Summer Fellowship Report

On

Dynamic Study on Wind Farm Modeling by Using OpenModelica and OpenIPSL

Submitted by

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Under the guidance of

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Sincerely,

Gandra Mahesh

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Chapter 1

Introduction

1.1 Introduction to OpenIPSL

OpenModelica is a free/libre and open-source modeling 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 Introduction to Wind Farm Modelling

The proper modeling of wind farm projects in systems studies is becoming increasingly important to system operators. In the past decade, wind power has evolved into a significant renewable energy source which continues to grow rapidly. Wind farms are growing in size and complexity and they consist of many units with significant power output.

In a power system there are always limitations as to how much power can be transmitted from one point to another point. The limitations depend on thermal limits, angle stability limits or voltage stability limits.

The objective of this report is to present the most significant characteristic and specific aspects of detailed wind farm modeling. A specific case study is analyzed to identify the main requirements for wind farm connection to the transmission grid.

Chapter 2

Breif Description About WT1,WT2 and WT4

2.1 WT1 – Generic Wind Model Block Diagaram

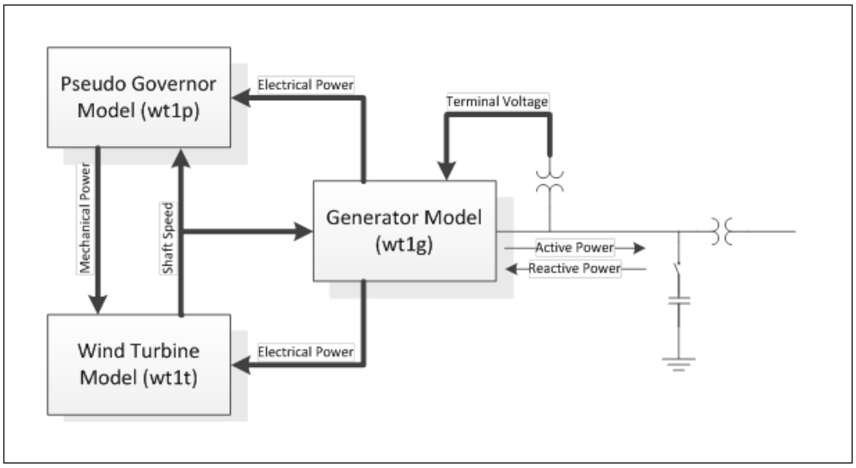

Figure 2.1: WT1 Block Diagram

2.1.1 Description about Induction Generator (wtg1)

The generator model wt1g is based on the standard PSLF model for an induction generator (genind), but without the mechanical components, i.e., the generator inertia which is included in the turbine model (wt1t). The model is initialized to match the power generation specified in the power flow. The reactive requirements of the generator are met by the addition of a fictitious shunt at the machine terminals.

2.1.2 Description about Turbine Model (wt1t)

The turbine wt1t 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 Htfrac = 0 the model can be switched to a conventional single mass representation

2.1.3 Description about Pseudo Governor Model (wt1p)

The pseudo governor model wt1p is an attempt to simplify and generalize the calculation of the aero-torque. This model was designed and developed after a thorough investigation of aerodynamic characteristics and pitch control of several vendor-specific wind turbines. Finally, the arrangement shown below was suggested. The model uses two inputs, one in terms of the blade rotor speed deviation and another in terms of the real power at the machine terminals. These two inputs combined are processed by a PI controller with non-wind-up limits. The filtered output is the mechanical power on the rotor blade side which is used by the wt1t model.

2.2 WT2 – Generic Wind Model Block Diagram

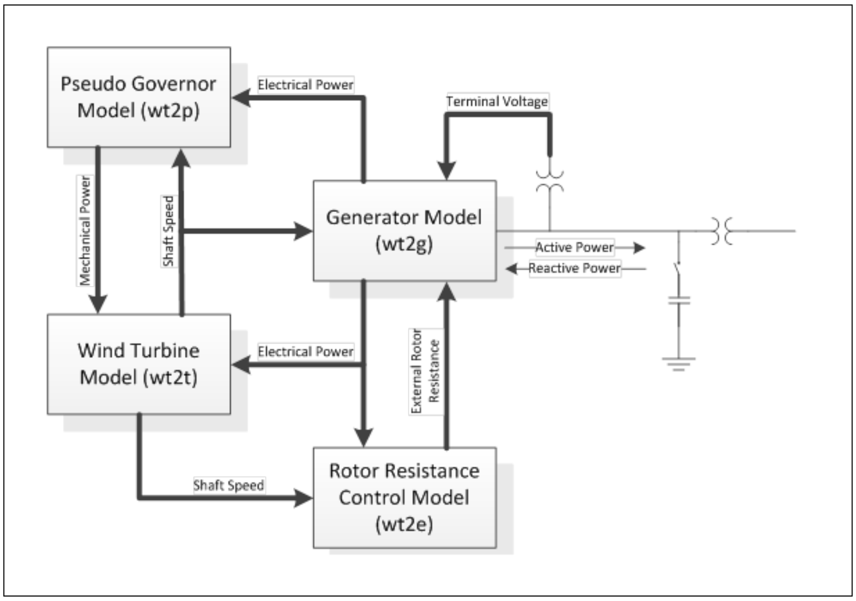

Figure 2.2: WT2 Block Diagram

2.2.1 Description about Induction Generator Model (wt2g)

The Generator model wt2g is a modified standard model of the induction machine with the logic for calculating the external rotor resistance at initialization and some other provisions included. This is the slightly modified model of the wound rotor induction machine.

2.2.2 Description about Turbine Model (wt2t)

The turbine wt2t 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 Htfrac = 0 the model can be switched to a conventional single mass representation

2.2.3 Description about Pseudo Governor Model (wt2p)

The pseudo governor model wt2p is an attempt to simplify and generalize the calculation of the aero-torque. This model was designed and developed after a thorough investigation of aerodynamic characteristics and pitch control of several vendor-specific wind turbines.

Finally, the arrangement shown below was suggested. The model uses two inputs, one in terms of the blade rotor speed deviation and another in terms of the real power at the machine terminals. These two inputs combined are processed by a PI controller with non-wind-up limits. The filtered output is the mechanical power on the rotor blade side which is used by the wt2t model.

2.3 WT4 – Generic Wind Model Block Diagram

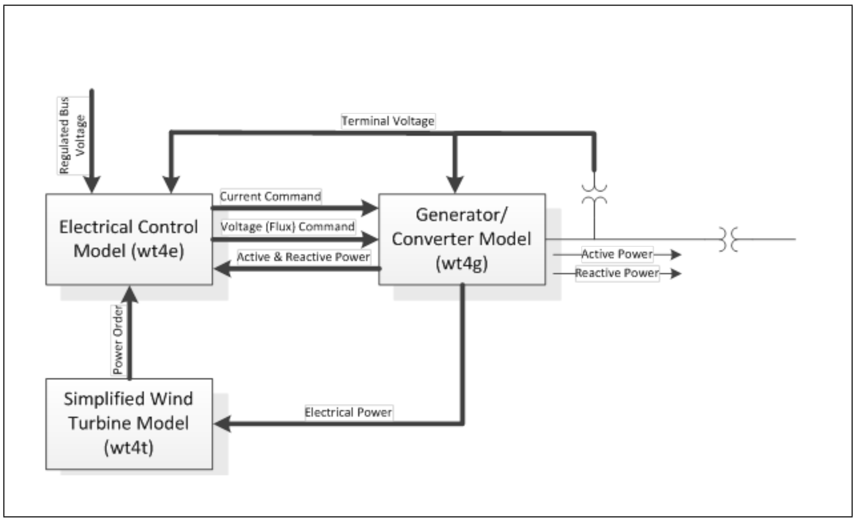

Figure 2.3: WT2 Block Diagram

2.3.1 Description about Generator/Converter Model (wt4g)

This model (wt4g) 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.

The **"High Voltage Reactive Current Management"** block limits the reactive current injected into the network equations such that the terminal voltage of the machine never exceeds Volim of nominal, as long as the converter is within current limits.

The **"Low Voltage Active Current Management"** block is designed to capture the characteristics of active power under very low voltage scenarios. This low voltage limit is designed to reduce the activity currently in a linear fashion. The linear function is somewhat like that shown in the "low voltage power logic" block but starts at Lvpnt1 p.u. voltage and declines to zero at Lvpnt0 p.u. voltage.

2.3.2 Description about Turbine Model (wt4t)

This model (wt4t) is an equivalent of the simplified wind turbine model. The wind turbine model represents the relevant controls and mechanical dynamics of the wind turbine. The model accepts the machine terminal active power from the electrical control model and the mechanical power calculated by the aerodynamic model. The turbine model sends a power order to the electrical control for the converter to deliver the requested power to the grid. The electric power delivered to the grid is returned to the turbine model for use in the calculation of rotor speed. The speed controller does not differentiate between shaft acceleration due to an increase in wind speed or due to system faults. In either case, the response is appropriate and relatively slow compared to electrical control. The turbine control acts to smooth out electrical power fluctuations due to variations in shaft power. By allowing the machine speed to vary around its rated value (120 %), the inertia of the machine functions as a buffer to mechanical power variations.

2.3.3 Electrical Control Model (wt4e)

The converter can be modulated intentionally to produce current at more than one operating frequency. Instead of the conventional practice of modulating the converter with a single dominant current (ignoring the harmonic issues for this discussion), the converter at hand is modulated to produce a unique unbalanced combination of ac currents. One current component in the converter is modulated at a variable frequency, positive sequence current, appropriate for the generator. Its frequency is controlled to maintain a slip frequency on the induction generator that gives optimum power output. The other current a component in the converter is a rated frequency, e.g., 60 Hertz, zero-sequence current. If the induction generator has no neutral connection, then zero-sequence current will not flow in the generator. A zero sequence filter, connected directly in parallel with the induction generator, collects this current. The filter can be as simple as star connected inductors or can be based on a zigzag transformer, for example. A zigzag transformer naturally blocks positive sequence current while allowing zero-sequence current to be collected at its neutral point. Therefore, a single-phase load can be supplied when connected between the filter's neutral point and the center point of the converter's split dc bus. If the single-phase load is active, the power factor can be modulated arbitrarily.

Chapter 3

WT3 – Generic Wind Model

The WT3 WECC generic wind turbine stability model was developed to simulate the performance of a wind turbine employing a doubly fed induction generator (DFIG) with the active control by a power converter connected to the rotor terminals.

The model is based on the detailed GE [1] wind turbine model and consists of four components: generator/converter, converter control, wind turbine, and pitch control. Several simplifications were made to the General Electric WTG [2] model, for instance: the active power control and General Electric Wind Inertia control were excluded. In the generic Type 3 generator/converter model, the flux dynamics are eliminated to reflect the rapid response of the converter to the higher level commands from the electrical controls.

The model also includes a Low Voltage Power Logic (which can be bypassed) used to limit the real current command during and immediately following sustained faults. The converter control model consists of two components: the reactive and active power control modules. The converter control dictates the active and reactive power to be delivered to the system via the current and voltage commands to the generator, Ipcmd, and Eqcmd, respectively. The reactive power order, Qord, can either be held constant or be computed by a separate model, the Wind Plant Reactive Power Control Emulator or the power factor regulator.

The Wind Plant Reactive Power Control Emulation represents a simplified equivalent of the supervisory VAr controller portion of the entire wind farm management system. The active power order is derived from the generator power and speed. The speed reference, ref, is obtained from a turbine speed setpoint vs. power output f(Pgen) curve. A very simplified aerodynamic model is used in the Type 3 generic WTG model. This model does not require the representation of the power coefficient curve. In the pitch controller model, the blade position actuators are rate-limited and there is a time constant associated with the translation of blade angle to mechanical output. The pitch control consists of two PI controllers that act on the speed and power errors.

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[1] GE means General Electric

[2] WTG means Wind Turbine Generator

3.1 Brief Description about WT3 modeling package

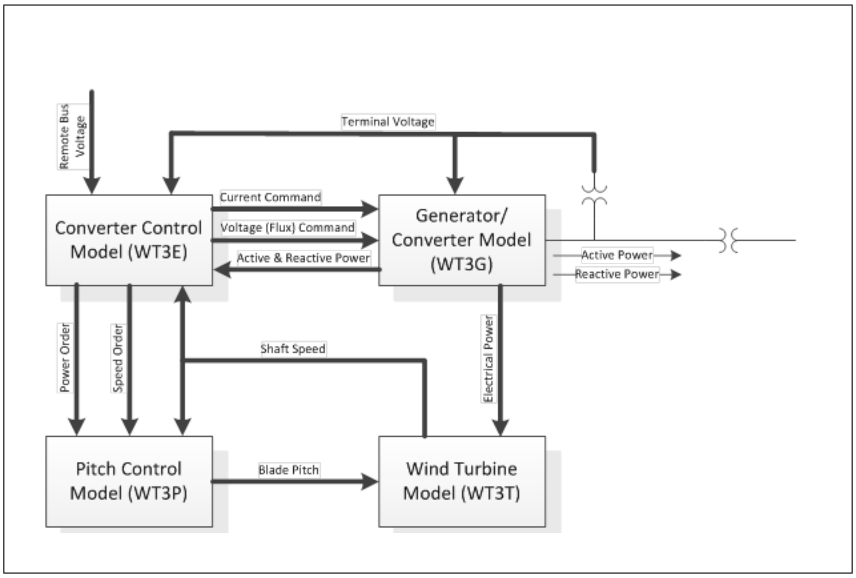

Figure 3.1: WT3 modeling package

The WT3 modeling package includes 4 main models as follows:
1.Generator/Converter Model WT3G
2.Electrical control model (converter control) for the Generic Wind Model WT3E
3.Mechanical control (wind turbine) for the WT3 Generic Wind Model WT3T
4.Pitch control model for the WT3 Generic Wind Model WT3P

WIND PLANT SPECIFIC ADJUSTMENTS:

- Varflg and Vltflg are flags that must be set by the user based on the setting defined for each WPP to be included in the case study.
- Fn = Fraction of WTG on the wind plant that are on-line. Used only for VAR control gain adjustment PFAref = initialized from load flow data.
- Vc is the controlled bus specified within the module WT3E. It can be terminal voltage or remote bus voltage or fictitious remote bus voltage.
- Xc is a fictitious reactance used to compute the voltage drop to offset the reference voltage of a known bus voltage Vrfq and a known branch current Ireg. (Vc= |Vrfq jXc Ireg |)
- Vw >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 modeling 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

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 3.1: Input data for WT3 Generator Model

Block Diagram of WT3 Generator

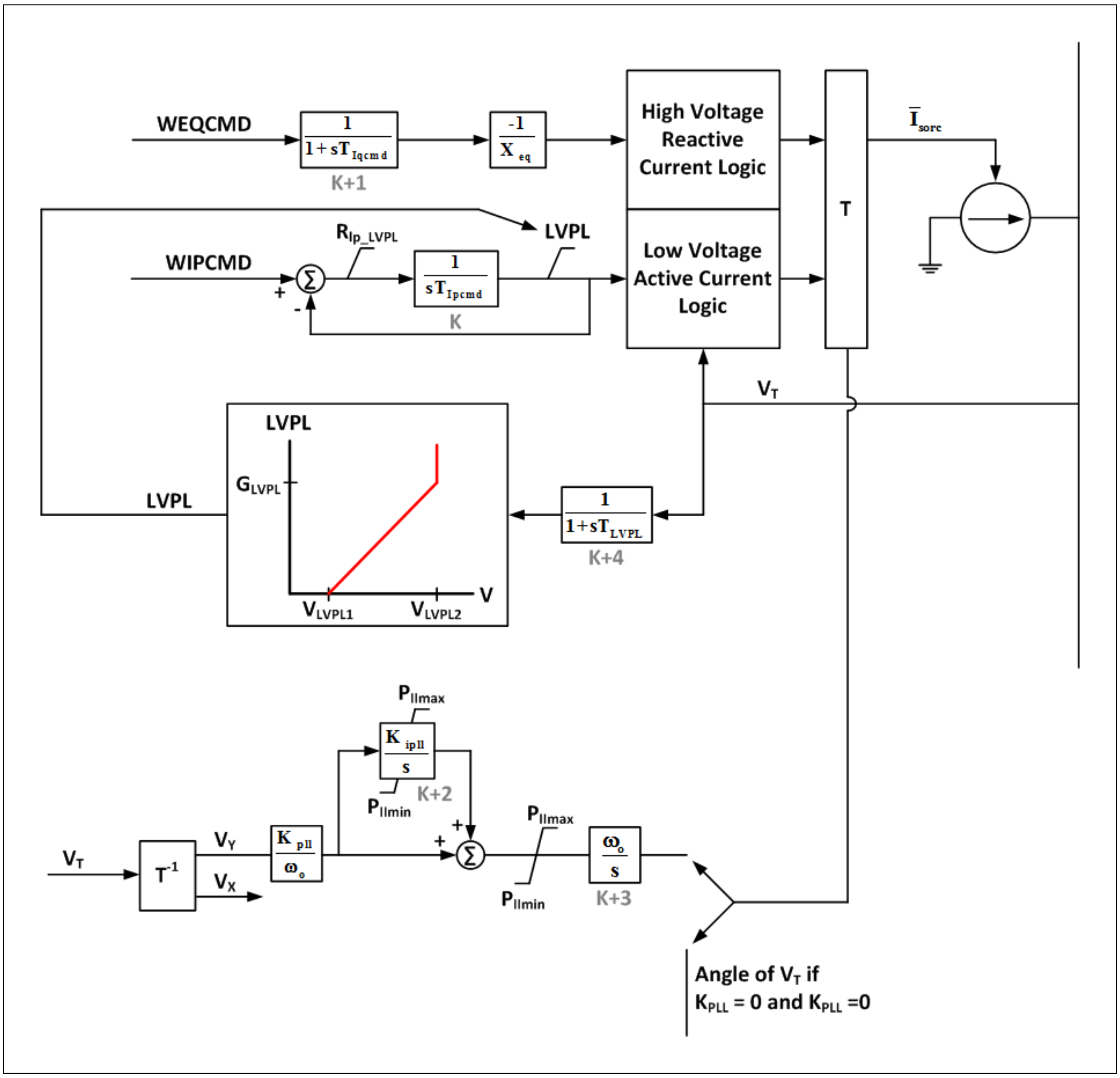

Figure 3.2: Block Diagram of WT3 Generator Model

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 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 Htfrac = 0 the model can be switched to a conventional single mass representation.

Input data for WT3 Turbine

Input data for WT3T	
Constants	Default Value and Description
J	1.25 (VW, Initial wind, pu of rated wind speed)
J+1	4.95 (H, Total inertia constant, sec)
J+2	0.0 (DAMP, Machine damping factor, pu P/pu speed)
J+3	0.7e-02 (Kaero, Aerodynamic gain factor)
J+4	21.98 (Theta2, Blade pitch at twice rated wind speed, deg.)
J+5	0.0 (Htfrac, Turbine inertia fraction (Hturb/H)[1])
J+6	1.8 (Freq1, First shaft torsional resonant frequency, Hz)
J+7	1.5 (Dshaft, Shaft damping factor (pu))
K	(Shaft twist angle, rad.)
K+1	(Turbine rotor speed deviation, pu)
K+2	(Generator speed deviation, pu)
K+3	(Generator rotor angle deviation, pu)
VARs	Description
L	Paero on the rotor blade side, pu
L+1	Initial rotor slip
L+2	Initial internal angle
L+3	Initial pitch angle
L+4	Paero initial

Table 3.2: Input data for WT3 Turbine Model

Block Diagram (Dual Mass)

To simulate one-mass mechanical system, set Htfrac =0. To simulate two-mass mechanical system, set Htfrac as 0 <Htfrac <1

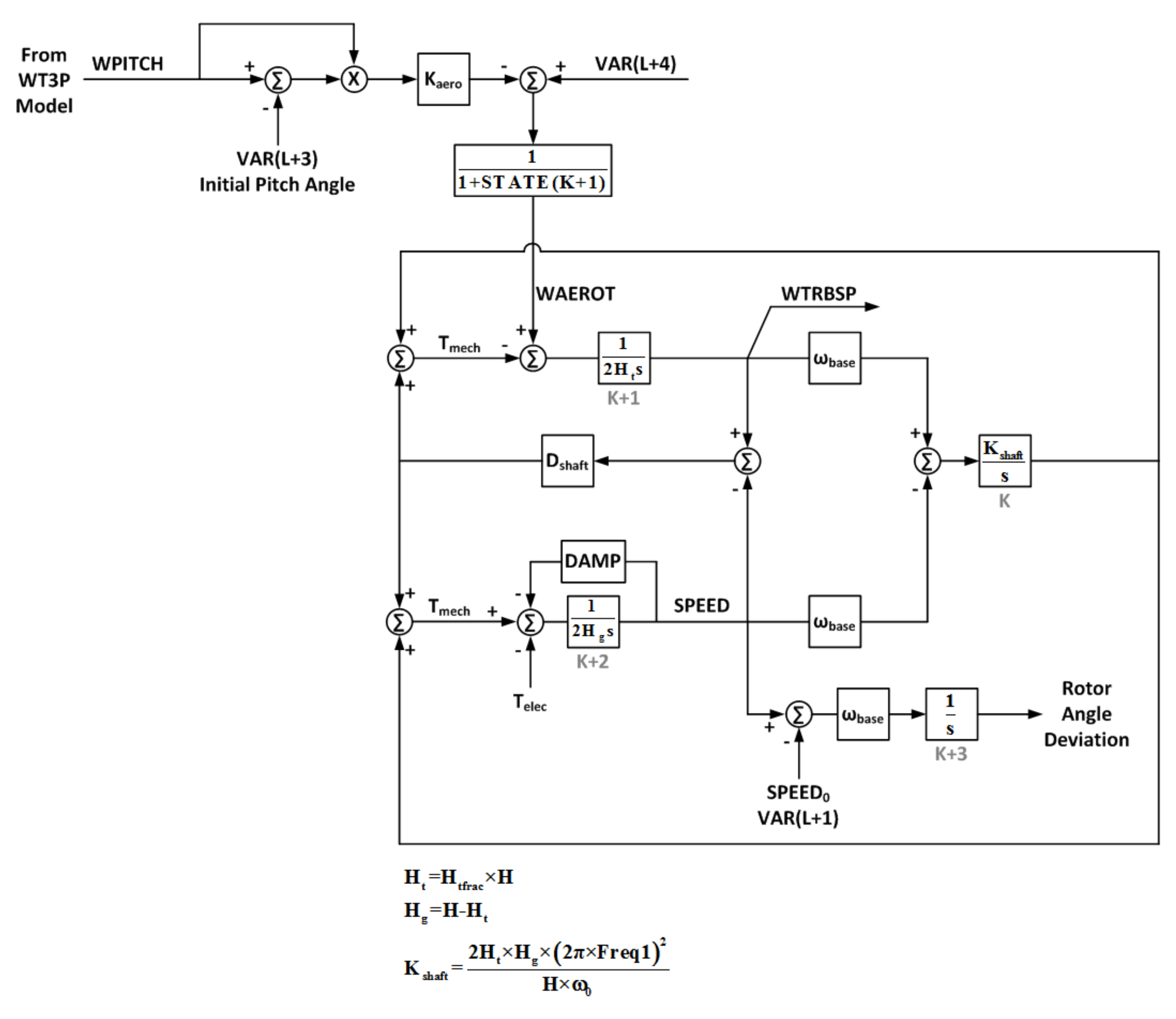

Figure 3.3: Block Diagram of WT3 Turbine Model

3.1.3 Pitch Control Model (WT3P)

Pitch control is the technology used to operate and control the angle of the blades in a wind turbine. The system is in general either made up of electric motors and gears or hydraulic cylinders and a power supply system. The pitch system is a closed-loop drive system. The turbine main controller calculates the required pitch angle from a set of conditions, such as wind speed, generator speed, and power production. The required pitch angle is transferred to the pitch system as a set point. If the actual angle is NOT the same as the set point, the system will direct power to the electric motor or fluid to the cylinder to make the actuator move the blade to the required angle.

Input data for WT3 Pitch Control

Input data for WT3P	
Constants	Default Value and Description
J	0.30(Tp, Blade response time constant)
J+1	150.0(Kpp, Proportional gain of PI regulator (pu))
J+2	25.0(Kip, Integrator gain of PI regulator (pu))
J+3	3.0(Kpc, Proportional gain of the compensator (pu))
J+4	30.0(Kic, Integrator gain of the compensator (pu))
J+5	0.0(TetaMin, Lower pitch angle limit (degrees))
J+6	27.0(TetaMax, Upper pitch angle limit (degrees))
J+7	10.0(RTetaMax, Upper pitch angle rate limit (degrees/sec))
J+8	1.0 (PMX, Power reference, pu on MBASE)
K	(Shaft twist angle, rad.)
K+1	(Turbine rotor speed deviation, pu)
K+2	(Generator speed deviation, pu)
K+3	(Generator rotor angle deviation, pu)
STATEs	Description
K	Output lag
K+1	Pitch control
K+2	Pitch compensation

Table 3.3: Input data for WT3 Pitch Control Model

Block Diagram of WT3 Pitch Control Model

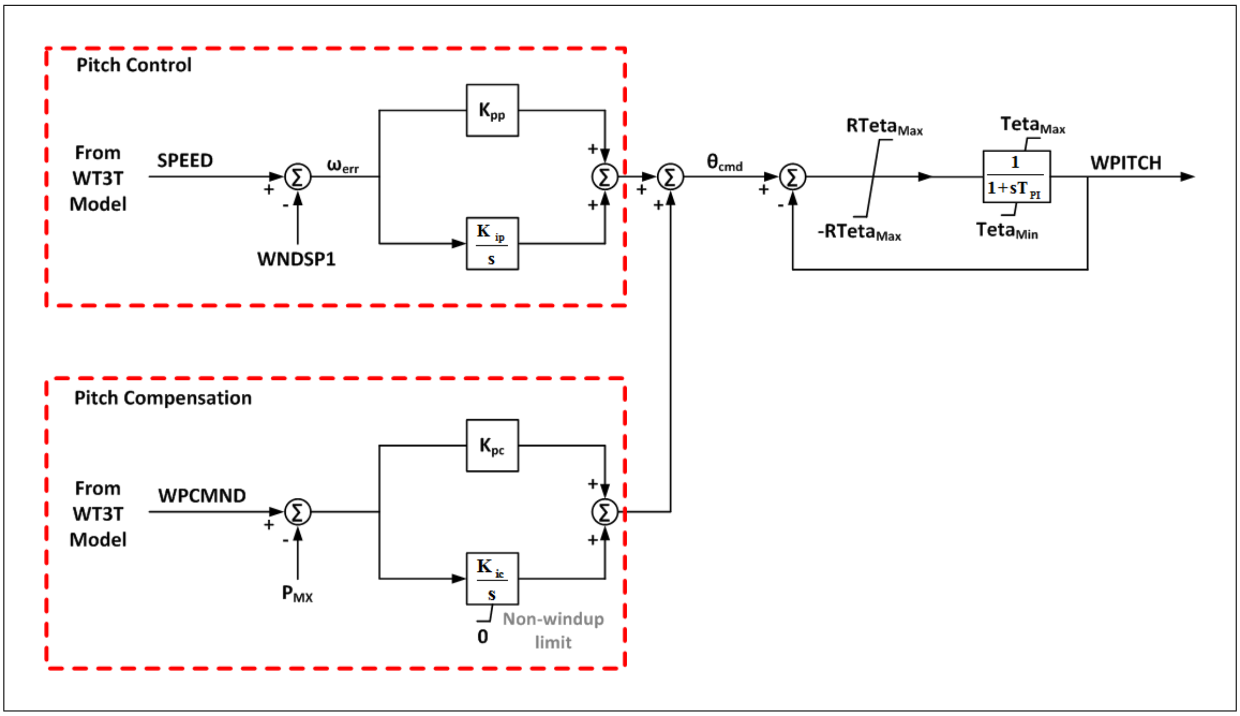

Figure 3.4: Block Diagram of WT3 Pitch Control Model

3.1.4 Converter Control Model (WT3E)

This model (WT3E) dictates the active and reactive power to be delivered to the system. The reactive controls including the emulation of the centralized Wind Plant reactive power controller are shown below. The switch, VARFLG, provides for 3 modes of control: constant reactive power, constant power factor angle, or voltage regulation by a wind plant reactive power controller. The switch, VLTFLG, provides for bypassing the closed-loop terminal voltage regulator, which is not used in all implementations and currently always set to 1. The non-linear function, f(Pelech), is used to model the desired WTG speed as a function of the power level. The input data for this function are values of the desired speed at several levels of power output, with linear interpolation to be used between specified values. The electrical control model WT3E can be used with WT3G1as well as with the improved WT3G2 models. When WT3E is used with the WT3G1model, it is recommended that ICON(M+2) be set to 1, and when used with WT3G2, the ICON(M+2) be set to 2. Input data for WT3E.

Input data for Converter Control Model (WT3E)

Input data for Converter Control Model (WT3E)	
Constants	Default Value and Description
J	0.15(Tfv, Filter time constant in voltage regulator (sec))

J+1	18.0(Kpv, Proportional gain in voltage regulator (pu))
J+2	5.0 (Kiv, Integrator gain in voltage regulator (pu))
J+3	0.0 (Xc, Line drop compensation reactance (pu))
J+4	0.05 (TFP, Filter time constant in torque regulator)
J+5	3.0 (Kpp, Proportional gain in torque regulator (pu))
J+6	0.60 (KIP, Integrator gain in torque regulator (pu))
J+7	1.12 (PMX, Max limit in torque regulator (pu))
J+8	0.10 (PMN, Min limit in torque regulator (pu))
J+9	0.296 (QMX, Max limit in voltage regulator (pu))
J+10	-0.436 (QMN, Min limit in voltage regulator (pu))
J+11	1.10 (IPMAX, Max active current limit)
J+12	0.05 (TRV, Voltage sensor time constant)
J+13	0.45 (RPMX, Max power order derivative)
J+14	-0.45 (RPMN, Min power order derivative)
J+15	5.0 (T_Power, Power filter time constant)
J+16	0.05(Kqi, MVAR/Voltage gain)
J+17	0.90(VMINCL, Min voltage limit)
J+18	1.20(VMAXCL, Max voltage limit)
J+19	40.0(Kqv, Voltage/MVAR gain)
J+20	-0.50(XIQmin)
J+21	0.40(XIQmax)
J+22	0.05(Tv, Lag time constant in WindVar controller)
J+23	0.05(Tp, Pelec filter in fast PF controller)
J+24	1.0(Fn, A portion of online wind turbines)
J+25	0.69(Pmin, Shaft speed at Pmin (pu))

J+26	0.78(ωP20, Shaft speed at 20% rated power (pu))
J+27	0.98((ωP40, Shaft speed at 40% rated power (pu))
J+28	1.12((ωP60, Shaft speed at 60% rated power (pu))
J+29	0.74((ωPmin, Minimum power for% operating at P100 speed (pu))
J+30	1.20((ωP100, Shaft speed at 100% rated power (pu))
STATEs	Description
K	Filter in voltage regulator
K+1	Integrator in voltage regulator
K+2	Filter in torque regulator
K+3	Integrator in torque regulator
K+4	Voltage sensor
K+5	Power filter
K+6	MVAR/Vref integrator
K+7	Verror/internal machine voltage integrator
K+8	Lag of the WindVar controller
K+9	Input filter of Pelec for PF fast controller
VARs	Description
L	Remote bus ref voltage
L+2	Q reference if PFAFLG = VARFLG
L+1	MVAR order from MVAR emulator=0
L+3	PF angle reference if PFAFLG=1
L+4	Storage of MW for computation of compensated voltage
L+5	Storage of MVAR for computation of compensated voltage
L+6	Storage of MVA for computation of compensated voltage

ICONs	Description
M	Remote bus # for voltage control; 0 for local voltage control
M+1	VARFLG: -1. Constant power factor control 0. Constant Q control 1. Use Wind Plant reactive power control
M+2	VLTFLG: 0. Bypass terminal voltage control 1. Eqcmd limits are calculated as VTerm + XIQmin and VTerm + XIQmax, i.e., limits are functions of terminal voltage 2. Eqcmd limits are equal to XIQmin and XIQ max
M+3	From bus of the interconnection transformer
M+4	To bus of the interconnection transformer
M+5	Interconnection transformer ID

Table 3.4: Input data for Converter Control Model (WT3E)

Block Diagram of Converter Control Model (WT3E)

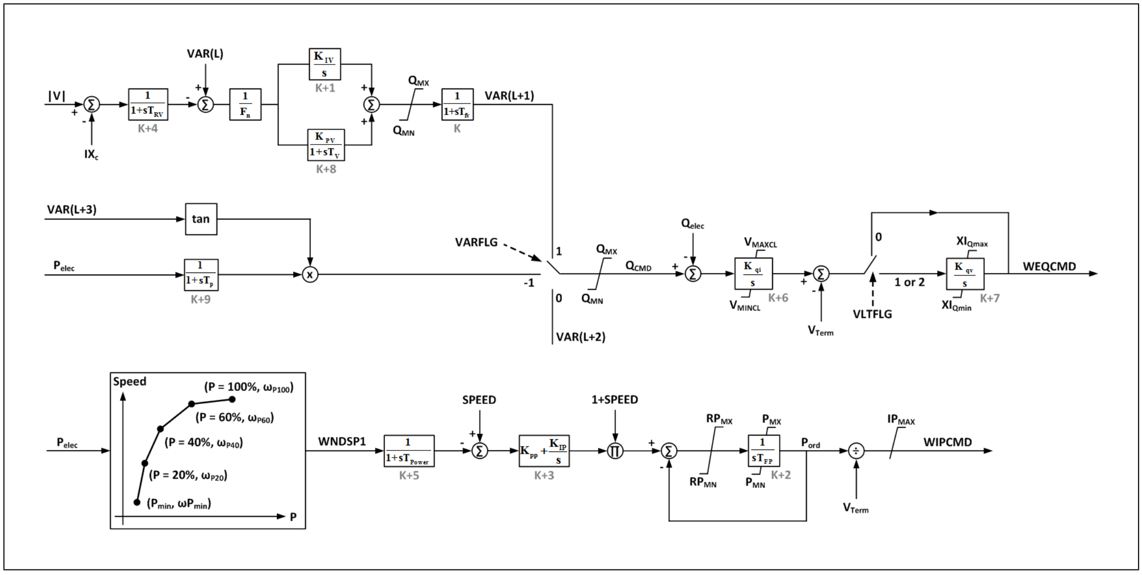

Figure 3.5: Block Diagram of Converter Control Model (WT3E)

Chapter 4

Wind Farm Modelling Approach By Using OpenModelica and OpenIPSL

4.1 Overview

All relevant planning data will be used for detailed modeling of Wind Farms using OpenIPSL simulation platform. In this case, two common calculations are essential for assessing the impact of Wind Farms on security and reliability of power systems:

- Power flow calculation
- Transient stability Studies

A **power flow calculation** to determine the power flows on transmission lines and transformers and the voltage profile of system bus bars. This calculation is fundamentally important for the planning and design of the connection of wind farms to the transmission grid. N-1 Security criterion is essential for the proper design of transmission networks to ensure the security and reliability of power supply. System performance is compared to operating limits and criteria. Short Circuit calculations also play a very significant role in the proper selection of high voltage equipment and the setting of protection relays.

The objective of **transient stability studies** refers to the synchronism of generators rotor angles in the power system. The result of transient stability assessment is used for preventing the occurrence of instability and correcting the potential dangerous scenarios to enhance the reliability. The power system response for a defined set of disturbances, typically three-phase and single-phase faults cleared by tripping of transmission elements such as lines, transformers, generators, or bus bars. The response of conventional or wind turbine generators is checked to see that all machines have an adequate stability margin, damping of power system oscillations is acceptable and that the voltage recovery following fault clearing is adequate.

4.2 Model description

The study was carried out on a large scale PSSE model of the Southeast Europe regional network, comprising 9 interconnected areas representing respective individual national networks. The Kosovo power system is modeled in detail: only the 400kV and 220kV portion of the regional network is modeled. The model consists of three simulation data files: power flow data, dynamic data, and sequence data. With the aim of analyzing the compliance of wind farms connected to the Kosovo transmission network with the Grid

Code (Wind), the study considered the 60MW wind farm project application for the so-called "Shtime" area which is known to have a very high potential of wind energy. The wind farm is planned to have 30 wind turbines, each rated at 2MW.

4.3 Design of wind farm connection to the transmission grid

The connection design of wind farms to the transmission grid is based on the requirements of the Grid Planning Code and Wind Code. A deterministic approach based on power flow studies was taken. The selected connection configuration for the study case was based on two main planning criteria:

- The N-1 Security criterion (system should be able to withstand the loss of any single components like lines, transformers, cables or generators)

Figure 3.1 shows the configuration of a wind farm connection to the 110kV transmission network for the study case. The Wind Farm Collector 35kV bus is connected via two 63MVA transformers to the 110kV transmission bus bar. The power generated by the wind farm will be transmitted through two 110kV lines. The 110kV transmission point of connection of the wind farm is characterized as a relatively weak node compared to other 110kV nodes in the network which are located closer to generation sources.

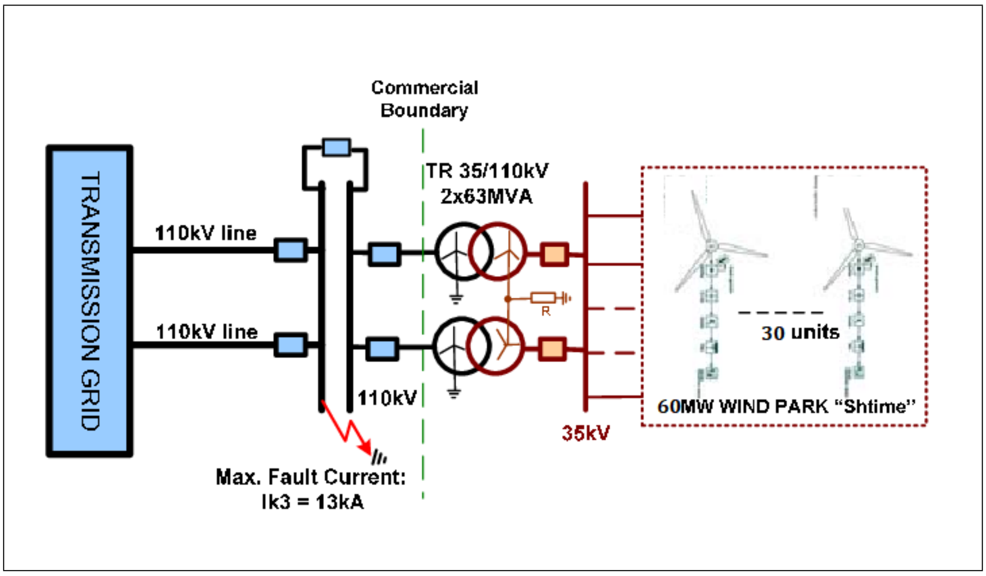

Figure 4.1: Connection of 60MW Wind Farm to Transmission Grid

4.4 Modeling for steady state analysis

The power system modeling including wind turbines for steady-state analysis in OpenIPSL is fairly simple, as shown in figure 3.2. Each wind turbine generator (WTG) is connected to a 690V bus and the WTGs are connected to the wind farm internal network through their 0.69/35 kV step-up transformers. The internal network is organized in eight rows or sections with five WTGs in each section. Within these rows, the wind turbines are connected through 35kV underground cables of different lengths and capacities depending on the location of each unit and the distance to the 35kV collector bus. The load flow solution provides the initial conditions for subsequent dynamic simulations. The maximum and minimum limits of active and reactive power must be respected to achieve a successful initialization. Inconsistencies between the power flow and the dynamic model will result in an unacceptable initialization.

Connection of 60MW Wind Farm to Transmission Grid by Using OpenIPSL

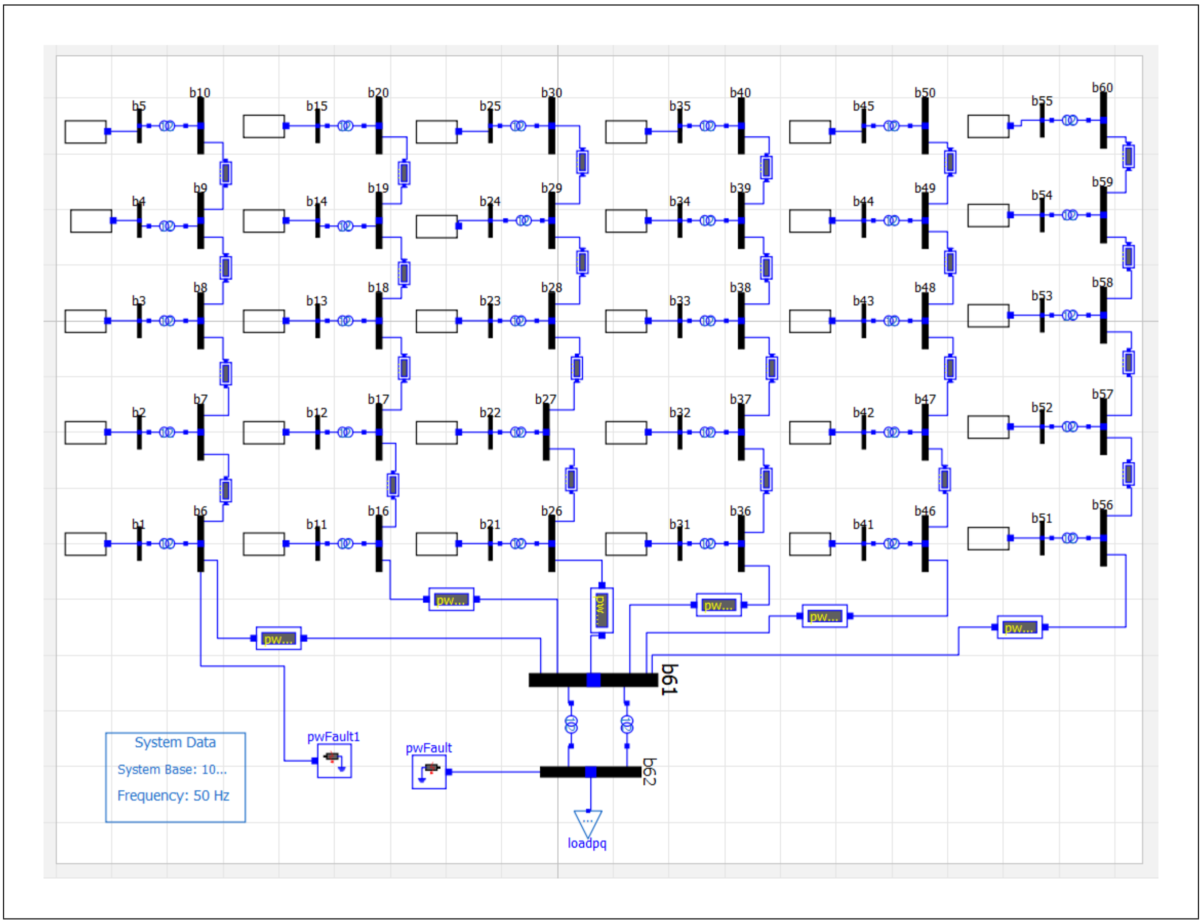

Figure 4.2: Connection of 60MW Wind Farm to Transmission Grid by Using OpenIPSL

4.5 Power flow modeling data for study case

WIND TURBINE GENERATOR DATA

WIND TURBINE GENERATOR DATA		
Symbol	Value	Unit
Sn	2	MVA
Qmax(Qmin)	0.65(-0.65)	MVAr
Pmax(Pmin)	2(0.1)	MW

Zsource	0+j0.8	pu
Mbase	2.1	MVA

Table 4.1: Wind Turbine Generator Data

WIND TURBINE TRANSFORMER DATA

WIND TURBINE TRANSFORMER DATA		
Symbol	Value	Unit
Sn	2	MVA
Sn	2.1	MVA
Unp/Uns	0.69/35	kV/kV
Ztr	0.0073+j0.06	p.u
Mbase	2.1	MVA

Table 4.2: Wind Turbine Transformer Data

35/110KV-TRANSFORMER DATA

35/110KV - TRANSFORMER DATA		
Symbol	Value	Unit
Sn	63	MVA
Unp/Uns	35/110	kV/kV
Ztr	0.0074+j0.196	pu
Ytr	0.0005 – j0.00149	p.u
Mbase	100	MVA

Table 4.3: 35/110KV-Transformer Data

35KV/110KV CABLE DATA

35/110KV - TRANSFORMER DATA				
C.Sec.mm2	I(Amp)	R(Ω/km)	X(Ω/km)	C(F/km)
50	175	0.391	0.23	0.16
150	350	0.126	0.2	0.24
240	465	0.076	0.19	0.28

Table 4.4: 35/110KV Cable Data

GENERATOR MODEL WT3G1

GENERATOR MODEL WT3G1 DATA		
Symbol	Value	Unit
Xeq	0.8	p.u
Pll gain	30	con
Pll integrator gain	0	con
Pll maximum	0.1	cons
Turbine MW rating	2	MW
Nr. of lumped WT-s	1	integer

Table 4.5: Generator Model WT3G1 Data

Power flow simulation results The power flow simulation on OpenIPSL uses the fast decoupled load flow method method. The load flow is calculated taking into consideration the deterministic approach. Regional winter peak demand and usual power exchange programs between TSOs of the South-East Europe power systems were considered for the base case scenario. The power flow simulations showed that some of the WTGs absorb different amounts of reactive power depending on the WTG terminal voltage level and the different length and capacitance of the 35kV connection cables.

In total, the wind farm internal network absorbs 10.4MVAr of reactive power, with total active power losses of 0.8MW at maximum wind farm output.No transformer or line in the transmission network was overloaded. The voltage profile complies with Grid Code requirements. An N-1 contingency assessment calculation was done to check the system security, resulting in the fact that no transformer or line in the transmission network was overloaded for any contingency. Thus, under steady-state conditions, the wind farm has no negative impact on the security and reliability of the transmission system. On the contrary, the injection of active power into the 110kV network, so far removed from other generation sources, has a beneficial impact by unloading some of the 110kV networks and reducing power losses. An additional simulation was done for the light load condition of the regional power systems to check possible over voltages in the Kosovo power system, resulting in the fact that the system voltages remained in an acceptable range. The main concern of operating with a high level of penetration of wind generation in the Kosovo power system relates to the impact of wind power variability on the power system balance, given the current shortage of system regulation reserves.

Chapter 5

Dynamic simulation results

For all simulations,the following conditions were applied:

- The fault applied is a bolted symmetrical three-phase applied one second after the start of the simulation.
- The fault clearing time is 9 cycles and the simulation time is 20 seconds

Figure 4.1 shows that during the fault on the 110kV connection point, the voltage drops to zero, whilst the 35 kV collector bus voltage drops to 0.12 pu. After fault clearance, the voltage at both locations gradually recovers to around 1.0 pu. The WTG terminal voltage shows a similar pattern, except that during the fault the minimum terminal voltage is 0.2pu, which is considerably higher than the faulted connection point voltage. The range of terminal voltage drop to other 40 WTG is from 0.2 pu to 0.23 pu, depending on the location of the installed units. The WTGs closest to the 35 kV collector bus has a maximal terminal voltage drop. The simulation results indicate that all 30 DFIGs have the ability to ride through the fault, which is in compliance with Wind Grid Code requirements.

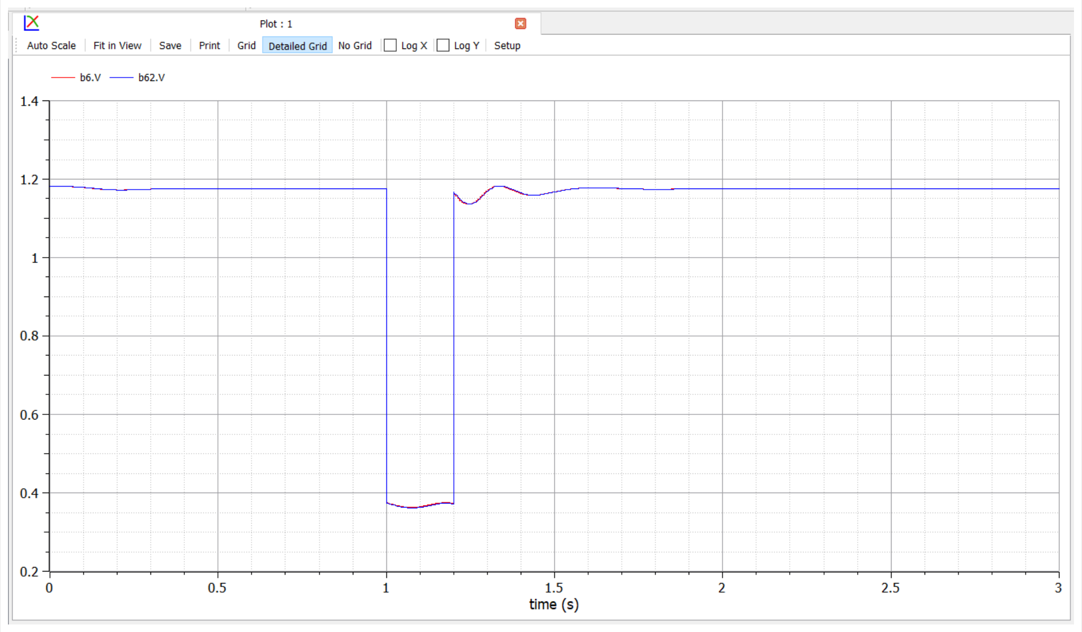

Figure 5.1: Voltage response after fault occur in the 35kv and 110kV

WTG terminal voltage response for series of Bus faults with various impedances

4.2 shows WTGs terminal voltage response for three different fault events, each with different fault impedance.The most critical case for the WTGs is when the fault occurs on the connection point to the transmission network.

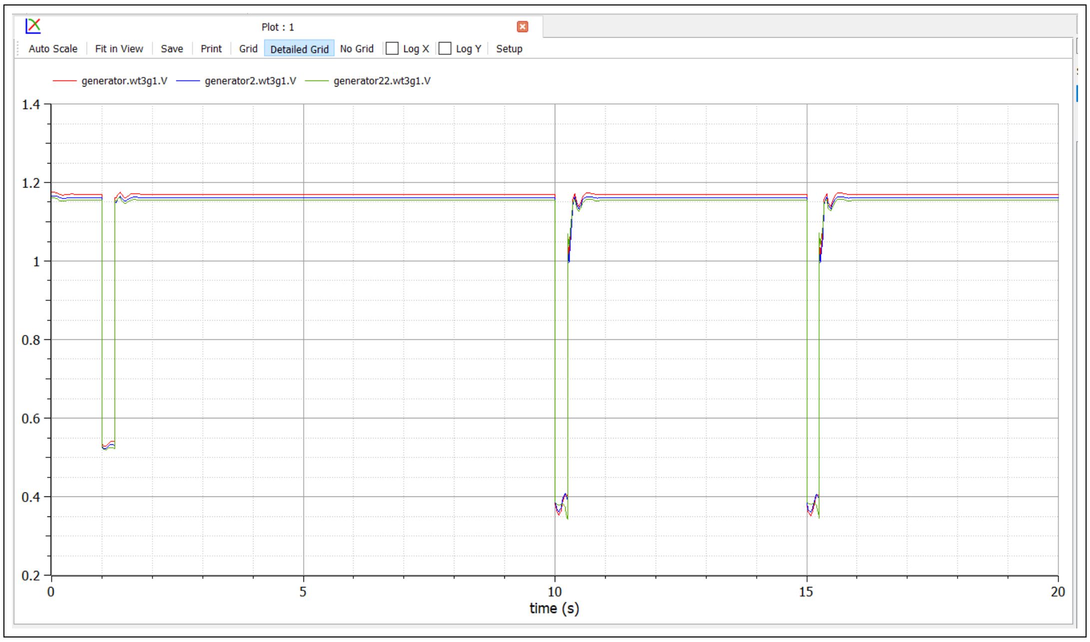

Figure 5.2: WTG terminal voltage response of Bus faults with various impedances

WTG active power response after fault

Figure 4.3 shows that during the fault the WTG electrical power output suddenly decreases to a very low value (0.001 pu or 2 kW). The difference between the mechanical input power and electrical output power causes an increase in the rotor speed and therefore the rotor starts to accelerate.
The torsion oscillation in the drive-train model is reflected in the output power of the wind turbines. Oscillation of power output after the fault is cleared will cause mechanical stress in the drive train system. Approximately ten seconds after the fault is cleared, the power output recovers to the pre-fault value of 2 MW.

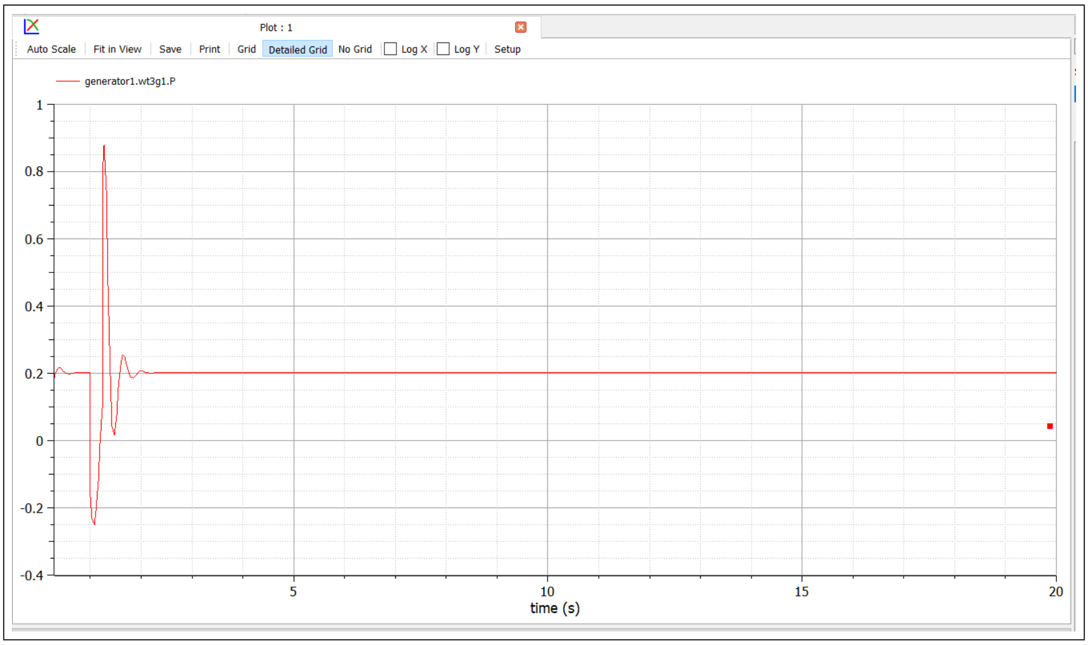

Figure 5.3: WTG active power response after fault

WTG reactive power response after fault

The reactive power outputs from three selected WTGs: generator2,generator3,generator4 are shown in figure 4.4. Before the fault occurs, unit generator3 was compensated, unit generator2 was injecting reactive power to the grid.During the fault, the rotor speed increases, giving a larger negative slip. This is because the electric power has decreased to almost zero whereas the mechanical power is assumed to be the same. As a result, the WT3P module responds by altering the blade pitch to decrease mechanical power. During the fault, we can see that all WTG units provide reactive power support to the grid, as is required by the Wind Grid Code.

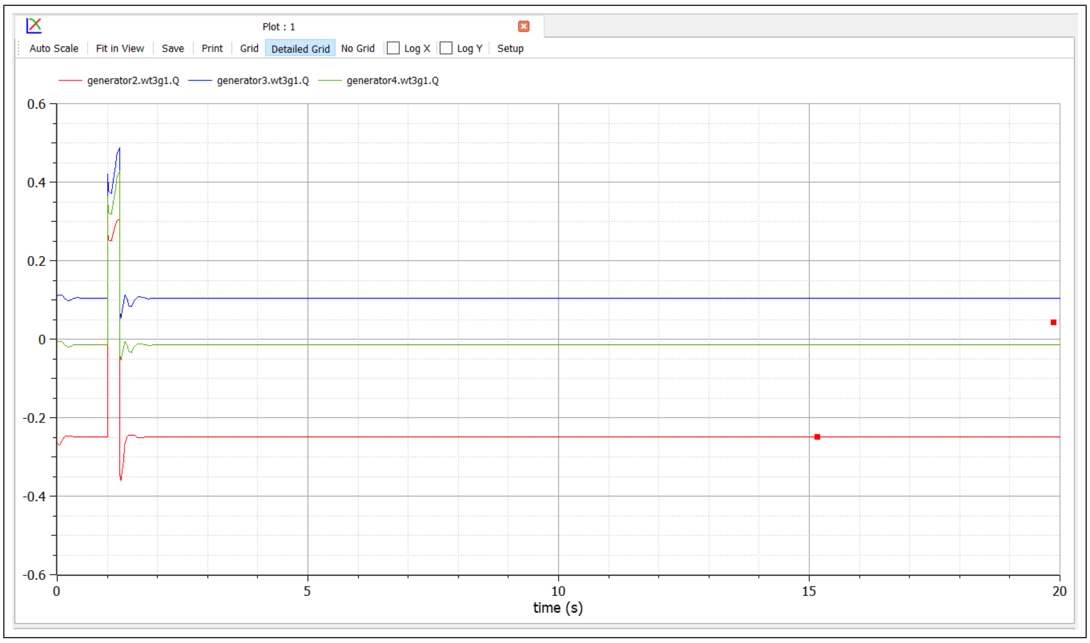

Figure 5.4: WTG reactive power response after fault

Conclusion & Reference

Conclusion

Power flow, short circuit, and dynamic analyses were carried out to check the influence of the 60MW wind farm on the Kosovo transmission system in respect of the grid code requirements. The large scale PSSE model was used for the computer simulation. The PSSE wind turbine stability model WT3 was used for the dynamic simulation to simulate the dynamic performance of DFIG technology WTGs.The overall conclusion of these analyses is that the 60MW wind farm project does influence the transmission system, but all of the requirements of the Grid Code relating to the wind farm connection were satisfied.

References

1.Long Term Electricity Balance 2011-2020, `www.kostt.com.`
2.Wind Grid Code, `www.kostt.com.`
3.Transmission Network Development Plan 2010-2019, `www.kostt.com.`
4.Grid Code-Planning Code `www.kostt.com.`
5.PSS/E manual, version 32
6.Generic WT3 user guide. PSS/E 32 Wind package.
7.Wind Power Integration Connection and system operational aspects; B. Fox, D. Flynn L. Bryans, N. Jenkins, M. O' Malley, R. Watson and D. Milborrow, The institution of Engineering and Technology London, 2007. pp.72-85
8.V.Akhmatov, Analysis of dynamic behavior of electric power systems with large amount of wind power, PhD Thesis, Technical University of Denmark, ISBN 87-91184-18-5 April 2003. pp.9-64
9.WT3 – Generic Wind Model
10.Wind Farm Modeling for Steady State and Dynamic Analysis