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Load Flow Analysis of EHV Networks using MiPower Software: A Case Study

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Abstract- **In power system number of small scale generations/renewable generations are increasing day by day due to its numerous advantages and various policies adopted by government. These generations are interconnecting to the existing power grid. Hence the load flow of the existing systems is changing due to addition of this generation. In this paper a case study is carried out for load flow analysis of existing power system where 13 MW generations is interconnected to power grid. In this paper the load flow analysis of EHV network is simulated by using MiPower software and analytical validation of simulation results are discussed.**

Keywords—Load flow, Newton Raphson Method, Fast Decoupled method, MiPower software, Small scale generations.

I. INTRODUCTION

Load flow studies are one of the most important aspects of power system planning and operation [1]. The load flow gives us the sinusoidal steady state of the entire system – voltages, real and reactive power generated and absorbed and line losses. The load flows between the lines are mainly depends on the magnitude of voltage and the power angle.

When the generations are attached to the existing system its load flow changes accordingly [2]. The objective of this paper is to simulate the load flows of existing system where 13 MW of generation is interconnected to power grid at 132kV level. The load flow studies are carried out by using MiPower software. The load flow is simulated by using fast decoupled method. The same system is validated by solving the load flow with analytical method and compared with the simulation results. The main objective of this paper is to analyze the load flow of existing system using MiPower software and to validate the simulation results analytically.

II. LITERATURE REVIEW

A. Issues and Challenges for interconnecting small scale generations to power grid

It is very important to properly integrate the small scale generation to the power grid as the small scale generations are intermittent in nature [3]. Particularly the challenges are for integrating PV, solar and for wind generation are more. Some of the challenges are as follows:

1. Power Quality
2. Power fluctuations
3. Storages
4. Protection Issues
5. Islanding

B. Load Flow

It is the important aspect of power system planning and operation [4]. The load flow provides the information regarding real power flow, reactive power flow, voltage magnitudes and its angle at different buses. It is very important to know the voltage magnitude and angles as it is required to keep in within limits for satisfactory performance. Once we find the voltage magnitude and its angle at each bus in steady state, we can find out real and reactive power flows between each bus. This power flow is important to know the over-loadings of lines. From the power flow we can find out the losses between the each bus. These values are required to keep the losses within acceptable limit [5]. The common methods to find out the load flow are as follows:

1. Gauss-Seildel method
2. Newton Raphson method
3. Fast decoupled method

For load flow studies it is assumed that the loads are constant and they are defined by their real and reactive power consumption. It is further assumed that the generator terminal voltages are tightly regulated and therefore are constant. The main objective of the load flow is to find the voltage magnitude of each bus and its angle when the powers generated and loads are pre-specified. To facilitate this we classify the different buses of the power system as listed below.

1. *Load Buses*: In these buses no generators are connected and hence the generated real power P_G and reactive power Q_G are taken as zero. The load drawn by these buses are defined by real power $-P_L$ and reactive power $-Q_L$ in which the negative sign accommodates for the power flowing out of the bus. This is why these buses are sometimes referred to as P-Q bus. The objective of the load flow is to find the bus voltage magnitude $|V_i|$ and its angle δ_i.

2. *Voltage Controlled Buses*: These are the buses where generators are connected. Therefore the power generation in such buses is controlled through a prime mover while the terminal voltage is controlled through the generator excitation. Keeping the input power constant through turbine-governor control and keeping the bus voltage constant using automatic voltage regulator, we can specify constant P_G and $|V_i|$ for these buses. This is why such buses are also referred to as P-V buses. It is to be noted that the reactive power supplied by the generator Q_G depends on the system configuration and cannot be specified in advance. Furthermore we have to find the unknown angle δ_i of the bus voltage.

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3. *Slack or Swing Bus*: Usually this bus is numbered 1 for the load flow studies. This bus sets the angular reference for all the other buses. Since it is the angle difference between two voltage sources that dictates the real and reactive power flow between them, the particular angle of the slack bus is not important. However it sets the reference against which angles of all the other bus voltages are measured. For this reason the angle of this bus is usually chosen as 0°. Furthermore it is assumed that the magnitude of the voltage of this bus is known.

In this paper we have carried out simulation by using fast decoupled method only.

1. Fast Decoupled method

Generally the power system have very high X/R ratio [5]. Hence the real power changes are less sensitive to change in voltage magnitude |*V*| but it is more sensitive for changes in phase angle δ. Whereas the reactive power are more sensitive to changes in voltage magnitude and less sensitive for change in phase angle δ. Therefore it is reasonable to set J2 and J3 of Jacobian matrix to zero. Hence the equation for ΔP and ΔQ becomes:

$$\begin{vmatrix} \Delta P \\ \Delta Q \end{vmatrix} = \begin{vmatrix} J_1 & 0 \\ 0 & J_4 \end{vmatrix} \begin{vmatrix} \Delta\delta \\ \Delta|V| \end{vmatrix} \qquad (1)$$

By solving this we get two decoupled equations which require less time to solve as compared with N-R method.

Hence finally after solving the above equations we get,

$$\Delta\delta = -|B'|^{-1} \frac{\Delta P}{|V|} \qquad (2)$$

$$\Delta|V| = -|B''|^{-1} \frac{\Delta Q}{|V|} \qquad (3)$$

Here B′ and B″ are the bus susceptance matrixes *i.e.* it is imaginary part of admittance matrix Y_{bus}. The bus susceptance matrix is constant and required to evaluate only once at beginning of the iterations. B′ is the order of (n-1). For voltage regulated buses the Q_i are not specified and hence the corresponding rows and columns of the Y_{bus} matrix are eliminated, hence we get B″ matrix of the order of (n-1-m) where 'n' is the total number of buses and 'm' is the number of voltage controlled buses.

The fast decoupled method requires more iteration than N-R method, but the time required is considerably less and we get rapidly the power flow solutions.

III. SYSTEM UNDER STUDY

Figure 1 shows the single line diagram of the system under study. A 220 kV substation is considered. A 220 kV bus is connected to EHV grid. A two 220/132 kV 100 MVA transformers are connected between 220 kV and 132 kV bus. At 132 kV bus, loads are connected through different 132 kV lines, which are not shown in diagram. A small scale generation of about 13 MW at 11 kV voltage level is considered. The 11 kV voltage level is converted to 132 kV level by using 11/132 kV, 25 MVA power transformer. At 11 kV voltage level the load of 4 MW are considered for auxiliaries of small scale generation. The buses named as:

Bus number 1: 220 kV Bus (connected to power grid) taken as slack bus.

Bus number 2: 132 kV Bus is Load (P-Q) bus.

Bus number 4: 11 kV Bus is Voltage controlled (P-V) bus.

The load flow is carried out by using MiPower software with fast decoupled method.

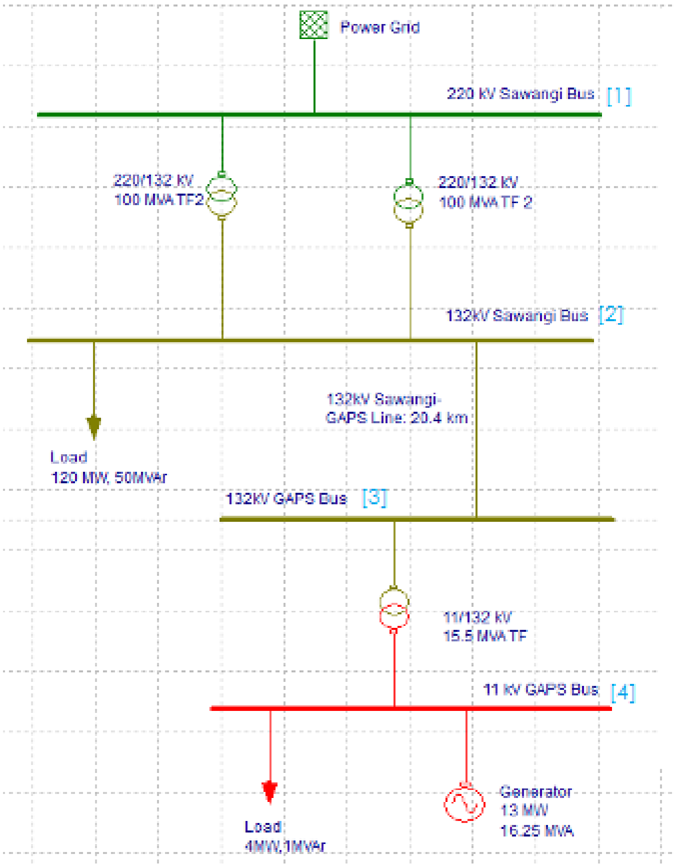

Figure 1: Single Line Diagram

The realistic data is considered for the simulation using fast decoupled method and then the simulation results are evaluated analytically.

1. System Data

The realistic system data are considered.

TRANSFORMER DATA

Transformer Numbers:

1. 220/132 kV 100 MVA
   Impedance: (0.00501+j0.10028) ohm
2. 220/132 kV 100 MVA
   Impedance: (0.00501+j0.10028) ohm
3. 11/132 kV 15.5 MVA
   Impedance: (0.01898+j0.37953)

TRANSMISSION LINE DATA

Line 1: 132kV GAPS Bus to 132 kV Sawangi Bus
Impedance: 0.01899+j0.4521
Km: 20.40

GENERATOR DATA

1. At 220 kV Sawangi Bus connected to Power grid.
2. At 11 kV GAPS Bus 13 MW, 11 kV Generator is connected.

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3. LOAD DATA

132 kV Sawangi Bus: 120 MW, 50 MVAr.

11kV GAPS Bus: 4 MW, 1 MVAR for station auxiliaries and lighting load.

IV. RESULTS

The load flow is simulated by using MiPower software and simulation results are validated analytically.

The summary of result obtained by MiPower software is as follows-

A. *Load Flow simulation by Fast Decoupled method*

The system is simulated in MiPower software by using Fast decoupled method. In Fast decoupled method the bus susceptance matrix are evaluated from Y_{bus} and the simulation is carried out.

In the system under study, the load flow solution converges into 5 iterations. The iterations required are normally more than Newton Raphson method but the calculation for fast and decoupled method is more easier than Newton-Raphson method as only bus susceptance matrix is evaluated only once at first iteration whereas for Newton Raphson method the Jacobian matrix are required for every iteration and becomes complicated to calculate.

The simulation result by using MiPower software is obtained as below-

1. BUS VOLTAGES AND POWERS

Node	V-Mag	Ang. In Degrees	MW	MVAr	Remarks
1 (220kV Sawangi)	1.0	0.00	111.443	52.271	Gen
2 (132 kV Sawangi)	0.9237	-3.56	120	50.00	Load
3 (132 kV GAPS)	0.9283	-3.36	0.00	0.00	-
4 (11 kV GAPS)	1.0	-1.21	13.00 4	6.749 1	Gen Load

2. TRANSFORMER FLOWS AND TRANSFORMER LOSSES

Sr.	FROM-TO (Node)	Forward Power		Loss		% Loading
		MW	MVAr	MW	MVAr	
1	1-2	55.72	26.13	0.20	4.18	61.5
2	1-2	55.72	26.13	0.20	4.18	61.5
3	4-3	8.998	5.749	0.02	0.47	68.9

3. LINE FLOWS AND LINE LOSSES

Sr.	Node	Forward Power		Loss		% Loading
		MW	MVAr	MW	MVAr	
1	132 kV Sawangi to 132 kV GAPS Bus	-8.967	-6.104	0.0250	-0.832	13.0

The summary result diagram is as shown in figure 2.

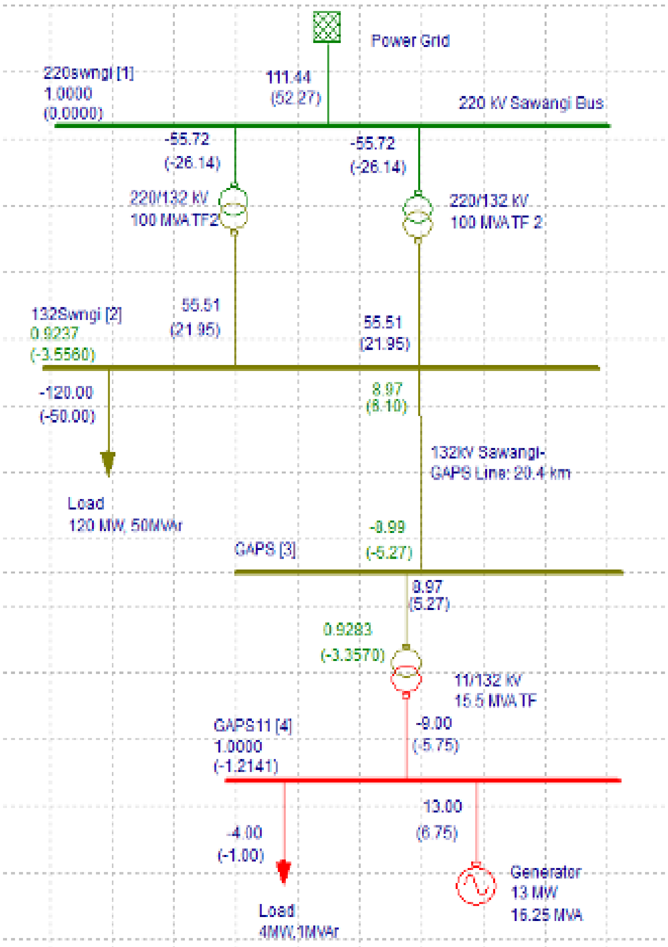

Figure 2: Summary result diagram of FD Load Flow

B. *Analytical solution by Fast Decoupled Method*

The same system is solved analytically by fast decoupled method. The analytical solution is as below-

From the given impedances of lines, transformers and generators the Y_{bus} is formed.

$$Ybus = \begin{bmatrix} 0.9023 - j18.04 & -0.95 + j18.948 & 0 & 0 \\ -0.95 + j18.948 & 8.894 - j38.69 & -7.89 + j18.80 & 0 \\ 0 & -7.89 + j18.80 & 8.95 - j40.01 & -1.028 + j20.57 \\ 0 & 0 & -1.0286 + j20.5711 & 0.9974 - j19.94 \end{bmatrix}$$

In our system bus 1 is considered as Slack bus. Hence the corresponding row and column of Y_{bus} is neglected. Therefore for B′ matrix taking only imaginary values of Y_{bus}, we get Bus susceptance matrix as

$$B' = \begin{vmatrix} -38.69 & 18.80 & 0 \\ 18.80 & -21.42 & 2.50 \\ 0 & 2.50 & -2.38 \end{vmatrix}$$

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The inverse of the above matrix is

$$[B']^{-1} = \begin{vmatrix} -0.0502 & -0.0503 & -0.0528 \\ -0.0503 & -0.103 & -0.1086 \\ -0.0528 & -0.108 & -0.5336 \end{vmatrix}$$

From the expression of real power given, at bus 2 to 4 and reactive power, at bus 3 and 4 are calculated.

$$P_i = \sum_{j=1}^{n} |Yij|\ |Vi|\ |Vj| \cos(\theta_{ij} - \delta_i + \delta_j) \qquad (4)$$

$$Q_i = -\sum_{j=1}^{n} |Yij|\ |Vi|\ |Vj| \sin(\theta_{ij} + \delta_j - \delta_i) \qquad (5)$$

The load and generation expressed in pu are

$$S_{2(sch)} = \frac{120+j50}{100} = 1.2+j0.5 \text{ pu}$$

$$S_{4(sch)} \text{ Load} = \frac{4+j1}{100} = 0.04+j0.01 \text{ pu}$$

$$S_{4(sch)} \text{ Generation} = \frac{13}{100} = 0.13 \text{ pu}$$

Hence, $S_{4(sch)}=0.13-0.04-j0.01=0.09+j0.01$

The slack bus voltage is $V_1 = 1\angle 0°$ and magnitude of voltage of bus 4 is 1 pu. Starting with initial estimates of $|V2°|=0$ pu and $\delta2°=0$, $\delta3°=0$, the power residuals computed as

$\Delta P_i^{(0)} = P_{i(sch)} - P_i^{(0)}$

$\Delta Q_i^{(0)} = Q_{i(sch)} - Q_i^{(0)}$

Hence the power flow algorithm given by equation 2 becomes as-

$$\begin{vmatrix} \Delta\delta 2° \\ \Delta\delta 3° \\ \Delta\delta 4° \end{vmatrix} = -[B']^{-1} \begin{vmatrix} \frac{\Delta P_2}{|V_2|} \\ \frac{\Delta P_3}{|V_3|} \\ \frac{\Delta P_4}{|V_4|} \end{vmatrix}$$

By solving this eq. we get the voltage phase angles.

Since bus 4 is Voltage controlled bus, the corresponding row and column of B' bus susceptance matrix are eliminated, then we get

$$[B''] = \begin{vmatrix} -38.69 & 18.80 \\ 18.80 & -21.42 \end{vmatrix}$$

The inverse of above matrix is

$$[B'']^{-1} = \begin{vmatrix} -0.0450 & -0.0395 \\ -0.0395 & -0.0813 \end{vmatrix}$$

Hence from equation 3, we get,

$$\begin{vmatrix} \Delta V_2^{(0)} \\ \Delta V_3^{(0)} \end{vmatrix} = -[B'']^{-1} \begin{vmatrix} \frac{\Delta Q_2}{|V_2|} \\ \frac{\Delta Q_3}{|V_3|} \end{vmatrix}$$

By solving this equation we get the phase voltage for first iteration.

The process is continued until the power residuals are within a specified accuracy.

The final results are as below:

1. BUS VOLTAGES AND POWERS

Node	V-Mag	Ang. In Degrees	MW	MVAr	Remarks
1 (220kV Sawangi)	1.0	0.00	110.24	51.2	Gen
2 (132 kV Sawangi)	0.922	-3.26	120.00	50.00	Load
3 (132 kV GAPS)	0.928	-2.69	0	0	-
4 (11 kV GAPS)	1.0	2.34	13 4	5.9 1	Gen Load

2. TRANSFORMER FLOWS AND TRANSFORMER LOSSES

Sr. N.	FROM-TO (Node)	Forward Power		Loss		% Loading
		MW	MVAr	MW	MVAr	
1	1-2	54.12	27.20	0.25	5.18	61
2	1-2	54.12	27.20	0.25	5.18	61
3	4-3	10.01	6.749	0.42	0.87	69

3. LINE FLOWS AND LINE LOSSES

Sr .N.	Node	Forward Power		Loss		% Loading
		MW	MVAr	MW	MVAr	
1	132 kV Sawangi to 132 kV GAPS Bus	-16.51	-9.80	0.0807	-0.707	24

V. CONCLUSION

In this paper the case study is carried out by using MiPower software. Then the simulation results are validated analytically.

The fast decoupled method is more superior to N-R method for the system having high X/R ratio. The number of iteration required is more for fast decoupled method but the calculations are easier than NR method.

After comparing the results obtained from MiPower software with analytical solution, it is found that the results are nearly equal. There is having little difference in the load flow values which may be due to decimal values used in software. Also the MiPower software adjusts the Y bus matrix for calculation purposes as it is the part of the software.

It will help system operator for forecasting of load flow data in the EHV networks.

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