors lines as well as the lack of sufficient spaces at ideal locations for new distribution substations to meet the increase in load demand [7], [8]. The proposed solution is by increasing the operating voltage from 11 kV to 33 kV to increase the capacity of the distribution network, so that the network is able to meet the future increase in load especially vertical increase [9].

In this work three methods; network reconfiguration, capacitors placement, and network voltage upgrading are used to increase network capacity and reduce voltage drop and power losses. The results of analyses of these methods are compared which shows the superiority of the proposed method of upgrading the voltage level of distribution network.

2. METHODOLOGY

There are several methods to improve the performance of distribution network in terms of reducing voltage drop and losses [10]. One of these methods is optimal reconfiguration of network to balance the feeder loading to reach the best network configuration, which reduces voltage drop losses. The second method is by capacitors placement to improve voltage profile and reduce losses. The third method is by upgrading the voltage to improve the performance of the distribution network in terms of reducing voltage drop and losses, as well as increasing the network capacity to meet the increase in future load [11].

2.1. Network reconfiguration

Network reconfiguration can be used to determine the best network configuration at one step of the design process. It is specified as changing the open/closed status of sectionalizing and connects switches to modify the topological structure of distribution networks. Depending on the size of the loads, the size and length of the conductor, the configurations can be switched manually or automatically [12]. Under normal operating conditions, changing the radial structure of the feeders on a regular schedule can significantly improve the overall system's operating conditions; such transfers are efficient not only in terms of changing the level of loads on the feeders being switched, but also in terms of reducing the overall system's operating costs [13].

The switching optimization function will assist in minimizing the losses (and hence lower the operating cost) or minimizing the voltage drops in the network by changing the network topology, while respecting voltage and loading limits [14], [15].

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

where: f is the objective function; n is total number of branches; R_i is resistance of branch i; Q_i is reactive power of branch i; P_i is active power of branch i; V_i is voltage on sending bus of branch i; D_i is switch on branch i, 1 for closed, 0 for open

The objectives of switching optimization are:

a. Minimize overload: reduces the most severe overloads. It may cause slight overloads on other sections in the process, since all consumers must be served.
b. Minimize voltage drop: reduces the most severe voltage problems (% over-voltage or % under-voltage). It may cause slight overloads on other sections in the process, since all consumers must be served.

$$V_{min} \le V_{load} \le V_{max}$$

where, V_{min} and V_{max}. are the lower and upper voltage limits, respectively.

c. Balance feeders by load: transfers load among feeders to equalize the % loading on the first section of each feeder.
d. Balance feeders by length: transfers portions of circuit among feeders to make the feeder lengths more equal. This may also improve the reliability on very long feeders.
e. Minimize kW losses (global branch exchange): transfers load by changing the interconnections together to find a more efficient way to serve local loads, and then choice to allow the addition of new switches. This implies that the technique will try and find new locations for the feeder interconnections.

Flowchart of switching optimization for distribution network is shown in Figure 1.

2.2. Capacitor placement

Capacitors enhance the performance of power distribution system by minimizing losses and reduce voltage drop [16], [17]. The voltage drop and power losses calculations are done on a single line diagram of the feeder as given in [18], [19].

a. Minimize kW losses: this objective aims to find the optimal capacitor locations and sizes in order to minimize the kW losses on the system. The analysis must prevent considering capacitors that do not reduce losses by enough amount and to prevent maximum voltage rise.

$$Deviation\,\% = \frac{v_{with\, capacitor} - v_{without\, capacitor}}{v_{without\, capacitor}} \times 100\% \tag{2}$$

b. Improve system voltage: this objective aims to find the optimal capacitor locations and sizes in order to improve the overall system voltage level and prevent maximum voltage rise [20], [21]
   - Capacitor equipment: the capacitors sizes to be installed are chosen from the list of capacitors available according to MOE.
   - Number of capacitors to install: specify the number of capacitors to install in the network.

The flowchart representing the methodology of optimal capacitor placement and sizing is shown in Figure 2.

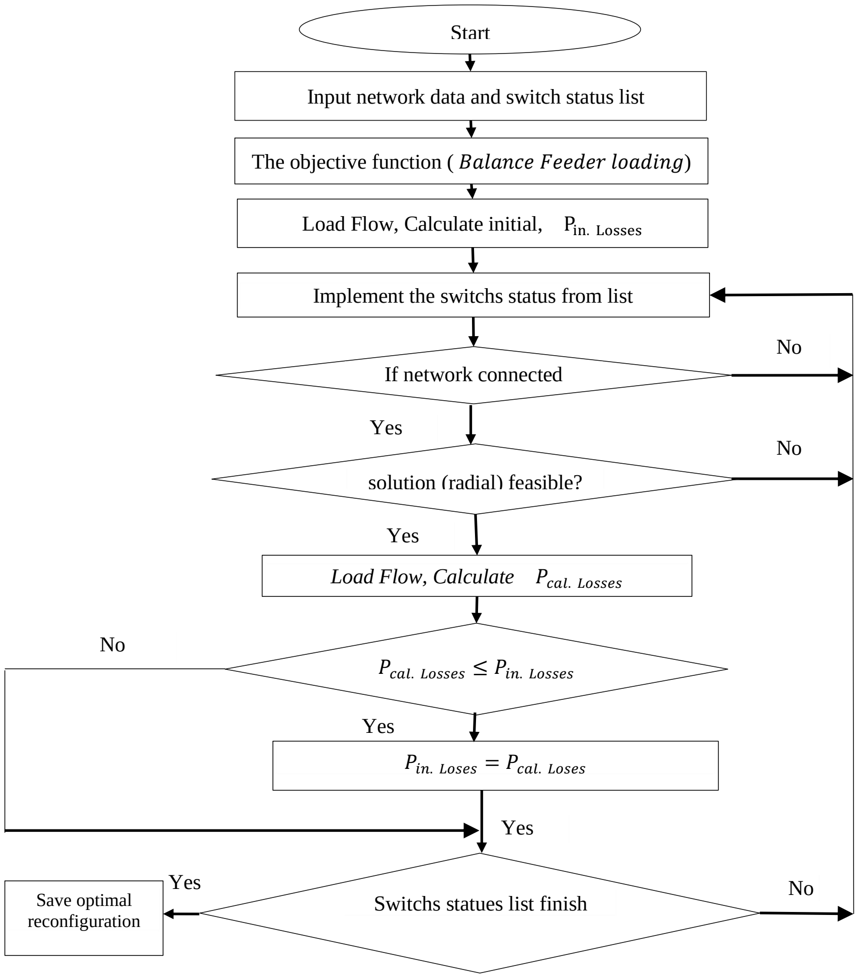

Figure 1. Flowchart of switching optimization for distribution network

2.3. Upgrading the operating voltage from 11 kV to 33 kV

The performance of distribution network is improved in this case using the proposed method by upgrading the voltage level of the distribution networks from 11 kV to 33 kV [22], [23]. This means [24]-[26]:

a. Remove the 33/11 kV distribution substations, which include 33/11 kV power transformers, 11 kV buses, and other components of the substation, and replacing them with 33 kV intermediate station that includes 33 kV buses and circuit breakers.
b. Remove the 11 kV network overhead and underground lines and replace them with 33 kV underground network. The load current of cable can be calculated by:

$$I = \frac{P}{\sqrt{3}\, V \cos \emptyset} \tag{3}$$

where: I is the current in Amp of the new 33 kV cable; P is the actual load power in kW (according to MOE) of the 11 kV cable to be replaced; V is the voltage 33 kV of the proposed system; $\cos \emptyset$ is the measured power factor of 11 kV feeders at actual load.

Cable conductor size is ($3 \times 150\ \text{mm}^2, 33\ \text{kV}$) determined according to IEC 60228 class/2 standard of MOE.

$$Feeder\ loading\ \% = \frac{Actual\ load\ current\ of\ feeder\ at\ rated\ voltage}{Rated\ current\ of\ feeder\ at\ rated\ voltage} \times 100\ \% \tag{4}$$

where, the rated current of feeder at rated voltages 11 kV and 33 kV are considered 300 A.

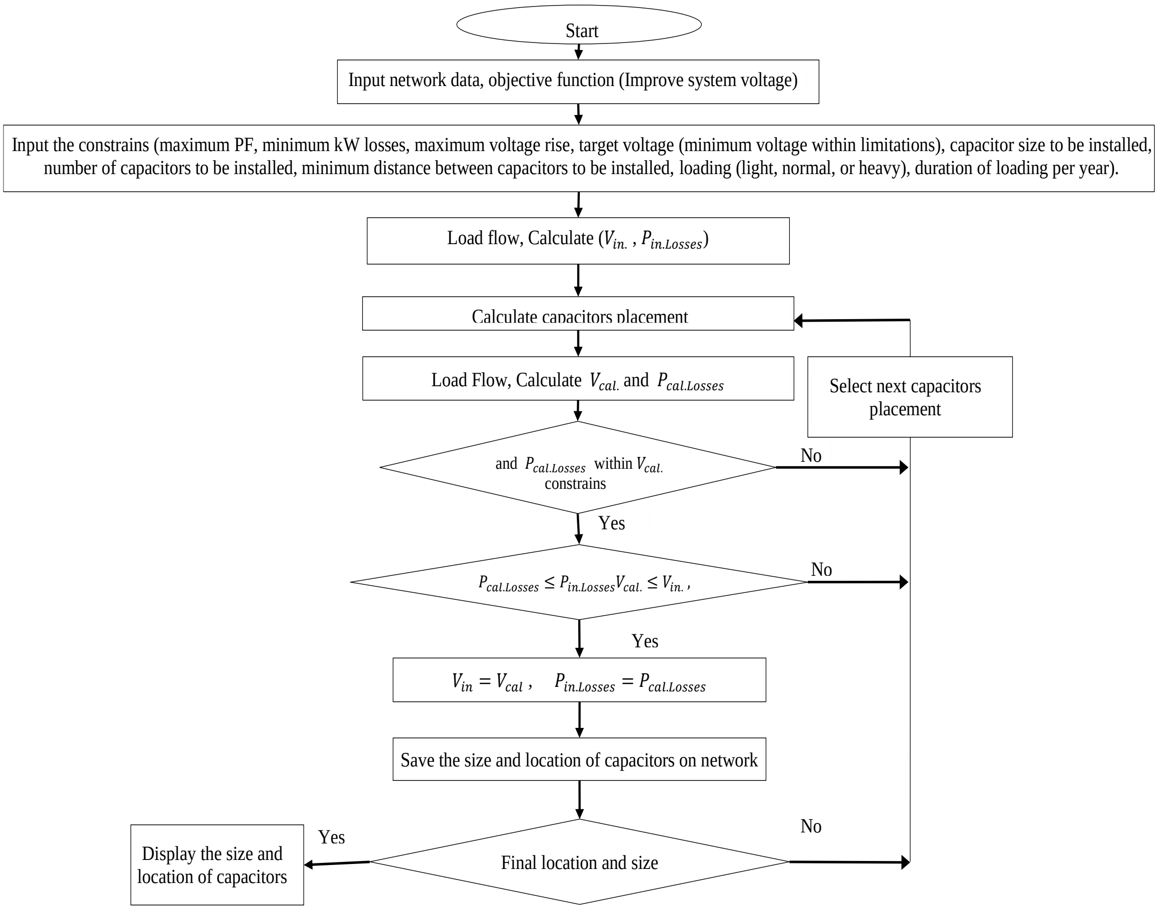

Figure 2. Flowchart representing the methodology of optimal capacitor placement and sizing

c. Remove consumer distribution transformers 11/0.416 kV and replace them with consumer distribution transformers 33/0.416 kV with same capacity to be installed at same locations of 11/0.416 kV distribution transformers [26]. The rating of the 33/0.416 kV distribution transformer is obtained by dividing the load demand on transformer by the power factor:

$$kVA = \frac{P}{\cos \emptyset} \quad (5)$$

where: kVA is load demand on transformer in kVA; P is load demand on transformer in kW; $\cos \emptyset$ is the measured power factor at actual load.
Percentage loading of distribution transformer is obtained from the expression:

$$Distribution\ transformer\ loading\ \% = \frac{Load\ demand\ on\ transformer\ kVA}{Rated\ capacity\ of\ transformer\ kVA} \times 100 \quad (6)$$

Total losses of transformer include no load losses and copper losses at load:

$$Total\ losses = No\ load\ losses + Copper\ losses\ at\ load \quad (7)$$

where no load losses and cooper losses are according to standard of MOE.

3. CASE STUDY: THE 5-MAIL POWER DISTRIBUTION NETWORK

In this case the 5-mail network existing in center of Basra City was analyzed at the expected future load using CYME software. The results of analyses show the weak points in the conventional network. To enhance the network performance different solutions were considered such as; optimal network reconfiguration, optimal capacitance placement, and the proposed method of rising the operating voltage of the distribution network to 33/0.416 kV.

3.1. The conventional 5-mail 33/11/0.416 kV system

The 5-mail distribution network with 33/11 kV substation in the center of Basra City, consist of two 33/11 kV, 31.5 MVA power transformers supplied by two 33 kV feeders one from AL-Academia 132/33 kV substation, 9.8 km long and the other 33 kV feeder from sharq–al-Basra 132/33 kV substation, 4.48 km long. The 11 kV outgoing overhead distribution feeders are twelve, five 11 kV feeders supplied from one 11 kV section and seven are supplied from the other 11 kV section. The total length of the 11 kV overhead lines of network feeders is 15.2 km with ACSR 120/20 conductors according to DIN-48204-MOE and 3.9 km of underground lines with $3 \times 150\ \text{mm}^2$, 11 kV cable according to IEC 60228 class/2 standard [MOE]. The 11/0.416 kV distribution transformers supplied from 11 kV distribution feeders are used to feed consumers.

The expected future increase in load demand for 5-Mail network for the next 10 years up to year 2032 is about 8% per year according to MOE. The existing 5-Mail network with conventional 33/11/0.416 kV system is analyzed using CYME software at the expected load after 10 years increase in demand and the results are given in Table 1. The 5-mail distribution network and substation simulated using CYME software, as shown in Figures 3 and 4.

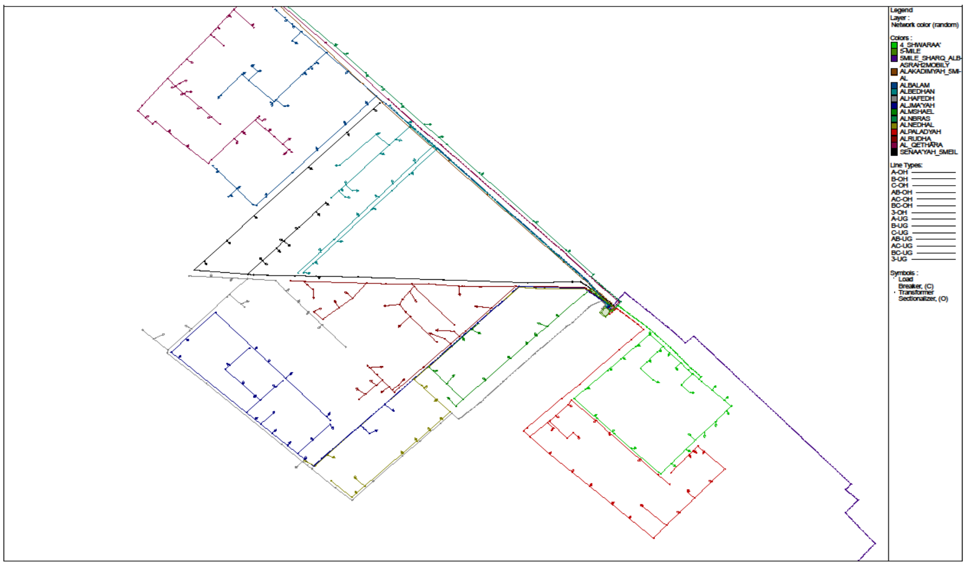

Figure 3. The existing 5-mail (a) 33/11/0.416 kV network at estimatedfuture increase in load demand simulated using CYME

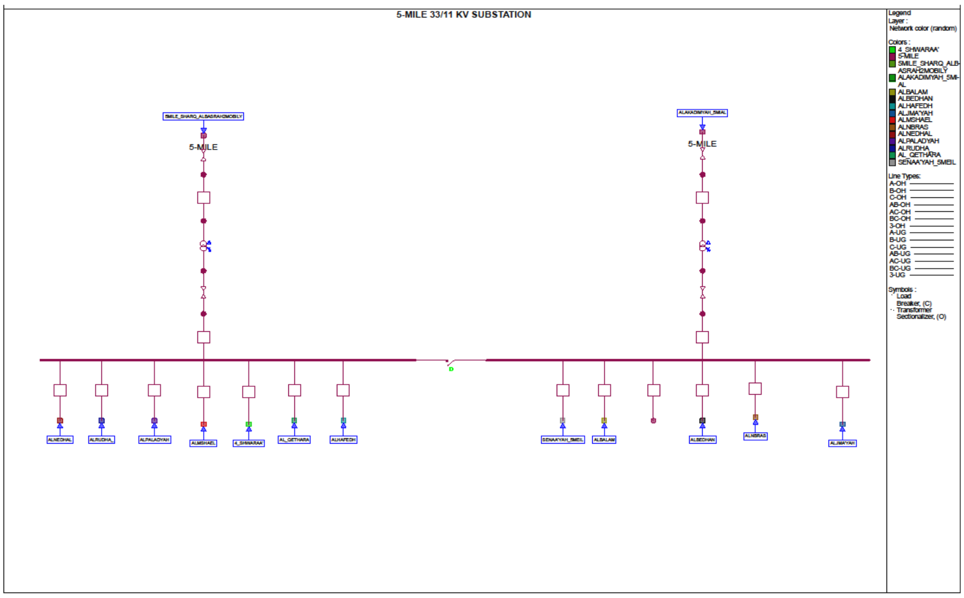

Figure 4. The existing 5-mail 33/11 kV substation and switchgear simulated using CYME

Table 1. Design results of 5-mail 33/11/0.416 kV conventional network and total losses of 11/0.416 kV distribution transformers at future load

Feeder ID	Load at 11 kV (Amp)	PF	Feeder loading (%)	No load losses of 11/0.416 kV transformers (kW)	Losses at average load of 11/0.416 kV transformers (kW)	Total losses of 11/0.416 kV transformers (kW)
SENAA'YAH_5MEIL	386	0.93	129	12.18	72.86	85.04
ALMSHAEL	326	0.92	109	9.85	59.17	69.02
4_SHWARAA'	378	0.96	126	18.89	69.67	88.56
ALRUDHA_	345	0.95	115	13.1	64.90	78.00
ALBALAM	518	0.97	173	17.59	94.68	112.27
ALNBRAS	315	0.97	105	9.58	57.81	67.39
ALNEDHAL	294	0.97	98	8.01	53.41	61.42
AL_QETHARA	501	0.97	167	17.32	92.06	109.38
ALHAFEDH	410	0.93	137	8.93	74.53	83.46
ALPALADYAH	296	0.88	99	16.4	54.43	70.83
ALBEDHAN	294	0.97	98	13.97	57.82	71.79
AL JMA'YAH	434	0.91	145	16.94	78.89	95.83
SUM	4497			162.76	830.22	992.98

3.2. The conventional 5-mail 33/11/0.416 kV system after re-configuration

In this case the optimal reconfiguration analysis is implemented on 5-mail conventional 33/11/0.416 kV network at future load using CYME for feeder loading balance using switching action, as shown in Figure 5. The switches status for re-configuration of the 5-mail conventional 33/11/0.416 kV system is given in Table 2.

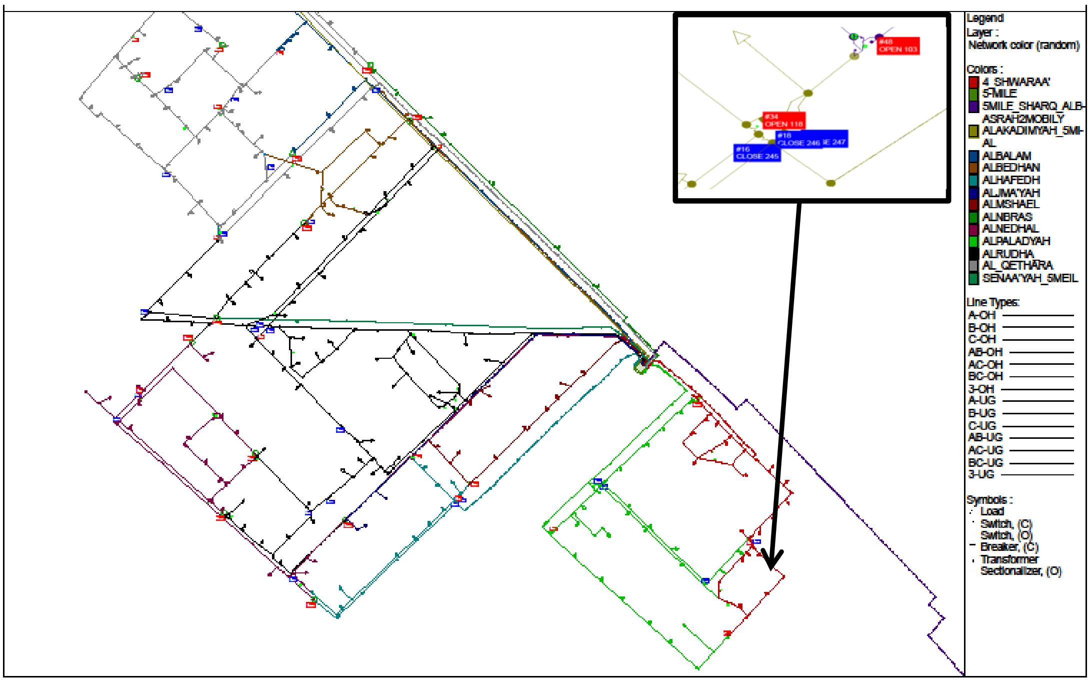

Figure 5. The 5-mail conventional 33/11/0.416 kV system at future load after optimal re-configuration using CYME

3.3. The conventional 5-mail 33/11/0.416 kV system after optimal capacitor placement

Optimal capacitor placement is suggested to improve voltage and to reduce losses. The optimal locations to install capacitors required to reduce the voltage drop are shown in Figure 6, while the capacitors capacity are given in Table 3.

3.4. The proposed 5-mail 33/0.416 kV system

In this case the operating voltage of 5-mail network is upgraded to 33 kV by using 33 kV intermediate station instead of 33/11 kV substation. The 33 kV intermediate station consist of two 33 kV sections one of them supplied five 33 kV distribution feeders and the other section supplied seven 33 kV distribution feeders. The twelve 33 kV distribution feeders with 3 × 150 mm², 33 kV cable according to IEC 60228 class/2 standard MOE supply the consumers by 33/0.416 kV distribution transformers. Design results and total losses calculations of distribution transformers for 5-mail network of the proposed 33/0.416 kV system at future load is given in Table 4.

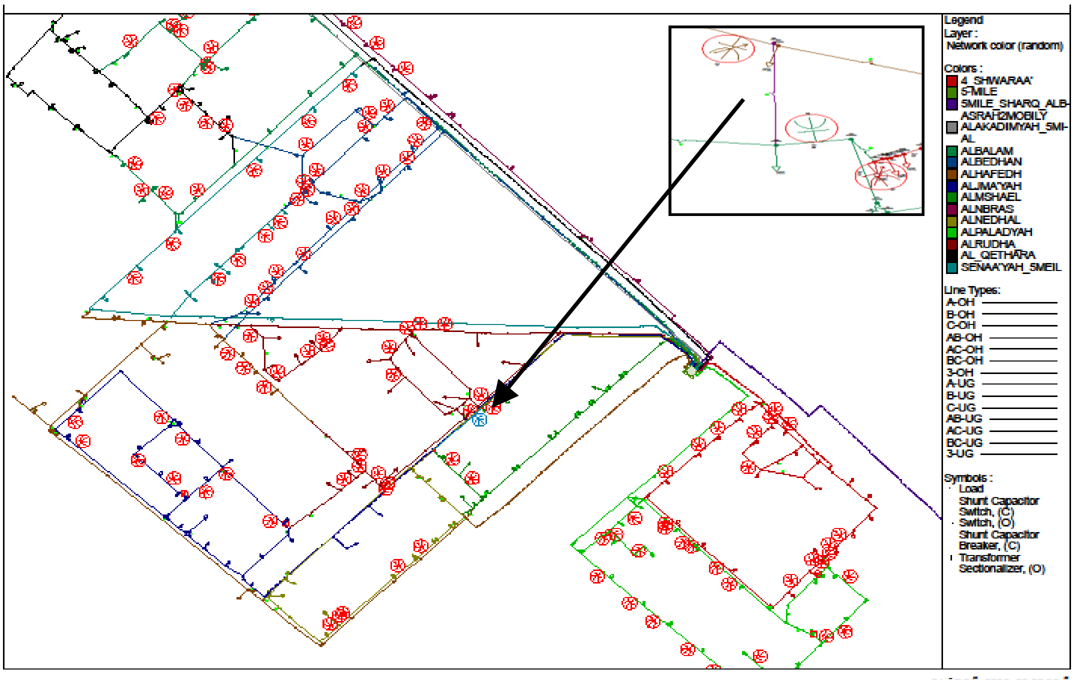

Figure 6. Capacitors placement for voltage drop reduction of 5-mail 33/11/0.416 kV system at future load

Table 2. Switches status for optimal reconfiguration of 5-mail conventional 33/11/0.416 kV system at future load

Switch ID	Action	Switch ID	Action	Switch ID	Action	Switch ID	Action
263	Close	242	Close	22694	Open	208	Close
125	Close	235	Close	22215	Open	250	Close
271	Close	259	Close	22341	Open	211	Close
266	Close	256	Close	10608	Open	245	Close
73	Close	249	Close	22707	Open	247	Close
8	Close	45	Close	131	Open	246	Close
13	Close	248	Close	40	Open	115	Open
230	Close	231	Close	224	Open	22111	Open
218	Close	282	Close	22143	Open	28	Open
217	Close	22271	Open	213	Open	10689	Open
69	Close	274	Open	78	Open	10670	Open
9	Close	22202	Open	103	Open	199	Open

Table 3. Capacitors capacity to reduce the voltage drop for 5-mail 33/11/0.416 kV system at future load

Feeder ID	Total cap (kVAR)	PF (%)
4_SHWARAA'	720	97.99
ALBALAM	1320	98.58
ALBEDHAN	780	99.01
ALHAFEDH	1530	95.17
ALJMA'YAH	1080	94.57
ALMSHAEL	1230	94.37
ALNBRAS	690	98.27
ALNEDHAL	690	98.07
ALPALADYAH	1410	95.82
ALRUDHA_	1050	98.31
AL_QETHARA	1350	97.51
SENAA'YAH_5MEIL	930	95.75

Table 4. Design results of 5-mail proposed 33/0.416 kV system and total losses calculations of distribution transformers at future load

Feeder ID	Load at 33 kV (Amp)	PF	Feeder loading (%)	No load losses of 33/0.416 kV transformers (kW)	Losses of 33/0.416 kV transformers at average load (kW)	Total losses of 33/0.416 kV transformers (kW)
SENAA'YAH_5MEIL	127	0.93	42	14.07	72.53	86.61
ALMSHAEL	107	0.92	36	11.27	59.86	71.14
4_SHWARAA'	124	0.96	41	21.7	69.80	91.51
ALRUDHA_	113	0.95	38	15.12	64.36	79.48
ALBALAM	170	0.97	57	20.16	95.54	115.71
ALNBRAS	103	0.97	34	10.99	58.17	69.16
ALNEDHAL	96	0.97	32	9.17	53.94	63.11
AL_QETHARA	164	0.97	55	19.88	92.40	112.29
ALHAFEDH	134	0.93	45	10.22	75.30	85.53
ALPALADYAH	97	0.88	32	18.83	54.72	73.55
ALBEDHAN	96	0.97	32	16.31	56.43	72.75
AL JMA'YAH	143	0.91	48	19.39	79.98	99.38
SUM	1474			187.11	833.09	1,020.21

4. RESULTS AND DISCUSSION

The voltage at far points of 11 kV feeders of 5-mail conventional 33/11/0.416 kV system, 5-mail conventional 33/11/0.416 kV system with reconfiguration, 5-mail conventional 33/11/0.416 kV system with capacitors placement, and the proposed 33/0.416 kV system, at future load are given in Table 5. The total losses at future load of 5-mail conventional 33/11/0.416 kV system, 5-mail conventional 33/11/0.416 kV system with reconfiguration, 5-mail conventional 33/11/0.416 kV system with capacitors placement, and the proposed 33/0.416 kV system are given in Table 6. The capital cost (cost of equipments, components, and installation according to MOE) is reduced about 36% when the operating voltage of 5-mail network upgraded to 33 kV for the same configuration and the same number and capacity of distribution transformers, as given in Table 7.

Table 5. Comparison of voltage/per phase at end point of feeder at distribution transformers of 5-mail conventional 33/11/0.416 kV system, conventional 33/11/0.416 kV system with reconfiguration, conventional 33/11/0.416 kV system with capacitor placement, and the proposed 33/0.416 kV system

Feeder ID	Voltage/per phase at end point of feeder at distribution transformers			
	Conventional 33/11/0.416 kV system	Conventional 33/11/0.416 kV system with reconfiguration	Conventional 33/11/0.416 kV system with capacitor placement	The proposed 33/0.416 kV system
4 SHWARAA'	198.2	196.1	200.8	235.8
AL_BALAM	181.7	196.8	184.7	233.3
AL_BEDHAN	182	195.4	185.2	233.3
AL_HAFEDH	196.8	196.6	199.5	235.8
AL_JMA'YAH	183.3	198.8	186.3	233.4
AL_MSHAEL	190	196.1	201.6	235.9
AL_NBRAS	182.1	196.7	185.1	233.4
AL_NEDHAL	199.1	194.2	201.6	235.9
AL_PALADYAH	198.7	196	201.3	235.9
AL_RUDHA	199.1	194	201.7	235.9
AL_QETHARA	192	190.2	193.7	235.5
SENAA'YAH_5MAIL	176	198	179.5	233

Table 6. Comparison of total losses at future load of 5-mail conventional 33/11/0.416 kV system, 5-mail conventional 33/11/0.416 kV system with reconfiguration, 5-mail conventional 33/11/0.416 kV system with capacitors placement, and the proposed 33/0.416 kV system

	Conventional 33/11/0.416 kV system	Conventional 33/11/0.416 kV system with reconfiguration	Conventional 33/11/0.416 kV system with capacitors placement	The proposed 33/0.416 kV system
Total losses of 33/11 kV power transformers (kW)	525.72	542.2	518.7	0.0
Total losses of 11/0.416 kV distribution transformers (kW)	993.0	993.0	993.0	0.0
Total losses of 33/0.416 kV distribution transformers (kW)	0.0	0.0	0.0	1,020.2
Total losses of overhead lines (kW)	2,737.4	1,100.1	2,737.0	0.0
Total losses of underground cables (kW)	719.2	937.2	708.7	1,213.1
Sumiton of total losses (kW)	4,975.3	3,572.5	4,957.3	2,233.3
Total losses (MW.h/year)	34,885.0	22,596.2	34,727.6	10,627.0
Total losses cost (k$ /year)	1046.55	677.89	1041.83	318.81
Ratio of total losses to the active power supply (%)	7.33	5.65	7.13	2.82

Table 7. Compression of the capital cost (cost of equipments and installation) at future load of 5-mail network between the conventional 33/11/0.416 kV system and the proposed 33/0.416 kV system

		Conventional 33/11/0.416 kV system			The proposed 33/0.416 kV system		
		Quantity	Cost ($)	Quantity	Cost ($)	Quantity	Cost ($)
Main supply feeders (km)		28.56	132,077	3,772,119	14.28	132,077	1,886,060
Substation		2	4,000,000	8,000,000	1	1,724,000	1,724,000
Distribution feeders	Overhead (km)	19.8	27,627	547,015	0	0	0
	Underground (km)	4.5	97,668	439,506	19.04	132,077	2,514,350
Distribution transformer /0.416 kV	250	60	6,896.00	413,760	60	12,759	765,540
	400	146	7,069.00	1,032,074	146	15,172	2,215,112
Total cost of equipments and installation ($)				14,204,473.7			9,105,061.4

5. CONCLUSION

The voltage drop at far points of 11 kV feeders in the conventional 33/11/0.416 system reduced from (26.7%-17%) to (20.8%-17.2%) after reconfiguration of 33/11/0.416 kV system and reduce to (25.4%-16%) after capacitor placement and reduced to (2.9%-1.7%) when operating voltage of the network upgraded to 33 kV in the proposed 33/0.416 kV system.

Feeder loading in the conventional 33/11/0.416 system reduced from (173%-98%) to (57%-32%) when operating voltage of the network upgraded to 33 kV in the proposed 33/0.416 kV system. The total losses (kW) of 5-mail network is reduced from 7.33% of total active power supply for 33/11/0.416 kV system to 5.65% of total active power supply with reconfiguration, and to 2.82% from the total active power supply for the proposed 33/0.416 kV.

The total losses (MW.h/year) is reduced from 34,885 MW-h /year with 33/11/0.416 kV system to 22,596 MW-h/year about 35% after reconfiguration of network, and reduced to 10,627 MW-h/year about 69.5% when the operating voltage upgraded to 33 kV with proposed 33/.416 kV system. The total losses cost ($/year) of 5-mail network is reduced about 35% after reconfiguration of network with 33/11/0.416 kV system and reduced about 69.5% when the operating voltage is upgraded to 33 kV for 33/0.416 kV system.

From the capital cost point of view, the prposed 33/0.416 kV system can meet the future increase in load demand without the need to add new 33 kV intermidate station and new 33 kV distribution feeders. Whereas in case of the conventional 33/11/0.416 kV system, the same increase in load demand requires addition of new 33/11 kV substation and new 11 kV distribution feeders. Thus, the capital cost can be reduced when using the proposed 33/0.416 kV system.

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BIOGRAPHIES OF AUTHORS

Salam Bnyan Abood was born in Basra, Iraq in 1979. He received a Bachelor's degree in Electrical Engineering from University of Basra, Iraq in 2001. He is currently studying toward a Master's degree of Science in Electrical Power Engineering at the University of Technology, Iraq. He can be contacted at email: eee.20.39@grad.uotechnology.edu.iq.

Thamir M. Abdul Wahhab received his BSc, MSc, and PhD degrees in electrical engineering/power from University of Technology- Iraq, Department of Electrical Engineering, in 1985, 1990, and 2009 respectively. Since 2002, he has been a Lecturer in the Department of Electrical Engineering, University of Technology- Iraq. He became Assistant Professor in April 2016. His fields of research interests include; power system protection, power distribution network analysis, electromagnetic fields, FEM analysis using ANSYS. He can be contacted at email: 30043@uotechnology.edu.iq.