ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

*(An ISO 3297: 2007 Certified Organization)*

**Vol. 3, Issue 7, July 2014**

DOI: 10.15662/ijareeie.2014.0307006

# Novel Load Flow Algorithm for Multi-Phase Balanced/ Unbalanced Radial Distribution Systems

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**ABSTRACT**: In this work, distribution system load flow analysis is formulated and tested for fundamental steady-state and harmonics power flow. For the steady-state analysis, a novel power flow formulation method for the general multiphase balanced and/or unbalanced radial distribution systems is presented. The special topology of the power distribution system has been fully exploited to facilitate obtaining a direct solution using the graph theory. Only one developed matrix used in conjunction with simple standard formulation is enough to obtain the power flow solution. This matrix is the branch-path incident matrix. A feature of using this method is that it significantly reduces the number of power flow equations, as compared to conventional methods, hence very low computation time and memory storage. The presence of nonlinear loads in the power system causes the circulation of harmonics currents in the system, leading to harmonics voltage drops. The harmonics flow analysis in this paper, uses the network techniques in conjunction with graph theory resulting in a powerful algorithm for nonlinear load flow analysis. Six pulse converters model were used to represent the nonlinear load. Two MATLAB programs have been built and used to solve for the load flow solution of standard test systems in both steady-state and harmonics cases. The results of the distribution system cases studies are presented and shows a very good resemblance with a standard results.

**KEYWORDS:** Distribution Networks, Novel Power flow, harmonic flow analysis, MATLAB.

## I.INTRODUCTION

The analysis of power distribution systems is animportant area of research activities due to the vitalrole of distribution systems as the final link between thebulk power system and consumers. Load flow is animportant tool for the analysis of distribution systems. Thistool must be able to model the special features ofdistribution systems such as unbalanced loads;un-transposed lines, radial and weakly meshed topology,grounded or ungrounded systems, high resistance toreactance(R/X) ratios, and single, two or three phase lines.Due to the high R/X ratios and unbalanced operation indistribution systems, the Newton-Raphson and ordinaryFast Decoupled Load Flow method may provide inaccurateresults and may not be converged. Therefore, conventionalload flow methods cannot be directly applied to distributionsystems.However, these algorithms have been formulated for transmission systems. In many cases, the radial distribution systems include un-transposed lines which are unbalanced because of single phase, two phase and three phase loads. Thus, load flow analysis of balanced radial distribution systems **[1], [2]** will be in efficient to solve the unbalanced cases and the distribution systems need to be analyzed on a three phase basis instead of single phase basis.Conventional ac electric power systems are designed to operate with sinusoidal voltages and currents. However, nonlinear loads cause distortion in the steady-state ac voltage and current waveforms. Periodic steady-state distortion can be very effectively studied by examining the components of a Fourier series representation of the waveforms. A harmonic analysis (harmonic study) is numerical tool applied to study the generation and propagation of harmonics in an arbitrary topology network **[3].** The level of power system harmonic voltages and currents has increased significantly and there has been a considerable interest in limiting harmonic signals by adopting standards which

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 7, July 2014

require analytical methods to calculate harmonics in power systems. The harmonic power flow calculations are becoming routine in many power utilities. They are being used regularly in predicting the degree of harmonic penetration in existing systems and in the design of new systems. The accuracy of the results obtained depends to a large extent on the accuracy of the mathematical models used for the various components and that of the simulation technique employed **[4, 5].**The objective of this work is to provide a novel power flow formulation method for the general multi-phase balanced and/or unbalanced radial distribution system. In the formulation, the special topology of distribution system is to be exploited, to reduce the number of power flow equations, and reduce the computation time and storage, as compared to conventional methods. In the present work a computer program in (MATLAB) is to be developed and applied to standard test systems then a comparison with the results of existing methods in the context of simplicity, accuracy, execution time, adaptability are to be evaluated. Finally, it is aimed to apply the developed method to analyse harmonics load flow in radial distribution systems.

There have been a lot of interests in the area of three phase distribution load flows. A fast decoupled power flow method has been proposed in **[6].** This method orders the laterals instead of buses into layers, thus reducing the problem size to the number of laterals. Using of lateral variables instead of node variables makes this method more efficient for a given system topology, but it may add some difficulties if the network topology is changed regularly, which is common in distribution systems because of switching operations. In **[7],** a method for solving unbalanced radial distribution systems based on the Newton-Raphson method has been proposed. Thukaram*etal*. **[8]** have proposed a method for solving three-phase radial distribution networks. This method uses the forward and backward propagation to calculate branch currents and node voltages. A three-phase fast decoupled power flow method has been proposed in **[9].** This method uses traditional Newton-Raphson algorithm in a rectangular coordinate system. In **[10],** a method for the solution of unbalanced three-phase power systems using the Newton-Raphson have been proposed in which, three-phase current injection equations are written in rectangular coordinates system. However, these methods are very cumbersome and need large computational time. A fast decoupled G-matrix method for power flow, based on equivalent current injections, and has been proposed in **[11]** .This method uses a constant Jacobian matrix which needs to be inverted only once. However, the Jacobian matrix is formed by omitting the reactance of the distribution lines with the assumption that R>>X; and fails if X>R.

## II.UNBALANCED THREE-PHASE MODEL

Figure (1) shows a three-phase line section model between bus i and j. the line parameters can be obtained using the method developed by Carson [12]. A 4×4 matrix, which takes into account the self and mutual coupling terms, can be expressed as

$$[Z_{abcd}] = \begin{bmatrix} Z_{aa} Z_{ab} Z_{ac} Z_{an} \\ Z_{ba} Z_{bb} Z_{bc} Z_{bn} \\ Z_{ca} Z_{cb} Z_{cc} Z_{cn} \\ Z_{na} Z_{nb} Z_{nc} Z_{nn} \end{bmatrix} \quad (1)$$

For a well-grounded distribution system, VN and Vn shown in fig.(1) are assumed to be zero, and Kron’s reduction can be applied in (1).

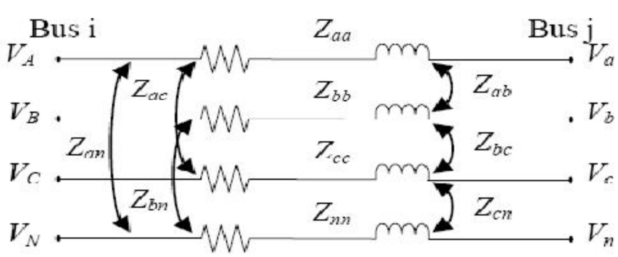


Fig. 1 A three phase line section.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 7, July 2014

Equation (2) is obtained after the elimination and therefore includes the effect of the neutral or ground wire and to be used in the unbalanced load flow calculation.

$$[Z_{abc}] = \begin{bmatrix} Z_{aa-n} & Z_{ab-n} & Z_{ac-n} \\ Z_{ba-n} & Z_{bb-n} & Z_{bc-n} \\ Z_{ca-n} & Z_{cb-n} & Z_{cc-n} \end{bmatrix} \quad (2)$$

The relations between the bus voltages and branch currents in fig.(1) can be expressed as:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} - \begin{bmatrix} Z_{aa-n} Z_{ab-n} Z_{ac-n} \\ Z_{ba-n} Z_{bb-n} Z_{bc-n} \\ Z_{ca-n} Z_{cb-n} Z_{cc-n} \end{bmatrix} \quad (3)$$

For any phase which fails to present, the corresponding row and column in this matrix will contain null-entries.

## III.FORMULATION OF THE PROBLEM

### 1. BRANCH-PATH INCIDENT MATRIX [BPM]

The incidence of branches to paths in a tree is shown by the branch-path incidence matrix, where a path is oriented from the reference node (substation in the distribution system) to a bus. The elements of this matrix are:

$BPM_{ij} = 1$ if the $i^{th}$ branch (B) is in the path from reference to the $j^{th}$ bus and is oriented in the same direction.
$BPM_{ij} = 0$ if the $i^{th}$ branch (B) is not in the path from reference to the $j^{th}$ bus.

With node (0) as reference the branch-path incident matrix associated with the tree shown in fig. (2) which is used as an example given in(4).

$$[\boldsymbol{BPM}] = \begin{bmatrix} \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} \\ \mathbf{0} & \mathbf{1} & \mathbf{1} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \end{bmatrix} \quad (\mathbf{4})$$

The building algorithm for the [BPM] is given [12]:

*i*. For a distribution system with m branch sections and n buses, the dimension of [BPM] is (m×m), (for distribution systems the number of branches is equal to (n-1)).
*ii.*For distribution system the [BPM] branch-path incident matrix have a (+1) in all diagonal elements.
*iii*. If a branch is located between bus *i* and bus *j*, copy the column of the $i^{th}$ path ($i^{th}$ bus) of the matrix [BPM] to the column of the $j^{th}$ path ($j^{th}$ bus).
iv. Repeat procedure (*iii*) until all the line sections (branches) is included in the branch-path incident matrix.

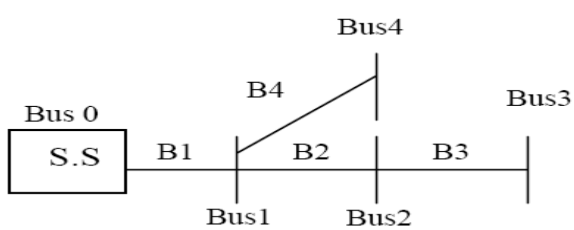


Fig. 2 Sample distribution system

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 7, July 2014

## 2. THE SYSTEM MODEL

For distribution system, the models which are based on the equivalent current injection, as described in [13] and [14] are used in this paper. At iteration K, the nodal current injection,$I_i^{(k)}$ at node( i) is calculated as,

$$I_i^{(k)} = \left(S_i / V_i^{(k-1)}\right)^* - Y_i V_i^{(k-1)} \quad (5)$$

Where

$V_i^{(k-1)}$ is the voltage at node-i calculated during the $(k-1)^{th}$ iteration.
$S_i$: Complex power injection at node-i.
$Y_i$: The sum of all the shunt elements at the node i.
i: is integer equal (1, 2, 3,… n).

## 3. SOLUTION TECHNIQUES & ALGORITHM

From graph [12] the bus impedance matrix can be found using simple relation between branch impedance (or primitive impedance matrix) and [BPM]. The relation between branch impedance matrix and [BPM] can be expressed as:

$$[Z_{BUS}] = [BPM]^t [Z_{BR}][BPM] \quad (6)$$

The relation between the bus current injections and voltage drop can be expressed as:

$$[DV] = [Z_{BUS}][I] \quad (7)$$

$$[DV] = [BPM]^t [Z_{BR}][BPM][I] \quad (8)$$

$$\left[DV^{k+1}\right] = [BPM]^t [Z_{BR}][BPM]\left[I^{(k)}\right] \quad (9)$$

$$V^{(k+1)} = [V_R] - [DV]^{(k+1)} \quad (10)$$

Where

$[Z_{BR}]$: Branch impedance matrix.
$[Z_{BUS}]$: Bus impedance matrix.
$[V_R]$: Vector whose elements are all equal to voltage of reference-bus (Substation).

Therefore, the solution for the distribution load flow can be obtained by solving eqns. (5) (9) and (10) iteratively. Figure (3), shows the flowchart of the overall algorithm.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 7, July 2014

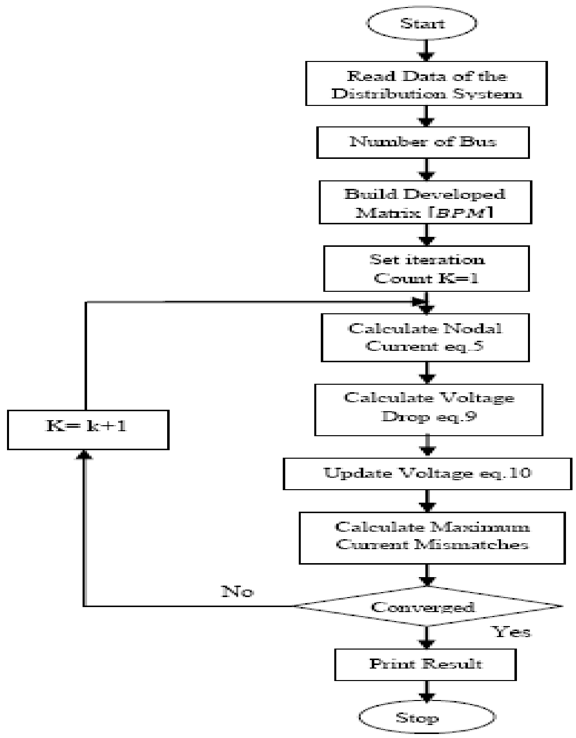


Fig. 3 Flowchart of the overall algorithm

## IV.HARMONIC LOAD FLOW

The proposed harmonic power flow method is based on Kirchhoff laws expressed by eq. (11) in conjunction with graph theory [15].

$$[V_h] = [Z_h][I_h] \quad (11)$$

Where

$[Z_h]$: is the complex nodal impedance matrix at harmonic order h.
$[V_h]$: is the complex nodal voltage vector at harmonic order h,
$[I_h]$: is the complex nodal injected current vector at harmonic order h.

The proposed harmonics load flow algorithm follows the steps:

*i.* Input data for load flow at power frequency.
*ii.* Calculate bus voltages and current injections.
*iii.* Input data for harmonic load flow:
• Maximum order of the harmonics to be considered.
• The negative sequence reactance of the source side.
• Specific data for the nonlinear loads.
*iv*. Build the bus incident matrix [A].
*v.* Formulate the bus admittance matrix using,

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 7, July 2014

$$[Y_{BUS}] = [A]^t[y][A] \quad (12)$$

*vi.* Using LU-decomposition obtain the bus impedance matrix.

$$[Z_{BUS}] = ([A]^t[y][A])^{-1} \quad (13)$$

$$I_h = \frac{I_1}{\left(h - \frac{5}{h}\right) \times 1.2} \quad (14)$$

$$\emptyset_h = h \propto + (h \pm 1)\theta_t \quad (15)$$

Where

LU: lower & upper diagonal matrix.
$I_1$: is the current amplitude at fundamental frequency absorbed for the power setting considered.
$\emptyset_h$ : is the harmonic current angular displacement.
h: The order of the harmonic.
$\propto$:Angle representing the delay between the moment of actual switching and that of natural switching.
$\theta_t$:Angle equal to the phase shift between similar primary and secondary voltages on the transformer supplying the rectifier.

*vii.* Solve equations (14) and (15) to obtain the harmonic currents generated at the nonlinear load bus for each harmonic order.
*viii.* Solve equation (11) to obtain the bus voltage at each harmonic order.
*ix.* Add fundamental and harmonic components.
*x.* Print results and plot.

## V. CASE STUDIES AND RESULTS

The power flow algorithm's presented in section (4) and (5) above are applied to radial distribution systems. These systems include:

### 1. A RADIAL DISTRIBUTION FEEDER FROM BAGHDAD CITY NETWORK

This feeder is an actual feeder selected from Baghdad city network (AL-Mansoor-No.11)whose single line diagram is shown in fig. (4).

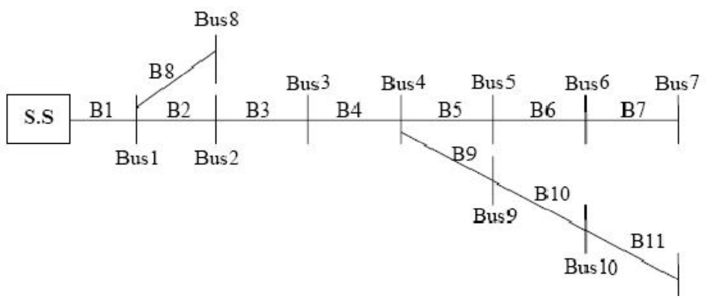


Fig. 4 Sample radial system from Baghdad city network (Al-Mansoor No. 11)

The feeder nominal voltage is 11.1 kV, and connected to AL-Mansoor substation. The system relevant data are given in table (1a & 1b) which are considered as abase values 11.1 kV and 2250 kVA [16]. All buses are loaded to 233kVA at 0.77 power factor lag except buses No-1 and No-4.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 7, July 2014

Table (1a) Line and cable Data, (SE: Sending end, RE: Receiving end)

| Bus SE | Bus RE | Length (km) | R (Ohm /km) | X (Ohm /km) |
|---|---|---|---|---|
| 0 | 1 | 0.450 | 0.124 | 0.106 |
| 1 | 2 | 0.150 | 0.33 | 0.35 |
| 2 | 3 | 0.200 | 0.33 | 0.35 |
| 3 | 4 | 0.025 | 0.33 | 0.35 |
| 4 | 5 | 0.250 | 0.33 | 0.35 |
| 5 | 6 | 0.100 | 0.33 | 0.35 |
| 6 | 7 | 0.075 | 0.33 | 0.35 |
| 7 | 8 | 0.050 | 0.33 | 0.35 |
| 8 | 9 | 0.100 | 0.33 | 0.35 |
| 9 | 10 | 0.035 | 0.33 | 0.35 |
| 10 | 11 | 0.150 | 0.33 | 0.35 |

Table (1b ) System Loading

| Node | P(kW) | Q(kVAR) |
|---|---|---|
| 1 | 0.000 | 0.000 |
| 2 | 178.711 | 149.504 |
| 3 | 178.711 | 149.504 |
| 4 | 0.000 | 0.000 |
| 5 | 178.711 | 149.504 |
| 6 | 178.711 | 149.504 |
| 7 | 178.711 | 149.504 |
| 8 | 178.711 | 149.504 |
| 9 | 178.711 | 149.504 |
| 10 | 178.711 | 149.504 |
| 11 | 178.711 | 149.504 |

The graph theoretic based load flow program is used to perform the analysis for this test case under balanced three phases loading of the feeder. The supply bus (S.S, in fig. (4)) voltage is considered (1.00) p.u. The results concerning bus voltages, currents and branch currents are presented in tables (2) and (3). The total feeder losses are (5.527+j5.4584) kVA. The results in Tables (2 and 3) conforms exactly those obtained by [16], which are using thedistribution flow method. The total execution time was 0.05 Sec.

Table (2) AL- Mansoor No. 11, Bus Voltages and Currents

| Bus | Bus Voltage Mag. (pu) | Bus Voltage Angle (Deg.) | Bus Current Mag. (Amp.) | Bus Current Angle (Deg.) | Bus Voltage Mag. (pu) Ref.(20) |
|---|---|---|---|---|---|
| 1 | 0.998 | - 0.0008 | 0 | 0 | 0.998 |
| 2 | 0.997 | - 0.0082 | 12.148 | - 39.923 | 0.997 |
| 3 | 0.9963 | - 0.0168 | 12.163 | - 39.932 | 0.996 |
| 4 | 0.9962 | - 0.0177 | 0 | 0 | 0.9962 |
| 5 | 0.9955 | - 0.0224 | 12.173 | - 39.937 | 0.9955 |
| 6 | 0.9954 | - 0.0236 | 12.175 | - 39.938 | 0.9954 |

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 7, July 2014

| | | | | | |
|---|---|---|---|---|---|
| 7 | 0.9953 | - 0.0241 | 12.176 | - 39.939 | 0.9953 |
| 8 | 0.9986 | -0.0294 | 12.136 | - 39.916 | 0.9986 |
| 9 | 0.9961 | -0.0187 | 12.166 | - 39.933 | 0.996 |
| 10 | 0.9959 | -0.0199 | 12.168 | - 39.934 | 0.9959 |
| 11 | 0.9958 | - 0.0201 | 12.169 | - 39.935 | 0.9958 |

Table (3) AL-Mansoor No. 11, Branch Currents

| SE | RE | Branch Current | |
|---|---|---|---|
| | | Mag. (Amp.) | Angle (Deg.) |
| 0 | 1 | 109.4753 | - 39.9321 |
| 1 | 2 | 97.3393 | - 39.9340 |
| 2 | 3 | 85.1917 | - 39.9356 |
| 3 | 4 | 73.0286 | - 39.9362 |
| 4 | 5 | 36.5245 | - 39.9381 |
| 5 | 6 | 24.3514 | - 39.9386 |
| 6 | 7 | 12.1761 | - 39.9389 |
| 7 | 8 | 12.1360 | - 39.9165 |
| 8 | 9 | 36.5041 | - 39.9343 |
| 9 | 10 | 24.3377 | - 39.9348 |
| 10 | 11 | 12.169 | - 39.9350 |

**2. THE IEEE 13 NODE TEST FEEDER**

The single line diagram of the IEEE 13nodetestfeeder system is shown in figure (5). The relevant data for this test system presents in [17].

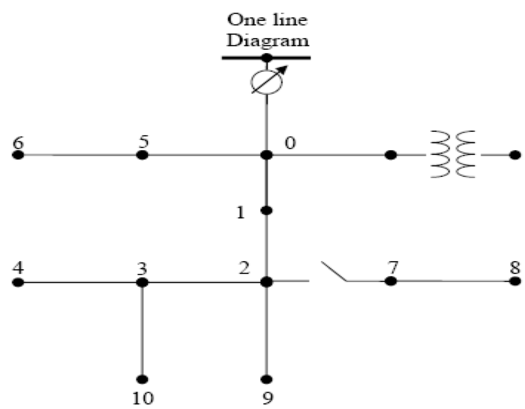


Fig. 5 IEEE 13-Bus radial distribution test system/7

The results for the IEEE-13 node system for the unbalanced loading conditions are shown in Table (4).The results of table (4) resemble those of [17] to less than 2 % as a comparison, the execution time for this case was 0.05 Sec.

Table (4) IEEE 13-Bus, Bus Voltages, base voltage 4.16 kV

| Phase | A-N | | B-N | | C-N | |
|---|---|---|---|---|---|---|
| Bus | Mag. | Ang. | Mag. | Ang. | Mag. | Ang. |

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 7, July 2014

| | Pu | Deg. | Pu | Deg. | Pu | Deg. |
|---|---|---|---|---|---|---|
| 1 | 1.0057 | -3.86 | 1.0465 | -122.03 | 0.9957 | 116.85 |
| 2 | 0.99 | -5.295 | 1.0529 | -122.34 | 0.977 | 116.02 |
| 3 | 0.9881 | -5.318 | - | - | 0.975 | 115.92 |
| 4 | - | - | - | - | 0.973 | 115.78 |
| 5 | - | - | 1.032 | -121.9 | 1.015 | 117.86 |
| 6 | - | - | 1.031 | -121.98 | 1.013 | 117.9 |
| 7 | 0.99 | -5.295 | 1.0529 | -122.34 | 0.977 | 116.02 |
| 8 | 0.9835 | -5.5456 | 1.0553 | -122.52 | 0.975 | 116.04 |
| 9 | 0.99 | -5.2952 | 1.0529 | -122.34 | 0.977 | 116.02 |
| 10 | 0.981 | -5.2455 | - | - | - | - |

Table (5) presents the overall power profile in the test system. Regarding system losses the resultgiven in [17] is equal toSLoss=(45.174+j120.9582) kVA compared to (45.173+j120.957) kVA which are very close.

Table (5) IEEE 13-Bus, System power profile

| | kW | kVAR |
|---|---|---|
| SystemInput Power | 3111.028 | 1230.715 |
| Load & Capacitor | 3065.855 | 1109.7574 |
| Losses | 45.173 | 120.957 |

### 3. THE IEEE 34 NODE TEST FEEDER

The single line diagram of the **IEEE 34**nodetest feeder system is shown in fig. (6). The data for this test system presents in [17].

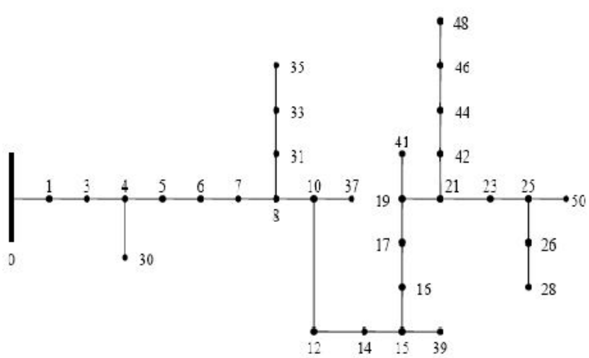


Fig. 6 IEEE 34-Bus test feeder

However the sample results for the IEEE-34 nodes, multiphase unbalanced operation system are given in table (6). The results are for samples nodes (0, 1, 2, 3, 4, and 30). Comparison of these results with those in [17] shows a very close resemblance for the nodes given above and slight discrepancies were noticed for those nodes after the regulators in the system. The reason for which is primarily due to the negligence of the regulator, transformers, and the concentration of the distributed loads as a spot loads. The execution time for this system and loading was 0.16 sec compared to 0.25 sec in [18].

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 7, July 2014

Table (6) IEEE 34-Bus, Sample Bus Voltages, Base voltage 24.9 kV

| Bus | A-N | | B-N | | C-N | |
|---|---|---|---|---|---|---|
| | Mag. Pu | Ang. Deg. | Mag. Pu | Ang. Deg. | Mag. Pu | Ang. Deg. |
| 0 | 1.05 | 0 | 1.05 | -120 | 1.05 | 120 |
| 1 | 1.0468 | -0.007 | 1.0479 | -120.03 | 1.0481 | 119.99 |
| 3 | 1.0447 | -0.0123 | 1.0466 | -120.06 | 1.0468 | 119.97 |
| 4 | 1.0046 | -0.11827 | 1.023 | -120.49 | 1.0242 | 119.79 |
| 30 | - | - | 1.0228 | -120.49 | - | - |

Only three cases above the power flow program were implemented using the MATLAB. The total number of iterations for a solution was three - iteration with a convergence tolerance of $1 \times 10^{-3}$. Finally, it is worthwhile to mention that for the IEEE-34 node system [18],theexecution time comparison for various load flow algorithms which are depicted in Fig. (7). In addition, theexecution time for the load flow solution is obtained by using the proposed method.

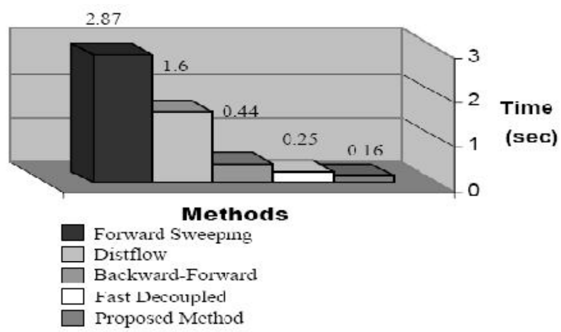


Fig. 7 IEEE 34-Bus, execution time comparison

### 4. HARMONICS TEST SYSTEM

This is a 12.5 kV radial distribution feeder with one generator (source side), four linear loads and one nonlinear load at bus-8 which is a six pulse rectifier. The system single line diagram is shown in Fig. (8), the system input data are given in [19], based on 10MVA. This test is used to illustrate the application of the proposed algorithm for solving the harmonics load flow problem in a balance radial distribution system with nonlinear load. The transformer represented by a series reactance only. The harmonic analysis was carried out up to the 19th harmonic order, assuming the effects from the higher order harmonics are negligible. The nonlinear load bus (bus-8) contains a six pulse converter. The characteristic harmonic orders for this nonlinear source are ($6K \pm 1$) where $K$ =1, 2, 3.

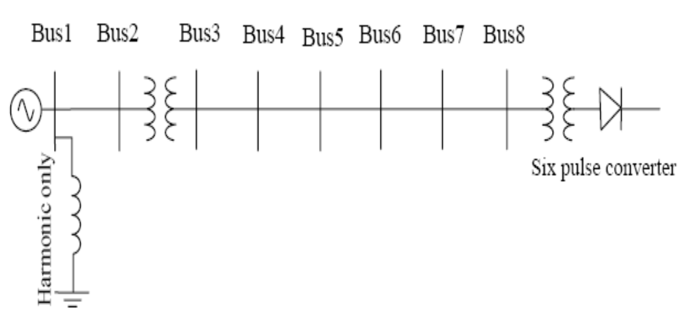


Fig. 8 Harmonics test system

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 7, July 2014

The fundamental, 5th, 7th, 11th, 13th, 17th and 19th harmonics calculated bus voltages are shown in Table (7). The decay in the harmonics voltages away from the harmonic bus (bus-8) is quite evident in Table (7).

Table (7) bus voltages at each harmonic order

| Harmonic order | Bus voltages | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Bus 1 | Bus 2 | Bus 3 | Bus 4 | Bus 5 | Bus 6 | Bus 7 | Bus 8 |
| $19^{th}$ | 0.0057∠ − 145.57 | 0.012∠ − 145.72 | 0.108∠ − 145.72 | 0.154∠ − 145.98 | 0.203∠ − 138.42 | 0.257∠ − 129.69 | 0.318∠ − 119.70 | 0.392∠ − 108.61 |
| $17^{th}$ | 0.0062∠ − 181.03 | 0.013∠ − 181.2 | 0.118∠ − 145.57 | 0.168∠ − 1481.49 | 0.221∠ − 174.75 | 0.278∠ − 166.93 | 0.343∠ − 157.91 | 0.419∠ − 147.80 |
| $13^{th}$ | 0.0076∠ − 170.298 | 0.015∠ − 70.519 | 0.142∠ − 70.519 | 0.202∠ − 70.901 | 0.266∠ − 65.827 | 0.333∠ − 59.849 | 0.405∠ − 52.859 | 0.487∠ − 44.891 |
| $11^{th}$ | 0.0084∠ − 103.83 | 0.017∠ − 104.09 | 0.157∠ − 104.09 | 0.224∠ − 104.54 | 0.294∠ − 100.32 | 0.367∠ − 95.289 | 0.445∠ − 89.360 | 0.5317∠ − 82.544 |
| $7^{th}$ | 0.011 ∠12.075 | 0.021 ∠11.6660 | 0.200 ∠11.6659 | 0.286 ∠10.9561 | 0.374 ∠13.4134 | 0.465 ∠16.4822 | 0.560 ∠20.1971 | 0.660 ∠24.5540 |
| $5^{th}$ | 0.013∠ − 18.226 | 0.026∠ − 18.799 | 0.242∠ − 18.779 | 0.346∠ − 19.793 | 0.453∠ − 18.306 | 0.562∠ − 16.281 | 0.675∠ − 13.737 | 0.793∠ − 10.692 |
| fundamental | 12.500∠0 | 12.464∠ − 0.194 | 11.927∠ − 3.710 | 11.639∠ − 5.166 | 11.335∠ − 6.328 | 11.150∠ − 7.281 | 11.021∠ − 8.032 | 10.948∠ − 8.563 |

The percent voltage distortion factor at each bus is shown in figure (9). The distortion factor variation pattern and values obtained compares very well with the results in [19].

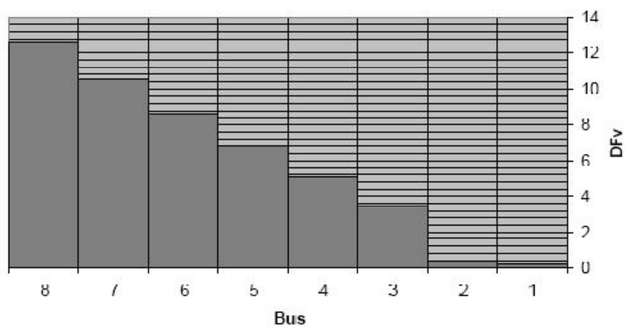


Fig. 9 Percent bus voltage distortion factor (DFv)

Figure (10) shows the harmonics voltage magnitude at each bus.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

**International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering**

*(An ISO 3297: 2007 Certified Organization)*

**Vol. 3, Issue 7, July 2014**

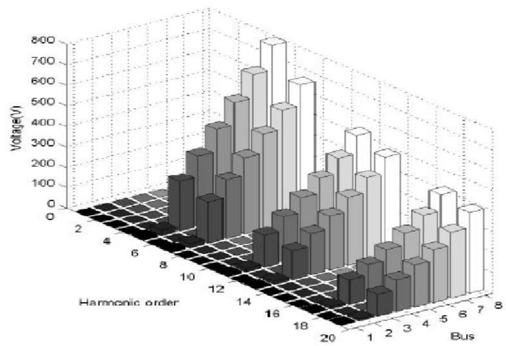


Fig. 10 Harmonics bus voltages

Figures (11)-(13), presents the voltage waveforms (one cycle) at selected buses, namely, buses 1, 4 and 8 respectively. The corruption in the waveform is quite clear being the highest in the non-linear load bus (bus-8) and the least at the farthest bus (bus-1).

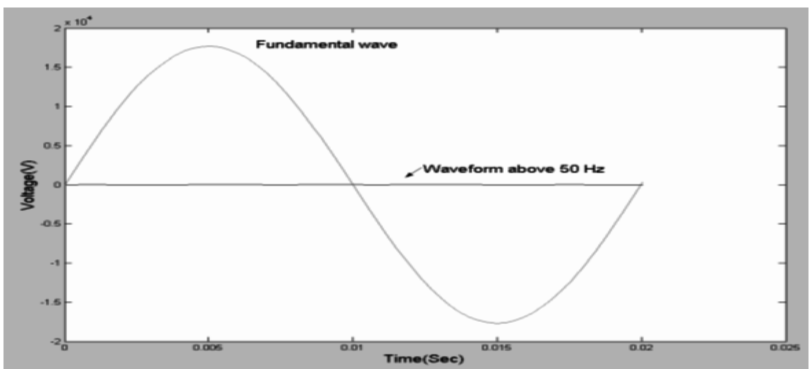


Fig. 11 (a) Fundamental and harmonics voltage waveforms at bus-1

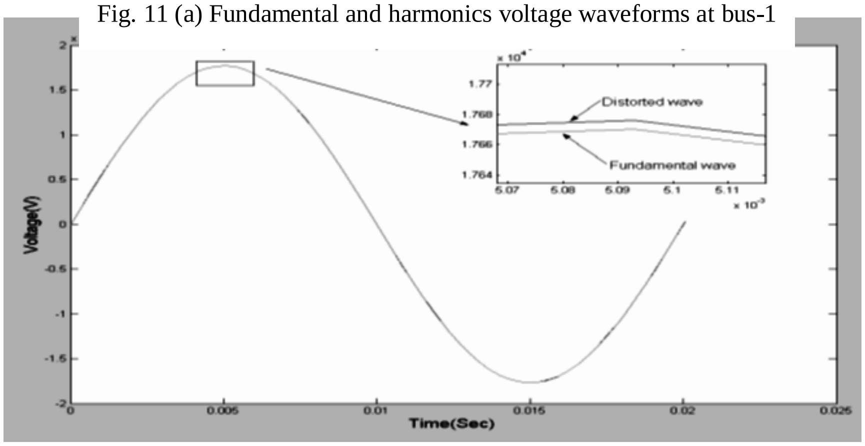


Fig. 11 (b) Fundamental and distorted voltage waveforms at bus-1

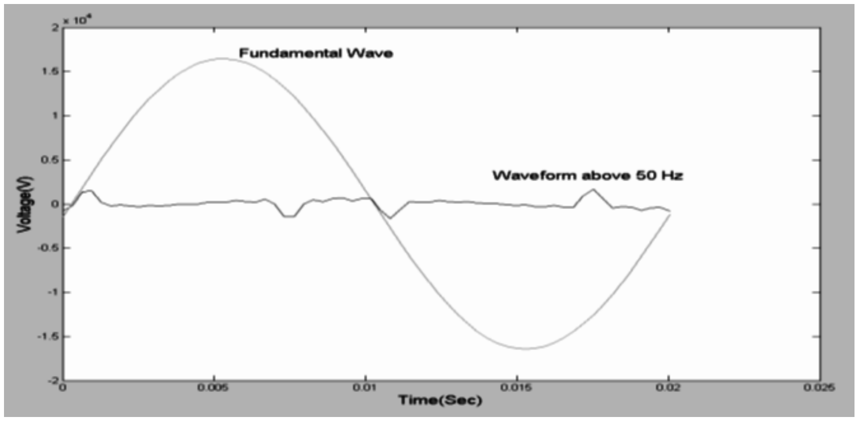


Fig. 12 (a) Fundamental and harmonics voltage waveforms at bus-4

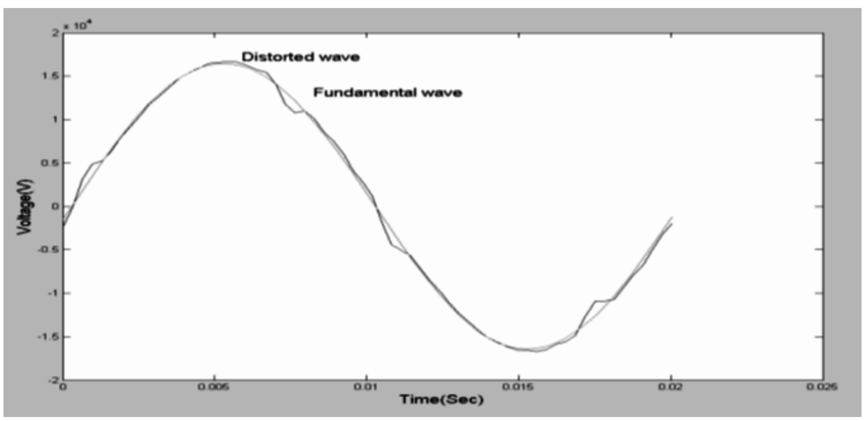


Fig. 12 (b) Fundamental and distorted voltage waveforms at bus-4

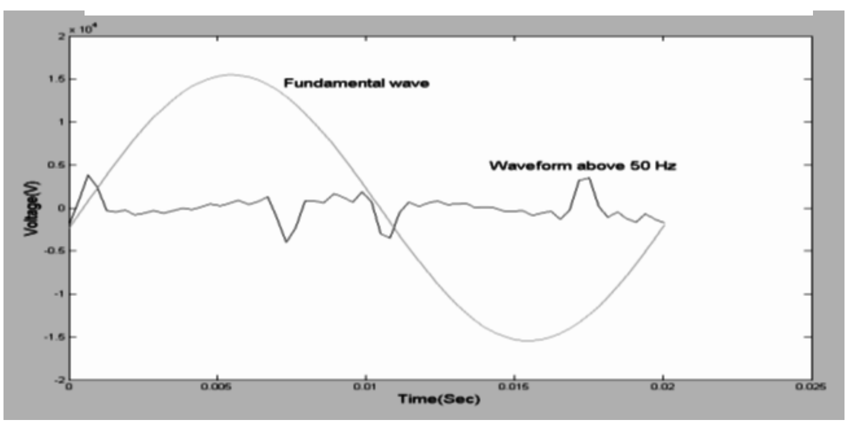


Fig. 13 (a) Fundamental and harmonics voltage waveforms at bus-8

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

*(An ISO 3297: 2007 Certified Organization)*

Vol. 3, Issue 7, July 2014

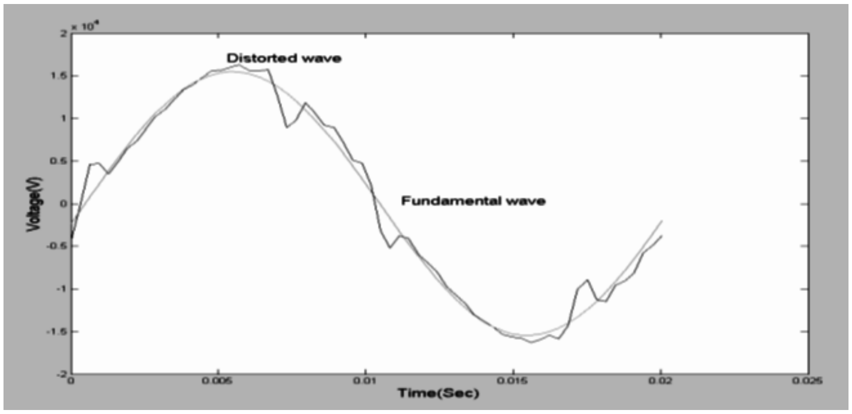


Fig. 13(b) Fundamental and distorted voltage waveforms at bus-8

## VI.CONCLUSION

A novel, fast, robust load flow algorithm applicable in electrical power distribution system analysis for various loading and phasing conditions is presented. The conformity of the results obtained for the different systems with those reported in the literature verifies the applicability and robustness of the proposed method. Work is going on to introduce the regulation, transformer and the distributed load nature if exists in the system, and to be reported in a future paper. The fast, low storage and versatility of the algorithm lends it effectively to computer automation applications in distribution systems.

The proposed harmonic power flow method is simple and fast based on Kirchhoff laws in conjunction with graph theoretic procedure. It is linear methods were no iterations are required, only the harmonic currents and the bus impedance for each harmonic order is needed. Therefore, compared to nonlinear methods, the proposed technique offers the benefits of very low computation time and storage. The six pulse converter approximate model been used along with the system components at the particular frequency. The overall conclusion prevailed showed that the harmonics flow is strongly connected to the nonlinear load position and definitely on the harmonic order.

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ISSN (Print) : 2320 – 3765
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