Effects of Load Modeling in Power Distribution System with Distributed Wind Generation

N. K. Roy, *Student Member, IEEE*, M. J. Hossain, *Member, IEEE*, and H. R. Pota, *Member, IEEE*

***Abstract*--This paper presents the impact of different types of load models in distribution network with distributed wind generation. The analysis is carried out for a test distribution system representative of the Kumamoto area in Japan. Firstly, this paper provides static analysis showing the impact of static load on distribution system. Then, it investigates the effects of static as well as composite load based on the load composition of IEEE task force report [1] through an accurate time-domain analysis. The analysis shows that modeling of loads has a significant impact on the voltage dynamics of the distribution system with distributed generation.**

***Index Terms*--composite load; distribution system; static load; wind turbine.**

I. Introduction

TRADITIONALLY, generators are connected in transmission networks, but in the near future, there will be significant generation in distribution networks. During the next ten years, renewable energy will emerge as a major enabler of the smart grid for the integration of small and medium sized renewable energy based generation into the Australian electricity grids. Therefore, analysis of distribution systems has become a very important part of the overall planning of power systems in order to improve reliability, safety, and economic benefits [2], [3]. One of the major concerns related to the distributed generation (DG) is the impact on system stability due to the interaction between generators and load characteristics.

The load of distribution network is constantly changing due to the variations of consumer demands. In certain industrial areas, it has been observed that under certain critical loading conditions, the distribution system experiences voltage collapse [4]. The study [5] showed that the strategically placed DG was able to increase the stability margin by increasing the stability limit threshold. However, this does not apply to all systems as the system loads play a major role in this aspect.

Connecting a generator to the distribution system will affect the flow of power and the voltage profiles [6]. The steady state voltage rise resulting from the connection of generators can be a major obstacle to their connection at the lower voltage level in distribution network [7]. The objective in [7] is to use static method to analyse steady state voltage stability which reported that the voltage at the point of connection (POC) will increase due to the greater export of real power and there will be a local voltage rise at the POC. The distribution system only for high penetration of heat & power (CHP) generation has been analysed in [7]. However, in case of induction type wind generator the voltage of the system may become lower than the acceptable level due to the inability of induction generators to support the reactive power for different types of load. The importance of load modeling in power system simulation studies is highlighted by IEEE Task Force on load representation for dynamic performance Analysis [8].

The main classifications of loads are in static and dynamic models. As a static load model is not dependent on time, it describes the relationship of the active and reactive power at all times to the voltage and/or frequency. The characteristics of load with respect to frequency are not critical for the phenomena of voltage stability but those with respect to voltage are. On the other hand, a dynamic load model expresses this active/reactive power relationship at any instant of time as a function of the past history of voltage and/or frequency. Static load models have been used for a long time for both purposes, that is, to represent static load components, such as resistive and lighting loads, and also to approximate dynamic components. This approximation may be sufficient in some of the cases but for the fact that load representation has critical effects in voltage stability studies. This situation may become worse due to the traditional static load models being replaced with dynamic ones [9].

The modeling of load is complicated because a typical load bus represented in a stability analysis is composed of a large number of devices, such as fluorescent and incandescent lamps, refrigerators, heaters, compressors, motors and furnaces, etc. The exact composition of load is difficult to estimate. Also, its composition changes depending on many factors, including time, weather conditions and the state of the economy.

In power flow studies, the common practice is to represent the composite load characteristic as seen from power delivery points. In transmission systems, loads can be represented by using constant power load models, as voltages are typically regulated by various control devices at the delivery points. In distribution systems, as most nodes are not voltage controlled, voltages vary widely along system feeders; therefore, the

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characteristics of load are more important in distribution system analysis [10]-[13].

Most of the papers in distribution system have analysed impact of distributed generation penetration in distribution system considering static load model [14]-[17]. In reality, distribution network has composite loads. However, investigation of the effect of composite loads has not been adequately covered in the available literatures considering generation in distribution network.

So, the main objective of this study is to investigate the impact of different load models on the voltage profile in distribution networks. The rest of the paper is organized as follows. Section II describes the modeling of the system. Simulation results showing the static and dynamic analysis with different types of load are given in Section III. Finally, the paper is concluded by brief remarks in Section IV.

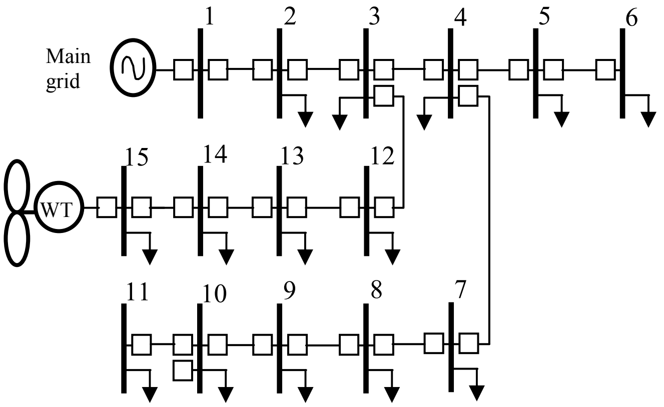

Fig. 1. Single line diagram of Kumamoto 15-bus distribution system [16]

II. SYSTEM MODELING

In this work, Kumamoto 15 bus distribution test system as shown in Fig. 1 is considered. A wind generator is connected at bus 15 and bus 1 is connected to the main grid. Here, the base power is 10 MVA and the base voltage is 6.6 kV, total load on the system is 6.301 MW, 0.446 Mvar. The distribution line is modeled as $R+jX$. The machine parameters, test system data with distribution of system loads in different nodes are given in Appendix.

The most important components of a constant speed wind are rotor, drive train, and the generator [18]. A two-mass drive train model of a wind turbine generator system (WTGS) is used in this paper as the drive train modeling can satisfactorily reproduce the dynamic characteristics of WTGS. The induction generator gets the power from the gear box through the stiff shaft. Here, time domain simulation is carried out with full non-linear model of the wind turbine generation system considering variable mechanical torque. In this paper, a third order model for both shaft and squirrel cage induction generator is considered as described in [19].

Static and composite load model is used in this paper for a comparative analysis. Static loads can be classified as follows [10].

Constant impedance load model (constant Z): A static load model where the power varies with the square of the voltage magnitude. It is also referred to as constant admittance load model.

Constant current load model (constant I): A static load model where the power varies directly with voltage magnitude.

Constant power load model (constant P): A static load model where the power does not vary with changes in voltage magnitude. It is also known as constant MVA load model.

Common static load models for active and reactive power are expressed in polynomial or exponential forms and can include, if necessary, a frequency dependence term. In this paper, we use the exponential form to represent static load as:

$$P(V) = P_0\left(\frac{V}{V_0}\right)^{\alpha} \tag{1}$$

$$Q(V) = Q_0\left(\frac{V}{V_0}\right)^{\beta} \tag{2}$$

where P and Q are active and reactive components of load, respectively, when the bus voltage magnitude is V. The subscript 0 identifies the values of the respective variables at the initial operating condition. The parameters of this model are the exponents α and β. With these exponents equal to 0, 1 or 2, the model represents the constant power, constant current or constant impedance characteristics of load components, respectively.

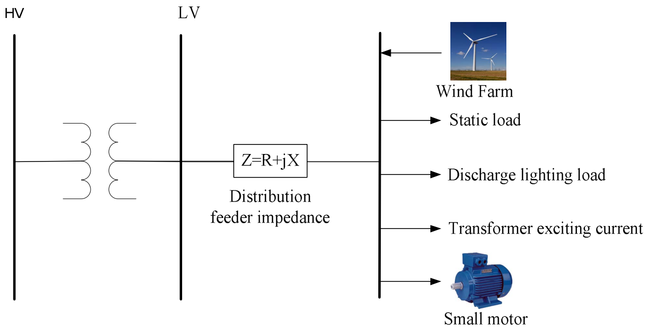

Fig. 2. Example of composite load

Composite load model represents the dynamic behavior of an aggregate group of small motors, electronic loads and static loads. An example of the composite load model representation is shown in Fig. 2. In this paper, the load components are aggregated based on IEEE Task force report [1], which assume a load delivery point consists of 30% static loads (space heating, cocking, water heater, clothes dryer, etc.) [20], 20% fluorescent lighting [20], and 50% small motors [21]. In this paper, the active components of static loads are represented by constant current models and reactive components by constant impedance models, as recommended in [8] for dynamic simulations.

III. SIMULATION RESULTS

A. Static Voltage Profile

The steady state voltage profile of the distribution test system without DG is shown in Fig. 3. It is seen that all bus voltages are within permissible limits (±0.05 pu) for all types of static loads. To see the impact of distributed generation in distribution network a wind generator is connected at bus 15 with a capacity of 50% of the total system load. The nodal voltages of the test system with this new generation are shown in Fig. 4 for different types of load. It is found that few nodes are below the permissible voltage level due to the integration of squirrel cage induction type wind generator. It is also seen that constant power load has highest voltage regulation followed by systems with constant current load and then by systems with constant impedance load.

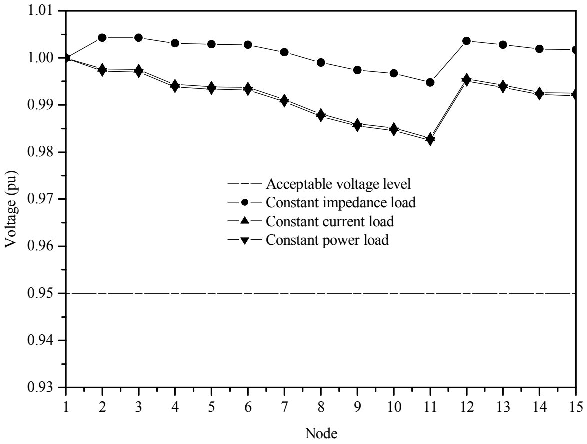

Fig. 3. Nodal voltages of Kumamoto15-bus test distribution system without distributed generation for different types load

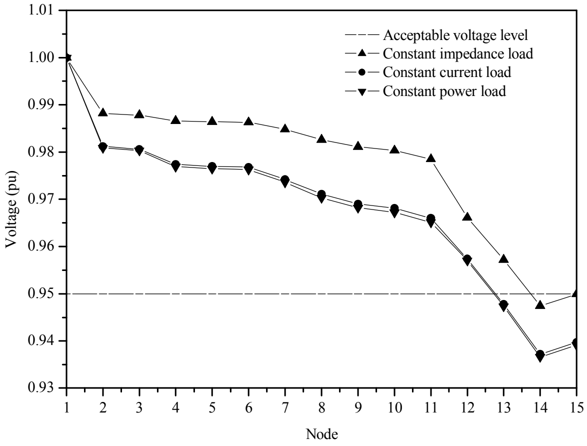

Fig. 4. Nodal voltages of Kumamoto15-bus test distribution system with distributed wind generation for different types load (50% wind penetration)

B. Dynamic Analysis

1) Sudden Opening of One Branch:

To see the dynamic voltage profile, the test system is tested with 50% wind penetration under fault condition with outage of the line connecting buses 1 and 2 for 1s. A fault is applied at t = 1s and removed at t = 2s. The simulated terminal voltage of wind generator for constant impedance, constant current, constant power, and composite loads is shown in Fig. 5. It is seen that voltage dip is lowest for constant impedance load and it takes less time to return to pre-fault condition, but composite load causes significant voltage dip and oscillations in distribution system compared to other static loads and it takes more time to return to pre-fault condition. This is due to the inability of wind generators to support the reactive power to composite load which consists of both static and dynamic loads. Dynamic loads are low power factor load with high reactive power demand. Real and reactive power flow of the wind generator for composite load under pre-fault, faulted, and post-fault conditions is shown in Fig. 6 and Fig. 7, respectively. It is seen that the system has large oscillations in power after following a disturbance with composite load.

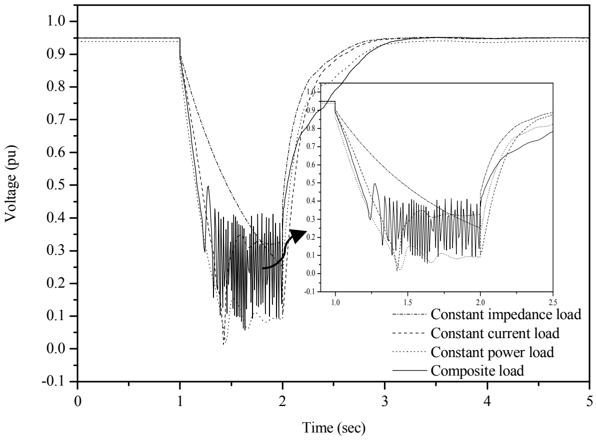

Fig. 5. Wind generator terminal voltage for different types load (sudden disconnection of the line 1-2)

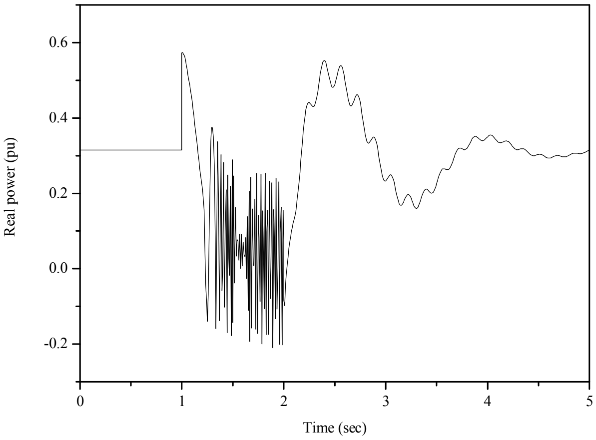

Fig. 6. Real power output of the wind generator for composite load (sudden disconnection of the line 1-2)

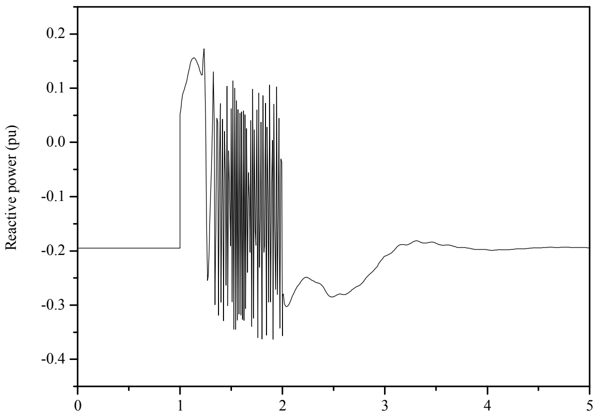

Fig. 7. Reactive power of the wind generator for composite load (sudden disconnection of the line 1-2)

2) Sudden Three-Phase Short Circuit Fault:

To see the effect of short circuit current, the test system is again tested with a sudden three phase fault at bus 2. A three-phase solid fault is applied t = 1s and eliminated at t = 2s. The short circuit resistance and reactance are zero. Wind generator terminal voltage for constant impedance, constant current, constant power, and composite loads is shown in Fig. 8. It is seen that system with static loads are less affected by short circuit current compared to composite load. Composite load takes much longer time to return to its pre-fault condition compared to other loads. The speed deviation of the wind generator for composite load is shown in Fig. 9. Real and reactive power flow of the branch 2-3 for composite load is shown Fig. 10 and Fig. 11, respectively and that of the branch 15-14 under the same condition is shown in Fig. 12 and Fig. 13, respectively. The oscillating power after eliminating the fault is quite high for branch 2-3. If these values are higher than the threshold limit then protection may react and trip this system from the main grid.

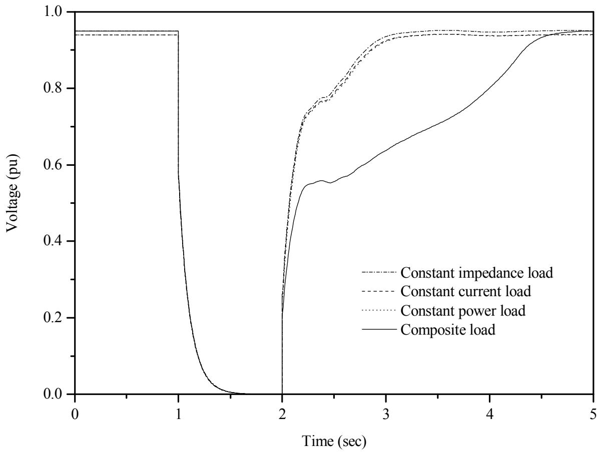

Fig. 8. Wind generator terminal voltage for different types load (sudden three-phase fault at bus 2)

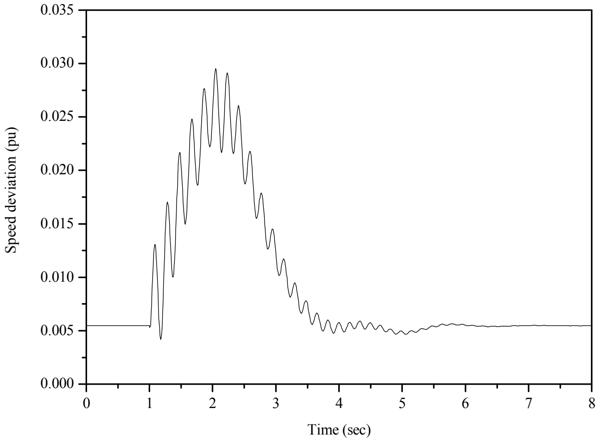

Fig. 9. Speed deviation of wind generator for composite load (sudden three-phase fault at bus 2)

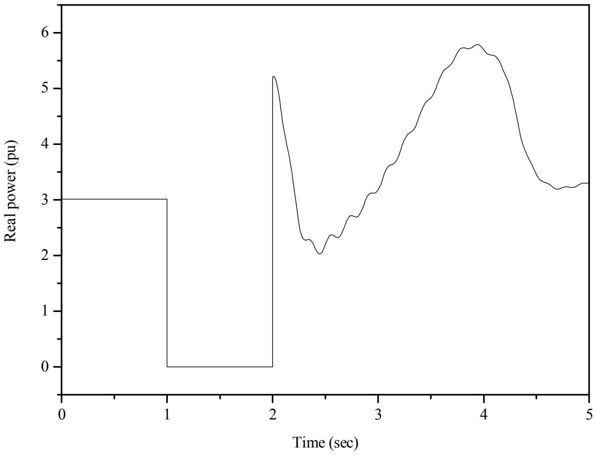

Fig. 10. Real power flow of branch 2-3 for composite load (sudden three-phase fault at bus 2)

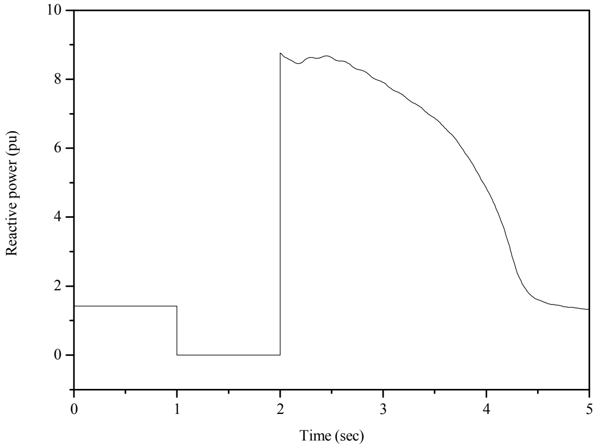

Fig. 11. Reactive power flow of branch 2-3 for composite load (sudden three-phase fault at bus 2)

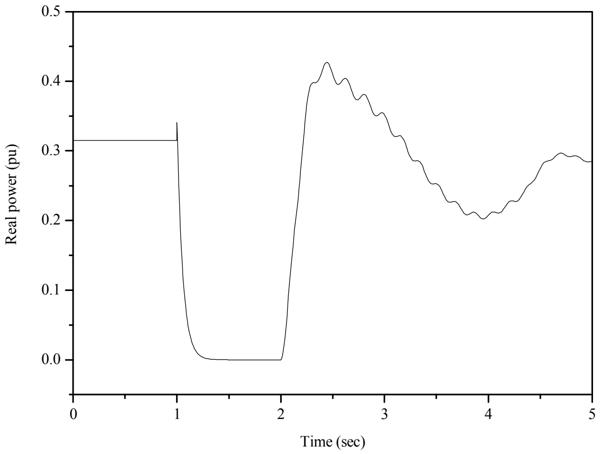

Fig. 12. Real power flow of branch 15-14 for composite load (sudden three-phase fault at bus 2)

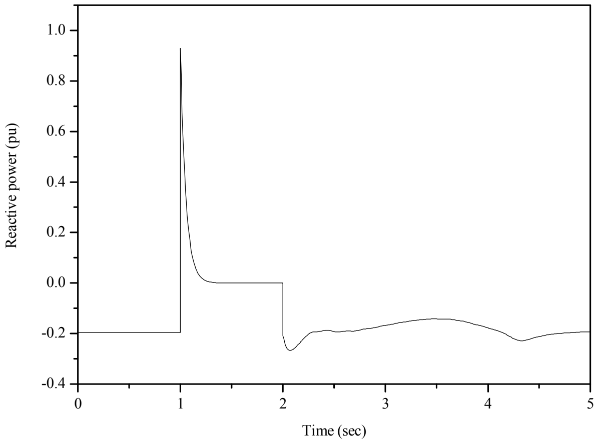

Fig. 13. Reactive power flow of branch 15-14 for composite load (sudden three-phase fault at bus 2)

IV. CONCLUSION

This paper investigates the impact of different types of load models on the voltage profile of a distribution system. Static analysis shows that a few nodes are below the permissible voltage level due to the integration of distributed wind generator which signifies that the system needs reactive power compensation. System with constant power load model exhibits high voltage drop along the feeder compared to other static loads. This voltage variation may become a serious problem for distribution network which can reduce the lifetime or damage the equipments connected to it. Dynamic analysis shows that voltage dips are highest for composite load and lowest for constant impedance load. Moreover, the composite load characteristics have slow response to return to its original state after a sudden disturbance. So it is important to choose appropriate load model as the behavior of a system following a disturbance, or the possibility of voltage collapse occurring, depends to a great extent on how the load is represented.

V. APPENDIX

TABLE I

LINE AND LOAD DATA OF KUMAMOTO 15 BUS TEST DISTRIBUTION SYSTEM [16]

Sending Node	**Ending Node**	**R (pu)**	**X (pu)**	**B (pu)**	**P_{load} (pu)**	**Q_{load} (pu)**
1	2	0.00315	0.075207	0.00000	0.02080	0.0021
2	3	0.00033	0.001849	0.00150	0.04950	0.0051
3	4	0.00667	0.030808	0.03525	0.09580	0.0098
4	5	0.00579	0.014949	0.00250	0.04420	0.0045
5	6	0.01414	0.036547	0.00000	0.01130	0.0012
4	7	0.00800	0.036961	0.03120	0.06380	0.0066
7	8	0.00900	0.041575	0.00000	0.03230	0.0033
8	9	0.00700	0.032346	0.00150	0.02130	0.0022
9	10	0.00367	0.016940	0.00350	0.02800	0.0029
10	11	0.00900	0.041575	0.00200	0.21700	0.0022
3	12	0.02750	0.127043	0.00000	0.01320	0.0014
12	13	0.03150	0.081405	0.00000	0.00290	0.0003
13	14	0.03965	0.102984	0.00000	0.01610	0.0016
14	15	0.01061	0.004153	0.00000	0.01390	0.0014

Bus voltage=6.6 kV, Base MVA= 10 MVA

The machine parameters used for the system are given below:
Induction generator parameters:
Power: 2 MW, Voltage: 690 V, Frequency, f=50 Hz, Self-damping: 0.008 pu, Rated slip: 0.02, Stator resistance, R_s=0.0121 pu, Stator reactance, X_s=0.0742 pu, Magnetizing reactance, X_m=2.7626 pu, Rotor resistance, R_r=0.008 pu, Rotor reactance, X_r=0.1761 pu
Two mass model parameters:
Inertia constant, H_m=2.6s, H_g=0.22s, Torsion damping, D_m=3 pu, D_g=0.6 pu Torsion stiffness, K_s=141 pu, Gearbox ratio: 23.75

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VII. BIOGRAPHIES

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