POSITIVE SEQUENCE POWER FLOW ANALYSIS OF IEEE 57 BUS POWER SYSTEM USING MATLAB-LOAD FLOW TOOL

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Abstract

The approach of symmetrical components of power flow analysis is the very salient technique to inspect the bus power flows in a 3-phase unbalanced and balanced power system network during the healthy or unhealthy case operation. There are various traditional programs available in the literature, which solve the single-phase equivalent power system models for power flow analysis. The main aim of this paper is to conduct a positive sequence power flow analysis on a balanced 3-phase IEEE 57 bus test case matlab Simulink model by using the Load Flow Tool. The present power system model consists of 7 thermal energy systems, each system configured with IEEE type-1 Excitation, Steam turbine, and Governor. The simulation study is useful for finding the bus voltages, active power losses and reactive power losses in the lines. However, there is an empirical analysis conducted with present results with the test case. There is a voltage improvement is observed at the buses with the present model. The efficiency of the model and convergence criteria perceive with the simulation results report. The simulink model is also useful for the steady-state analysis of power system network as well as the power flow analysis of the network with various grid connected renewable energy sources.

Keywords : IEEE 57 bus, Load Flow tool, Power Flow, positive sequence, Simulink model, thermal energy systems.

I. Introduction

The power flow analysis of a three-phase power system network has been an important topic since 1960. It is very important in less cost planning, demand management, designing, optimum operation and future expansion of a power system network [II]. Usually, the single-phase equivalent power flow analysis can be done by assuming phase voltages are equal magnitude and phase shifted by 120 degrees from each other with the assumption of imbalances in the system cannot consider. However, the solution of the network obtained from the nonlinear equations. In the
three-phase power flow problems, the magnitude of voltage and its phase angle at every bus calculate, prior to the active power and reactive power injections in transmission lines. There are various algorithms proposed in previous years to study power flows in the power system. Out of all methods, a three phase power flow analysis by NR method program describes the steady state operation of the power system network under the unbalanced conditions [VI]. Many studies present in power flow solution, address the initial guess, computational efficiency [V,IX,XIII], ill conditioned case [IV,VII,VIII], multiple cases [XI], and unsolved cases [XII]. The solution of these conditions can solve by an efficient manner by using vector based continuous NR method [I,III]. In an Electrical power system, the power flow analysis has more accurate results when all the system components represent in a very detailed manner [X].

The genesis of a power flow solution, with sequence component form, uses a sequence component transformer, Generator, decoupled sequence transmission line models. The power flow analysis of three phase power system network solution is in either phase frame of sequence components frame. The advantage of the sequence component of the solution is a reduction in the size of the problem. Therefore, in symmetrical three-phase power flow has less computation time, stable convergence, useful for single-phase representation and need less computer storage. Therefore, the differences between single phase and three phase sequence power flows are:

- Bus admittance matrix size
- Variable number
- Variable type
- Positive sequence circuit input data field value
- Reliability of bus voltage with the previous iteration results in bus voltage of all sequence circuits.

In addition to these, include unbalanced loads in the problem. In both, the cases NR method and Fast decoupled method are used. However, there are two disadvantages, firstly, unable to solve 6n (or) two 3n nonlinear simultaneous equations in large power system networks. Secondly, conventional methods fail to inverse the Jacobean matrix.

The conventional power flow solution does not consider the controlling of power balance and power exchange between connected networks. Moreover, the solution of power flow problem is very important in interconnected power system networks. Mostly in the large scale power system, distribution automation, AC-DC hybrid systems, etc., these applications repeatedly require power flow study, there are various algorithms proposed in the earlier days for the solution of the load flow problem in distribution systems. Those are categorized into two, the first one is General distribution system topology which uses bus voltage as state variable for the solution, and the second one is based on special network structure. National wide the consumption of electricity is increasing; therefore power system network has been growing day to day. A small problem causes a blackout in the network; therefore keep the security under overloading condition is very important. Therefore, it is essential to integrate the non-conventional energy resources such as solar power generation, wind
power generation, etc. However, the main power generating units connected to the main transmission system and additional non-conventional generating units connected to the distribution transmission section. In a big power system network, the solution of non-linear equations is very tedious in practice with the direct methods of NR power flow methods. Such situation LU factorization is used, in this scheme of power flow speed up the computation of power flow solution and increase the speed of convergence of different loading conditions. The main limitation of the Fast Newton-FGMRES method is the scale of the problem is very bad during the solution. The Scalable Newton-Krylov method is very fast which can solve the power flow problem in the 30s which is 120 times faster.

In an interconnected system, the power flow analysis can be done by the interconnection of sub-areas and its coordination. In this system ‘AGC’s maintain the power exchange between areas; the power flow solution can be improved by considering the multi area ‘AGC’s operation because it ignores the general power flow formations. However, to obtain the power flow solution total network split into sender and receiver areas and get the result by the asynchronous iterative method. A bus wise analysis based power flow is very useful for bus based voltage solution and transmission line branch wise power flow. The power balance equations of the power system model expressed in either polar form or Cartesian form. The bus wise power balance equations Jacobean matrix represents the healthy condition of the power system network and the positive sign of the voltage stability of the system under the loading conditions. Therefore, the bus wise NR method presents the Voltage Collapse Index (VCI) for every transmission line and represents the lines likely to effects. In the power flow studies, it is most essential to make sure that the operating condition of the current is the stability of voltage upon the contingencies. The margin of stability identified as two types, firstly, dynamic stability which is obtained by time domain simulation and secondly, steady state stability, which is obtained from load flow studies which are for a long time span. In this analysis, traditional NR solution fails to converge at a maximum load ability point and the solution does not converge for a small value of $j$. This issue can overcome by introducing new bus apart from three types of buses.

This paper uses the load flow tool based power flow analysis of the real time simulink model of IEEE 57 bus test case power system; it is one of the largest power system networks. A balanced three phase simulink model design as per the available test case data. The dynamic Simulink model consists of 57 buses, 7 thermal power stations, 63 pi model transmission lines, and 17 tap-setting transformers. After successful preparation of the Simulink model, the load flow tool block assigns to each bus. Power Flow analysis carries out on model to verify the magnitude of voltage, phase angle, Active power and reactive power injection at all the buses. The final results compared with the test case for assessing the improvement of results with the present model.

This paper organization for the coming topics as follows: Power system model, thermal generating station discussed in section II, Load flow methodology discussion in section III, Verification of numerical results and comparison with test case discussion in section IV, Paper Concluded in section V. A brief description of Future scope in section VI.

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II. Power Systems Structure

The Fig. 1 represents the proposed 57 bus test case power system network, it has transmission buses and distribution buses. The nominal voltage of transmission buses is a 138kv (line to line) which are from bus 1 to bus 17. Remaining all buses are distribution buses which have nominal voltage is 69kv (line to line). All the transmission lines modeled as three-phase pi model transmission lines, this system consists of 7 generating stations. In this paper, all the generating stations are replaced as Thermal generating stations, which consisting of IEEE type-1 excitation to control the voltage of the synchronous generator, the steam turbine, and governor system control the steam flow so that the system frequency maintain at the desired level. The block diagram of the generating station is shown in Fig. 2. The thermal energy systems are located at 1, 2, 3, 6, 8, 9 & 12 buses. However, out of all 57 buses, the 1st bus is considered as the Slack bus (Vδ), 2, 3, 6, 8, 9 & 12 as generator (PV) buses and remaining all are considered as load (PQ) buses. Each thermal generating system has a 13.8kv Synchronous generator of 3000Mva and a step up transformer to increase voltage to nominal voltage of the bus. However, there are 17 distribution transformers step down the voltage levels from the main bus to the distribution bus.

Fig. 1. Proposed IEEE 57 bus power system single line diagram
Fig. 2. Thermal power generating station with a steam turbine, Governor and IEEE Type 1 Excitation.

III. Power Flow Methodology

The matlabLoad Flow Tool simulates the system by using the Newton Raphson method algorithm and displays the solution of all the buses. The positive sequence power flow solution technique applied to the present model, which computes voltage (V), phase angle (δ), active power (P) and reactive power (Q) in positive sequence form [26]. The mathematical procedure involving positive sequence power flow is as follows:

Generally, the power flow solution starts from the steady state of the network and perform solution until a satisfactory solution obtained. In the three-phase power system network currents ($I^a b c$) and voltages ($V^a b c$) expressed as the symmetrical components by using the transformation’s matrix.

The symmetrical components transformation matrix ($T_s$) is,

$$[T_s] = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix}$$  \hspace{1cm} (1)

Where, $a = 1\angle 120$, $a^2 = 1\angle 240$ (2)

The symmetrical component form current ($I^{0 1 2}$) and voltage ($V^{0 1 2}$) are,

$$[I^{0 1 2}] = [T_s]^{-1}[I^a b c]$$  \hspace{1cm} (3)

$$[V^{0 1 2}] = [T_s]^{-1}[V^a b c]$$  \hspace{1cm} (4)
The complex power flow in the transmission line is,

\[ S^{a \ b \ c} = (p^{a \ b \ c} + jQ^{a \ b \ c}) \]  

(5)

The symmetrical component form of active \((P^{0 \ 1 \ 2})\) and reactive \((Q^{0 \ 1 \ 2})\) powers are,

\[ S^{0 \ 1 \ 2} = (P^{0 \ 1 \ 2} + jQ^{0 \ 1 \ 2}) = I^{0 \ 1 \ 2} * Y^{0 \ 1 \ 2} \]  

(6)

\[ [P^{0 \ 1 \ 2}] = [T_s]^{-1} [p^{a \ b \ c}] \]  

(7)

\[ [Q^{0 \ 1 \ 2}] = [T_s]^{-1} [Q^{a \ b \ c}] \]  

(8)

Symmetrical component admittances matrix \((Y_s^{0 \ 1 \ 2})\) of power system by using \(T_s\) admittance matrix \((Y_t^{a \ b \ c})\),

\[ [Y_s^{0 \ 1 \ 2}] = [T_s]^{-1} [Y_t^{a \ b \ c}] [T_s] \]  

(9)

\[ [Y_s^{0 \ 1 \ 2}] = \begin{bmatrix}
  y_{00} & \ldots & y_{0q} & y_{10} & \ldots & y_{1q} & y_{11} & y_{12} & \ldots & y_{1q} \\
  \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\
  y_{n1} & \ldots & y_{nq} & y_{10} & \ldots & y_{1q} & y_{11} & y_{12} & \ldots & y_{1q} \\
  \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\
  y_{10} & \ldots & y_{nq} & y_{n1} & \ldots & y_{nq} & y_{n1} & y_{n2} & \ldots & y_{nq} \\
  \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\
  y_{n1} & \ldots & y_{nq} & y_{n1} & \ldots & y_{nq} & y_{n1} & y_{n2} & \ldots & y_{nq} \\
  \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\
  y_{n1} & \ldots & y_{nq} & y_{n1} & \ldots & y_{nq} & y_{n1} & y_{n2} & \ldots & y_{nq} \\
\end{bmatrix} \]  

(10)

The nodal current equation in terms of sequence component form of ‘n’ bus power system network is,

\[ [I_0^{0 \ 1 \ 2}] = \sum_{j=1}^{n} [Y_j^{0 \ 1 \ 2}] * [Y_s^{0 \ 1 \ 2}] \]  

(11)

In Matrix form is,
From equation (6) & (11)

\[
(P_0^{12} - j Q_0^{12}) = [V_i^0] \sum_{j=1}^n [V_j^0] * [Y_j^0] + [V_i^1] \sum_{j=1}^n [V_j^1] * [Y_j^1] + [V_i^2] \sum_{j=1}^n [V_j^2] * [Y_j^2]
\]

Active power and reactive powers in sequence form

\[
P_i^{12} = Re \left( [V_i^0] \sum_{j=1}^n [V_j^0] * [Y_j^0] + [V_i^1] \sum_{j=1}^n [V_j^1] * [Y_j^1] + [V_i^2] \sum_{j=1}^n [V_j^2] * [Y_j^2] \right)
\]

\[
Q_i^{12} = Im \left( [V_i^0] \sum_{j=1}^n [V_j^0] * [Y_j^0] + [V_i^1] \sum_{j=1}^n [V_j^1] * [Y_j^1] + [V_i^2] \sum_{j=1}^n [V_j^2] * [Y_j^2] \right)
\]
The Objective of the solution is to find sequence voltages \( V_{12} \) so that the \( P_{12} = P_{12}^{0} \) and \( Q_{12} = Q_{12}^{0} \).

\[
\begin{align*}
\Delta P_{i}^{012} &= \begin{bmatrix} P_{st}^{012} \end{bmatrix} - \begin{bmatrix} P_{i}^{012} \end{bmatrix} \\
\Delta Q_{i}^{012} &= \begin{bmatrix} Q_{st}^{012} \end{bmatrix} - \begin{bmatrix} Q_{i}^{012} \end{bmatrix}
\end{align*}
\]

(16)

(17)

Where convergence factor \( \varepsilon \) is

\[
\varepsilon = 0.0001
\]

(18)

Therefore,

\[
\begin{align*}
\Delta P_{i}^{012} &\leq 0.0001 \\
\Delta Q_{i}^{012} &\leq 0.0001
\end{align*}
\]

(19)

IV. Results

The power flow solution successfully converged in 5 iterations for convergence factor of 0.0001. All the tabulated values expressed in p.u with base values of 138kV and 100Mva. The TABLE I show bus voltages with the corresponding phase angle and load connected at the bus. The voltage at each bus with all the loads is maintained to the nominal voltage. The leading phase angles show the additional reactive power capability of the bus. The TABLE II showing the powers injection at starting of line and powers living at the same transmission line. It also shows the active and reactive power losses in pi model lines. The graphs show the comparison of load flow results with respect to the test case load flow results. Therefore, the improvement of the voltage profile shown by Fig. 3; leading phase angle of bus shown in Fig. 4; sending side active powers and reactive powers of the line in Fig. 5; receiving side active power and reactive power of line in Fig. 6. All these comparisonsshow bus wise variations of voltage, phase angleand power injections of transmission lines in real time scenario.

(A) NUMERICAL RESULTS
TABLE I BUS VOLTAGE AND PHASE ANGLE

| Bus. No | Bus Voltage | Load | Bus. No | Bus Voltage | Load |
|---------|-------------|------|---------|-------------|------|
|         | Mag (pu)    | Ang (deg) | P (pu) | Q (pu) |         | Mag (pu) | Ang (deg) | P (pu) | Q (pu) |
| 1       | 1.13        | 24.90 | 0.55    | 0.17  | 30     | 1.03    | -15.66   | 0.04   | 0.02  |
| 2       | 1.13        | 18.60 | 0.03    | 0.88  | 31     | 1.01    | -15.82   | 0.06   | 0.03  |
| 3       | 1.12        | 0.75  | 0.41    | 0.21  | 32     | 1.01    | -13.82   | 0.02   | 0.01  |
| 4       | 1.10        | -4.51 | --      | --    | 33     | 1.01    | -13.89   | 0.04   | 0.02  |
| 5       | 1.11        | -11.80| 0.13    | 0.04  | 34     | 0.99    | -13.78   | --     | --    |
| 6       | 1.12        | -14.90| 0.75    | 0.02  | 35     | 1.00    | -13.14   | 0.06   | 0.03  |
| 7       | 1.05        | -18.27| --      | --    | 36     | 1.01    | -12.56   | --     | --    |
| 8       | 1.04        | -19.64| 1.50    | 0.22  | 37     | 1.02    | -11.86   | --     | --    |
| 9       | 1.03        | -17.85| 1.21    | 0.26  | 38     | 1.06    | -9.17    | 0.14   | 0.07  |
| 10      | 1.01        | -14.76| 0.05    | 0.02  | 39     | 1.01    | -12.20   | --     | --    |
| 11      | 1.00        | -13.78| --      | --    | 40     | 1.00    | -12.94   | 0.06   | 0.03  |
| 12      | 1.03        | -12.21| 3.77    | 0.24  | 41     | 1.05    | -13.81   | 0.06   | 0.03  |
| 13      | 1.00        | -9.51 | 0.18    | 0.02  | 42     | 1.04    | -13.97   | 0.07   | 0.04  |
| 14      | 0.99        | -6.09 | 0.11    | 0.05  | 43     | 1.04    | -13.80   | 0.02   | 0.01  |
| 15      | 1.03        | 0.39  | 0.22    | 0.05  | 44     | 1.06    | -6.41    | 0.12   | 0.02  |
| 16      | 1.00        | -2.62 | 0.43    | 0.03  | 45     | 1.08    | 0.08     | --     | --    |
| 17      | 1.03        | 10.44 | 0.42    | 0.08  | 46     | 1.10    | -6.30    | --     | --    |
| 18      | 1.14        | -4.62 | 0.27    | 0.10  | 47     | 1.08    | -8.31    | 0.30   | 0.12  |
| 19      | 1.06        | -8.11 | 0.03    | 0.01  | 48     | 1.08    | -8.71    | --     | --    |
| 20      | 1.01        | -9.80 | 0.02    | 0.01  | 49     | 1.10    | -9.67    | 0.18   | 0.09  |
| 21      | 1.06        | -9.81 | --      | --    | 50     | 1.09    | -12.25   | 0.21   | 0.11  |
| 22      | 1.06        | -9.82 | --      | --    | 51     | 1.09    | -14.76   | 0.18   | 0.05  |
| 23      | 1.05        | -10.16| 0.06    | 0.02  | 52     | 1.07    | -19.67   | 0.05   | 0.02  |
| 24      | 1.04        | -15.20| --      | --    | 53     | 1.06    | -20.15   | 0.20   | 0.10  |
| 25      | 1.04        | -15.24| 0.06    | 0.03  | 54     | 1.08    | -19.21   | 0.04   | 0.01  |
| 26      | 0.99        | -15.24| --      | --    | 55     | 1.10    | -17.91   | 0.07   | 0.03  |
| 27      | 1.05        | -17.79| 0.09    | 0.01  | 56     | 1.04    | -12.98   | 0.08   | 0.02  |
| 28      | 1.07        | -18.23| 0.05    | 0.02  | 57     | 1.03    | -12.25   | 0.07   | 0.02  |
| 29      | 1.09        | -18.38| 0.17    | 0.03  | TOTAL  | 10.5    | 2.52     |        |       |

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### TABLE II FROM BUS AND TO BUS POWER INJECTIONS OF TRANSMISSION LINES

| S.No | From Bus | To Bus | Flow P (pu) | Flow Q (pu) | Flow P (pu) | Flow Q (pu) |
|------|----------|--------|-------------|-------------|-------------|-------------|
| 1    | 1        | 2      | -0.26       | -0.12       | 4.76        | -1.02       |
| 2    | 2        | 3      | -0.30       | -0.17       | 4.51        | -0.30       |
| 3    | 3        | 4      | -0.07       | -0.32       | 3.09        | -0.07       |
| 4    | 4        | 5      | -0.26       | 0.36        | 1.12        | -0.26       |
| 5    | 5        | 6      | -0.35       | 0.57        | 1.43        | -0.35       |
| 6    | 6        | 7      | 0.54        | -0.49       | 0.82        | 0.54        |
| 7    | 7        | 8      | 0.33        | -0.30       | 0.65        | 0.33        |
| 8    | 8        | 9      | 0.36        | -0.35       | -0.58       | 0.36        |
| 9    | 9        | 10     | 0.17        | -0.19       | -0.29       | 0.17        |
| 10   | 10       | 11     | 0.58        | 0.73        | -0.72       | 0.58        |
| 11   | 11       | 12     | 0.33        | 0.12        | -0.33       | 0.33        |
| 12   | 12       | 13     | 0.49        | -0.39       | -0.82       | 0.49        |
| 13   | 13       | 14     | 0.29        | 0.38        | -1.26       | 0.39        |
| 14   | 14       | 15     | 2.05        | 0.07        | -1.96       | 0.26        |
| 15   | 15       | 16     | 1.27        | 0.59        | 5.56        | 0.98        |
| 16   | 16       | 17     | 2.40        | 0.54        | 2.71        | 0.60        |
| 17   | 17       | 18     | 0.66        | 0.04        | 2.86        | 0.66        |
| 18   | 18       | 19     | 0.18        | -1.67       | 0.59        | 1.80        |
| 19   | 19       | 20     | 0.23        | -0.23       | 0.44        | 0.23        |
| 20   | 20       | 21     | 0.23        | -0.23       | 0.44        | 0.23        |
| 21   | 21       | 22     | 0.44        | -0.44       | 0.95        | -0.40       |
| 22   | 22       | 23     | 0.04        | -0.05       | 0.38        | 0.04        |
| 23   | 23       | 24     | 0.01        | 0.01        | -0.37       | -0.02       |
| 24   | 24       | 25     | 0.01        | -0.01       | -0.93       | 0.34        |
| 25   | 25       | 26     | 0.75        | -0.28       | -0.64       | 0.34        |
| 26   | 26       | 27     | 0.66        | -0.71       | -1.88       | 0.94        |
| 27   | 27       | 28     | 0.19        | -0.12       | -2.04       | 0.94        |
| 28   | 28       | 29     | 0.25        | -0.12       | -2.11       | 0.94        |
| 29   | 29       | 30     | 0.13        | -0.09       | -1.93       | 0.34        |
| 30   | 30       | 31     | 0.10        | -0.09       | -0.64       | 0.34        |
| 31   | 31       | 32     | 0.10        | 0.04        | -1.88       | 0.94        |
| 32   | 32       | 33     | 0.04        | 0.04        | -2.04       | 0.94        |
| 33   | 33       | 34     | 0.01        | -0.01       | -2.11       | 0.94        |
| 34   | 34       | 35     | 0.13        | -0.09       | -1.93       | 0.34        |
| 35   | 35       | 36     | 0.10        | 0.04        | -1.88       | 0.94        |
| 36   | 36       | 37     | 0.10        | 0.04        | -2.04       | 0.94        |
| 37   | 37       | 38     | 0.10        | 0.04        | -2.11       | 0.94        |
| 38   | 38       | 39     | 0.10        | 0.04        | -1.93       | 0.34        |
| 39   | 39       | 40     | 0.10        | 0.04        | -1.88       | 0.94        |

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(B) COMPARISON WITH TEST CASE

![Simulink Voltage (VS) and Test case Voltage (VT) comparison](image1)

Fig. 3. Simulink Voltage (VS) and Test case Voltage (VT) comparison

![Simulink Voltage Angle (AS) and Test case Voltage Angle (VT) comparison](image2)

Fig. 4. Simulink Voltage Angle (AS) and Test case Voltage Angle (VT) comparison
V. Conclusion

In this paper load flow tool is used for the power flow analysis of three phase simulink model of IEEE 57 bus power system network. It is one of the easiest method, which allows easy computation of power flows and losses in any part of the network by placing the tool. If the solution does not satisfy, it allows easy modifications in the power system, so that the modifications can continue until the satisfactory results obtained.
VI. Future Scope

The present simulink model is very useful for various analyses and applications used in real time power systems. Reactive power compensation and power quality improvement can perform by using various FACTS devices such as STATCOM, SSSC, UPFC, IPFC, etc. Analysis of the power Oscillations and damping by applying various techniques to power System Stabilizers such as Fuzzy, ANFIS, ANN, etc. Apart from those, real time analysis of network with various grid connected renewable sources like solar power and wind power.

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