ISSN: 2278-4632
Vol-11 Issue-01 March 2021

Accurate Modeling of Induction Motor Loads in a Distribution Network's Load Flow Analysis

PRADIP KUMAR SAHOO[1]

Assistant professor Department of Electrical Engineering, Raajdhani Engineering college, Bhubaneswar, India

***Abstract*— The purpose of the research is to do a load flow analysis of a distribution network in the scenario where induction motor loads predominate. An induction motor's load representation on the distribution network is created for a specific operating situation by examining its precise comparable circuit. As a voltage and frequency dependent load, the induction motor is thereby accurately represented. An extensive case study serves as proof that an induction motor must be represented using a precise load model. By conducting the load flow analysis over a complicated distribution network with multiple loops and distributed generations, the convergence of the load flow solution with the accurate modelling of induction motor loads is ensured.**

***Index Terms*—Distribution network, induction motor, ZIP load, distributed generation.**

I. Introduction

The development of microgrids and the introduction of demand side management programmes have recently drawn more attention to the classic subject of HE distribution system load flow analysis. A distribution network, in contrast to a transmission network, is a low voltage system with a very high R/X ratio. As a result, in order to analyse the load flow of a distribution network and carefully consider bus voltage magnitude fluctuations, specialist methodologies are required. Traditional distribution networks lack any inherent energy sources, making them passive. In [1]–[8], methods for the load flow analysis of a passive distribution network are described. However, distribution systems are now coming out with embedded energy due to the increased interest in renewable energy sources earning the status of the active distribution network. There are also a few techniques that are reported in literature for the load flow analysis of an active distribution network [9]-[12].

Constant impedance, constant current, and constant power (sometimes known as ZIP) loads are the usual load models used in the load flow analysis of a distribution network [13]. In the load flow analysis, an induction motor is typically treated as a constant power load [14]. The specific approach can function effectively even in the absence of significant induction motor demands. However, in the case of an active distribution network or microgrid, the picture may be very different. For example, there can be large number of induction motor loads over the microgrid established for an industrial park. When induction motor loads predominate, the load flow solution may be insufficiently accurate if induction motor loads are modelled as constant power loads. This, in turn, may result in inaccurate operational decisions.

The exact modelling of induction motor loads in the distribution system power flow analysis is addressed in this work with the goal of increasing the accuracy of the load flow solution. The load torque applied to an induction motor can be used to represent a certain operating situation. The induction motor's power consumption is then calculated as a function of the terminal voltage and system frequency. As a voltage and frequency dependent load, an induction motor may therefore be exactly modelled. Any of the various load flow analysis techniques can easily fit the closed form of the expression produced for the power drawn by an induction motor. The load flow analysis is carried out for an active distribution network by considering different modes of the generator operation with and without system frequency variation.

The remainder of the essay is structured as follows. The general processes involved in the load flow studies of various power distribution systems are summarised in Section II. In Section III, the proposed induction motor load modelling for the load flow analysis is covered. In Section IV, a case study that was conducted to demonstrate the usefulness of the suggested work is described. Section V serves as the paper's conclusion.

II. General Framework for the Load Flow Analysis of a Distribution Network

A passive distribution network's load flow analysis is simply based on updating the load currents iteratively to account for each load element's unique voltage dependence. The load flow analysis of a distribution network is performed using one of two fundamental methodologies that are described in the literature. The first one is the Gauss Zbus method, which updates the load currents at each node simultaneously throughout each load flow cycle. The second method is called the ladder iterative methodology [15], and it involves tracing the nodes from the leaves to the root in order to update the load currents in a sequential manner. However, a poorly meshed system cannot instantly use the ladder iterative method. Consequently, a higher level of iteration is necessary to convert the original meshed

ISSN: 2278-4632
Vol-11 Issue-01 March 2021

network into a radial network by replacing a link in the form of loads on the terminal buses [16]. For an active distribution network, two different modes of operation of the embedded generators can be considered. In one case, a generator is controlled to deliver only a fixed amount of active power at a fixed terminal voltage. This can be referred to as the P-V mode of operation. The load flow analysis for such an active distribution network can be carried out by running an outer loop of iteration for converting the P-V buses either into P-Q buses [17] or into V-□ buses [18]. For the latter approach, Gauss □□□□ technique can be used for updating load currents in the inner loop of iteration.

In the case of an islanded microgrid, it is common to operate generating sources in the drooping mode. In the case of the drooping mode of operation, the active power produced by a generator is linked to the system frequency and the reactive power produced is linked to the terminal voltage magnitude. The drooping mode of operation is defined with respect to a reference set of frequency, voltage magnitude, active power and reactive power. The deviation in the active power output is maintained proportional to the frequency deviation, whereas, the deviation in the reactive power output is maintained are measured with respect to the reference quantities. Similar to how a voltage-dependent load is handled, a generator's reactive power adjustment can also be handled in this manner. However, updating the system frequency and the generator's active power output necessitates an outer loop of iteration [19]. On the reactance of the distribution line, the impact of frequency change is thought to be minimal. The active power output of the generator is handled in the inner loop of iteration in the same way that a continuous power load is handled. Any frequency-dependent loads must have their power level adjusted in the outer loop of the iteration if they are present. The frequency update in the outer loop of iteration is carried out based upon the slack bus power requirement calculated in the inner loop. The outer loop of iteration is aborted after making the slack bus power requirement zero.

It should be noted that even while a generator may genuinely operate in the drooping mode, the power scheduling process often assumes the P-V mode of operation. In the event that the system loads are perfectly maintained at projected levels, the reference values are then set in a manner that meet with the load flow results corresponding to the drooping mode of operation. To discover the new system state after a sudden change in load, generation, or network topology in real-time, the load flow analysis with consideration of generator droop characteristics is specifically needed.

III. Induction Motor Load Modeling

The equivalent circuit of induction motor [20] is shown in Figure 1. By representing the induction motor equivalent circuit in Thevenin's form as in Figure 2, the torque equation

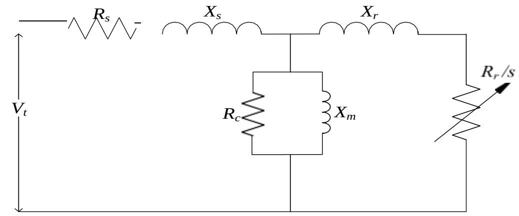


Fig. 1. Equivalent circuit of induction motor

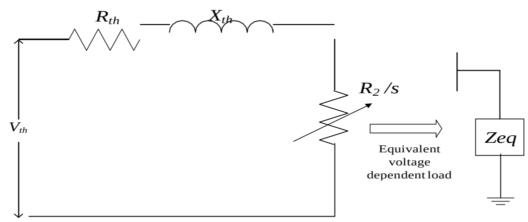


Fig. 2. Thevenin's representation of the equivalent circuit

can be derived as follows.

Here, indicates the number of poles in induction motor and is grid frequency in radian per second.

As mentioned previously, the operating condition of an induction motor is specified by the load torque applied on it. For particular values of grid frequency and the motor terminal voltage, the induction motor slip can be determined by solving the following quadratic equation.

There, exist two solution of the slip, out of which, the smallest positive value is to be considered.

After calculating the slip, the equivalent impedance of the induction motor can be derived, from which, the current drawn by the induction motor for the given grid frequency and terminal voltage can be easily determined. Therefore, the steps to include induction motor loads in the load flow analysis appear as follows.

Step1: For the presently calculated grid frequency and bus voltage, determine the induction motor slip by solving the above mention quadratic equation.

Step2: After calculating the slip, calculate the induction motor equivalent impedance.

Step3: Determine the current drawn by the induction motor and add it to the net nodal load current.

ISSN: 2278-4632
Vol-11 Issue-01 March 2021

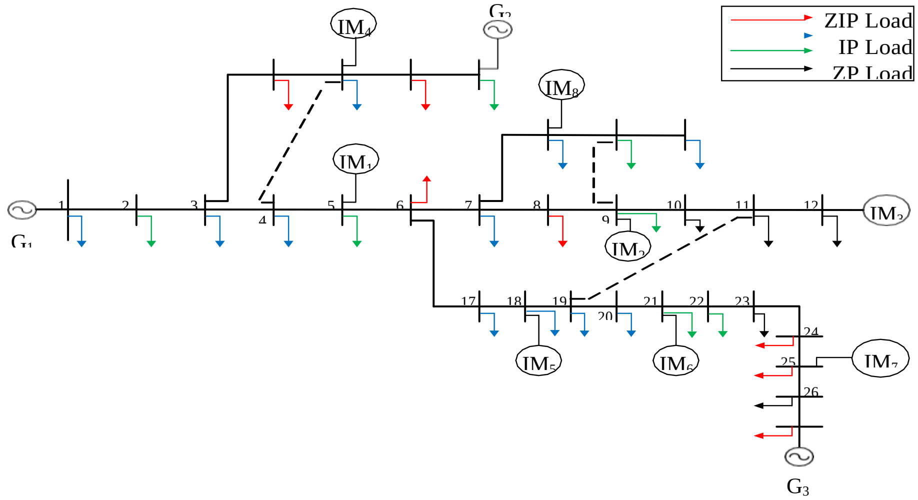


Fig. 3. 30 bus weakly meshed distribution system with induction motor and generator

IV. Case Study

The specific case study is carried out to demonstrate the necessity of accurate induction motor modelling in the load flow analysis of the distribution system. For the case study, a 30-bus distribution network is taken into consideration, as seen in Figure 3. Tables I, II, and III, respectively, present the line, load, and generator statistics for the specific system. Table IV lists the induction motor parameters. For all induction motors, the stator and rotor parameters are assumed to be the same.

Investigated in particular is the inaccuracy in load flow results brought about by the induction motor's traditional portrayal as a constant power load. Both the P-V and drooping modes of generator operation yield results. Table III lists the control parameters for several generators that correspond to the drooping mode of operation. No further shunt compensation is taken into account for the current investigation. The slack bus is assumed to be Bus 1. Figures 4 and 5 compare the outcomes of induction motor load models that are traditional and accurate for the P-V mode of generator operation.

It is clear from Figure 4 that the voltage magnitudes predicted by the constant power model of the induction model for Buses 9, 10, 11, 12, 28, 29 and 30 greatly deviate from the observed values. Such an error in the load flow calculation could have the practical result of causing voltage collapse at some buses because of insufficiently arranging the reactive power compensation. Results corresponding to the droop controlled generator operation are produced in Figures 6 and 7.

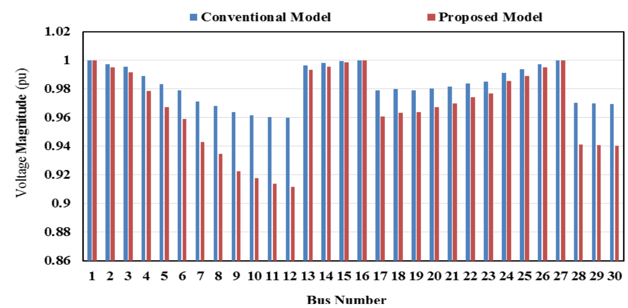


Fig. 4. Bus voltage magnitudes for the P-V controlled generator operation.

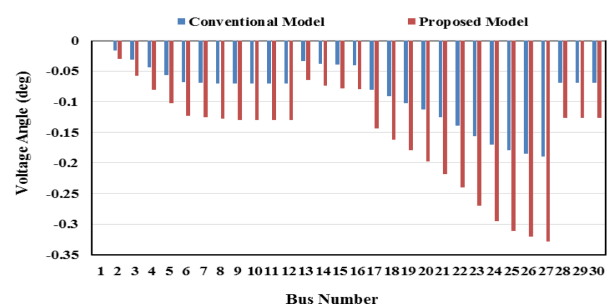


Fig. 5. Bus voltage angles for the P-V controlled generator operation.

The error introduced in the load flow calculation because of the constant power modelling of induction motor is more prominent in the case of droop controlled generator operation.

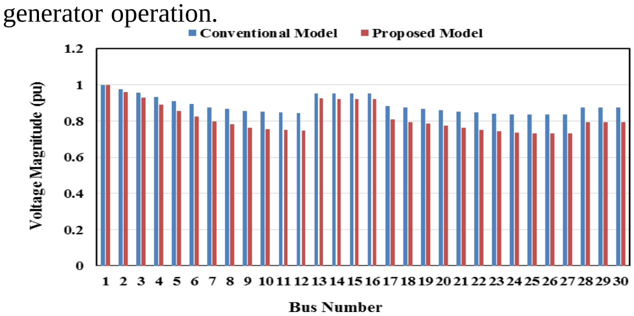
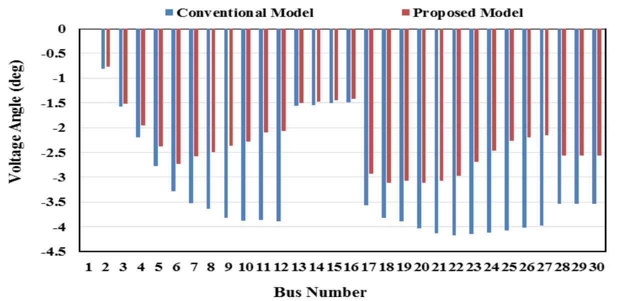


Fig. 6. Bus voltage magnitudes for the droop controlled generator

ISSN: 2278-4632
Vol-11 Issue-01 March 2021



operation.

Fig. 7. Bus voltage angles for the droop controlled generator operation.

The stability of a microgrid powered by renewable energy sources is also seriously threatened by the incorrect estimation of bus voltage magnitudes and angles. A system level study, in which the system dynamics are first to be linearized around the equilibrium that is determined from a load flow analysis, is required to tune certain controller parameters. As a result, the calculation of the load flow is inaccurate, which leads to inaccurate determination of the system equilibrium. In turn, this leads to improper parameter tuning, which ultimately worsens the stability of the system.

V. CONCLUSION

The study presents a step-by-step technique for the load flow analysis of an induction motor load distribution network. An induction motor is accurately modelled as a voltage dependent load, in contrast to the traditional constant power model. At each iteration of the load flow computation, straightforward procedures are devised for figuring out the induction motor current. The active distribution network is the focus of particular attention. Both the P-V and drooping modes of generator functioning are the subject of studies. It is also acknowledged that the loads on induction motors vary with frequency. Converged load flow solutions are always produced, despite the induction motor modeling's increased complexity when applied to an active distribution network. The case studies show that the load flow may contain major inaccuracies results in the case induction motors are represented as constant power loads.

TABLE I SYSTEM LINE DATA

Branch number	From bus	To bus	Resistance (pu)	Reactance (pu)
1	1	2	0.0967	0.0397
2	2	3	0.0886	0.0364
3	3	4	0.1359	0.0377
4	4	5	0.1236	0.0343
5	5	6	0.1236	0.0343
6	6	7	0.2598	0.0446
7	7	8	0.1732	0.0298
8	8	9	0.2598	0.0446
9	9	10	0.1932	0.0298
10	10	11	0.2083	0.0186
11	11	12	0.0866	0.0149
12	3	13	0.1299	0.0223
13	13	14	0.1732	0.0298
14	14	15	0.0866	0.0149
15	15	16	0.0433	0.0074
16	6	17	0.1483	0.0412
17	17	18	0.1359	0.0377
18	18	19	0.1718	0.0291
19	19	20	0.1562	0.0355
20	20	21	0.1962	0.0355
21	21	22	0.2165	0.0372
22	22	23	0.3165	0.0372
23	23	24	0.2598	0.0446
24	24	25	0.1732	0.0198
25	25	26	0.1083	0.0186
26	26	27	0.0866	0.0149
27	7	28	0.1299	0.0223
28	28	29	0.2299	0.0223
29	29	30	0.1299	0.0273
30	4	14	0.1732	0.0298
31	9	29	0.0866	0.0149
32	11	19	0.0433	0.0074

TABLE II SYSTEM NOMINAL LOAD DATA

	Constant power load		Constant current load		Constant impedance load		Induction motor load	
Bus No	Active power (pu)	Reactive power (pu)	Active power (pu)	Reactive power (pu)	Active power (pu)	Reactive power (pu)	Active power (pu)	Reactive power (pu)
1	0.00367	0.00191	0.00044	0.00022	0	0	0	0
2	0.00307	0.00148	0	0	0.00083	0.00041	0	0
3	0.00368	0.00195	0.00014	0.00012	0	0	0	0
4	0.00268	0.00191	0.00027	0.00019	0	0	0	0
5	0.00469	0.00231	0	0	0.00015	5.23E-05	0.01491	0.00404
6	0.00368	0.00191	0.00064	0.00022	0.00037	0.00019	0	0
7	0.00368	0.00191	0.00094	0.00032	0	0	0	0
8	0.00268	0.00191	0.00043	0.00032	0.00063	0.00022	0	0
9	0.00468	0.00191	0	0	0.00025	0.00012	0.01491	0.00404
10	0.00368	0.00291	0	0	0	0	0	0
11	0.00307	0.00158	0	0	0	0	0	0
12	0.00261	0.00132	0	0	0	0	0.01491	0.00404
13	0.00158	0.00082	0.00016	8.24712E-05	0.00042	1.82E-05	0	0
14	0.00468	0.00191	0.00047	0.00019	0	0	0.01491	0.00404
15	0.00368	0.00291	0.00037	0.00029	0.00094	0.00033	0	0

16	0.00054	0.00033	0	0	5.40E-05	3.29E-05	0	0
17	0.00368	0.00191	0.00084	0.00022	0	0	0	0
18	0.00568	0.00191	0.00016	1.91379E-05	0	0	0.00746	0.00202
19	0.00368	0.00191	0.00037	0.00019	0	0	0	0
20	0.00368	0.00151	0.00037	0.00015	0	0	0	0
21	0.00768	0.00191	0	0	0.00028	0.00012	0.004028	0.00109
22	0.00368	0.00191	0	0	3.68E-05	1.91E-05	0	0
23	0.01268	0.00191	0	0	0	0	0	0
24	0.00368	0.00191	0.00014	2.19138E-05	0.00054	0.00022	0	0
25	0.00054	0.00033	6.53998E-05	3.32874E-05	5.40E-05	3.29E-05	0.01491	0.00404
26	0.00368	0.00191	0	0	0	0	0	0
27	0.00568	0.00191	0.00057	0.00019	0.00016	0.00012	0	0
28	0.00158	0.00082	0.00012	5.82471E-06	0	0	0.00746	0.00202
29	0.00368	0.00158	0	0	0.00031	0.00016	0	0
30	0.00158	0.00082	0.00016	8.24712E-05	0	0	0	0

TABLE III GENERATOR DATA

Bus no.	PV mode of operation		Droop mode of operation		
	Active power output (pu)	Terminal voltage (pu)	Active power output (pu)	Voltage droop coefficient (pu)	frequency droop coefficient (pu)
1	-	1	0.1	0.05	0.05
16	0.1	1	0.1	0.1	0.1
27	0.1	1	0.1	0.2	0.2

TABLE IV INDUCTION MOTOR DATA

Machine parameters	Values (pu)
Rs	0.031
Xs	0.1
Xm	3.2
Rr	0.018
Xr	0.18
T	1

REFERENCES

[1] J. H. Teng, “A direct approach for distribution system load flow solutions,” *IEEE Trans. Power Del.*, vol. 18, no. 3, pp. 882-887, Jul. 2003.
[2] G. W. Chang, S. Y. Chu, and H. L. Wang, “An improved backward/forward sweep load flow algorithm for radial distribution systems,” *IEEE Trans. Power Syst.*, vol. 22, no. 2, pp. 882-884, May 2007.
[3] A. Losi and M. Russo, “Object-oriented load flow for radial and weakly meshed distribution networks,” *IEEE Trans. Power Syst.*, vol. 18, no. 4, pp. 1265-1274, Nov. 2003.
[4] W. W. Price, K. A. Wirgau, A. Murdoch, J. V. Mitsche, E. Vaahedi, and
M. A. El-Kady, “Load modeling for power flow and transient stability computer studies,” *IEEE Trans. Power Syst.*, vol. 3, no. 1, pp. 180-187, Feb. 1988.
[5] Y. Ju, W. Wu, B. Zhang, and H. Su, “Loop-analysis-based continuation power flow algorithm for distribution networks,” *IET Gener., Transm., Distrib.*, vol. 8, no. 7, pp. 1284-1292, Jul. 2014.
[6] W. C. Wu and B. M. Zhang, “A three-phase power flow algorithm for distribution system power flow based on loop-analysis method,” *Int. J. Electr. Power Energy Syst.*, vol. 30, no. 1, pp. 8-15, Jan. 2008.
[7] D. Rajicic, R. Ackovski, and R. Taleski, “Voltage correction power flow,”
IEEE Trans. Power Del., vol. 9, no. 2, pp. 1056-1062, Apr. 1994.
[8] D. Das, D. P. Kothari, and A. Kalam, “Simple and efficient method for load flow solution of radial distribution networks,” *Int. J. Electr. Power Energy Syst.*, vol. 17, no. 5, pp. 335-346, Oct. 1995.
[9] A. Augugliaro, L. Dusonchet, S. Favuzza, M. G. Ippolito, and E. R. Sanseverino, “A new backward/forward method for solving radial distribution networks with PV nodes,” *Elect. Power Syst. Res.*, vol. 78, no. 3, pp. 330-336, Mar. 2008.
[10] H. Sun, D. Nikovski, T. Ohno, T. Takano, and Y. Kojima, “A fast and robust load flow method for distribution systems with distributed generations,” in *Proc. Smart Grid and Clean Energy Technol.*, vol. 12, no. 4, pp. 236-244, Dec. 15, 2011.
[11] C. S. Cheng and D. Shlrmohammadi, “A three-phase power flow method for real-time distribution system analysis,” *IEEE Trans. Power Syst.*, vol. 10, no. 2, pp. 671-679, May 1995.
[12] S. Khushalani, J. M. Solanki, and N. N. Schulz, “Development of three- phase unbalanced power flow using PV and PQ models for distributed generation and study of the impact of DG models,” *IEEE Trans. Power Syst.*, vol. 22, no. 3, pp. 1019-1025, Aug. 2007.
[13] U. Eminoglu and M. H. Hocaoglu, “A new power flow method for radial distribution systems including voltage dependent load models,” *Elect. Power Syst. Res.*, vol. 76, no. 1-3, pp. 106-114, Sep. 2005.
[14] Y. H. Liu, W. J. Lee, and M. S. Chen, “Incorporating induction motor model in a load flow program for power system voltage stability study,” in *Proc. IEEE Int. Conf. Elect. Mach. and Drives*, vol. 3, pp. 7.1-7.3, May 1997.
[15] W. H. Kersting, “A method to teach the design and operation of a distribution system,” *IEEE Trans. Power App. Syst.* vol. 103, no. 7, pp. 1945-1952, Jul. 1984.
[16] D. Shirmohammadi, H. W. Hong, A. Semlyen, and G. X. Luo, “A compensation-based power flow method for weakly meshed distribution and transmission networks,” *IEEE Trans. Power Syst.*, vol. 3, no. 2, pp. 753-762, May 1988.
[17] G. X. Luo and A. Semlyen, “Efficient load flow for large weakly meshed networks,” *IEEE Trans. Power Syst.*, vol. 5, no. 4, pp. 1309-1316, Nov. 1990.
[18] Y. Ju, W. Wu, B. Zhang, and H. Sun, “An extension of FBS three-phase power flow for handling PV nodes in active distribution networks,” *IEEE Trans. Smart Grid*, vol. 5, no. 4, pp. 1547-1555, Jul. 2014.
[19] G. Daz, J. G. Aleixandre, and J. Coto, “Direct backward/forward sweep algorithm for solving load power flows in AC droop-regulated microgrids,” *IEEE Trans. Smart Grid*, article in press, Sep. 2015.
[20] B. Amin, *Induction Motors: Analysis and Torque Control*, 1st ed. Berlin, Germany: Springer, 2010.