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TECHNICAL EVALUATION OF RENEWABLE ENERGY INTEGRATION INTO TSHWANE ELECTRICITY NETWORK

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ABSTRACT
In this paper technical evaluation is performed on a part of the Tshwane Electricity Network (South Africa) incorporating distributed renewable energy sources. The whole network is first analysed to identify the areas under threat of instability due to overloading. Distributed generation employing different renewable energy supplies is then injected at some strategic points. Simulation studies are conducted using PSCAD/EMTDC. The models used are wind turbines driving induction generators to represent wind energy, steam/gas turbines driving synchronous generators to represent the energy from waste and photovoltaic (PV) modules to represent the solar energy. Various fault conditions are considered with varying penetration levels of the distributed generators to evaluate their impact on the network in terms of frequency, voltage and current.

KEY WORDS
Distributed generation, renewable energy, grid integration, dynamic analysis

1. Introduction

South Africa is currently undergoing a major energy crisis. The electricity demand is more than the plant capacity most of the time, leading to the frequent load shedding operations. Many international companies are interested in investing in South Africa to help alleviate the problem.

This study is concerned with technical evaluation of renewable energy integration in Tshwane/Pretoria electricity network. Only about 20% of the energy consumed in Tshwane Municipality is produced locally, with the rest coming from the major electricity utility company ESKOM. South Africa uses coal, its major indigenous energy resource, to generate most of its electricity and a significant proportion of its liquid fuels. Because of this, South Africa is the 14th highest emitter of greenhouse gases.

Most parts the Tshwane Electricity Network is already overloaded. This coupled with the present power shortages calls for an investigation into the possibly of supplementing the available supply with distributed renewable energies and a study of the impacts of such supplies on the network.

Many studies have been done about the impact of the renewable energies on an electrical network [3]-[5],[9]. This study will incorporate different models of renewable energies for possible use in Pretoria. Based on a topographical study of Pretoria [12],[16], three systems are of particular interest.

The first one is a synchronous generator to simulate the behaviour of a waste turbine [17]. A waste-to-energy plant which is designed and operated to burn municipal waste combines a high pressure steam turbine/generator cycle and a combustion turbine/generator cycle; wherein the exhaust gas from the combustion turbine is utilized to superheat high pressure steam prior to entering the steam turbine. The combination of the combustion turbine/generator cycle with the steam turbine/generator cycle enables operation of the waste-to-energy plant at high pressure and high temperature resulting in greatly increased thermal cycle efficiency. In the simulations, the waste turbines deliver an output power of 8MW.

The second type involves an induction generator model combined with a wind turbine to model the behaviour of wind farm connected to the network [10],[13],[14]. The different examples given in PSCAD software library have been used to find a wind turbine of 1.5 MW

The last case concerns the modelling of photovoltaic modules liked to the network [10],[11],[14].

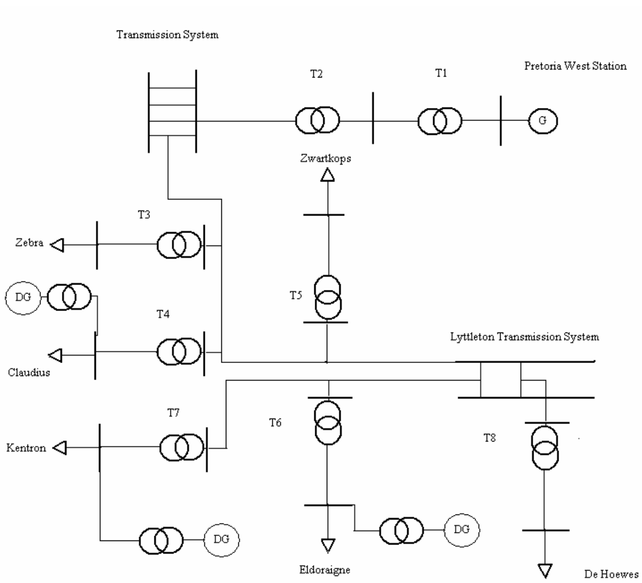
To evaluate the impact of the different renewable energy supplies, different faults are applied at the main generator (Pretoria West Station), and the behaviour of the network is then studied, incorporating the Distributed Generators (DGs). Three phase fault and a single phase fault have been applied into the tests.

The results of this study can be applied in other cities in South Africa and using different examples as synchronous generators for the wind turbines.

2. System Modelling

2.1 Pretoria Network

First of all, a section where a power station can be installed and areas where there is an overload are chosen, in this case Pretoria West power station and surrounding areas have been simulated. DGs will be tested at Kentron, Eldoraigne and Claudius [12].



The Pretoria West station is linked to the transmission system. The voltage is subjected to two transformations before reaching at the transmission level. Then, the power is distributed all over the network. All the loads here are real areas around Pretoria and have been configured during the simulation.

2.2 Induction Generator for a Wind Turbine

We will insert in the simulation 3 wind turbines of 1.5 MW. Wind is not very strong in Pretoria but related to the topographic analysis there are some places in Pretoria that can accept wind turbines like in Pretoria South where the altitude is a bit higher.

The generator is based on a three phase induction motor excited by the stator. The generators have three pairs of poles and the wind speed has been fixed at 10m/s.

Concerning the voltage and the current in three phases the following set of equations will be used:

According to the stator at t = 0:

$$i_a(t) = I_s\sqrt{2}\cos\alpha_s \tag{1}$$

α corresponds to the angle between rotor and stator, i_a is the current on the first phase. I_s is the nominal current.

We can deduce the current on the two other phases:

$$\begin{aligned} i_b(t) &= I_s\sqrt{2}\cos\left(\alpha_s - \frac{2\pi}{3}\right) \\ i_c(t) &= I_s\sqrt{2}\cos\left(\alpha_s + \frac{2\pi}{3}\right) \end{aligned} \tag{2}$$

Concerning the voltage we have:

$$\underline{V_a}(t) = R_s . I_a + \frac{d\varphi_a}{dt} \tag{3}$$

V_a is the voltage on the first phase, Rs is the resistance of the stator and φ is the magnetic flux of the stator.

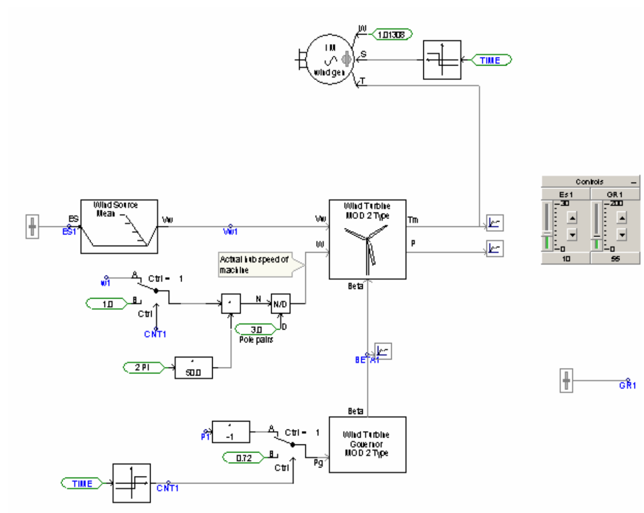


Figure 1. Model of wind turbine under PSCAD modified for the simulation

The parameters applied to obtain an output power of 1.5MW are given in fig2.

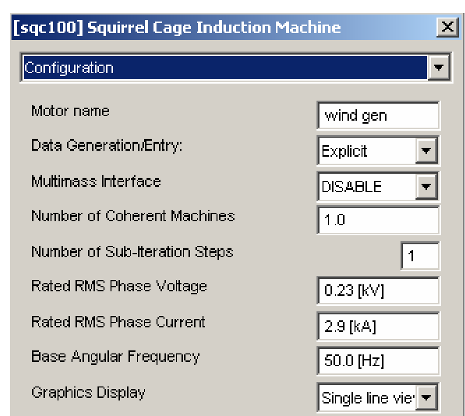


Figure 2. Parameters of the induction motor of the wind turbine

The power delivered by the turbine is given by the equation: P = √3.U.I cos φ and is equal to 4MW

We will apply a power factor PF (cos φ) equal to 0.85 in all the simulation, so as to be as close as possible to the reality.

2.3 Synchronous Generator for Waste Turbines

To model the system for a waste turbine, we will use a three phase synchronous generator.

The equations related to the generator and which are already incorporated into the software are quite the same as the induction motor. The only difference is that the magnetic field of the rotor has to be scaled on the magnetic field of the stator to be in synchronism speed.

The equivalent circuit of the generator is given in the figure below:

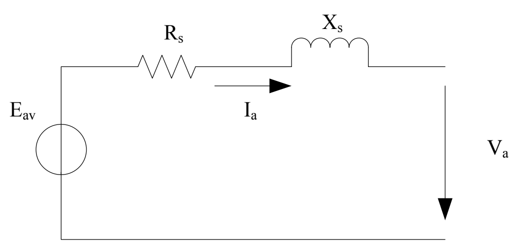


Figure 3. The equivalent circuit of synchronous generator

When $I_a = 0$ we have the tension created by the rotor field

$$\underline{V_a}(t) = (R_s . j\omega L_s)\underline{I_a} + \frac{d\varphi_a}{dt} + E_{av} \quad (4)$$

ω_s represents the angular frequency related to the frequency of 50Hz.
L_s is the length of the magnet.
E_{av} is the vacuum power when the i_a is equal to zero.

The parameters applied to the synchronous generators are given below.

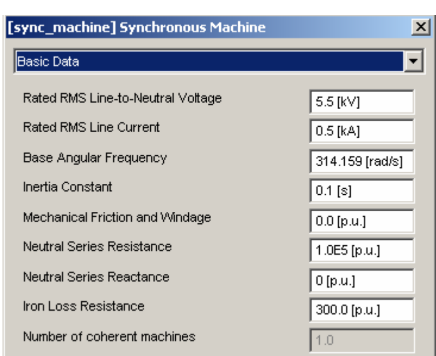


Figure 4. Synchronous generator parameters

The output power of the generator is about 4MW. This is a perfect machine with the effect of saturation neglected.

2.4 Photovoltaic (PV) Panel

The equation for a single-diode model including series and shunt resistances is: [11]

$$I = I_{sc} - I_1\left(e^{\frac{q(V+Rs.I)}{kT}} - 1\right) - \frac{(V+R_s.I)}{R_{sh}} \quad (5)$$

where I_{sc} is the light-generated current (short-circuit value assuming no series and shunt resistance), I_1 is the dark saturation current, Q is the charge of an electron (Coulomb), K is the Boltzmann constant (j/K), T is the cell temperature (K), I and V are the cell current (A) and voltage (V), R_s and R_{sh} are the series and shunt resistance.

2.5 Simulation and the analysis

In the simulation of the network, two different kinds of faults will be applied at the Pretoria West station to see how the system recovers after a fault and how the different DGs can help the system. It is already known that the power produced by the power station is only 20% of the power consumed by the loads in Pretoria. The main power station gives 120 MVA to the network. The total of the load for the first simulation with the waste turbine is about 109 MVA and the power produced by the three waste turbines is about 16 MW.

The voltage is required to remain between 0.9 and 1.1 per unit under all conditions.

For the wind turbine, we have reduced the loads in order to capture the impact of the power generated. The power produced by the two wind turbines is equal to 3 MW.

3. Simulation and Results

3.1 System with wind turbines

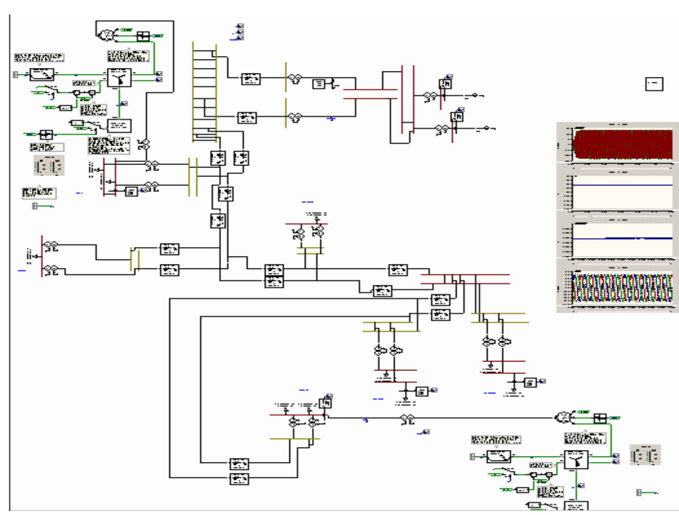


Figure 5. System with the wind turbines

The fault is applied just after the main generator. The wind turbines are to be installed at Kentron and Zebra in the network.

3.2 Results of a single phase fault with wind turbines

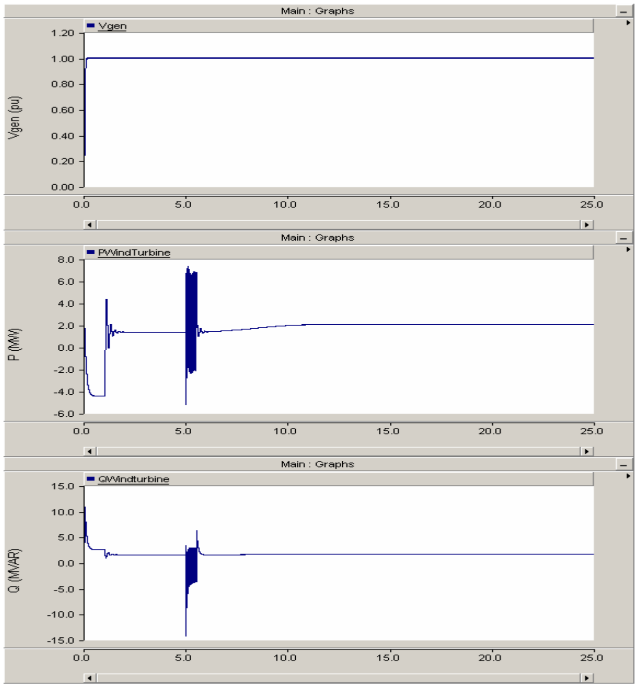


Figure 6. Power of the main station, active power delivered by the wind turbine in MW, reactive power delivered by the wind turbine in MW

For the wind energy conversion system the active power delivered by the generator is between 1.4 and 2 MW. The reactive power is about 1.66 MVAR. It can be seen that the power is completely recovered after the fault after 0.5 seconds of perturbation.

The voltage profile is depicted in the figure below. In the first curve, a single phase fault is observed in the blue phase. The other curves represent the action of the fault under different loading conditions in Eldoraigne, (the first one without the wind turbines, and the second with the wind turbines). We can see that the power is just up to 0.90. In the case where wind turbines are included we can see that the power is a bit smaller. This means that the wind turbine does not have a positive impact on the load when it is directly attached and linked to the load but has an improving impact on the loads of the other areas.

3.3 System with waste turbines and a three phase fault

The system with three synchronous generators driven by waste turbines is shown next. The system is the same as in the previous case, but with a bigger load to adequately capture the impacts when power is injected from the synchronous generators.

The system is subjected to a three phase fault, with a fault time of 0.5s, which is considered a very bad case for the network.

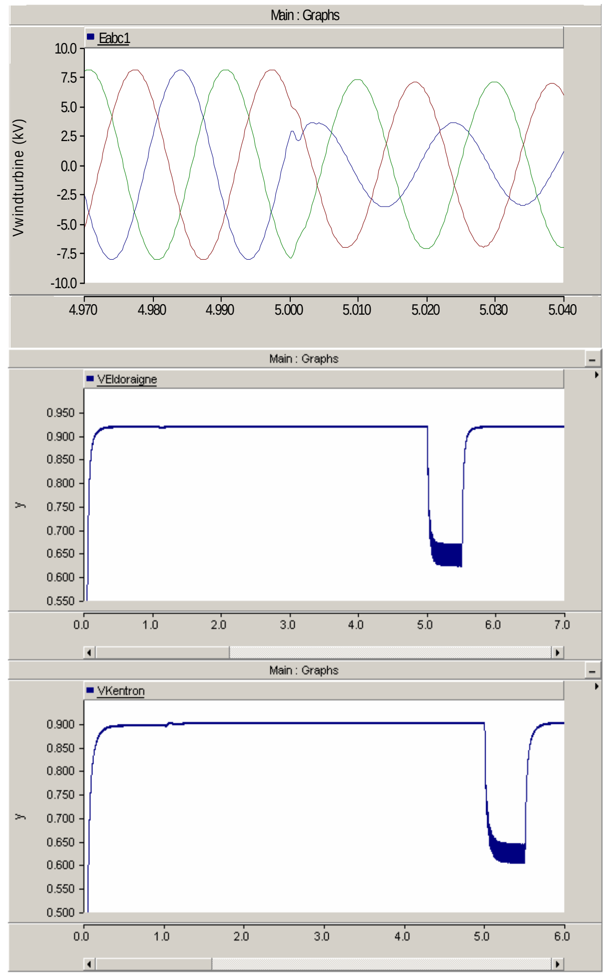


Figure 7. Transformed three phase voltage of the wind turbine in Kentron in kV, voltage profile on the Eldoraigne load in p.u, voltage profile on the load in Kentron with the wind turbine in p.u

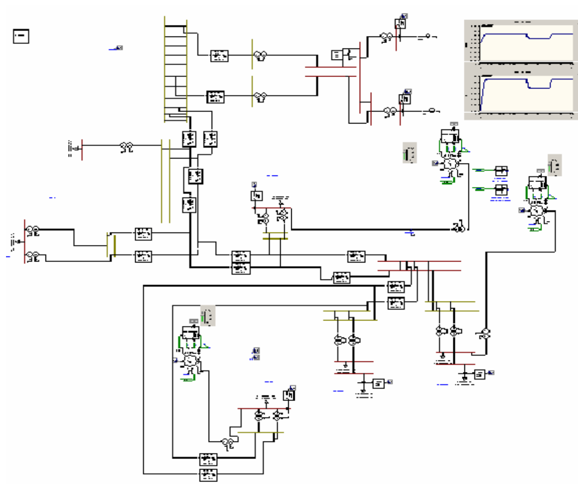


Figure 8. System with the synchronous generators modelling the behaviour of waste turbines

3.4 Results of a three-phase fault with wind turbines

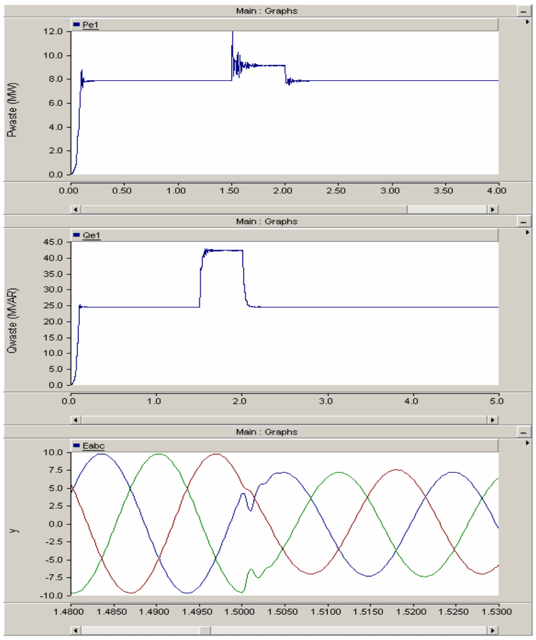


Figure 9. Active power delivered by the synchronous generator (MW), reactive power, three phase voltage at the load with the three phase fault (kV)

Here, it can be observed that the synchronous generator with the parameters mentioned before, delivers a lot much power compared to the wind turbine, about 8MW and 25 MVAR. We have not considered the control system here, but just a perfect synchronous machine. The reactive power delivered by the generator is not taken into account because the value is very high and a compensating controller will be required, for example, to cancel as much as possible reactive power but delivering less harmonic pollution into the network.

The results show how energy from waste impacts on the system under different loading and fault conditions. Applying such a system has several advantages because the emissions of steam or gas emissions can be reinserted into compressors and passed into turbines to produce combined heat and power.

In the south of the city, between Pretoria and Johannesburg there is quite a big industrial activity. Three sites are proposed for the synchronous generators based on topographical analysis and system load situation. The sites are: Zwartkops, Kentron and DieHoewes.

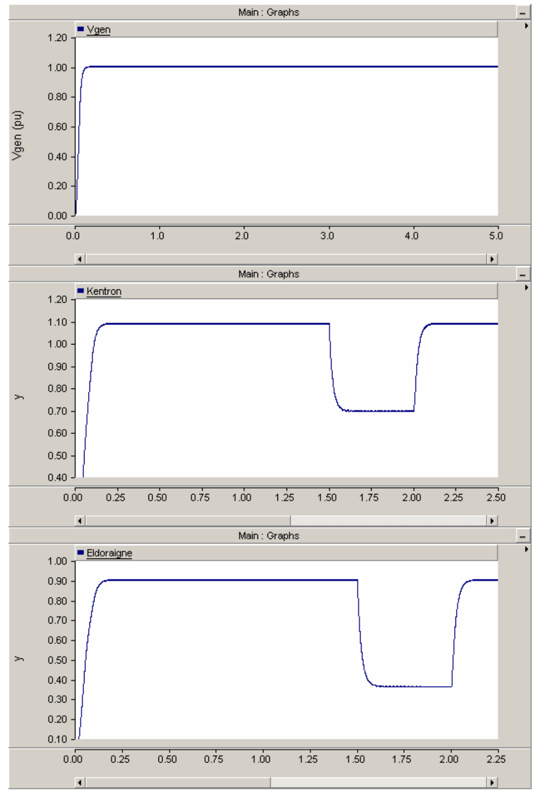


Figure 10. Power delivered by the main generator, voltage profile of the load receiving the waste turbine, voltage profile of the load with the turbines

Here the results are interesting and show perfectly the difference between the loads receiving the power from the synchronous generators and when there is no additional power. On one hand, the Kentron load receives the energy and the voltage rises up to 1.1 p.u, while in the Eldoraigne case the voltage rises up to 0.9 p.u.

Now, in relation to the three phase fault, as can be seen on the Kentron load, the fault is highly compensated by the power generated. The voltage goes down to 0.75 p.u., which can be easily compensated by the power provided by ESKOM and the waste turbine.

Looking at the Eldoraigne load, it is seen that the fault has a big impact on the voltage. The power goes down to 0.40 p.u. This means that the difference between the voltage with the synchronous generator and without is about 0.35 p.u, which is a considerable amount taking into account the size of the loads.

4. Conclusion

This study was based on the Tshwane electrical network but can be applied in many other places in South Africa or even all over the world. The aim of the study was to evaluate the impacts of various energy supplies on the network using PSCAD 4.2. The energy sources considered here were wind energy and energy from the industrial waste (steam or gas emissions). The impact of wind turbine generators is not as big as that from synchronous generators but it remains interesting for the Tshwane Municipality.

Future studies will concentrate on photovoltaic panels as the area receives about 300 days of sun a year. Another area will be the application of a good control and command system for the network under distributed generation.

Acknowledgement

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