Summer Fellowship Report

On

Dynamic Study of 69 Bus Radial Networkswith Distributed Generation Using OpenModelica and OpenIPSL

Submitted by

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Under the guidance of

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Acknowledgment

First and foremost, I would like to thank **Prof. Kannan Moudgalya** for establishing this fellowship, which I believe was an excellent introduction to me on open source software and technologies. His suggestions greatly improved the quality of the project.

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Sincerely,

Aritra Banerjee

Contents:

Chapter 1

Introduction

1.1. Introduction to OpenIPSL:

OpenModelica is a free/libre and open-source modelling and simulation environment. Itis built on top of Modelica language. It employs an equation-oriented approach in solving a given set of equations. OpenModelica contains a very exhaustive library called Modelica Standard Library (MSL) which is a collection of different libraries from different domains such as electrical, mechanical, hydraulic, mathematics, etc. Since MSL doesn't have any Power System library, it is not of much use for Electrical Engineers if users intend to use OpenModelica for power system simulation by the help of OpenIPSL library Modelica can also be used for Power Systems Simulations.

1.2. Difference between Transmission System Analysis and Distribution System Analysis:

	Transmission System Analysis	Distribution System Analysis
1.	Interconnected System	Radial or Weakly Meshed System
2.	Transposed Lines	Un-transposed Lines
3.	Balanced loads	Unbalanced Loads
4.	High X\R Ratio	Low X\R Ratio
5.	Fewer Components	Many Components (Capacitor, Regulator, Distributed Generation etc.)
6.	Constant Power Loads	Different load and their Voltage dependence

1.3. Introduction to Radial Network with Distributed Generation:

Distribution systems hold a very significant position in the power system since it is the main point of link between bulk power and consumers. Effective planning of radial distribution network is required to meet the present growing domestic, industrial and commercial load day by day. In the early days of electrical power distribution system, different feeders radially came out from the substation and connected to the primary of distribution transformer.

Radial distribution is the type of power distribution where the power is delivered from the main branch to sub-branches then it split out from the sub-branches again. It is the cheapest network configuration.

Radial distribution network should possess the following characteristics:

1. The system should support energy supply at minimum operation and maintenance cost and should satisfy the social and engineering aspects.

2. It must satisfy the continuous changing of the load demand for active and reactive power.

3. Unlike other forms of energy, electricity is not easily stored and thus, adequate "spinning" reserve of active and reactive power should be maintained and controlled in an appropriate manner.

4. The power supply must meet the following specific standards to maintain the quality of service offered:

a. Regulated voltage

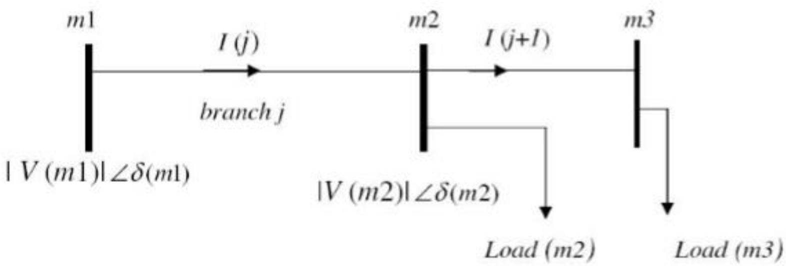
b. Well maintained constant frequency

c. Level of reliability/security that guarantees consumers satisfaction.

The objective of this report is to present the most significant characteristic and specific aspects of detailed Radial Network with Distributed Generation modelling.

1.4. Mathematical Model of Radial Distribution Network:

In Radial Distribution Network's, the large R/X ratio causes problems in convergence of conventional load flow algorithms. For a balanced Radial Distribution Network, the network can be represented by an equivalent single-line diagram. The line shunt capacitances at distribution voltage level are very small and thus can be neglected. The simplified mathematical model of a section of a Radial Distribution Network is shown in Fig 1.1



The Complex power fed to node i can be represented by,

$S_i = V_i(LI)_i = P_i + jQ_i$..(1)

$(LI)_i$=$(\frac{S_i}{V_i}) = \frac{PL_i - jQL_i}{V_i}$..(2)

=$\frac{\sqrt{PL_i^2 QL_i^2}}{|V_i|} \frac{\tan^{-1}(-QL_i/PL_i)}{-\theta_{v_i}}$..(3)

= $|LI_i|\theta_i$

= $|LI_i|\cos\theta_i + j|LI_i|\sin\theta$ ....(4)

Where , $|LI_i| = \frac{\sqrt{PL_i^2 + QL_i^2}}{|V_i|}$..(5)

$\theta_i = \theta_{v_i} - \tan^{-1}(QL_i / PL_i)$..(6)

Branch Current calculation:

I_{br_j}=$\sum_{i=1}^{n} |LI_i|cos\theta_i$+$j\sum_{i=1}^{n} |LI_i|sin\theta_i$

= Re (I_{br_j})+Im(I_{br_j})

I_{br_j}= $|I_{br_j}|\angle I_{br_j}$where$|I_{br_j}|$=$\sqrt{[\{\text{Re}\left(I_{br_j}\right)^2\} + \{\text{Im}\left(I_{br_j}\right)^2\}]}$ ....(7)

and $\angle I_{br_j}$= $\tan^{-1}$ Im(I_{br_j})/Re (I_{br_j})..(8)

Voltage Calculation:

V_r=$V_s - I_{br}.Z_{br}$

$$|V_r||\angle\theta V_r = |V_s|\angle\theta V_s - |I_{br}|\angle\theta I_{br}.|Z_{br}|.\angle\theta Z_{br}$$

$$= |V_s|\angle\theta V_s - |I_{br}|.|Z_{br}|\angle\theta I_{br} + \theta Z_{br}$$

$= |V_s|\angle\theta V_s - |I_{br}|.|Z_{br}|\angle\emptyset$..(9)

On equating real and imaginary part equation (9) can be splitas,

$|V_r|cos\theta V_r = |V_s|cos\theta V_s - |I_{br}|.|Z_{br}|cos\emptyset$ .... (10)

And $|V_r|sin\theta V_r = |V_s|sin\theta V_s - |I_{br}|.|Z_{br}|sin\emptyset$............................... (11)

Where $\emptyset = \theta I_{br} + \theta Z_{br} = \tan^{-1}\frac{\text{Im}(I_{br_j})}{\text{Re}\ (I_{br_j})}$+$\tan^{-1}\frac{(X_{br})}{(R_{br})}$.......................(12)

On squaring and adding equations (10) and (11) results in,

$$|V_r|^2 = |V_s|^2 + |I_{br}|^2.|Z_{br}|^2 - 2|V_s|.|I_{br}|.|Z_{br}|\{cos\theta V_s cos\emptyset + sin\theta V_s sin\emptyset\}$$

$$= |V_s|^2 + |I_{br}|^2.|Z_{br}|^2 - 2|V_s|.|I_{br}|.|Z_{br}|\cos(\theta V_S - \emptyset) \text{ ....(13)}$$

On dividing equation (11) by equation (10), following expression results,

$$\theta V_r = \tan^{-1}\frac{|V_s|\sin\theta V_S - |I_{br}|.|Z_{br}|\sin\emptyset}{|V_s|\cos\theta V_S - |I_{br}|.|Z_{br}|\cos\emptyset}$$

Thus, once branch currents are computed, the node voltages are estimated using the above equations. Hence, the complexity of the solutions lies in the computation of branch currents. This paper presents a relatively simple and efficient procedure to identify the leaf node of a Radial Distribution Network and subsequently estimate the branch currents and node voltages.

Chapter 2

Brief Description about Genrou

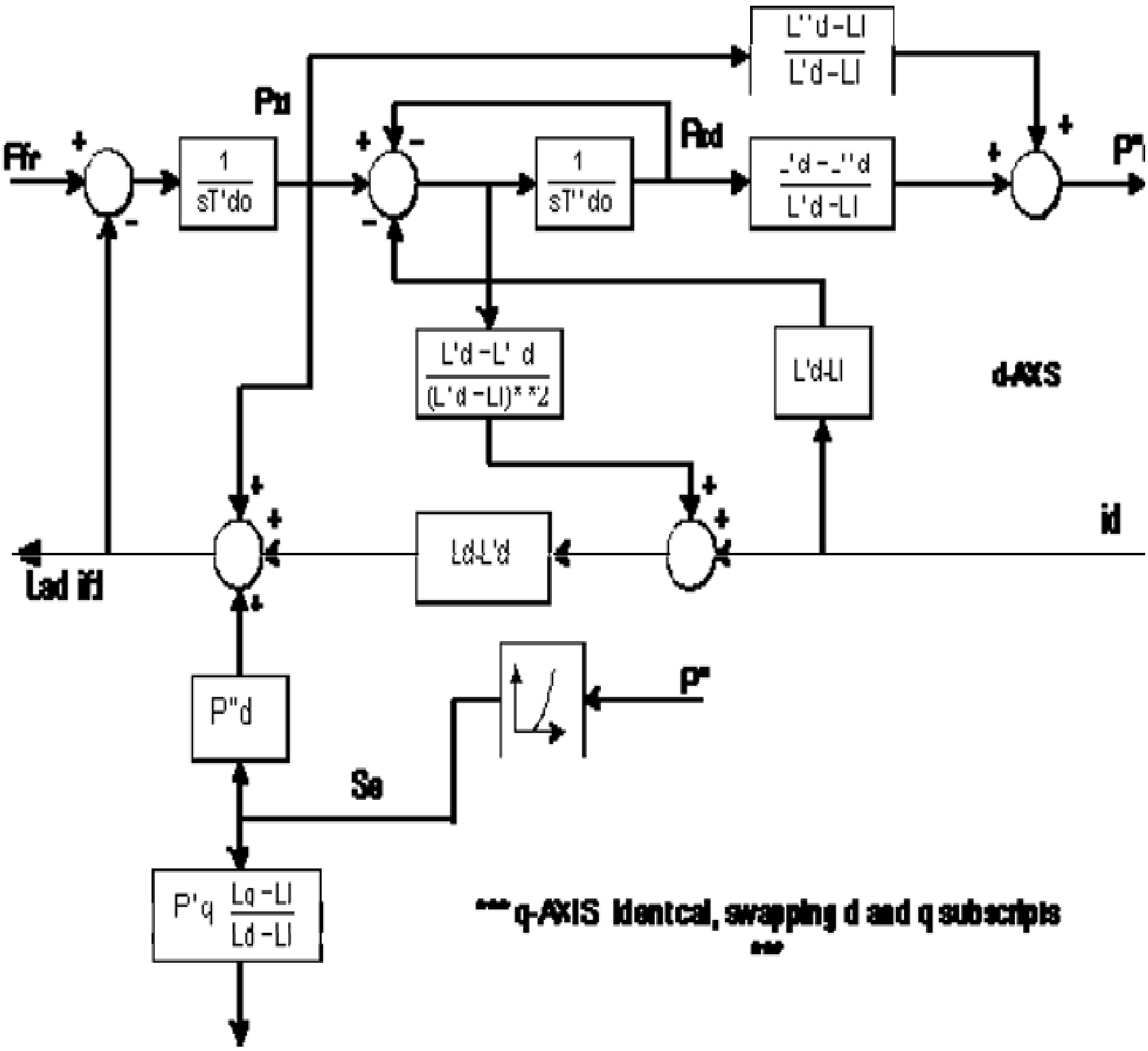


Fig 2.1. Genrou Block Diagram

2.1. Description of Genrou:

- GENROU develops an additive saturation term as a function of a “voltage behind sub transient reactance”. This mathematically defined voltage is reasonably closely related to the flux linking the machine across the air gap.
- GENROU recognize variation of the inductance coefficients of the machine implicitly and handle saturation by developing a term to be added on to the field current that is calculated on the basis of the unsaturated inductance coefficients.
- At steady state all the derivate of state variables are equal to zero, and additionally, all the generator stays synchronous,$\omega_r = \omega_{ref} = 1$, the speed derivate is zero$\Delta\omega_r = 0$. For model Genrou equations are following.

$$0 = \frac{P_m - D\Delta\omega_r}{\omega_r} - \mathrm{T}_e$$

$$0 = \omega_0 \Delta\omega_r$$

$$0 = \frac{1}{\mathrm{T'}_{\mathrm{d0}}}\left(E_{fd} - X_{ad}I_{fd}\right)$$

$$0 = \frac{1}{\mathrm{T'}_{\mathrm{d0}}}\left(E_{fd} - X_{aq}I_{1q}\right)$$

$$0 = \frac{1}{T''_{d0}}\left(E'_q - \psi_{kd} - (X'_d - X_l)i_d\right)$$

$$0 = \frac{1}{T''_{q0}}\left(E'_d - \psi_{kq} - \left(X'_q - X_l\right)i_q\right)$$

which implies that,

$$0 = P_{m0} - T_{e0}$$

$$0 = E_{fd0} - X_{ad0}I_{fd0}$$

$$0 = X_{aq0}I_{1q0}$$

$$0 = E'_{q0} - \psi_{kd0} - (X'_d - X_l)i_{d0}$$

$$0 = E'_{d0} - \psi_{kq0} - (X'_q - X_l)i_{q0}$$

And we can also have,

$$X_{ad0}I_{fd0} = i_{d0}(X_d - X'_d) + E'_{q0} + S_e|\psi''_0|\psi''_{d0}$$

$$0 = -i_{q0}(X_q - X'_q) + E'_{d0} - S_e|\psi''_0|\frac{X_q - X_l}{X_{d-}X_l}\psi''_{d0}$$

By doing proper manipulating, the equation above can be reduced to,

$$(X_q - X''_q)i_{q0} + \psi''_{q0}K = 0$$

$$K = (1 + S_e|\psi''_0|\frac{X_q - X_l}{X_{d-}X_l})$$

With the stator voltage equation described, all of initial value the variables can be determined if the magnitude of the flux linkage and current are specified. However, the voltage and current phasor $V_T\angle\theta_V$, $I_{t0}\angle\theta_{i0}$given by the power flow solution is expressed in synchronous reference frame. But the initial rotor position is also an unknown. Proper manipulating should be made in order to solve the equations. By transferring the quantities from d_q-axes to network coordinate and applying the Simpson's formulas, can be manipulated to be expressed with δ0, and the quantities on synchronous reference frame,$I_{t0}\angle\theta_{i0}$and $\psi''_0\angle\theta_{p0}$

$$(X_q - X''_q)i_{r0}\cos(\delta_0) + i_{r0}\sin(\delta_0) + K(\psi_{r0}\cos(\delta_0) + \psi_{i0}\sin(\delta_0)) = 0$$

$$\Longrightarrow$$

$$|I_{t0}|(X_q - X''_q)\cos(\theta_{i0} - \delta_0) + K|\psi''_0|\cos(\theta_{p0} - \delta_0) = 0$$

2.2. Genrou model with Saturation:

The GENROU model including saturation is presented below. There are three commonly used saturation functions used in power system transient stability software.

Name	Function
Quadratic	Sat(x)= $B(x-A)^2$
Scaled - Quadratic	Sat(x)= $\frac{B(x-A)^2}{x}$
Exponential	Sat(x)= Bx^A

Table 2.1: Value of Genrou model with Saturation

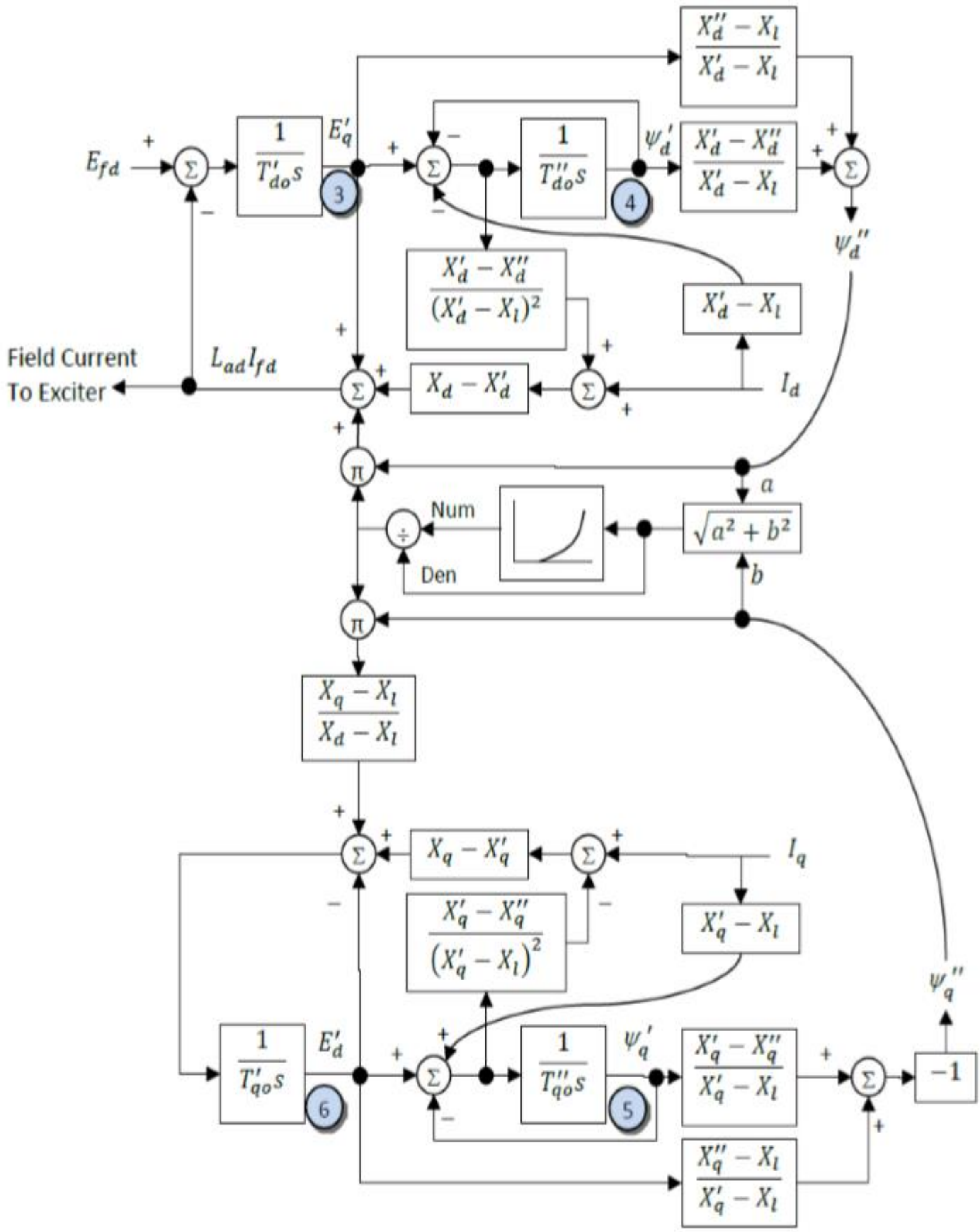


Fig 2.2: GENROU model with saturation

2.3. Genrou model without Saturation:

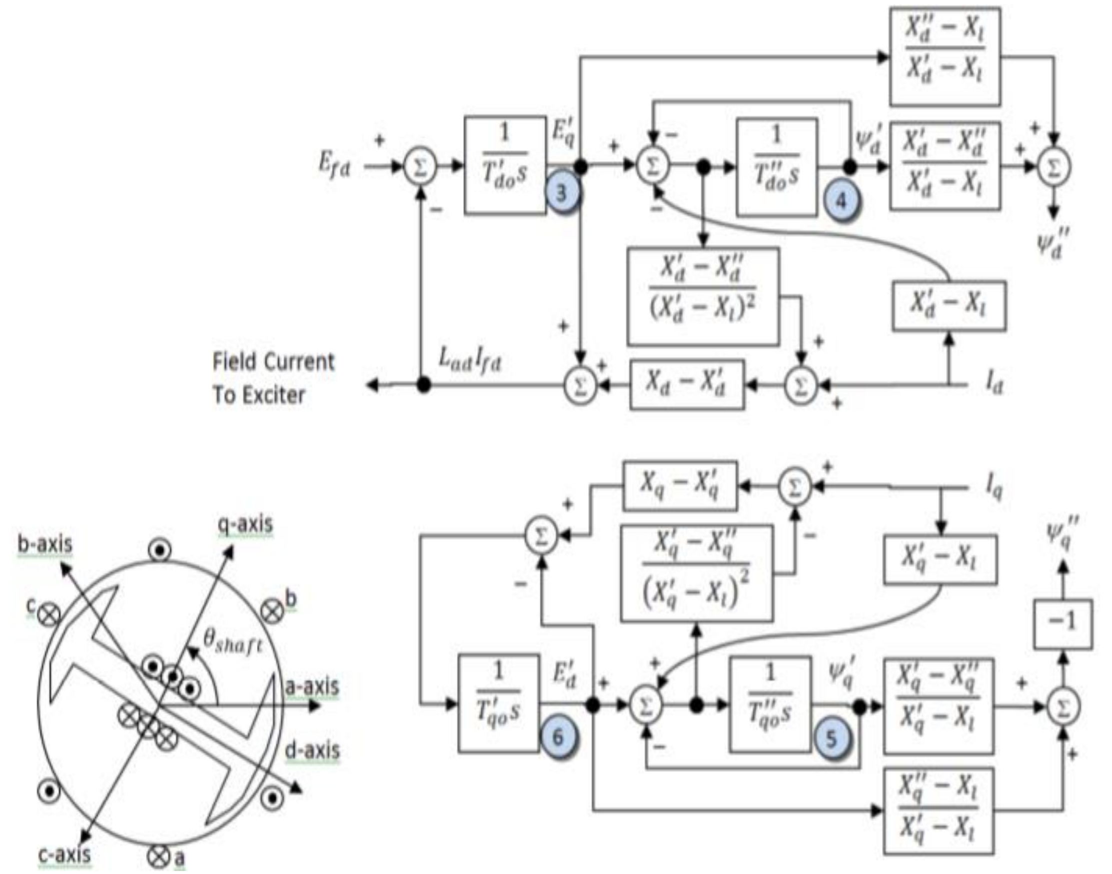


Fig 2.3: GENROU model without saturation

Electrical Torque, Network Interface Equations, Mechanical Swing Equations and conversion of Network interface to Network Reference are given below.

Network Interface Equations	Electrical Torque
$Z_{source} = R_a + jX''_d$ $Y_{source} = \dfrac{1}{R_a + jX''_d} = G + jB$ $v_d + jV_q = \dfrac{d}{dt}(\psi''_d + j\psi''_q)$	$\psi_q = \psi''_q - I_q X''_d$ $\psi_d = \psi''_d - I_d X''_d$ $T_{elec} = \psi_d I_q - \psi_q I_d$ $= \psi''_d I_q - \psi''_q I_d$

Table 2.2: Value of Genrou model without saturation

Chapter 3

WT3 – Generic Wind Model

The dynamic behaviour of wind turbine generators (WTGs) is quite different to that of synchronous generators. A schematic is provided in Figure 3.1. The fidelity of the underlying models depends on the accuracy of system studies. Developing and manufacturing of turbine are highly restricted from disclosing. In some cases, they have released models that describe functionally similar behaviour, though such practise is not common. The dynamic behaviour of a type-3 WTG, as seen from the grid, is therefore dominated by controller response rather than physical characteristics. This is in marked contrast to traditional synchronous generators, where behaviour is governed by device physics. Controller limits play an integral role in the dynamic performance of type-3 WTGs. Intrinsic interactions between continuous dynamics and limit-induced discrete events suggest that type-3 WTGs may be classified as hybrid dynamical systems. The hybrid nature of dynamics also has implications for small disturbance studies. The studies presented in this report focus on the WECC generic type-3 model. This model has been chosen because it is widely used, and is indicative of type-3 models that are generally available. All such generic models are an approximation of the actual dynamics exhibited by a WTG. It is important, though, that this approximation reflects the physical reality of the modelled device.

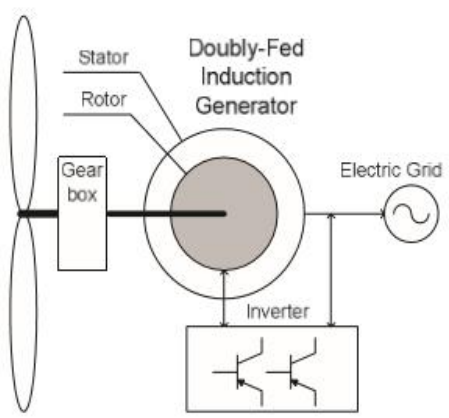


Fig 3.1: Schematic diagram of a type-3 wind turbine generator.

3.1. Introduction to WT3 – Generic Wind Model:

The complete WTG model is divided into four functional blocks, as indicated in Figure 3.2.

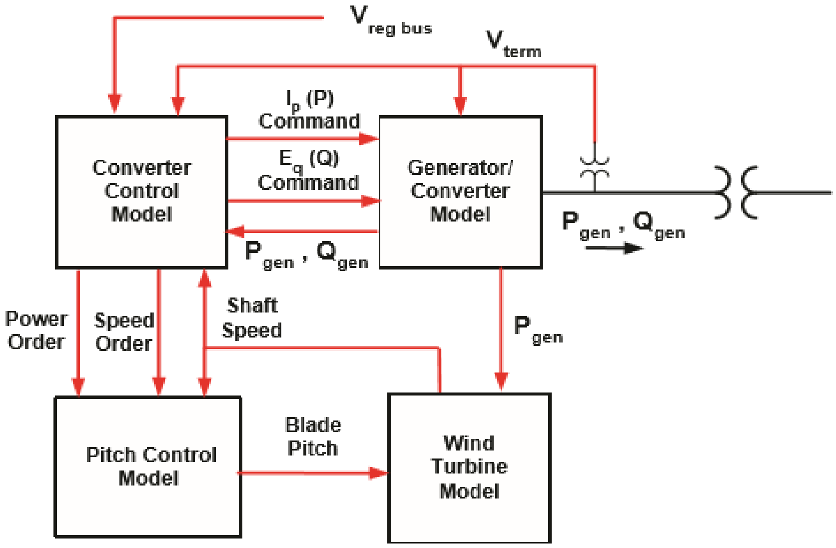


Fig 3.2: Type-3 WTG dynamic model connectivity

The WT3 modelling package includes 4 main models as follows:

1. Generator/Converter Model WT3G.

2. Pitch control model for the WT3 Generic Wind Model WT3P.

3. Mechanical control (wind turbine) for the WT3 Generic Wind Model WT3T

WIND PLANT SPECIFIC ADJUSTMENTS:

• Var_{flg} and Vlt_{flg} are flags that must be set by the user based on the setting defined for each WPP to be included in the case study.

• F_n = Fraction of WTG on the wind plant that are on-line. Used only for VAR control gain adjustment PFA_{ref} = initialized from load flow data.

• V_c is the controlled bus specified within the module WT3E. It can be terminal voltage or remote bus voltage or fictitious remote bus voltage.

• X_c is a fictitious reactance used to compute the voltage drop to offset the reference voltage of a known bus voltage Vr_{fq} and a known branch current I_{reg}.

• V_w>1.0 p.u. will be used to initialize pitch angle.

3.1.1 Generator/Converter Model (WT3G):

This model (WT3G) is an equivalent of the generator and the field converter and provides the interface between the WTG and the network. Unlike a conventional generator model, it contains no mechanical state variables for the machine rotor – these are included in the turbine model (WT3T). Further, unlike conventional generator models, all of the flux dynamics have been eliminated to reflect the rapid response to the higher-level commands from the electrical controls through the converter. The net result is an algebraic, controlled-current source that computes the required injected current into the network in response to the flux and active current commands from the electrical control model. For modelling an aggregation of several (N) WTGs, MVAb must equal the N times the MVA rating of a single WTG. There are two different generator/converter models available, namely WT3G1 and WT3G2. The WT3G2 model, which is recommended for new dynamic setups, includes improvements in the original WT3G1. The original WT3G1 model is being retained for reasons of backward compatibility.

Input data for WT3 Generator:

Constants	**Default Value and Description**
J	0.20 (Tiqcmd, Converter time constant for IQcmd)
J+1	0.0 (Tipcmd, Converter time constant for IPcmd)
J+2	0.0 (KPLL, PLL gain)
J+3	0.0 (KIPLL, PLL integrator gain
J+4	0.10 (PLLMAX, PLL max. limit)
J+5	1.50 (Prated)
J+6	0.50 (VLVPL1, LVPL voltage 1 Low voltage power logic
J+7	0.90 (VLVPL2, LVPL voltage 2)
J+8	1.0 (GLVPL, LVPL gain)
J+9	1.20 (VHVRCR, High Voltage Reactive Current (HVRC) logic, pu voltage)
J+10	2.0 (CURHVRCR, HVRC logic, current (pu))
J+11	5.0 (RIp LVPL, Rate of active current change)
J+12	0.02 (T LVPL, Voltage sensor for LVPL, second)
STATES	**Description**
K	Converter lag for Ipcmd
K+1	Converter lag for Eqcmd
K+2	PLL first integrator
K+3	PLL second integrator
K+4	Voltage sensor for LVPL

VARs	Description
L	(delta Q), over voltage correction factor
ICONs	**Description**
M	Number of lumped wind turbines

Table 3.2: Input data for WT3 Generator Model

Block Diagram of WT3 Generator:

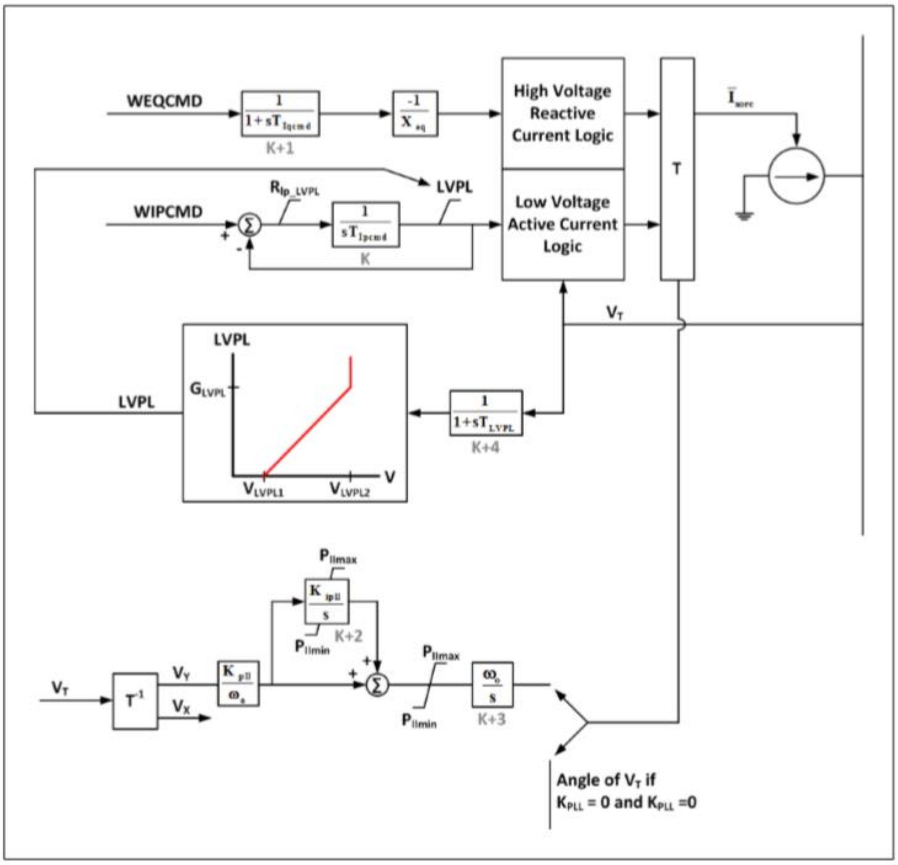


Fig 3.5: Block Diagram of WT3 Generator Model

High-voltage reactive current management and Low-voltage active current management represent logic associated with the dynamic model and the ac network solution. The actual implementation of this logic may be software dependent.

3.1.2 Pitch Control Model (WT3P):

The pitch control model WT3P is shown in Figure 3.6. Of particular interest is the implementation of the non-windup limiter on the pitch angle θ.

"The Pitch Control and Pitch Compensation integrators are non-windup integrators as a function of the pitch, i.e., the inputs of these integrators are set to zero when the pitch is in limits (PI_{max}orPI_{min}) and the integrator input tends to force the pitch command further against its limit."

To illustrate, consider the case where θ is on its lower limitPI_{min}. A negative input to the pitch-control integrator would cause the corresponding state $x_p$to reduce, which in turn would force θ further against its PI_{min}limit. To prevent that wind-up effect, the integrator is blocked under such conditions. Similarly, the pitch-compensation integrator is blocked when its input is negative. When θ is on its upper limitPI_{max}, blocking of the up-stream integrators occurs when their respective inputs are positive.

The equations describing the WT3P model can be written,

$$\frac{d\omega_{ref}}{dt} = \frac{1}{T_{sp}}(f(P_{gen}) - \omega_{ref}) \quad (1)$$

$$\frac{dT_\omega}{dt} = K_{itrq}(\omega - \omega_{ref}) \times y_{freeze} \quad (2)$$

$$\frac{dP_{ord}}{dt} = P_{ord,rtlm} \times y_{mx,sw} \times y_{mn,sw} \quad (3)$$

$$P_{ord,rate} = \frac{1}{T_{pc}}(\omega\left(T_\omega + K_{ptrq}(\omega - \omega_{ref})\right) - P_{ord} \quad (4)$$

$$\frac{dx_p}{dt} = K_{ip}(\omega - \omega_{ref}) \times y_{fr,1} \quad (5)$$

$$\frac{dx_c}{dt} = K_{ic}(p_{ord} - P_{set}) \times y_{fr,2} \times y_{sw} \quad (6)$$

$$\frac{d\theta}{dt} = \theta_{rtlm} \times y_{mx,sw} \times y_{mn,sw} \quad (7)$$

$$\theta_{rate} = \frac{1}{T_{PI}}(\theta_{cmd} - \theta) \quad (8)$$

$$\theta_{cmd} = x_p + x_{c+}K_{pp}(\omega - \omega_{ref}) + K_{pc}(P_{ord} - P_{set}) \quad (9)$$

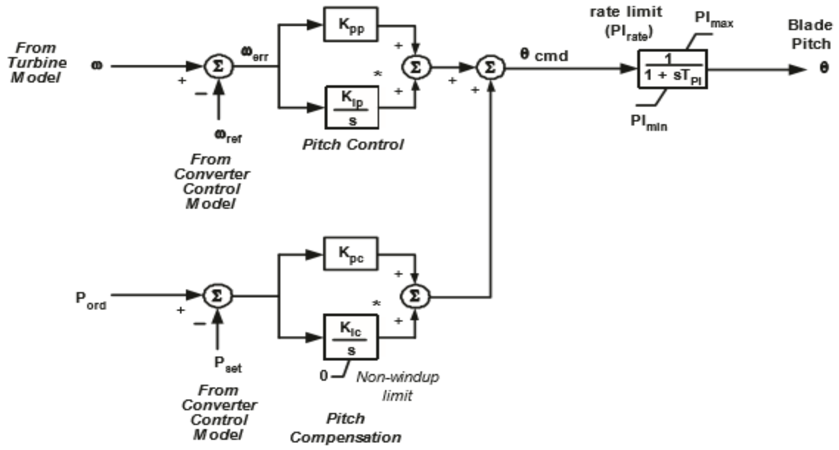


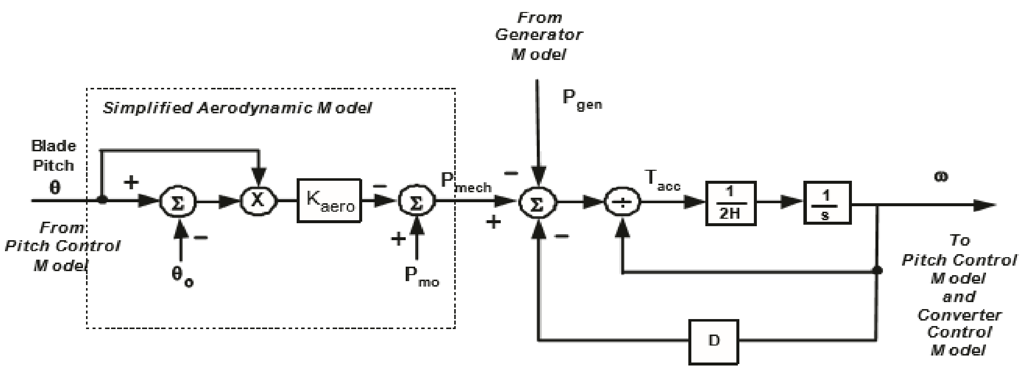
Fig 3.6: Pitch control model WT3P

3.1.3 Turbine Model (WT3T):

The turbine WT3T model uses the two-mass representation of the wind turbine shaft drive train. It calculates the speed deviations of the rotor on the machine and the blade sides. By setting the turbine inertia fraction $Ht_{frac} = 0$ the model can be switched to a conventional single mass representation. The single-mass model suffices for the discussions in this report. The model consists of two parts, 1) a simplified model of the aerodynamic relationship between blade pitch θ and mechanical power P_{mech}, and 2) a model of the shaft dynamics. The damping constant D is always zero, so the single-mass WT3T model can be described by,

$\frac{d\omega}{dt} = \frac{1}{2H\omega}(P_{mech} - P_{gen})$ ....(10)

$P_{mech} = P_{mo} - K_{areo}\theta(\theta - \theta_0)$.............(11)



3.7: Single-mass turbine model WT3T

Chapter 4

Distributed Generation

4.1 Introduction to Distributed Generation:

Distributed generation is an approach that employs small-scale technologies to produce electricity close to the end users of power. DG technologies often consist of modular (and sometimes renewable-energy) generators, and they offer a number of potential benefits. In many cases, distributed generators can provide lower-cost electricity and higher power reliability and security with fewer environmental consequences than can traditional power generators.

In contrast to the use of a few large-scale generating stations located far from load centres – t he approach used in the traditional electric power paradigm- DG systems employ numerous, but small plants and can provide power onsite with little reliance on the distribution and transmission grid. DG technologies yield power in capacities that range from a fraction of a kilowatt [kW] to about 100 megawatts [MW]. Utility-scale generation units generate power in capacities that often reach beyond 1,000 MW.

4.2 Brief Description about distributed generation:

With current initiatives on smart grid and sustainable energy, distributed generations (DGs) are going to play vital role in the emerging electric power systems. To fully exploit the potential advantages of DGs, it is necessary to re-think the basic philosophy governing the electricity distribution system. The future active network will effectively and efficiently link small and medium scale electric power sources with costumer demands. DG is often used as back-up power to enhance reliability or as a means of deferring investment in transmission and distribution networks, avoiding network charges, reducing line losses, deferring construction of large generation facilities, displacing expensive grid-supplied power, providing alternative sources of supply in markets and providing environmental benefits. However, depending on the system configuration and management, these advantages may not be true. In recent years, DG has become an efficient and clean alternative to the traditional electric energy sources, and recent technologies are making DGs economically feasible. Now-a-days, DGs are the part of distributed energy resources (DERs) which also include energy storage and responsive loads. The major driving forces behind the increased penetration of DGs can be categorized into environmental, commercial and regulatory factors. Brief notes on Distributed Generation is following,

- Distributed Generation (DG) employs smaller smaller-size generators.
- The electricity is usually generated by low-emission technology like wind, solar PV, fuel emission technology like wind, solar PV, fuel cells etc. Cells.
- These are distributed through the power system but are concentrated mainly closer to system but are concentrated mainly closer to the loads.

4.2.1 Distributed Generation Technologies:

Due to maturing technologies and increasing size of DGs, which play a significant and topical phenomenon in power system, there is as yet no universal agreement on the definition of DGs. These are also known as embedded generations or dispersed generations.

Current definition of DG is very diverse and range from 1kW PV installation, 1 MW engine generators to 1000 MW offshore wind farms or more.

The some of the popular DG technologies are listed below:

- Reciprocating Diesel or Natural Gas Engines
- Micro-Turbines
- Combustion Gas Turbines
- Fuel Cells
- Photovoltaic (PV) system
- Wind Turbines

Above technologies can be considered as renewable DGs. The other technologies could also be called renewable DG if they are operated with bio-fuels. Similarly, to the centralized generation, the following three generation technologies are normally used for distributed generation: synchronous generator, asynchronous generator, and power electronic converter interface.

4.2.2 Role and Integration of DGs in the Power Systems:

Different types of Distributed Generations (DG) are available and it is expected to grow in the future years. DG includes the application of small generators, scattered throughout a power system, to provide the electric power needed by electrical customers. Such locally distributed generation integrated to power system has several merits from the view point of environmental restriction and location limitations, as well as transient and voltage stability in the power system. A lot of work has been reported in literature for optimal location of DGs integrated in the distribution network. The suitable size of DGs for efficient and reliable supply is also a concern. However, the size of the DGs depends on the several factors such as availability of input energy, space, economic and environmental concerns. In the present day, power system is becoming more and more complex in structure, operation, control, management and ownership. These DGs are required to solve various existing problems of power systems and can be useful in future for providing the ancillary services, aggregation technology etc.

4.3 Distributed wind power generation:

Wind power generation is power generation that converts wind energy into electric energy. The wind generating set absorbs wind energy with a specially designed blade and converts wind energy to mechanical energy, which further drives the generator rotating and realizes conversion of wind energy to electric energy. The commonly used wind power generation systems include the direct-driven wind power generating set and the double-fed wind power generating set; the direct-driven wind power generating set is connected to the grid through a full power converter, while the double-fed wind power generating set is connected to the grid through a double-fed converter. Fig. 4.1 shows a direct-driven permanent magnet synchronous wind power generation system. For this system, wind energy drives the wind turbine rotating, which further drives the generator running, converting mechanical energy into electric energy. The stator of the permanent magnet synchronous generator outputs AC power with variable amplitude and frequency. By passing through an AC/DC rectifier, the AC power will be inverted into DC power, and then, with a DC/AC inverter, the output DC power will be inverted to AC power and connected to the AC grids. The power flows unidirectional from the wind turbine to the AC grid. When it is only required to be connected to DC grids, the DC/AC inversion step can be omitted. Fig. 4.2 shows the double-fed wind power generation system. Both the stator and the rotor of the double-fed generator can supply power to the grid, in which the rotator is connected to the grid through a converter, while the stator is connected to the grid directly. In case of speed change of the generator rotator, the converter will ensure the stator rotating magnetic field and the grid are in the same frequency by regulating the frequency of exciting current.

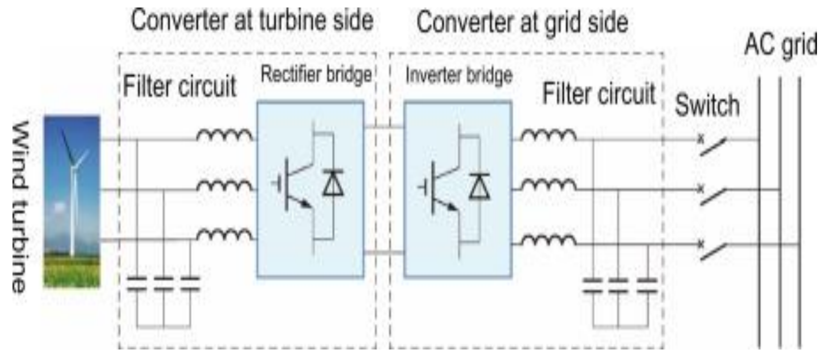


Fig4.1: Direct-driven permanent magnet synchronous wind power generation system.

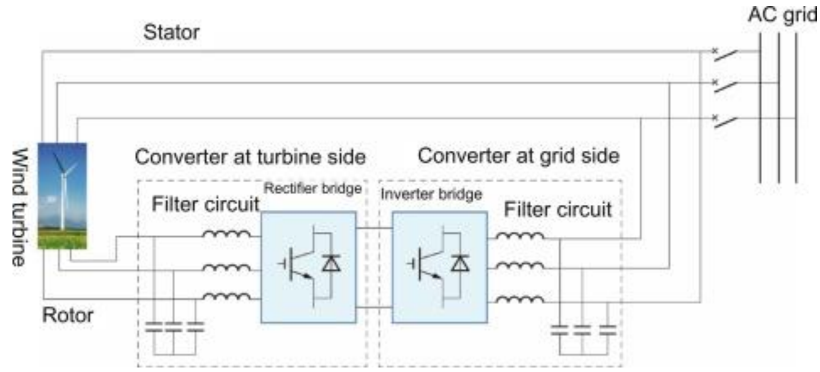


Fig 4.2: Double-fed wind power generation system.

4.3.1. Advanced AC and DC technologies to connect offshore wind farms into electricity transmission and distribution networks:

Wind power generation, particularly offshore wind power, has been the subject of dramatically increasing interest in recent years. Various types of configuration of offshore wind farms are required to collect and transfer the offshore wind power to onshore grids with sufficient efficiency and reliability. Wind turbine technologies and power electronics converters provide wind power developers and operators with the options necessary to achieve wind power transmission targets.

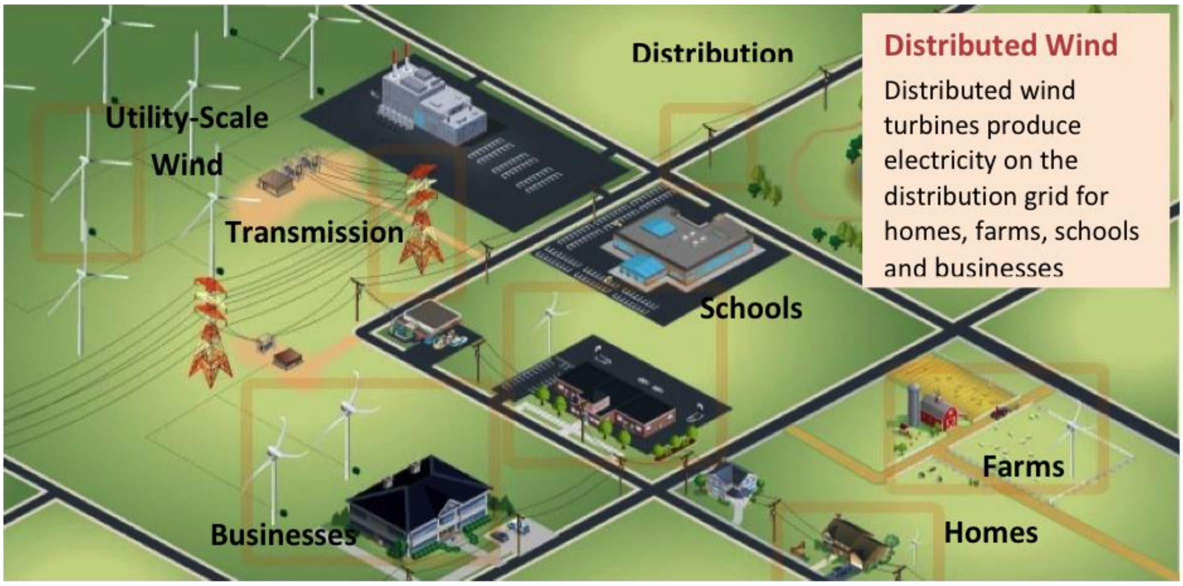
In this chapter, major configurations and features of both AC and DC wind generators are illustrated. The AC generators include the fixed-speed induction generator (FSIG), doubly fed induction generator (DFIG) and full-power converters for induction generators and permanent magnet synchronous generators (PMSG). The DC wind generators cover DC power output obtained through AC–DC rectifiers and directly through DC generators.

4.3.2. Defining Distributed Wind:

Wind systems are characterized as distributed based on the following criteria:

- Proximity to end-use: wind turbines installed at or near the point of end-use for the purposes of meeting onsite load or supporting the operation of the local (distribution or micro) grid.
- Point of interconnection: wind turbines connected on the customer side of the electric meter or directly to the local grid

Distributed wind energy systems are connected either physically or virtually on the customer side of the meter (to serve onsite loads) or directly to the local distribution or micro grid (to support local grid operations or offset nearby loads). This distinction differentiates typically smaller distributed wind systems from power generated at wind farms comprised of dozens or hundreds of multi-MW wind turbines and sent via transmission lines to substations for subsequent distribution to loads. A picture of distributed wind turbines on distribution grid source is following,



Distributed wind turbines on the distribution grid. Source: U.S. Dept. of Energy

Chapter 5

Radial Distribution System and Simulation by Using OpenModelic and OpenIPSL

5.1 Overview:

All relevant planning data will be used for detailed modelling of Radial Distribution System and Simulation using OpenIPSL simulation platform. In a three-phase ac power system active and reactive power flows from the generating station to the load through different networks buses and branches. The flow of active and reactive power is called power flow or load flow. Power flow studies provide as systematic mathematical approach for determination of various bus voltages, there phase angle active and reactive power flows through different branches, generators and loads under steady state condition. In order to obtain a reliable power system operation under normal balanced three phase steady state conditions, it is required to have the followings:

- Bus voltage magnitudes remain close to rated values
- Generator operates within specific real and reactive power limits.
- Transmission lines and transformers are not overloaded

Power flow analysis is used to determine the steady state operating condition of a power system. Power flow analysis is widely used by power distribution professional during the planning and operation of power distribution system.

5.2 Model description:

The radial type of distribution system is used extensively to serve the light- and medium-density load areas where the primary and secondary circuits are usually carried overhead on poles. His distribution substation or substations can be supplied from the bulk-power source over radial or loop sub transmission circuits or over a sub transmission grid or network. The radial system gets its name from the fact that the primary feeders radiate from the distribution substations and branch into sub feeders and laterals which extend into all parts of the area served. The distribution transformers are connected to the primary feeders, sub feeders, and laterals, usually through fused cut outs, and supply the radial secondary circuits to which the consumers' services are connected. Here we can see similarly a radial distribution system consist of 69 busses with 1 generator connected with first bus, and 48 loads.

5.3 Method for load-flow solution of radial distribution networks:

5.3.1 Backward/ Forward Sweep Method:

Let us consider a radial network, the backward/forward sweep method for the load-flow computation is an iterative method in which, at each iteration two computational stages are performed: The load flow of a single source network can be solved iteratively from two sets of recursive equations. The first set of equations for calculation of the power flow through the branches starting from the last branch and proceeding in the backward direction towards the root node. The other set of equations are for calculating the voltage magnitude and angle of each node starting from the root node and proceeding in the forward direction towards the last node. In a transmission system, we know that X by R ratio is very high. Due to high X by R ratio there will be decoupled effect means your P will be basically depending on angle of the voltage that is delta and Q will mainly depend upon your voltage difference delta V. And, because of this decoupling effect Jacobean metrics of Newton Raphson will be diagonal dominating, and it help in fast convergence. Therefore, load flow methods which is used in the transmission line is neither efficient nor simple for distribution system. A distribution system, having very poor X by R ratio, generally unbalanced, and radial or weakly meshed in nature requires to develop different load flow algorithm, which is more efficient and simpler. The algorithm should demand very less memory, good convergence and equipped with acceptable accuracy. One of the classical algorithms for load flow study is backward forward sweep load flow algorithm.

A. Forward sweep Method

The forward sweep is basically a voltage drop calculation with possible cur-rent or power flow updates. Nodal voltages are updated in a forward sweep starting from branches in the first layer toward those in the last. The purpose of the forward propagation is to calculate the voltages at each node starting from the feeder source node. The feeder substation voltage is set at its actual value. During the forward propagation the effective power in each branch is held constant to the value obtained in backward walk.

B. Backward Sweep Method

The backward sweep is basically a current or power flow solution with possible voltage updates. It starting from the branches in the last layer and moving towards the branches connected to the root node. The updated effective power flows in each branch are obtained in the backward propagation computation by considering the node voltages of previous iteration. It means the voltage values obtained in the forward path are held constant during the backward propagation and updated power flows in each branch are transmitted backward along the feeder using backward path. This indicates that the backward propagation starts at the extreme end node and proceeds towards source node.

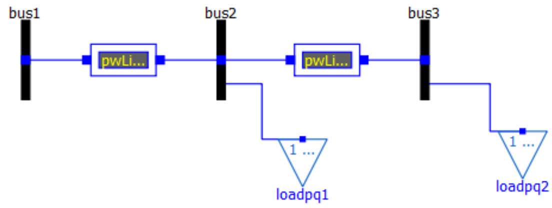


Figure 5.1: Simple 3 bus system

Let us see working of the backward forward sweep load flow algorithm using a three-bus system, shown in figure: 5.1 including reference bus. In the given system, at node 2 and 3, say the loads are $P_{L2}+jQ_{L2}$ and $P_{L3}+jQ_{L3}$.The voltage at bus 1 is $V_S \angle 0^{\circ}$. And it will remain constant for all iterations. Therefore, voltage at bus 2 and bus 3 is Vs ∠0°. Here, bar on the voltages represents vector quantity, but for brevity many times it will be written simply as V_2 and V_3, which actually represent complex quantity.

$$I_2{}^2 = \frac{P_{L2} + jQ_{L2}}{V_2}$$

$$I_3{}^2 = \frac{P_{L3} + jQ_{L3}}{V_3}$$

$$I_{23}{}^2 = I_3{}^2$$

$$I_{12}{}^2 = I_{23}{}^2 + I_2{}^2$$

$$V_2{}^2 = V_S \angle 0° - Z_{12} I^2{}_{12}$$

$$V_3{}^2 = V_2{}^2 - Z_{23}I_{23}{}^2$$

5.3.2 Direct Approach Based Load Flow Analysis: Weakly Meshed System

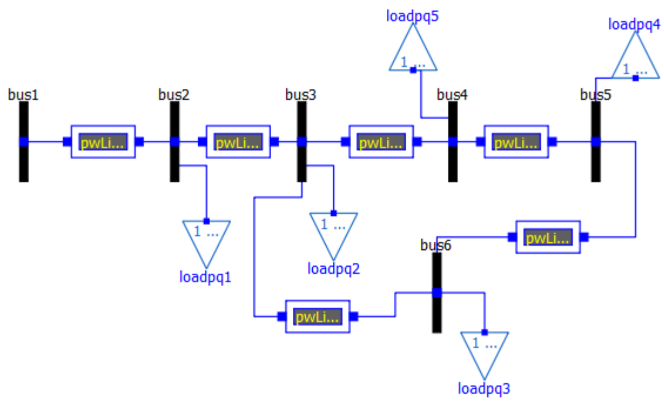


Fig 5.2: Diagram of Weakly Meshed System

Here, consider 1 weakly mesh system where say node 5 and node 6 is connected such that there is 1 loop which is getting formed. So, in this particular branch, there will be current, say I56, is flowing in given direction. So, hereby applying KCL at node number 5, then I can write your I45 will be equal to your current I5 plus I56. Whereas branch current I36 will be load current I6 and I56, here I56 will be in opposite direction of current in the line 5-6.

$I_{12} = I_2 + I_{23} = I_2 + I_3 + I_4 + I_5 + I_6$ .... (1)

$I_{23} = I_3 + I_{34} + I_{36} = I_3 + I_4 + I_5 + I_{56} + I_6 - I_{56} = I_3 + I_4 + I_5 + I_6$ .... (2)

$I_{34} = I_4 + I_{45} = I_4 + I_5 + I_{56}$ .... (3)

$I_{45} = I_5 + I_{56}$ .... (4)

$I_{36} = I_6 - I_{56}$ .... (5)

$I_{56} = I_{56}$ .... (6)

However, the matrix of node current contains node current as well as loop branch current, here it is I_{56}. in this elimination of the element related to loop current produces radial system BIBC matrix. So, there are actually branch currents with an extra branch, which is added to form loop and has loop current I_{loop}. So, basically, in matrix form the whole branch current written as

I_{branch} current and I_{loop} current. So, we have got BIBC matrix for weakly meshed system.

5.3.3 Gauss Implicit Z - Matrix Method

The implicit Z-bus method is the most commonly used method. The method works on the principle of superposition as applied to the system bus voltages. According to the principle of superposition, only one type of source is considered at a time for the calculation of bus voltages. An iterative procedure is used in this method. Initially, all the bus voltages are assumed to be equal to the swing bus voltage (only swing bus is considered as the source in the system with all the current injections at load buses taken as zero). In the next step, since the current injections and bus voltages are dependent on each other, these quantities are required to be determined iteratively. The swing bus is short-circuited while calculating the component of bus voltages due to the current injections. The following steps are involved in this algorithm:

1. The bus voltages are assumed to have some initial, value. The Y-bus (Y_B) is formed.

2. The current injections are computed by using equation 3 for which the recent values of bus voltages are taken.

3. The voltage deviations (VD) due to current injections are computed by the factorization of Y-bus,

$$I^k = [Y_B][VD]^K$$

4. The voltage deviations calculated in step 3 are superimposed on the no load bus voltage (VNL). Hence, the bus voltages are updated as,

$$V^{k+1} = V_{NL} + [VD]^k$$

5. The convergence is checked. If the method has not converged, then steps from 2 to 4 are repeated.

5.4 Simulation Results and Case Studies:

This Model is approached by using OpenModelica and OpenIPSL. Model consists of 1 generator and 69 busses with 48 loads; the generator is connected to bus number 1 of rating 12. 7kv.power is delivered from the main branch, bus 1 and bus 2 to sub-branches then it split out from the sub-branches again.

5.4.1 Design of Radial Distribution Network

The design of radial distribution network is based for easier protection and voltage control and all though control of power flow also. Model is characterised by 2 cases, in first case total system is connected with Genrou of rating 12.7kv and Base power of Machine is 10 MVA and in case 2 WT3G (Wind Turbine) is connected with radial distribution network. The power generated by Genrou will be transmitted through the entire system shown in figure 5.2. Genrou recognize variation of the inductance coefficients of the machine implicitly and handle saturation by developing a term to be added on to the field current that is calculated on the basis of the unsaturated inductance coefficients, and in figure 5.3 we can observe that entire system is connected with WT3G. A Fault is connected (PW Fault) with bus number 35 for both cases which is considered as line to line fault. Each and Every load is considered as Constant PQ Load.

Connection of69 Bus Radial Networks

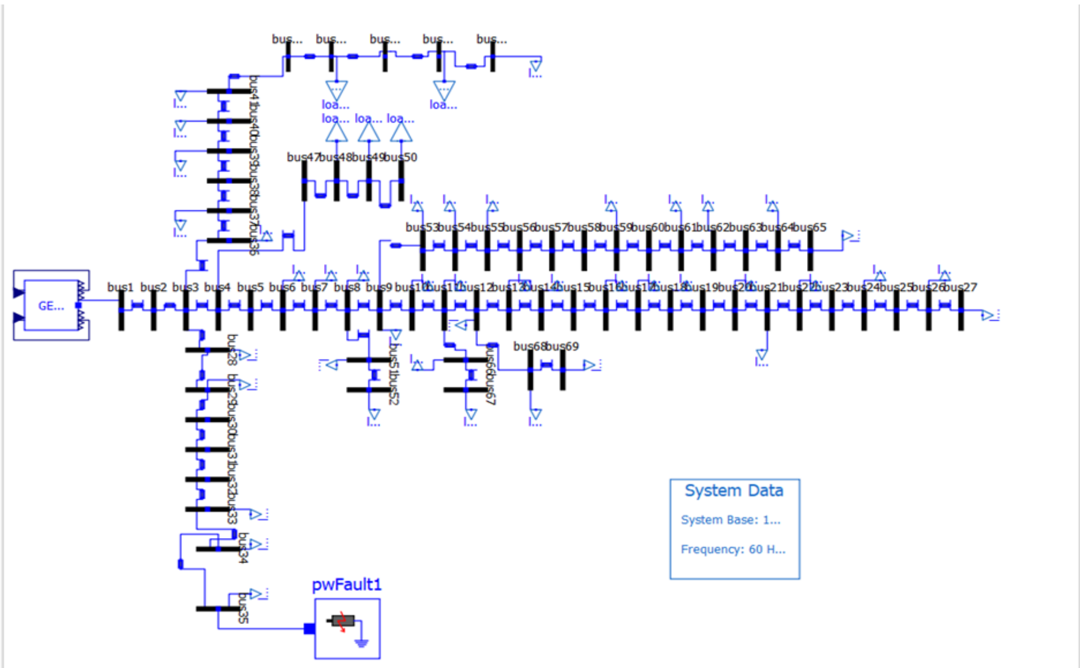


Fig 5.2: 69 Radial Distribution network with Genrou by using OpenModelica

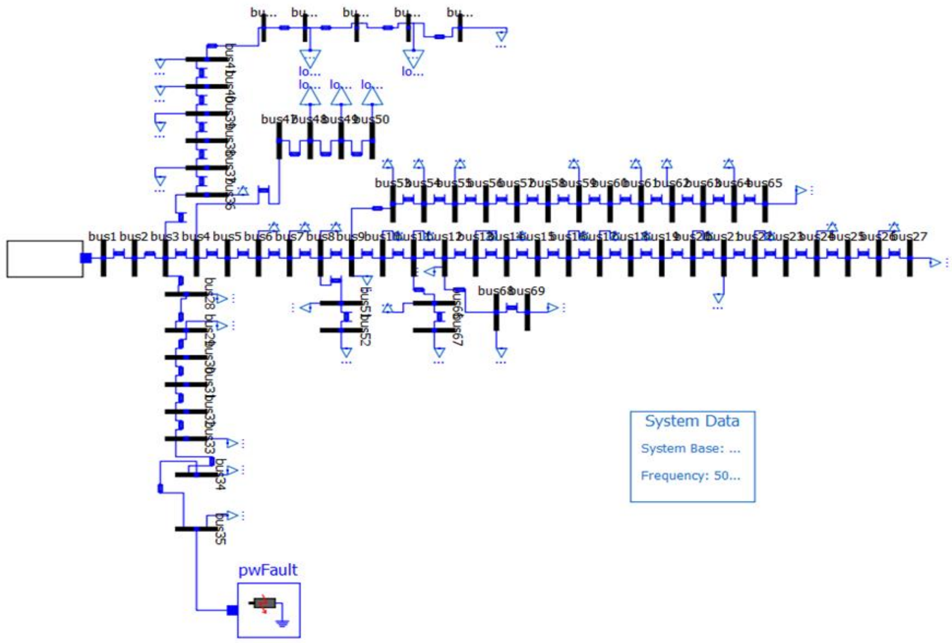


Fig 5.3: 69 Radial Distribution network with WT3G by using OpenModelica

5.4.2 Power flow modelling data for case study:

GENROU DATA:

Symbol	Value	Unit
P_0	4.21	MW
Q_0	2.88	Mvar
anglev	0.934373	deg.
delta	-143.542	deg.
Te	0.417013	pu
Xl	0.12	

Table 5.1: Genrou Data from Model

WIND TURBINE GENERATOR DATA:

Symbol	Value	Unit
P_0	4.21	MW
Q_0	2.88	Mvar
anglev	-0.5716	deg.
delta	-0.5735	deg.

Table 5.2: Wind Turbine Generator Data from Model

Chapter 6

Dynamic simulation results

For all simulations, the following conditions were applied:

- The fault applied is a bolted symmetrical three-phase applied 0.886 second after the start of the simulation in bus 35.
- The Fault is applied with duration of 0.4 sec for case 1 and 0.5 sec for case 2

Voltage regulators are not present and manual excitation control is used. This implies that in steady- state, the magnitude of the voltage source is determined by the field current which is constant. Transient stability is judged by the first swing, which is normally reached within one or two seconds. Figure 6.1 shows that during the fault, and after the fault occurs dynamic result has come with a small oscillation.

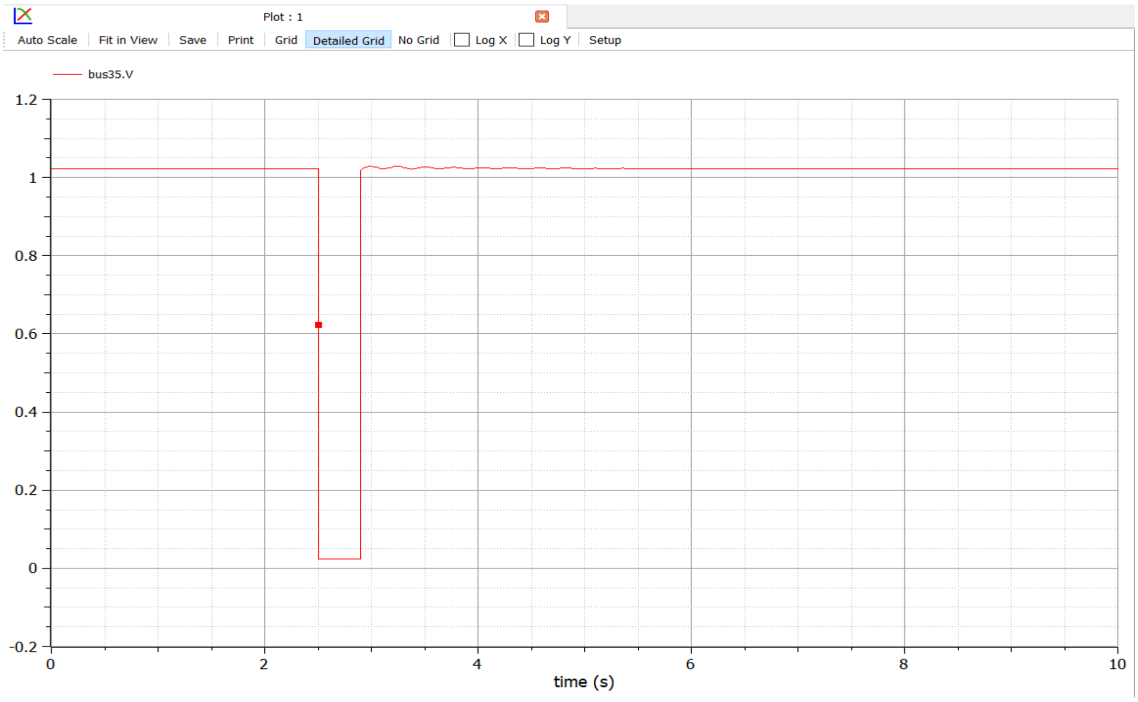


Fig 6.1: Dynamic Result of bus 35

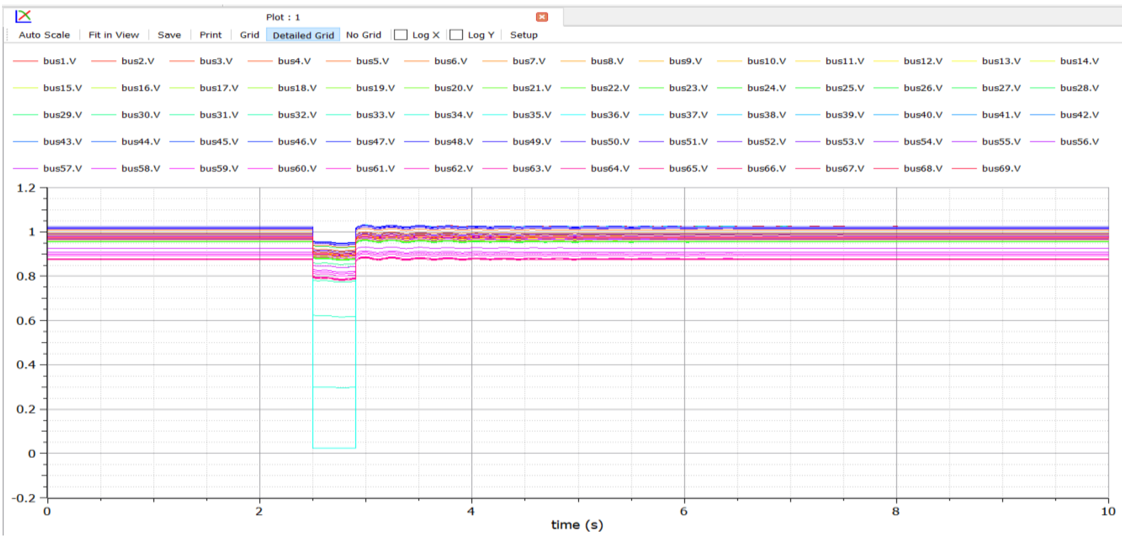


Fig 6.2: Dynamic Result of 69 bus for case 1

In case 2. Instead of the usual field winding fed with DC and an armature winding where the generated electricity comes out there are two three phase winding one stationary and one rotating both separately connected to outside of generator. WT3G is connected with entire system instead of genrou.

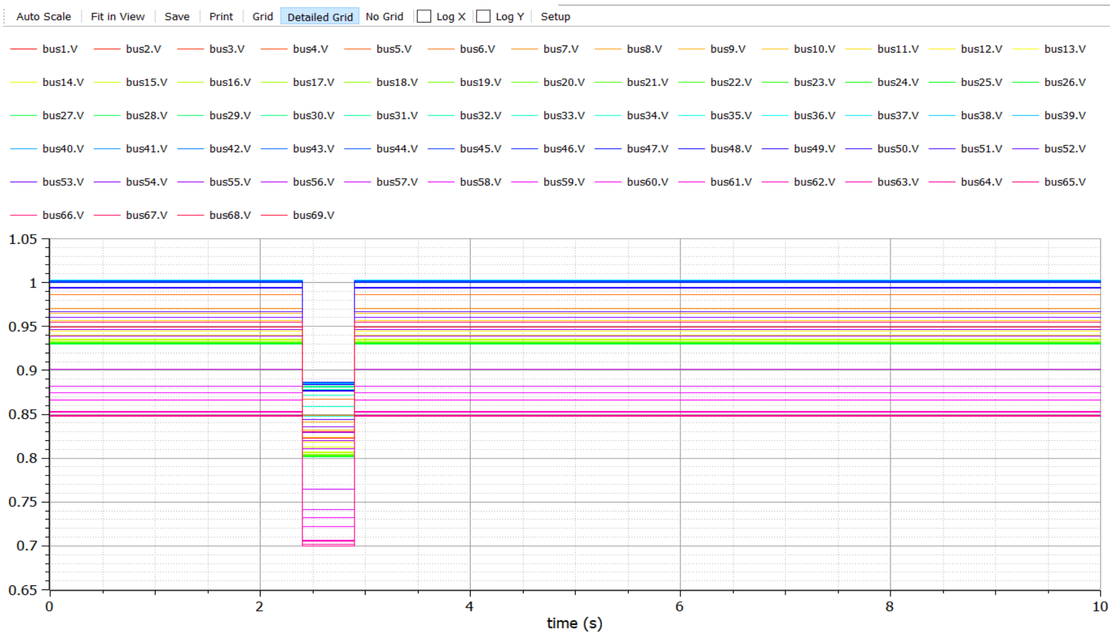


Figure 6.3: Steady State analysis of 69 bus with WT3G

The stability of the model in case 2 when WT3G is connected it is totally dependent on the modelling of the wind turbine generator type 3. Here this total package is consisting of constant PQ load modelling. So we observe from figure 6.4 and 6.5 that there is no oscillation is coming after the fault occurs, the system is in stable condition.

Conclusion

Power flow and dynamic analyses were carried out to check efficiency and practical impacts of our industry of Radial Distribution Network. The PSSE Wind turbine stability model WT3 was used for the dynamic simulation of Radial Distribution Network. Moreover, Distributed Generation is most efficient and very cost effective, so by this modelling and simulation we can conclude that radial distribution system consists of easier voltage control, easier fault location and easier protection.

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