Improvement of Voltage Profile Using Practical Adaptive Intelligent Algorithm in Iraqi Electrical Distribution Network

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Abstract :

Improving distribution network performance is a motivating task, especially with heavily loaded feeders. The disturbances can directly affect the power quality, it can produce instantaneous voltage dip followed by voltage variation and followed by undesired voltage profile. Finding the optimal solution is a composite difficult task, this is due to network complexity, enormous components, load variation and other factors. To improve the voltage profile of a realistic Iraqi distribution network, a practical adaptive intelligent technique is applied in this work using five strategies inside a genetic based algorithm to investigate all possible successful solutions. It is proved that this technique can overcome the voltage dip and provide the optimal practical decision to improve the voltage profile and hence power quality. Five heavily loaded practical 11kV feeders is digitized, analyzed and finally studied. An optimal switch mode and conductor modifications are achieved, the results are applied to the network successfully creating an improved voltage profile.

Keywords: Voltage Dip, Power Quality, Distribution Systems, Network Optimization, Genetic Algorithm, Improving Voltage Profile.

تحسين مستويات الفولتية باستخدام خوارزمية ذكية عملية في شبكة توزيع الطاقة الكهربائية في العراق

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المستخلص :

ان تحسين شبكات التوزيع الكهربائية هو عمل مهم خصوصا مع مغذيات التوزيع عالية الاحمال التي تؤثر فيها التخلخلات بشكل مباشر على جودة القدرة الكهربائية من خلال توليد انحدار لحظي بالفولتية يتبعه تذبذب بالفولتية ثم ينتج مستويات فولتية غير نظامية.

ان إيجاد الحلول المثلى لهذه المشكلة هو موضوع مركب وصعب لأسباب تتعلق بتعقيد الشبكات واعداد مكونات الشبكات الهائلة بالإضافة الى تغير الاحمال المستمر وعوامل أخرى .

لتحسين مستويات الفولتية لشبكة توزيع واقعية تم تسخير خوارزمية ذكية تستخدم خوارزمية جينية بداخلها خمسة استراتيجيات عملية لإيجاد كافة الحلول الناجحة التي تعوض الانحدار وتزودنا بالقرار العملي الأمثل لتحسين مستويات الفولتية وبالتالي تحسن من جودة القدرة الكهربائية .تم نمذجة خمسة مغذيات توزيع واقعية بجهد ١١ كيلو فولت وتحليل بياناتها ثم دراستها بالخوارزمية المقترحة ، تم الحصول على حلول مثلى تتضمن امثل جدول لتشغيل فواصل الشبكات وتحديث الموصلات وتم تطبيقها على الشبكة وانتجت مستويات فولتية محسنة .

الكلمات الافتتاحية: انحدار الفولتية ، جودة القدرة الكهربائية ، أنظمة التوزيع ، حلول الشبكات المثالية ، الخوارزمية الجينية ، تحسين مستويات الفولتية .

Introduction

Faults in distribution systems cannot be eliminated completely, many mitigation techniques may be used to decrease their negative consequences on consumer side. Disturbances is considered as faults and can also adversely affect consumers in different manners especially the ones related to voltage. Furthermore, it is mutually coupled to heavily loaded networks.

Voltage dip is considered as one of the most effective voltage disturbances [1], its occurrence is linked with both network and consumer side .In network side it is directly proportional to distribution system faults, loss in transformers and conductors as well as improper transformer tap changer setting. With regards to consumer, high load consumption and low power factor loads can also result in voltage dip, this may be followed by out-of-standard voltage variation in voltage level, and then if it is not eliminated it will adversely affect the voltage profile of the network and hence service quality. In addition, harmonic generators, sensitive equipments and motor starting will definitely likewise lead to voltage dip.

The voltage disturbances can be classified into transient and sustained, the transient is hard to trace unless modular dispatch control and monitoring system is adopted. Network events related to faults, load variation, switching operations are of the most transient voltage disturbances. These results power quality reduction and may lead to out-of-standard power frequency voltage level. Due to this fact, the consumer service as well as load performance and response will be negatively affected especially in case of voltage sensitive equipments [2].

Distribution Voltage Dip and Control

During faults, heavy loads, motors start as in air conditioning units, pumps and compressors, the voltage dependent loads may be adversely affected as well as the affection of the network performance [3]:

$$= (V/V_o)^{\propto_p}$$

$$= (V/V_o)^{\propto_q}$$

where P, Q and V are consequently the present network active power, reactive power and voltage consequently, that alter with time, while P_o, Q_o and V_o are the nominal fixed values.

$\propto_p$ and $\propto_q$ represent respectively the active and reactive powers sensitivities to voltage variation and hence disturbances.

During a voltage dip the rotating machines feed current back to the system which may support the voltage, induction and synchronous motors, which are of different boost abilities. The load response, especially for motors supplementary disrupt the network voltage by drawing inrush high current in order to speed up again [4]. These special effects are moderately severe in areas in which large percentage of motor loads exists [5]. In Iraq, especially in the summer, all consumer categories use air-conditioning units in addition to electrical water pumps and hence the distribution feeders become heavily loaded. Due to this fact, it is essential to genuinely consider voltage profile variation in distribution studies. The network under study is of 11kV overhead lines which records high failure rate compared with underground cables. In such case it is important to have the proper strategies to overcome the consequences of voltage dip.

Primary and secondary distribution network planners may use various strategies to control the voltage, on-load and off-load tap changer, proper conductors, capacitor placement, re-phasing and sectionalizing. One or a combination of these strategies must be selected carefully, tested then applied to minimize voltage dip and hence restore the system voltage profile to pre-disturbance or near pre-disturbance standard voltage.

Deciding what is the optimal combination of the above strategies is the main task of this work to improve the network voltage profile under faults, heavy load periods, cyclic motor starting and future load growth.

Mathematical Model

In order to represent a distribution feeder precisely, a realistic model is required for both network components and load.

Network components that exist in the test system are the MV/LV transmission line conductors, transformer, and capacitor banks, while loads are represented by an aggregate load model approach [6]. The mathematical model can be represented by the following:

i. **Network Components***:*

1. Transmission Line: for both MV/LV overhead transmission lines, the lines are represented as a short transmission lines neglecting the electric field effects i.e the line capacitance and hence its charging current. The magnetic field is considered by representing it by the line inductance. In addition, the conductor type and dimensions are also considered by means of wire resistance.
2. Transformers: the MV/LV transformers are represented by its series impedance and impedance voltage drop, the off-load tap changer setting is considered.

Aggregating all network components provides the $\overline{Z_T}$ network impedance [7]

ii. Load Representation

Electric loads are represented using exponential load modeling by *LoadExpo* MATLAB package by considering frequency and voltage dependent polynomial based genetic algorithm [2] resulting in $\overline{Z_L}$ load reactance.

iii. Network Performance

The equivalent circuit of a distribution feeder is as shown in the Figure (1).

$$V_s\angle\delta = I\angle\theta\ (Z_T\angle\theta + ZL\angle\emptyset \qquad (3)$$

Where V_s and I are the transmission line sending voltage and current respectively, Z_L is the load model impedance and Z_T is the aggregate network impedance.

$$\overline{V_s} = I \times (co$$

$$= \mathfrak{U}\ I\ Z_T$$

Where $\mathfrak{U}$ is an impedance depending factor represented by :

$\mathfrak{U}$

While the magnitude of receiving end voltage can be obtained by:

$$V_r = I\, Z_L$$
$$= \frac{1}{\mathfrak{U}} \frac{Z_T}{Z_L} V_s \qquad (7)$$

In similar manner the receiving end active power is:

$$P_r = \frac{Z_T}{\sqrt{\mathfrak{U}}} \left(\frac{V_s}{Z_L}\right)^2 cos\,\emptyset \qquad (8)$$

The percent voltage deviation for lagging power factor system can be expressed in matrix form:

$$= \left(\frac{V_s}{V_r} - 1\right)$$

Where Q_r is the receiving end reactive power .

Voltage Profile Improvement Strategies

Observing equation (10) the voltage dip is inversely proportional to the square of receiving end voltage, and therefore, any slight voltage dip can directly affect the network performance. At the same time, it is directly proportional to the network impedance as well as conductor resistance. Hence, selecting the best conductor size is fundamental at network planning and pre-investment stage [8], after many years of load growth the motivation towards optimum conductor modification has become crucial, the modification can be performed in many ways. In this work, proper network modification is performed using the following modification constraints:

1. Network Loss Reduction should be maximized
2. Voltage dip should be minimized
3. Cost should be minimized
4. Conductor modification horizon should be selected carefully
5. Switch mode proper status

All the above constraints are adopted in this work as in the following steps:

a) Network Loss Reduction Test

$$= \sum_{n=1}^{m} V_n I_{nm}^*$$

where

$$c = \text{Conductor Number } (1 = original\ , 2 = modified\ )$$

$$m = \text{Number of buses}$$

in the radial feeder
$V_n I_{nm}^{*\,c}$ is the loss in section nm
regarding conductor c

In equation (11) the total feeder loss is estimated for all sections regarding test conductor *c* with the following Feeder Loss Violation *FLV* constraint:

$$FLV = \begin{cases} 1 & if\ NL^{c+1} \geq NL^{c} \\ 0 & whatever\ else \end{cases} \quad (12)$$

Both equations (11) and (12) are repeated for all candidate conductors without violation (*FLV=0*) and then a percent Network Loss Improvement matrix *NLI* is given by:

Next, this matrix is modified to eliminate all non-valid *FLV* conductors and the network loss reduction test algorithm is explained in Figure (2).

a) Voltage Dip Reduction Test

Where VD^{cs} is the total voltage dip in feeder for conductor *c* and switch mode *s* subjected to the following Voltage Drop Violation *VDV* constraint:

$$= \begin{cases} 1 \ \ if \ \ VL \\ 0 \qquad w \end{cases}$$

The percent Voltage Dip Improvement matrix *VDI* is then given by:

$$= \left(\frac{VD^{cs+1}}{VD} \right.$$

b) Cost Minimization

The above tests are carefully implemented while selecting the minimum cost conductor, the conductor cost is directly proportional to its size [9] observing the following Conductor Cost Test *CCT* constraint:

$$= \begin{cases} 1 \ \ if \ \ Cos \\ 0 \qquad w \end{cases}$$

The Conductor Cost Factor matrix *CCF* is illustrated by:

c) Conductor Modification Horizon

When NL^C and *VD* are high, conductor modification can be achieved by updating the lowest performance section conductor *c* by higher size conductor *c+1*, the candidate section or sections to be updated is selected by implementing the following search horizon:

Find Sectio

d) Switch Mode Status

Interconnected distribution network contains switches and load break switches to improve network performance and reliability [5]. To improve voltage profile the on-off status of those switches should be optimum, the optimum solutions in distribution network can be successfully found by implementing intelligent techniques. In this work, genetic based algorithm is adopted to find the best on-off status regarding the following population chromosome:

$$X_i^j = (n_c, SW(1), SW(2), \ldots, SW(\Pi), F) \quad (19)$$

Where

i=1,2,…selected number of chromosomes (n_c)

j=1,2,…decided number of generations (n_g)

SW is the switch (Π) status as in the following:

$$= \begin{cases} 1 \; if \; th \\ 0 \; if \; th \end{cases}$$

Where *F* is the fitness function (≠ 0)

In order to achieve the best voltage profile, the fitness function *F* is designed to include all network modification constraints in equations (13), (16) and (18), the fitness evaluation is valid only when selecting the optimal cost conductor regarding equation (17) as in the following representation:

$= [NLI$

Where τ^1, τ^2, τ^3 are the percent fitness indices and must be selected carefully is such that:

$$\tau^1 + \tau^2 + \tau^3 = 1 \qquad (22)$$

As the individual index increase, its related constraint is considered to be more important from the network planner point of view, note that *NLI* and *CCF* is economic factors while *VDI* is technical.

Genetic Algorithm

In order to meet the optimal solution to improve the network performance regarding voltage dip, Genetic Algorithm GA is adopted to select the optimal solution regarding network switch decision as in the following steps:

1. Selection

Represents the start point of algorithm, it is performed by initial chromosome status setting regarding the current *SW* mode for certain number of switches.

2. Initial Population

A definite number of individuals n_c are generated randomly to form the first-generation solution matrix.

3. Fitness

The criteria of any solution violation are discovered by estimating the fitness for each individual in the initial population matrix.

4. Crossover and Mutation

Random individuals will be selected with arbitrary swap points to be coupled to generate new survival with enhances fitness, a new generation solution matrix will be generated.

5. Designate Best Decisions

Performed by accepting the best fitness individuals.

Adaptive Intelligent Algorithm

In order to discover the best practical, technical and economical solutions to improve the voltage profile in practical heavily loaded distribution feeders the improvement strategies a, b, c, d and e are recommended to be implemented. Finding the optimal solution requires the adoption of effective intelligent technique. In this work, a genetic algorithm is used in parallel with the adaptive strategies to reduce the voltage dip as well as system loss. The suggested algorithm is depicted as in the following phases:

I. Digitize the network into parameters data matrix, aggregate all network components into $\overline{Z_T}$.
II. Represent the load $\overline{Z_L}$ using *LoadExpo*.
III. Input the network voltage and load profile.

IV. Present the candidate conductors matrix.
V. Start the genetic algorithm as shown in Figure (3).
VI. Display the optimal solution regarding the best SW status and new conductors.

Case Studied

A practical distribution network in Baghdad area adopted to implement the proposed voltage profile improvement strategies under voltage disturbances. In this work, we carefully selected a practical heavily loaded feeders and a voltage dip is designated during peak load season. Five 11kV feeders from Al-Jamea’a 132/33/11 substation and are digitized as shown in Figure 4 using CYME7.1 software, then the following implementations are completed:

1) For accurate component representation, all network components like cables, conductors, capacitors, switches, transformers are represented and then aggregated into single $\overline{Z_T}$ by network aggregation algorithm [7].

Next, practical load profile is considered using a realistic data acquisition for 12 days in peak summer period (during August 2018). Then the LoadExpo [2] is applied to achieve an optimized realistic load model and hence $\overline{Z_L}$. This is indicated in Table 1 by considering active and reactive power load model weighting factors.

2) Using MATLAB, the load profile for 260 continuous hours as well as the feeders network data are presented in matrix form.
3) Voltage profile improvement strategies is implemented starting from network loss reduction test that is achieved by analysising all sections in each feeder searching for voltage dip under maximum power demand, then max dip sections

are located, furthermore *FLV* is implementing for the violated sections to explore for candidate conductors by applying the technique described in Figure 2 and equations 11 to 16. Conductor modification is applied for violated sections, then loss is recalculated, and finally the *NLI* matrix as shown in Table 2.

4) Adaptive intelligent algorithm is processed as described by Figure 3 in parallel with the voltage profile improvement strategies using Equations 17 to 22. The fitness indices use in equation 22 are:
$\tau^1 = \tau^2 = 30\% \ , \tau^3 = 40\%$

To select only the best fitness individuals, new multi solution are achieved regarding two patterns, first the updated conductors and second the switch mode status *SW* for 26 existing switches in addition to 7 suggested to achieve lower *NL* as well as *VDI* and *CCT*. The best fitness multi solutions (optimal four individuals) regarding updated *SW* and conductors are illustrated in Table 3.

Table 3 indicates that the best individual is X_{30}^{9} i.e it is the best optimal solution due to its high fitness. Network performance improvements are achieved by applying the suggested five strategies specified combined by this individual. The network optimal revisions and updates that can provide the best voltage profile improvement are as shown in Table 4.

Conclusions

The network under study is selected due to heavy loads and large voltage dip during peak periods, the voltage dip is allocated as shown in Table 2. At the same time a large network loss is recorded, each section is examined carefully and then the violated sections is designated and prepared to apply the voltage profile improvement strategies suggested by this work to find the best solution to improve both loss and voltage dip, this is achieved by revising conductor sizes and network switching modes using GA. Under our study, it was essential to suggest new switches in 7 locations to reduce the overloading of feeders and to achieve more improvements, The NLI matrix gives clear indication about the correct conductor modification horizon, and in parallel with VD and CCT can provide the optimal modification suggestions successfully by using adaptive intelligent technique.

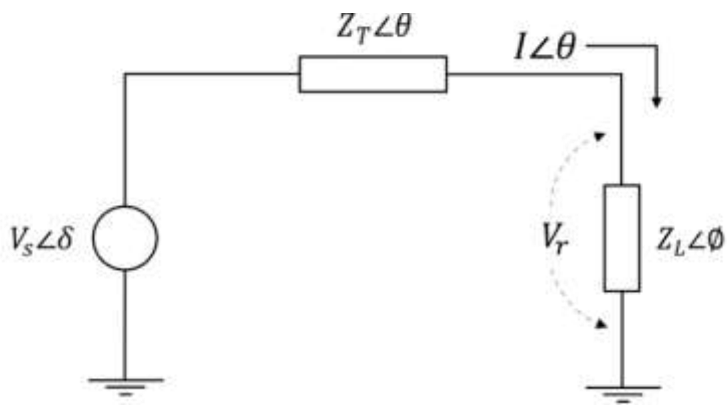
The challenge in this work is that we have vast number of switch mode *s* possibilities (2^{33}=8.59E9) which characterize a non-containable horizon to be studied, adaptive intelligent technique can successfully limit this horizon by:

I. Initially, locking specific switches to a specific status like the switches at the beginning of the feeders that should be always on
II. Then streaming the remaining horizon by applying three constraints *NLI ,CCF and VDI*.
III. Finally, by adopting GA to investigate each candidate solution fitness and then selecting, crossover and mutation to acquire the optimal solution.

Using n_c=16 in n_g=30 generations only, the GA solutions reach convergence and provides practical optimal multi solutions, implementing one of these optimal solutions positively improves the voltage profile as shown in Table 3. The fast convergence time and multi solutions are the main advantage of this adaptive technique.

Figure 1

Distribution Feeder Equivalent Circuit



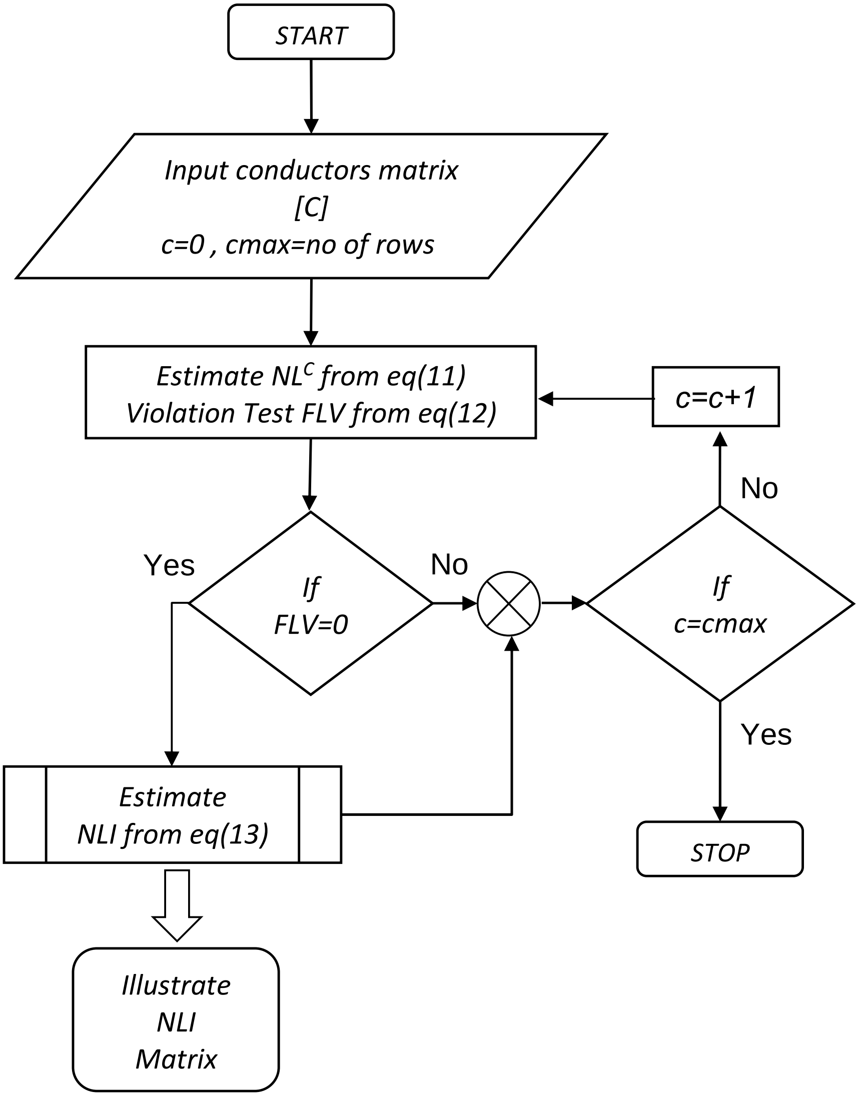


Figure 2

Network Loss Reduction Test

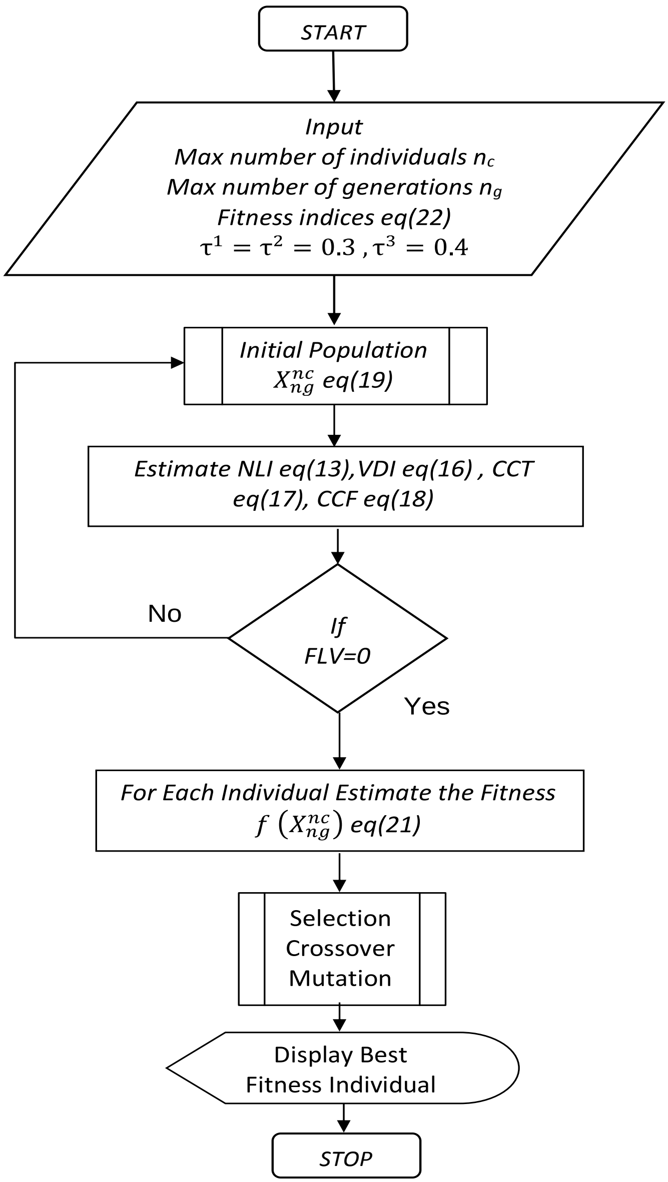


Figure 3

Genetic Algorithm Voltage Profile Optimization

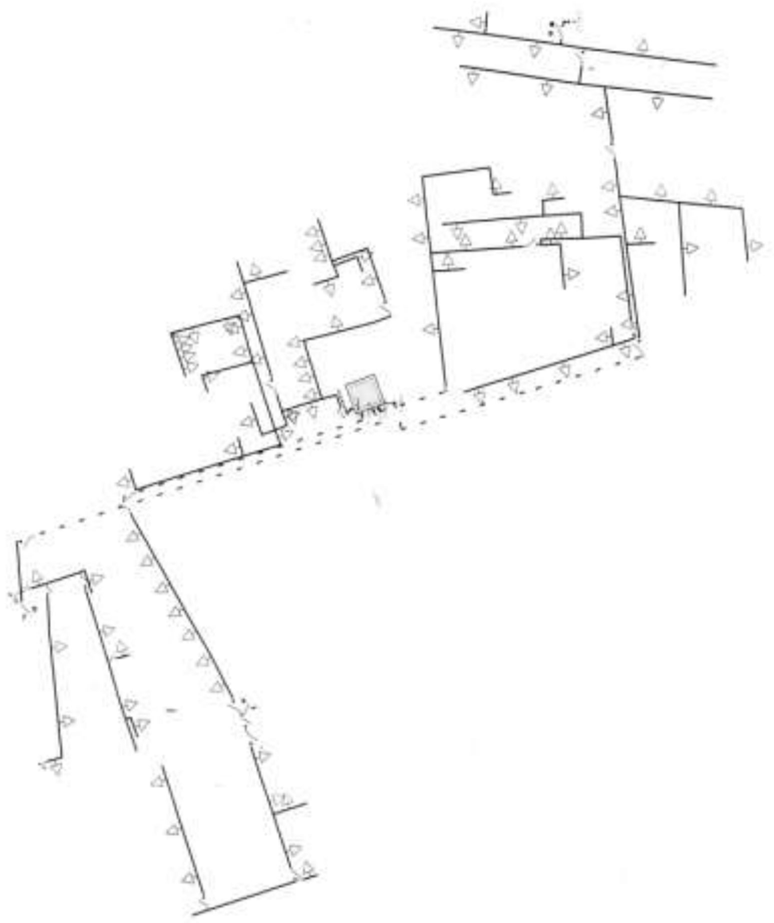


Figure 4

Al-Jamea'a 11kV Distribution Network

Table 1
Network Aggregation and Load Model

	Po				Qo				ZT Ohm		ZL Ohm	
	MW	a1	a2	a3	MVAR	b1	b2	b3	R	XL	R	XL
FD2	4.55	0.7240	0.1435	0.1325	0.93	0.4580	0.0738	0.4682	16.959	18.617	5.018	1.087
FD4	4.23	0.6680	0.2378	0.0942	1.89	0.3267	0.1467	0.5266	9.119	10.128	4.773	0.937
FD9	4.61	0.7830	0.1672	0.0498	1.748	0.5713	0.2090	0.2197	11.442	12.608	4.523	1.293
FD17	4.58	0.6780	0.0782	0.2438	1.653	0.3765	0.1765	0.4470	23.829	26.614	6.133	1.182
FD18	4.74	0.7330	0.1389	0.1281	0.76	0.2145	0.2531	0.5324	21.706	24.437	4.658	1.165

Table 2
Network Loss Reduction Test

	Voltage Dip		FLV		NLI
	No of Sections	Max Dip	Violation	Sections	
FD2	19	14.35%	no	3-19	13.45%
FD4	22	15.38%	no	12-22	18.30%
FD9	17	9.75%	no	11-17	7.92%
FD17	15	12.88%	no	5-15	11.40%
FD18	34	17.34%	no	6-34	20.33%

Table 3
Adaptive Intelligent Algorithm Multi Solution Output

J=30 X (i)	NLI	CCF %	VDI	Fitness Indices			Fitness
6	5.23%	22.05%	4.39%	0.3	0.3	0.4	0.0994
14	5.49%	31.81%	6.02%				0.13598
2	5.06%	36.59%	6.10%				0.14935
9	5.83%	45.32%	5.74%				0.17641

Table 4
Network Optimal Revisions and Updates

	Conductor Update	No of Updated Sections	Switch Mode Update	Optimal SW Status Update (From-To)		
FD2	Yes	6	yes	SW2-2(0-1)	SW2-4(1-0)	-
FD4	Yes	3	yes	SW4-1(0-1)	SW4-3(1-0)	SW4-4(1-0)
FD9	Yes	11	no	-	-	-
FD17	Yes	3	yes	-	SW17-2(1-0)	-
FD18	Yes	15	yes	SW18-2(0-1)	SW17-3(0-1)	SW17-6(1-0)

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