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Renewable Distributed Generation Models in Three-Phase Load Flow Analysis for Smart Grid

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Abstrak

Makalah ini menyajikan model pembangkit energi terbarukan terdistribusi (RDG) tiga fase dalam perhitungan aliran daya dan analisis pengaruhnya ketika terhubung dalam sistem gabungan. Model RDG yang telah dibahas terdiri dari fotovoltan (PV) dan pembangkit turbin angin (WTG). Simpul kendali tegangan dan simpul injeksi daya komplek digunakan dalam pemodelan pembangkit. Pengembangan ini sesuai untuk aplikasi pada analisis sistem daya grid cerdas. Kombinasi data transmisi dan distribusi IEEE digunakan untuk menguji algoritma dalam masalah sistem distribusi tiga fase kondisi seimbang dan tidak seimbang. Hasil simulasi menunjukkan bahwa peningkatan jumlah dan ukuran RDG telah memperbaiki profil tegangan dan mengurangi rugi-rugi.

Kata kunci: *aliran daya tiga fase, grid cerdas, pembangkit terdistribusi, photovoltan, turbin angin*

Abstract

The paper presents renewable distributed generation (RDG) models as three-phase resource in load flow computation and analyzes their effect when they are connected in composite networks. The RDG models that have been considered comprise of photovoltaic (PV) and wind turbine generation (WTG). The voltage-controlled node and complex power injection node are used in the models. These improvement models are suitable for smart grid power system analysis. The combination of IEEE transmission and distribution data used to test and analyze the algorithm in solving balanced/unbalanced active systems. The combination of IEEE transmission data and IEEE test feeder are used to test the the algorithm for balanced and unbalanced multi-phase distribution system problem. The simulation results show that by increased number and size of RDG units have improved voltage profile and reduced system losses.

Keywords: *distributed generation, photovoltaic, smart grid, three-phase load flow, wind turbine*

1. Introduction

The fossil fuels such as coal, oil and natural gas are non-renewable, limited in supply and one day will be depleted. The price of this energy increase year by year related to decreasing in its availability. With the increase in the price of traditional petrochemical fuels for generation energy, the employment of renewable resource generation as alternative energy becomes more feasible, practical and realizable. Therefore, distributed generation (DG) using renewable energy sources will increase in recent years.

Distributed generation using renewable energy sources, such as wind, solar photovoltaic and hydro power has received considerable attention in recent years. Wind turbine generation (WTG) and photovoltaic (PV) are the world's fastest growing electricity generation technology. Global wind power capacity reached 94,100 megawatts by the end of 2007and available wind turbine sizes with capacities up to 3500 kW [1]. A lot of researchers have been studying the wind speed characteristics and its potential as a wind power generation in many countries worldwide [2]. Grid-connected PV production has been increasing by an average of more than 20 percent each year since 2002. At the end of 2009, the cumulative global PV installations surpassed 21,000 MW [3].

Future distribution grids will have a high penetration of distributed generation (DG) as discussed in [4] and what has been described as smart grid [5].The increasingly number of installation of generation in low and medium voltage level has changed many distribution systems from a passive system to be an active network [6]. The active network will have many

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DG which different electrical technologies. Specific RDG units have different electrical characteristics, which impact/result in power system analysis. The electric power supply by photovoltaic is dependent on sunlight radiation and ambient temperature. The active power generated by wind turbine generation depends on wind speed. The specific RDG units have to be modeled accurately in order to get an accurate analysis result. Therefore, there is a need to improve RDG model to cover whether related distributed energy resources in smart grid power system analysis.

2. Research Method

The power flow analysis of a power grid containing distributed generation is the foundation of studying steady-state characteristics of future power system operation. The integration of RDG units be increasing and give the benefit contribution to existing grid power system operation, provide low-cost green energy, reduce transmission and distribution (T&D) losses and improve overall power quality and reliability [7].Distributed generations (DGs) are generally modeled as PV or PQ nodes in power flow studies for distribution system. However, the specified P, Q and V values depend on the type of DG. This research presents the modeling of wind turbine generation and photovoltaic as RDG units.

2.1. Wind Turbine Generator Modeling

A lot of researchers have been studying the wind speed characteristics and its potential as a wind power generation in many countries worldwide. The wind turbine generator unit in a load flow analysis can be modeled as PV bus or PQ bus. However, the WTG preferred model is as a PQ injection source rather than voltage controlled device (PV bus). The general wind turbine model using basic speed and power relations presented in [8] to calculate the output power is given by:

$$P_W = \tfrac{1}{2}\rho.A.\upsilon^3.C_P \quad (1)$$

Where: P is power in watts, ρ is air density in kg/m^3, A is the rotor swept area m^2, v is the wind speed in m/s, and C_p is rotor efficiency.

The power output can also be taken from power-speed curve provided by the manufacturer. The different companies provide different wind turbine curve. By using the curve wind speed can be plot to find specified power input in power-flow calculation.

The reactive power (Q) is specified or if power factor, cos φ, is specified, Q is calculated by using:

$$Q = -P \tan(\cos^{-1}\varphi) \quad (2)$$

The more accurate model, P and Q calculated from Induction (asynchronous) generator parameters using the equation 3.

$$P + jQ = \left(\frac{Z_a}{Z_a + Z_c}\right)^* P_m \left(\frac{Z_a}{Z_a + Z_c} - \frac{Z_c P_m}{V_2^2}\right) \quad (3)$$

Where: P_m is mechanical power, Za, Zb and Zc calculated from steady-state representation of the asynchronous machine parameters, $V_2$is rotor voltage.

In this paper, the sequence components three-phase power-flow algorithm and model [8] are used for developing three-phase WTGs model. The new class library to model WTG has been added in object oriented power system model [9,10] using visual C++ programming.

2.2. Photovoltaic Model

A photovoltaic (PV) system converts sunlight into electricity. The basic device of PV system is the PV cell may be grouped to form panels or arrays. The photovoltaic system require electronics converter to regulate voltage and current to track maximum power point (MPP) of the device.

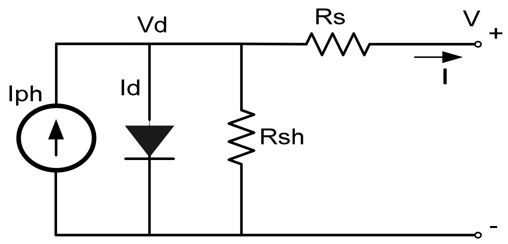

Figure 1. Photovoltaic model

The practical equivalent circuit of PV panel consists of a current source in parallel with a diode and inclusion of additional series resistance (Rs) and shunt resistance (Rsh) as shows in Figure.1. The value of current and voltage are depending on the solar irradiance and the ambient temperature.

The voltage-current (VI) equation of PV panel [11] is given by:

$$I = I_{ph} - I_0 (e^{\left(\frac{q(V+I.Rs)}{a.Ns.k.T}\right)} - 1) - \frac{(V + I.Rs)}{Rp} \quad (4)$$

Where:
- I_{ph}: the current generated by the incident light (directly proportional to the sun irradiation),
- I_0 : the reverse saturation of the diode,
- q : the electron charge (1.60217646 x 1019 C),
- k : the Boltzmann constant (1.3806503 x 10-23 J/K),
- T : temperature of the p-n junction,
- N_s : number of cells connected in series and a is the diode ideality constant.
- R_s : the equivalent series resistance
- R_p : the equivalent parallel resistance

The light generated current, I_{ph} is calculated depending on solar radiation and temperature as follows:

$$I_{ph} = (I_{ph,n} + K_I \Delta_t) \frac{G}{G_n} \quad (5)$$

Where:
- $I_{ph,n}$: the light-generated current at the nominal condition
- K_I : current coefficient
- Δ_t : the different of actual and nominal temperatures,
- G : the irradiation
- Gn : the nominal irradiation respectively

The reserve current saturation is given by equation 6:

$$I_0 = \frac{I_{sc} + K_I \Delta_t}{e^{(V_{oc} + K_V \Delta_t)/aV_t} - 1} \quad (6)$$

Where:
- K_V : voltage coefficient
- $V_t = N_s kT/q$

The parameters required which can be obtained from the manufacturer's module specifications include short-circuit current, open-circuit voltage, and temperature coefficients.

The equation for the PV cell power can be written as Equation 7.

$$P = V\left[I_{ph} - I_0 (e^{\left(\frac{q(V+I.Rs)}{a.Ns.k.T}\right)} - 1) - \frac{(V+I.Rs)}{Rp} \right] \quad (7)$$

If the PV module uses solar tracking devices, the maximum power point (MPP) of the PV power can be obtained by solving differential equation of PV power to PV voltage equal to zero using Newton Raphson based nonlinear equation. However if the module is fixed the incidence angle will determine the effective irradiance value. The value of the calculated solar module output power is then used as an input to the load flow as a PQ bus with Q set to be zero.

3. Description of The Test System

The proposed model tested and analyzed using Standard IEEE data and it combination without and with DGs. The combination of IEEE 14 bus [12] and IEEE 13 node feeder [13] used to test and analyze the algorithm in solving balanced/unbalanced active systems. The combination of IEEE 14 bus data and IEEE 13 node radial feeder known as the composite system shows in Figure 2.

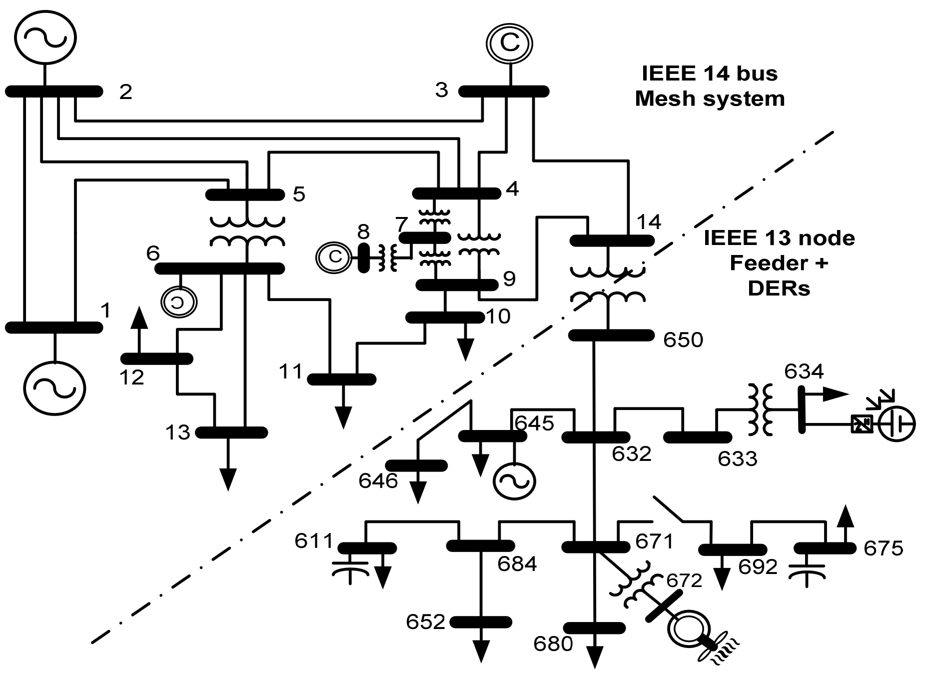

Figure 2. IEEE 14 bus + 13 node test feeder with Cogen, PV and WTG connected

In RDG analysis, three DG units from different kinds of DG technologies were installed in three different locations. A cogeneration DG was directly connected to node ID 645, a PV was connected to new node ID 672 via step down transformer connected to node ID 671 of original node and a WTG was connected at the original node ID 634. The load flow analysis was performed by using per-unit values on a base 100 kVA and was solved for 0.0001 phase voltage mismatch.

The simulation cases presented five different scenario of generation connection. The first case presents the scenario where source is from utilities only without DGs. The next cases show the installation of three different DGs connected in different location. The case 2 represented when DGs from renewable resources not available, so the DG supply only from cogeneration unit. The case 3 represented when the wind speed not enough to produce power and case 4 represented DG supply from Cogen and WTG units due to the absence of PV generation during the sunset. The case 5 shows the hybrid system during all DERs units connected.

4. Results and Analysis

Simulation results for this test case are summarized in Table 1. The results show that, the voltage is increased with the increase number and size of DG units installed in the network. The worst voltage result is in Case 1 which has no DG unit installed in the system. Case 5 has the best result with all DGs connected in the network. In this case, the voltages at all nodes are already within the permissible voltage violation. The maximum voltage is 1.09 p.u., similar to the specified value of bus ID 8 in the original IEEE 14 bus system.

Table 1 The Results of IEEE 14 bus + 13 node test feeder with DG

Cases	| V| (p.u.)		DG Supply		NEMA Voltage Unbalanced Factor (VUF)
	Min	Max	(kW)	(kVAr)	(p.u.)
1	0.859 (B,675)	1.09 (ABC, 8)	0	0	0.060 (633,634)
2	0.918 (A,652)	1.09 (ABC, 8)	600	1000	0.042 (633,634)
3	0.920 (A,652)	1.09 (ABC, 8)	1040.3	1000	0.042 (633,634)
4	0.918 (A,652)	1.09 (ABC, 8)	1040	810.5	0.042 (633,634)
5	0.958 (B,646)	1.09 (ABC, 8)	1440.3	2371.6	0.040 (633,634)

NEMA: National Electrical Manufacturers Association

The increased number and size of DG units installed in the network have decreased Voltage Unbalanced Factor (VUF) to below 5% as shown in Table 1.

The effect of DGs in the composite system IEEE 14 bus and IEEE 13 node feeder on voltage profile are given in Figure 4 for the three-phases. The results show that, the voltage is increased by increasing number and size of DG units installed in the network. The lowest voltage curve is in Case 1, where there is no any DG unit installed in the system. Case 5 gives the best result where cogeneration modeled as PV node. In this case, the voltage nodes are slightly higher than cases 2–4, which correspond to the partial DG installation and cogeneration modeled as PV node with Q limit. If the Q limit is used, the PV node will be automatically converted to a PQ node, when Q limit is achieved. In this case, the cogeneration will operate as a PQ injection source rather than voltage controlled device. However, the reactive power generation from the DG units for Case 5 is the highest i.e. 2371.6 KVAr to maintain the voltage at cogeneration node equals to 1.0 p.u.

The voltage patterns for system 14 bus for three-phase are the same due to the fact that this system is actually a balanced system. The maximum voltage is 1.09 p.u. at bus ID 8. This value is the same as the specified value of the original IEEE 14 bus system for generation bus. The voltage variations among phases are shown in Figure 3 for the 13 node feeder, which is an unbalanced system.

Figure 4 shows the DG generation and system loss comparison for all the cases. Losses for Case 1, which corresponds to no DGs, are used as base case. The results show that, the increased number and size of DG units installed in the network have decreased system losses or increased loss reduction.

Loss reduction for Cases 5, which corresponds to the maximum DGs is 384.4 kW higher than cases 2–4, which correspond to partial DGs installation and Cogen modeled as PV node with Q limit. The unbalanced power system analysis shows that the presence of DG model as voltage controlled devices (PV nodes) has been significant in improving the voltage profile and also has reduced the total system losses. The reduced losses are due to the reduction of currents flowing in the transmission network as more power is supplied in the distribution system.

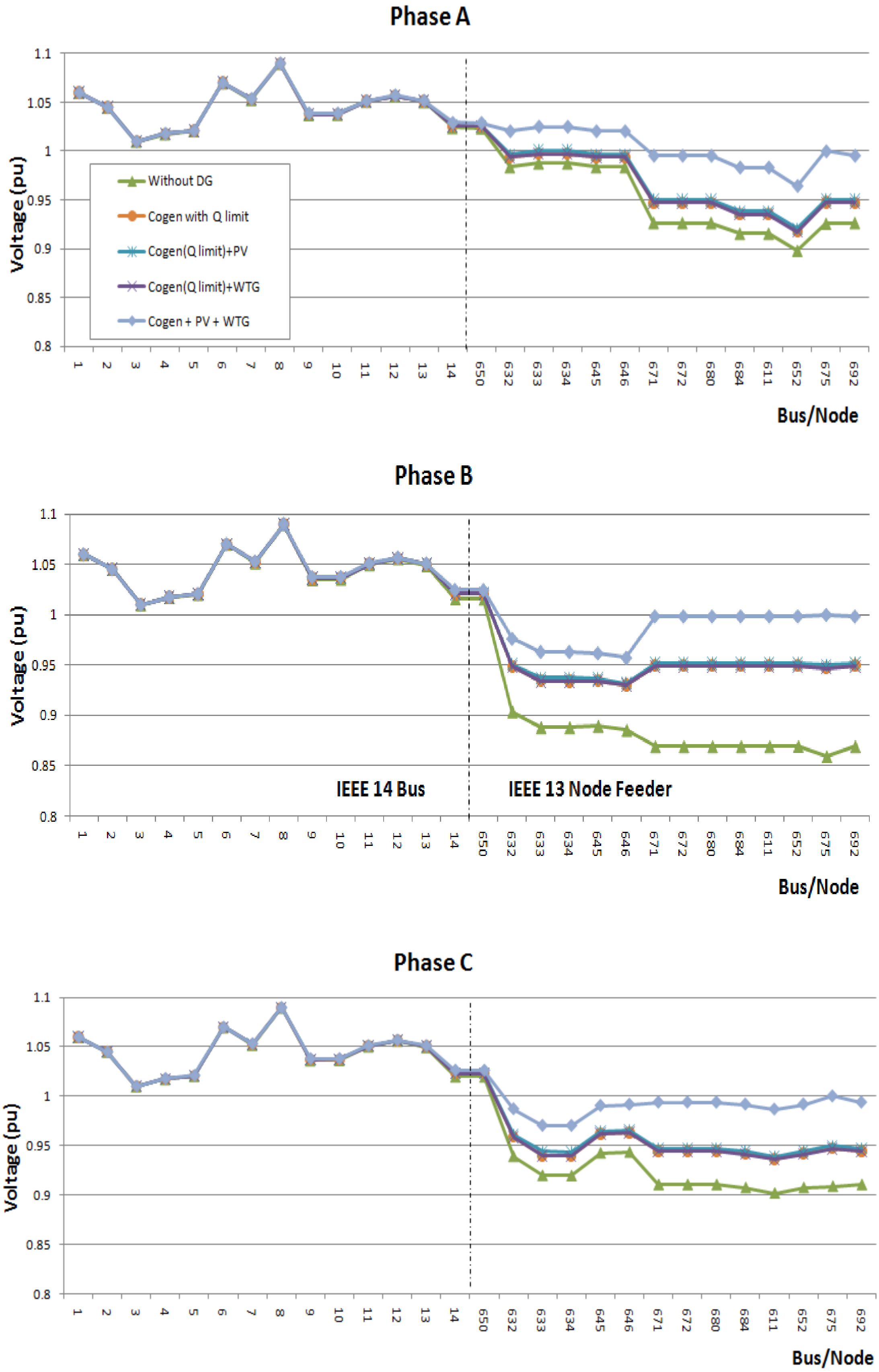

Figure 3. Voltage profile comparison of the composite system

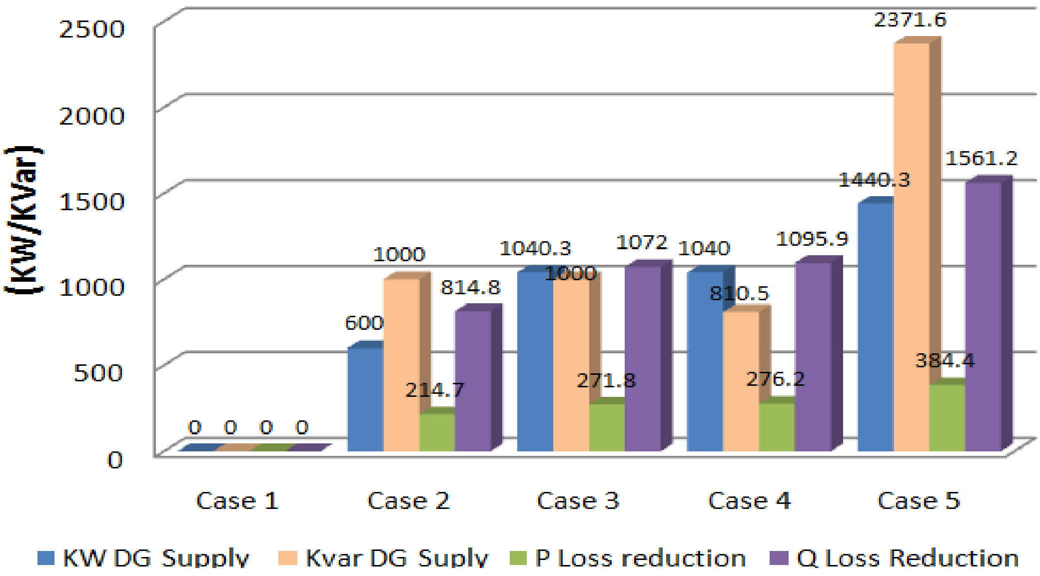

Figure 4. DG Generation and Loss Reduction of the composite system

4. Conclusion

The paper has presented renewable distributed generation (RDG) models as three-phase resource in load flow computation. The RDG models that have been considered comprise of photovoltaic (PV) and wind turbine generation (WTG). The voltage-controlled node and complex power injection node are used in the models. These improvement models are suitable for smart grid power system analysis. The variation of wind speed (m/s) for WTG, solar radiation (W/m²) and temperature (°C) for PV have been simulated. The simulation results show that the proposed DG model can be used to analyze DG impacts in the unbalanced meshed and radial distribution system. The integration of DG into an existing distribution network can improve the voltage profile, decrease VUF and reduce total system losses.

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