TUD COST Action TU1304

Wind energy technology reconsideration to enhance the concept of smart cities (WINERCOST)

IMPACT OF WIND POWER GENERATION ON THE STABILITY OF SMALL ENERGY SYSTEM

COST STSM Reference Number: COST-STSM-TU1304-26764

SHORT TERM SCIENTIFIC MISSIONS REPORT

Background

- *Participant of the Short Time Scientific Mission:*

Dr.-Ing. Tomasz Bakoń
Warsaw University of Life Sciences – SGGW
Faculty of Production Engineering
Department of Fundamental Engineering
Energy Management Division
Nowoursynowska 164, 02-787 Warsaw / Poland

- *Host Persons and Host Institution:*

Prof. Dr. Ing. Cyril Spiteri Staines
B.Eng.(Hons), Ph.D.(Nottingham), M.I.E.T., M.I.E.E.E.
Dr. Ing. John Licari
B.Eng.(Hons), Ph.D.(Cardiff), M.I.E.T., M.I.E.E.E.
University of Malta
Faculty of Engineering
Industrial Electrical Power Conversion
MSD 2080, Msida / Malta

- *Mission Topic*

- ✓ Power electronic use in the large and small electricity system
- ✓ Exchange of experiences on grid effects caused by power electronics devices installed in the wind turbines in the electricity system
- ✓ Study of the differences and similarities between existing wind turbines in Poland and possible configurations for Malta for the electrical and grid protection point of view
- ✓ Analysis of the behavior of the grid stability and the potential of possible blackout incident in the small grid caused by wind turbine control and safety settings depending on the voltage changes in the grid
- ✓ Impact of Malta–Sicily HVAC submarine interconnector
- ✓ Participate in the Training School "Advantages in Wind Energy Technology organized by University of Malta (26. May – 31. May 2015)

Results included in this report based on the of MATLAB simulations carried out during the stay by University of Malta and research performed aerial by participant and in host institution.

- *Time of the mission*

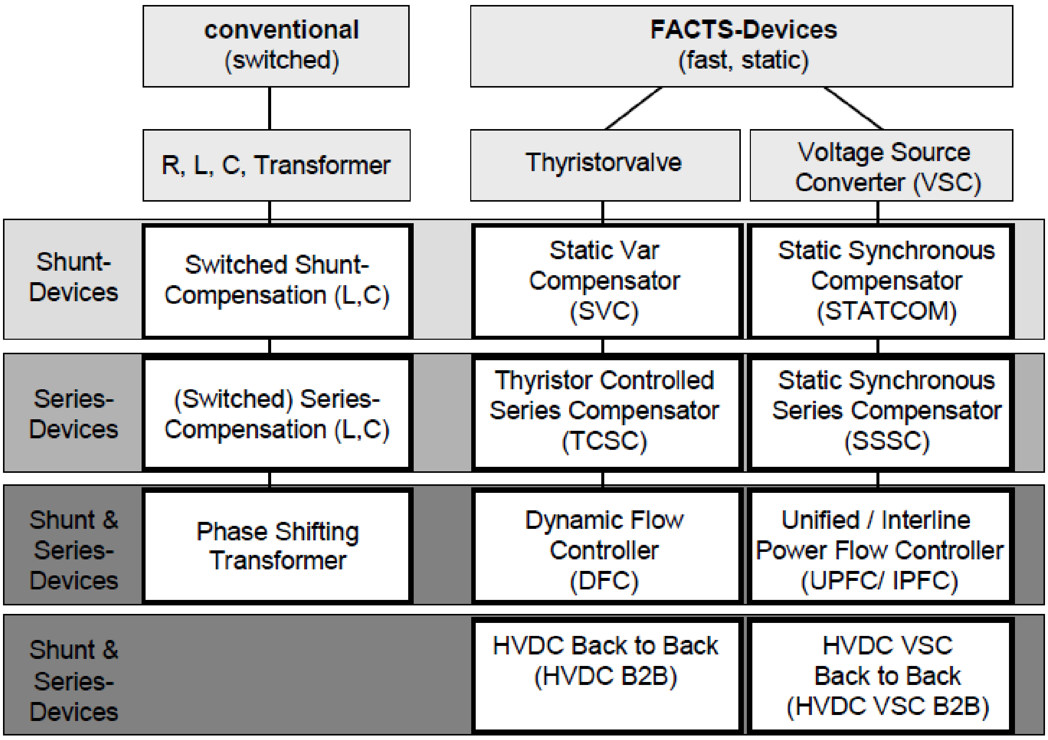
The mission started on the 18. Mai 2015 and ended on 31. Mai 2015.

Power electronic use in the large and small electricity system.

In today's open access environment, transmission systems are being required to provide increased bulk power transfer capability and to accommodate a much wider range of possible generation patterns. This has led to an increased focus on transmission constraints, which may be due to thermal, voltage or electromechanical stability limits, and on the means by which such constraints can be alleviated. In addition, utilities have to take account of increased environmental sensitivity to potential reinforcement solutions. FACTS (Flexible AC Transmission System) devices offer a versatile alternative to conventional reinforcement methods with potential advantages of increased flexibility, lower cost and reduced environmental impact.

For all the following equipment use power electronics for grid support:

- SVC (Static Var Compensator)
- STATCOM (Static Synchronous Compensator)
- BESS (Battery Energy Storage System)
- SMES (Superconducting Magnetic Energy Storage)
- TCSC (Thyristor Controlled Series Compensator)
- SSSC (Static Synchronous Series Compensator)
- TCPAR (Thyristor Controlled Phase Angle Regulator)
- UPFC (Unified Power Flow Controller)
- HVDC (High Voltage Direct Current)
- SCDC (Self Commutated Direct Current)



Overview of main FACTS devices

AC connections are used for the large majority of wind farms, as it is a relatively simple way to connect, and for most applications provide the most economic solution. Wind farms can be connected to the grid by overhead lines or cables. From offshore sites submarine cables are typically needed to reach land. Long distance overhead lines may be needed on land for the transportation of large scale wind power to the load centers. Cable sections may be needed also on the land, if planning consent cannot be obtained for the cheaper overhead line option for the complete route. Whether power electronics is required or provide economic benefits depends strongly on the length of the lines, and on the strength of the ac network at the point of grid connection of the wind farm. Due to their different electrical parameters a cable is considered long if its length exceeds about 100 km whereas an overhead line is labeled “long” with a length of typically more than about 400 km.

Whilst an ac connection is often convenient and simple, it is necessary to ensure that issues such as AC voltage control, dynamic and transient stability limits, resonances and power quality have been adequately considered. Power electronic equipment may provide significant benefits for the interconnection of large scale wind farms, helping to overcome any of these issues.

Power electronic equipment can either be designed for shunt compensation i.e. connected between phases of the AC grid or for series compensation i.e. connection in series in the phases of the AC grid or a combination of shunt and series compensation.

Exchange of experiences on grid effects caused by power electronics devices installed in the wind turbines in the electricity system.

Benefits of a SVC for a large AC connected wind farm

Wind farms equipped with variable speed machines associated with full or partial converters can have a built-in reactive power (VAR) management, however, all wind farms using fixed wind speed turbines require separate non-active power management. Moreover, traditional VAR management by capacitor banks may have a negative impact in the context of wind generation because frequent starting and stopping will often provoke voltage step changes. Employing dynamic VAR devices, alone or in combination with switched capacitor banks, eliminates the negative consequences of the traditional solution. Both the wind farm developer and the utility benefit from this approach.

From the wind farm viewpoint:

- The wind farm remains connected thanks to mitigation of voltage transients coming from the grid. So grid connection requirements are met, power output and revenues are also maximized.
- Capacitor-bank switching events are minimized, and step-voltage changes that they cause are eliminated.

From the utility viewpoint:

- Voltage variations due to uncompensated wind farm operation as well as large reactive power demands are cancelled.
- To control the voltage at the connection point, there is no more a need to install breaker switched capacitor banks on the transmission system. Given the continuing growth of wind power generation, the need for maintaining system reliability and security remains an ongoing concern. Upon appearance of a system fault especially near a wind generator, the rotating machine speeds up and its slip increases. In order not to lose stability of the system, many grid codes require that the generators remain in operation and continue to supply power after clearance of the fault.

Rapid reactive power control during and after a system fault provides a means of restoring the generator slip to its normal value, and thereby prevents the wind generator from tripping. Therefore, after the fault is cleared, the generators remain connected and are ready to supply power to the system. By providing reactive power control and support for the ac network voltage, an SVC can increase the fault ride through capability of a wind farm. The ability of the SVC to provide continued reactive power control both during the and also after the fault period can be of great benefit to the ac network. For example, power system swings may result in the rise and fall of the system voltage and the SVC can be designed to dampen such swings, subject to the limitations of its rating.

When long radial ac connections are necessary from a wind farm to the grid or the load centre, then a SVC may provide stabilization of the voltage on the line, and can be used to extend the distance over which the power can be transmitted.

During normal system conditions the SVC can also provide reactive power ancillary services to the AC network, no matter the operation status of the wind farm. This means that the converter ratings within the wind farm can be minimized, to only consider the need for active power transfer.

Reactive compensation devices, such as the SVC can also help to suppress voltage fluctuations due to generator starting and stopping action, or changes in wind velocity, and can therefore remove voltage quality issues, e.g. flicker.

Benefits of a STATCOM for a large AC connected wind farm

The benefits obtained by using a STATCOM at the grid connection of a wind farm include all those mentioned above for the SVC and the following:

- As the STATCOM appears to the network as a voltage source it is capable of injecting current into a fault in the network. This can be beneficial for the protection system.
- Because of the larger reactive power support capability at low ac voltage, when compared with a SVC, a STATCOM with a lower rating is typically able to provide at least equivalent performance to that of a SVC.
- The STATCOM can help mitigating the flicker due to variations of reactive power absorbed by induction machine-based wind farms. Due to its faster response, when compared with a SVC, the STACOM provides a more powerful reduction of flicker. The reactive power required by the farm is evaluated and a controller drives the STATCOM inverter so as to generate the adequate quantity, making it possible to reduce drastically the reactive power flows towards the grid and therefore, the associated flicker.

Benefits of Energy Storage for a large AC connected wind farm

Depending on the technology and on the rating of the energy storage systems, they can:

- improve power quality,
- smooth the voltage and power variations due to wind turbulences,
- smooth power variations in a time scale of minutes, hours or even days,
- solve steady state current constraints in the interconnection,
- participate in voltage and frequency control of the ac network,
- help wind farms to withstand voltage dips,
- guarantee the active power supply to the network.
- enable generation to be shifted from low spot price periods to high spot price periods,
- be used to manage transmission constraints and to minimize energy spill.

Study of the differences and similarities between existing wind turbines in Poland and possible configurations for Malta for the electrical and grid protection point of view.

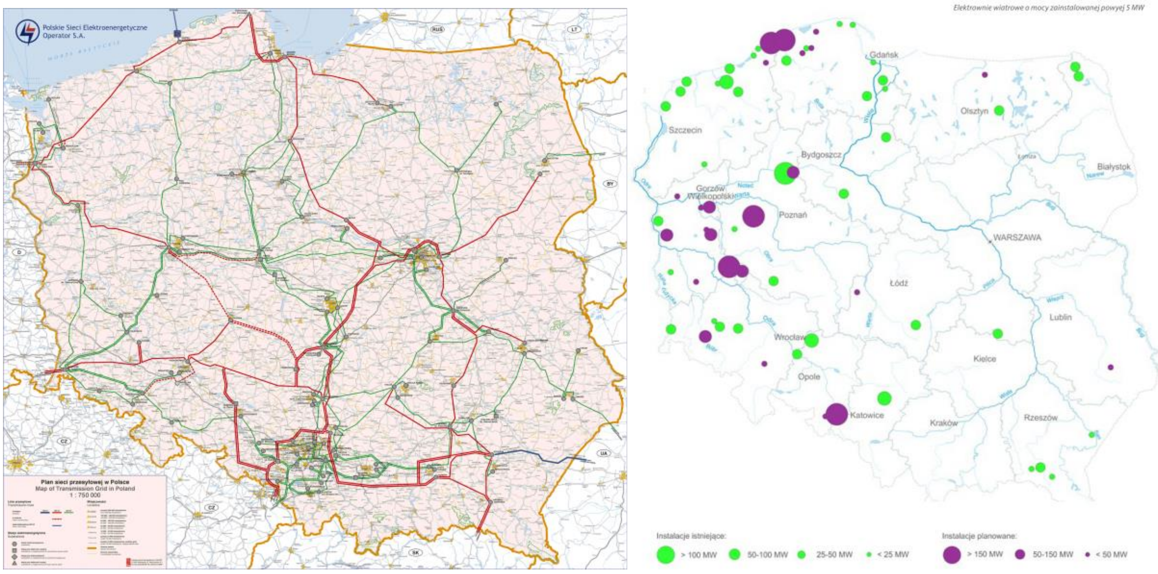
	Installed 2013	End 2013	Installed 2014	End 2014
EU Capacity (MW)				
Austria	308.4	1,683.8	411.2	2,095
Belgium	275.6	1,665.5	293.5	1,959
Bulgaria	7.1	681,1	9.4	690.5
Croatia	81.2	260.8	85.7	346.5
Cyprus	-	146.7	-	146.7
Czech Republic	8	268.1	14	281.5
Denmark*	694.5	4,807	67	4,845
Estonia	10.5	279.9	22.8	302.7
Finland	163.3	449	184	627
France	630	8,243	1,042	9,285
Germany	3,238,4	34,250.2	5,279,2	39,165
Greece	116.2	1,865,9	113.9	1,979.8
Hungary	-	329.2	-	329,2
Ireland	343.6	2,049.3	222.4	2,271.7
Italy	437.7	8,557.9	107.5	8,662.9
Latvia	2.2	61.8	-	61.8
Lithuania	16.2	278.8	0.5	279.3
Luxembourg	-	58.3	-	58.3
Malta	-	-	-	-
Netherlands	295	2,671	141	2,805
Poland	893.5	3,389.5	444.3	3,833.8
Portugal*	200	4,730.4	184	4,914.4
Romania	694.6	2,599.6	354	2,953.6
Slovakia	-	3.1	-	3.1
Slovenia	2.3	2.3	0.9	3.2
Spain	175.1	22,959.1	27.5	22,986.5
Sweden	689	4,381.6	1,050.2	5,424.8
UK	2,075	10,710.9	1,736.4	12,440.3
Total EU-28	**11,357.3**	**117,383.6**	**11,791.4**	**128,751.4**

Wind power installed in European Union (EWEA)

On the 31.03.2015 in Poland was installed 3951.26 MW wind power in 961 wind farms, at the same time in Malta are connected to grid only some (ca. 20) small turbines. Under consideration is the construction of large power plants and offshore wind farms. The biggest wind farms in Poland and the biggest wind turbines installed on Maltese Islands are listed in the tables.

	Localization	Turbine manufacturer	The number of turbines	Installed power	Starting year
1.	Margonin	Gamesa	60	120 MW	2010
2.	Karścino-Mołtowo	Iberdrola	60	90 MW	2008
3.	Kisielice	GE	43	76.5 MW	2007
4.	Iłża	Vestas	30	60 MW	2014
5.	Pągów	Vestas	17	51 MW	2012
6.	Tychowo-Noskowo	Nordex	20	50 MW	2009
7.	Jędrzychowice	Vestas	25	50 MW	2013
8.	Tymień	Vestas	25	50 MW	2006
9.	Linowo	Vestas	24	48 MW	2013

The biggest Polish wind farms (all use horizontal axis)



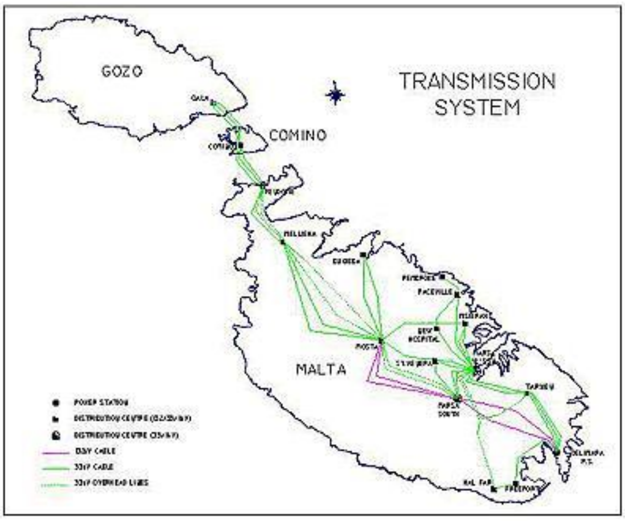
High Voltage grid in Poland – right (pse.com.pl) and wind farm over 5 MW localization – left, green marked existing farms and violet planed (globenergia.pl)

So far, the Maltese Government has planned the development of two small onshore wind farms in the 2013-2015 period: the Wied Rini project (10.2 MW) and the Hal Far project (4.2 MW). However, the greatest contribution towards the 10% target would be from a large offshore floating wind farm at Sikkal-Bajda, 1.5 km from L-Ahrax tal-Mellieha (95 MW), which is expected to generate 40% of the Maltese 2020 renewable energy share. At this time only some small wind turbines are installed on Maltese Islands.

In fact, such technologies enjoy a relatively high resistance to strong winds and have the potential to exploit whichever wind directions without having to be reoriented continuously. Hexicon Corporation, a Swedish offshore wind farms operator, filed a Project Description Statement with the Swedish Energy Agency, the Malta Resources Authority and the Ministry of Agriculture, Natural Resources and Environment of the Republic of Cyprus, for a large floating offshore wind plant with 36 turbines based on a 460 meters hexagonal platform (see the image below). In case the project is approved, it will be eventually funded (4.5 bln EUR) via the Ner300 Programme, a financial instrument adopted by the European Commission and the European Investment Bank with the aim of subsidizing state of the art renewable energy technologies using the capital raised through the sale of 300 million European Emission Allowances (i.e. rights to emit one tone of carbon dioxide, each sold for 10 EUR) on the carbon market. The gigantic 54 MW floating plant will be located 11 nautical miles from the northeast shore of Malta where water depths are between 150 and 300 meters. A cable would link the wind-farm to an offshore substation. The platform is anchored by cable, but is able to turn 360 degrees within 30 minutes. The Swedish company says in the Project Description Statement that its floating wind farm, supplying 9% of Malta's electricity, will enable Malta to meet its EU commitment to generate 10% of its energy from renewable sources by 2020 (assuming that this is in addition to the two small onshore wind farms mentioned above producing the other 1%).

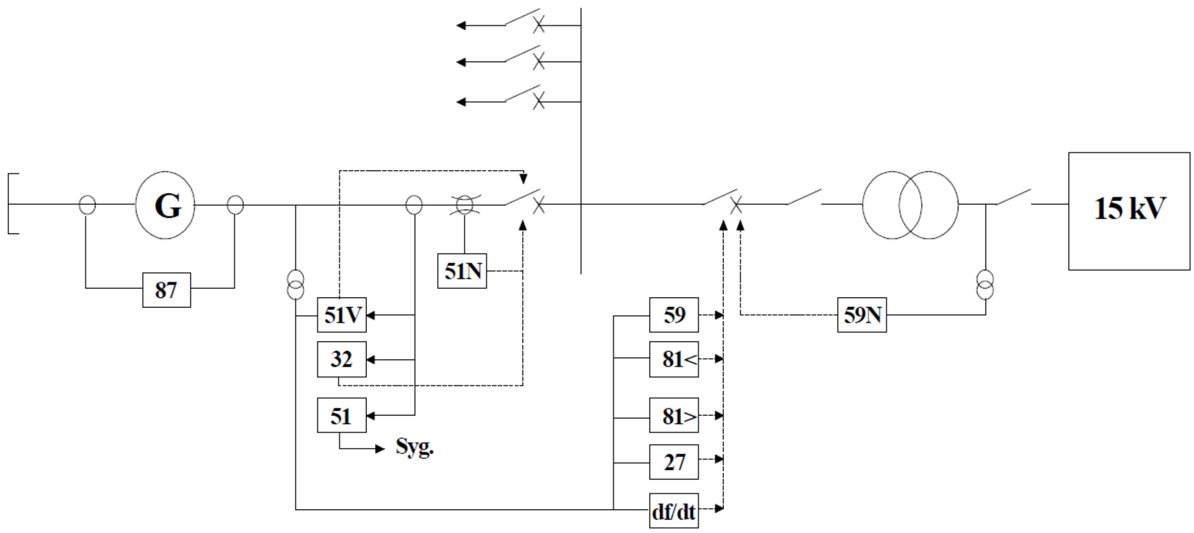
	Localization	Turbine, manufacturer	Axis, Position	Installed power	Starting year
1.	Cirkewwa, Ferry Terminal	n/a	Horizontal	15 kW	2012
2.	Xrobb il-ghagin	Proven	Horizontal	6 kW	2008
3.	Xrobb il-ghagin	Aeolos	Vertical	6 kW	2008
4.	Msida, University of Malta	Enervolt	Vertical	3 kW	2010
5.	Ramlet il-Qortin, Mgarr,	Proven	Horizontal	2.5 kW	2008
6.	Luqa, Wasteserv	Proven	Horizontal	2.5 kW	n/a
7.	Hal Far, Wasteserv	Proven	Horizontal	2.5 kW	2008
8.	Pembroke, Primary School	Helix	Vertical	2 kW	n/a
9.	Mriehel, Wasteserv	Helix	Vertical	2 kW	n/a

The biggest Maltese wind turbines



Medium and High Voltage grid of Maltese Island (enemalta.com.mt)

Compared to conventional power station generators installed in generators wind turbines are small. The required protection system for small (ca. 2 MW) generator connected to the medium voltage grid is presented on the figure below. Taking into account the map of Maltese electrical grid (above) and that a single wind turbine would be switched on because of the location and power range to the Medium Voltage grid, this system could be also implemented on Malta too.



Small power generator connected to the 15 kV grid containing basic (87, 51N, 51V, 32, 51) and additional (59, 27, 81>, 81 <, 59N, df/dt) protection relays

(27 – Undervoltage Relay, 32 – Reverse Power Relay, 51 – AC Inverse Time Overcurrent Relay, 59 – Overvoltage Relay, 81 – Frequency Relay, 87 – Differential Protective Relay)

In the case of Polish wind farms grid operator requires that they can work in the following frequency range:
- at frequencies in the range 49.5 – 50.5 Hz at rated power,
- at frequencies in the range 48.5 – 49.5 Hz with power more than 90% of capacity resulting from the the current wind speed for at least 30 minutes,
- at frequencies in the range 48.0 – 48.5 Hz with power more than 85% of capacity resulting from the the current wind speed for at least 20 minutes,
- at frequencies in the range 47.5 – 48.0 Hz with power more than 80% of capacity resulting from the the current wind speed for at least 10 minutes,
- at a frequency lower than 47.5 Hz the wind farm can be excluded from the network with delay time agreed with the operator of the transmission system,
- at frequencies in the range 50.5 – 51.5 Hz wind farm must be able lasting working with a power of which is limited with increasing frequency to zero at a frequency 51.5 Hz,
- at a frequency greater than 51.5 Hz the wind farm should be excluded from the network not later than after 0.3 s, unless otherwise specified in the conditions of connection.

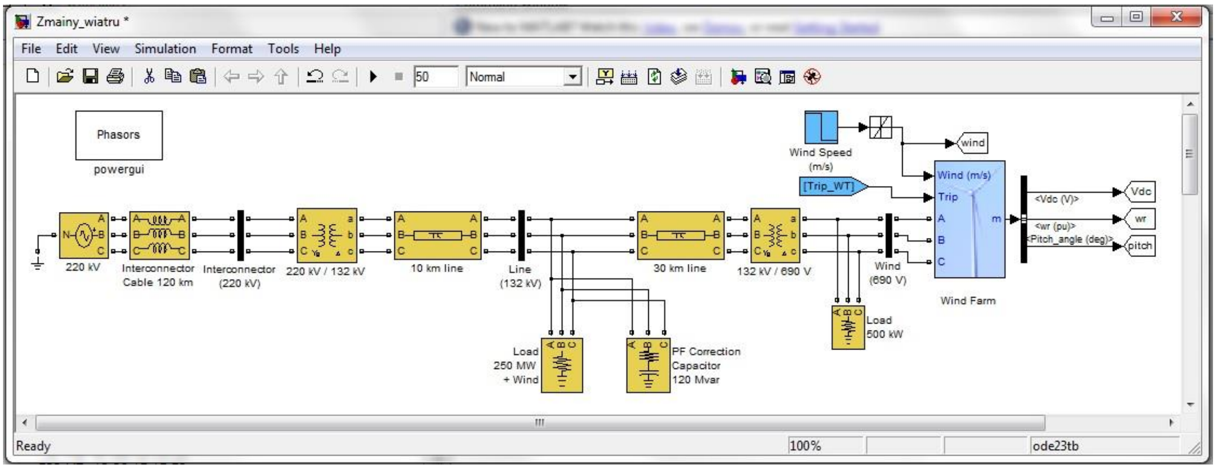
Grid provider also requires that a farm with a capacity of 50 MW or higher is adapted to participate in the regulation of frequency in the system, by changing the power when grid frequency changes. This requirement applies to the full range of load wind farm. The transmission system operator shall define in terms of connecting wind farms with a nominal output of 50 MW or higher, the conditions for its participation in frequency control and the required control parameters, to the extent specified in the table below.

Value name	The value required for a particular wind farm (min and max)	
Active power control range of wind farm for the purpose of frequency control system	0 %	25 %
The Dead Zone frequency control for the farm (relative to 50Hz)	0 Hz	0.5 Hz
Changing of the system frequency resulting in the change farm load by 100%	3 %	20 %

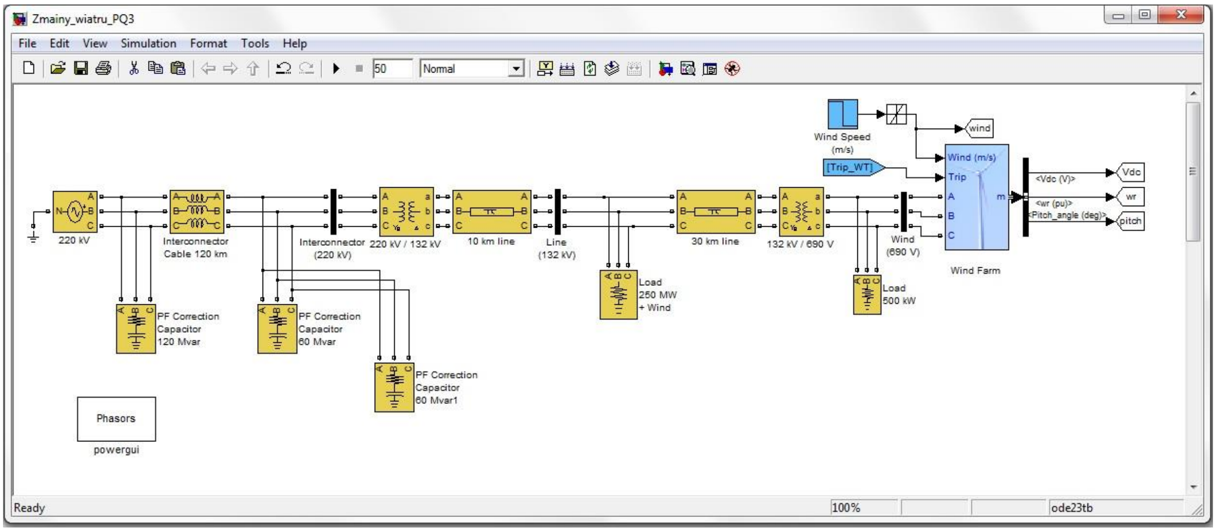
Analysis of the behavior of the grid stability and the potential of possible blackout incident in the small grid caused by wind turbine control and safety settings depending on the voltage changes in the grid.

Malta rather lags behind regarding the development of renewable energy in comparison to the other EU member states. The share of renewable energy in total final consumption in 2011 was 0.4%. This represents a large percentage increase compared to 2005, when the proportion was zero, but major actions are required to reach the 2020 goal of 10%. Meanwhile, renewable electricity generation amounted to 0.1% in 2011 (Eurostat 2013). In Malta, nearly all energy is produced from imported oil products, thus making the country in particular vulnerable to oil price shocks. Energy policies mainly address the reduction of energy dependence including the promotion of renewable energies, grants for insulation in buildings and the construction of an electricity grid interconnection to Sicily. The interconnection will in particular increase grid stability, allow for electricity imports/exports thus reducing dependence on oil while at the same time reducing the greenhouse gas intensity of the national electricity sector. The Maltese 2020 target is a limitation to emission growth of +5% (compared to 2005) but in actual fact emissions have already increased by 7% between 2005 and 2011. According to the latest national projections submitted to the Commission and taking existing measures into account, it is expected that the target will be met with a margin of 1 percentage point: 4% grow in 2020 compared to 2005.

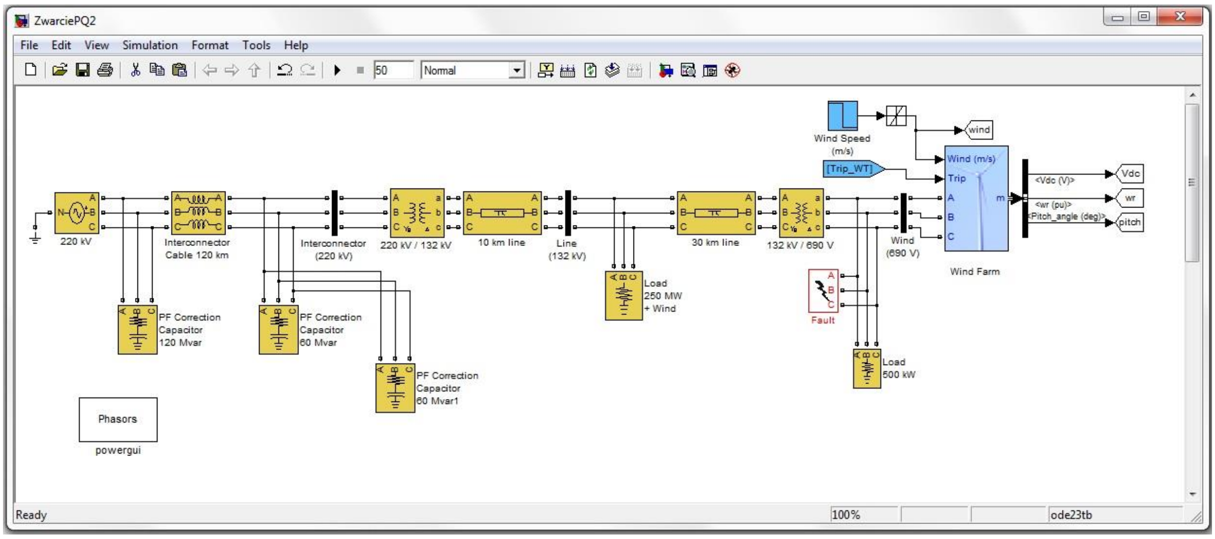
During STSM some Mablab Simulink models have been created. They were to determinate the impact of wind farm meets the renewable energy target 2020 (ca. 5 – 10%) on Maltase energy grid. Replacement wind farm with double feed induction generator was connected to the high voltage grid (132 kV) according to the figures below. Schemes are in the form of print screens for Matlab Simulink models.



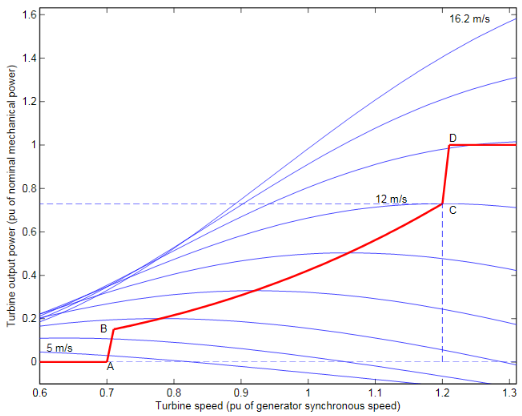
Matlab Simulink simplified model for wind farm connected to the Maltese grid with interconnector Malta-Sicily



Matlab Simulink simplified model for wind farm connected to the Maltese grid with interconnector Malta-Sicily with non-active power compensation



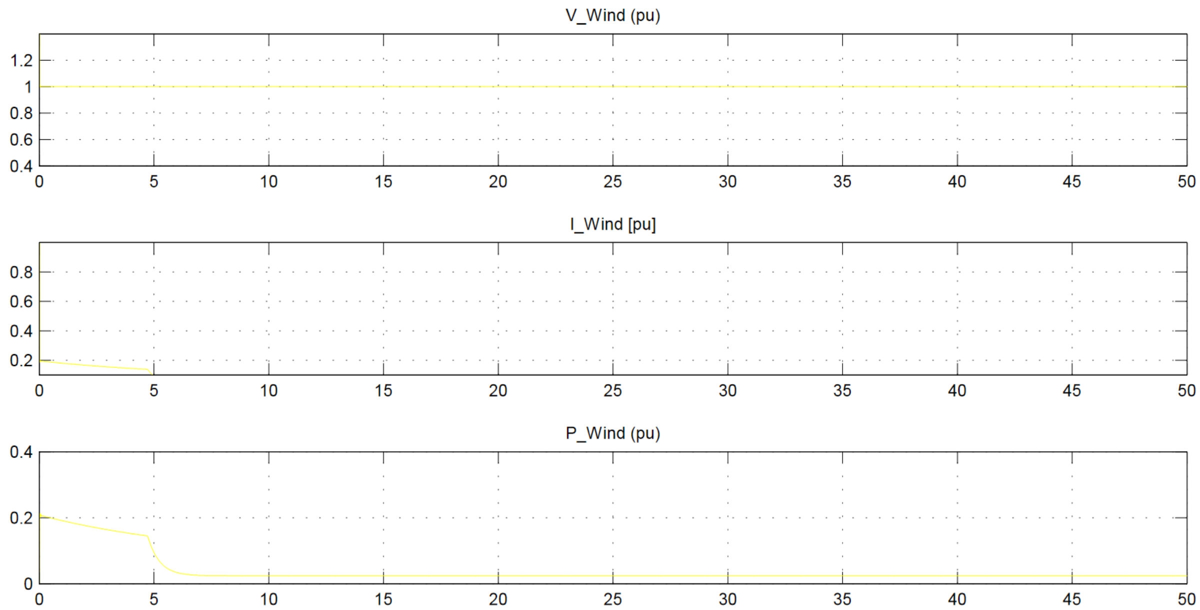
Matlab Simulink simplified model for wind farm connected to the Maltese grid with interconnector Malta-Sicily with non-active power compensation and fault modeling of by wind turbine



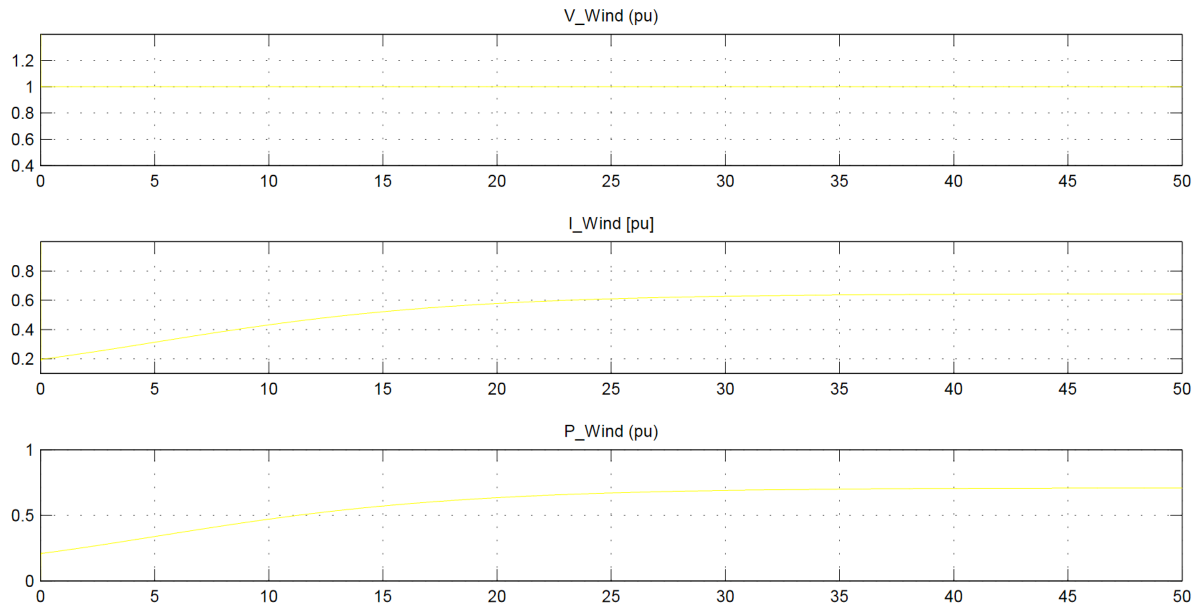
Turbine Power Characteristics (Pitch angle beta = 0 deg)

Energy production

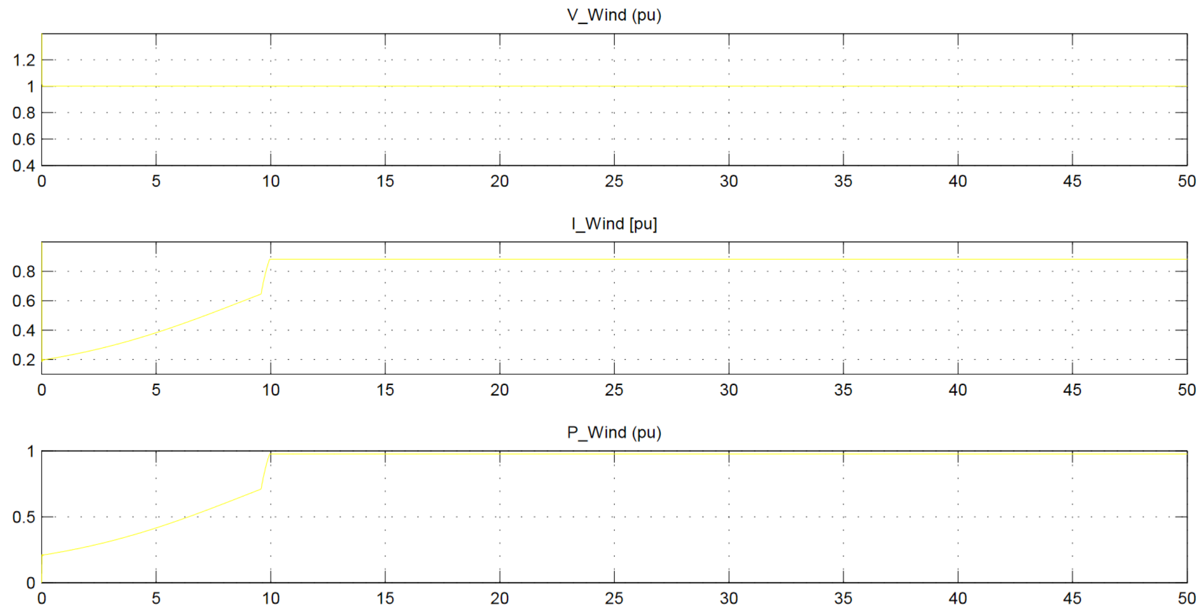
On the following figures is presented energy production according to wind speed (5 m/s, 12 m/s and 15 m/s) at the same initial values.



Wind farm voltage (pu), current (pu) and active power (pu) generated by **wind speed 5 m/s**



Wind farm voltage (pu), current (pu) and active power (pu) generated by **wind speed 12 m/s**

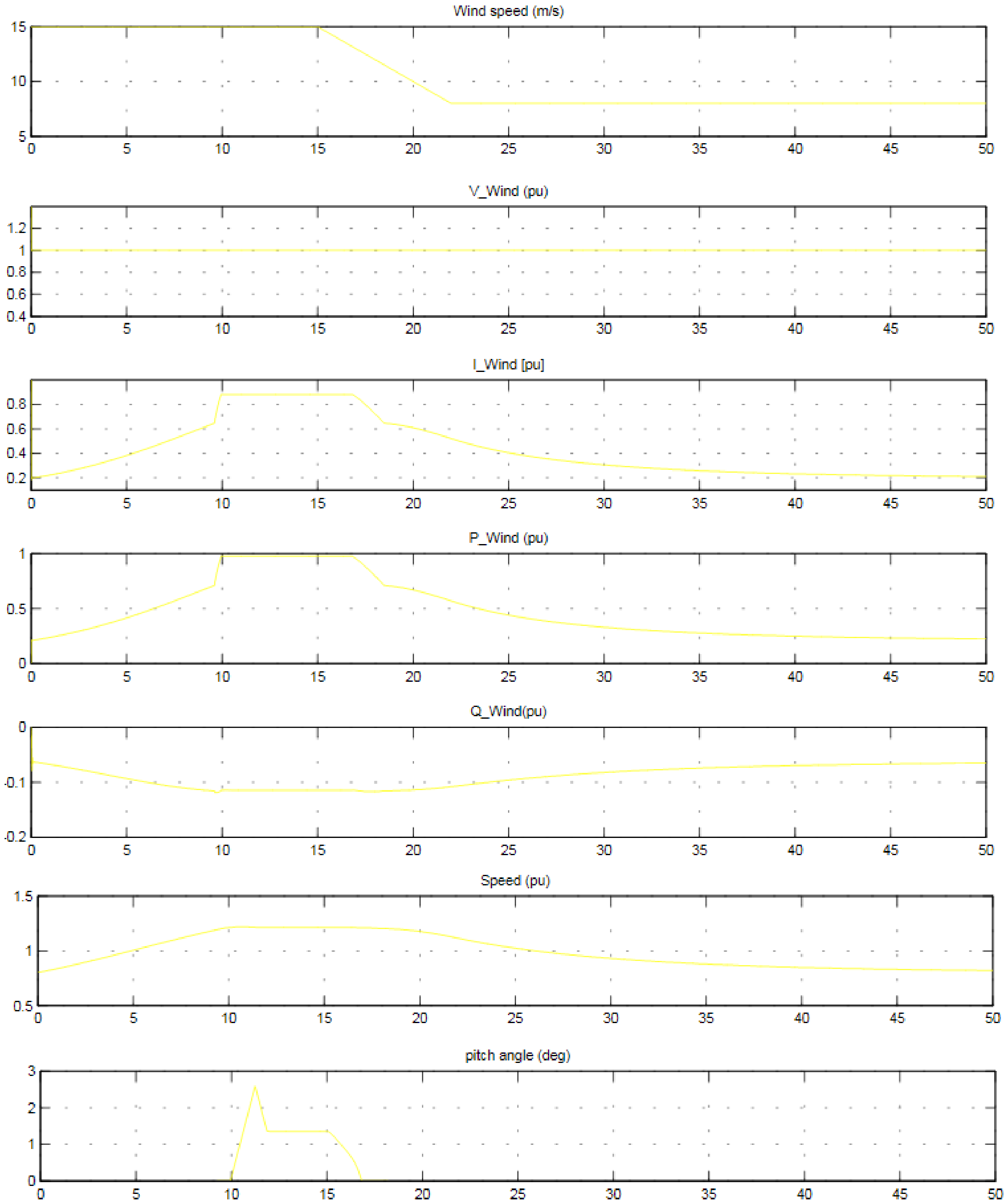


Wind farm voltage (pu), current (pu) and active power (pu) generated by **wind speed 15 m/s**

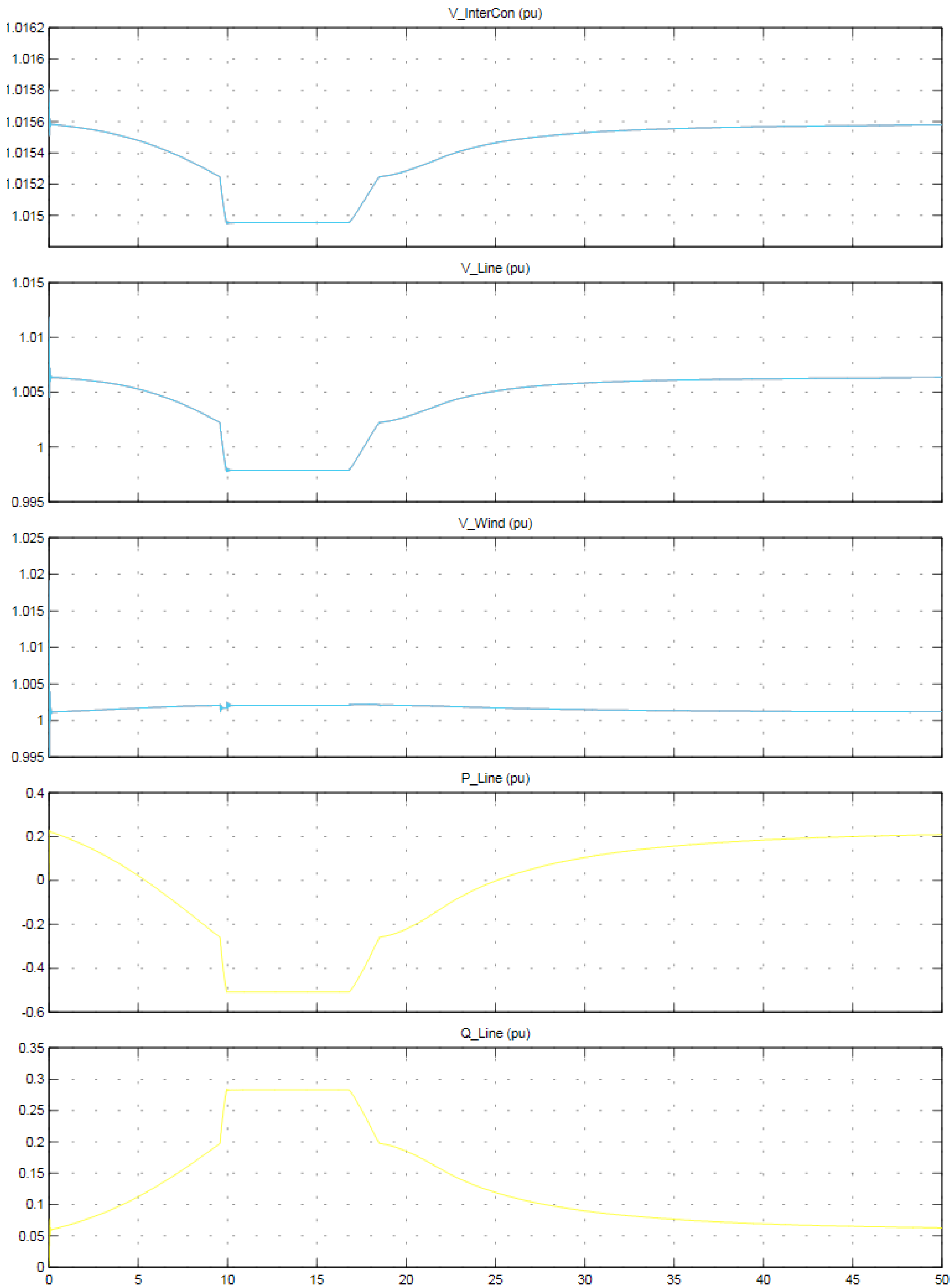
The impact of changes in wind speed on energy production by the wind farm and the need for consumption of non-renewable energy sources. In this simulation assumed that the desired power will be delivered from continental Europe network via Malta – Sicily Interconnector. It can be seen by comparing the parameters P_Wind and P_Line. All power values ware normalized wind farm nominal power (according to the previous chapter ca. 10 MW).

Fault type	***Wind speed starting value***	***Wind speed end value***
None	5	15
	8	15
	12	5
	15	0
	15	8
1-phase-ground	12	12
line-line		
line-line grounded		
3-phase grounded		

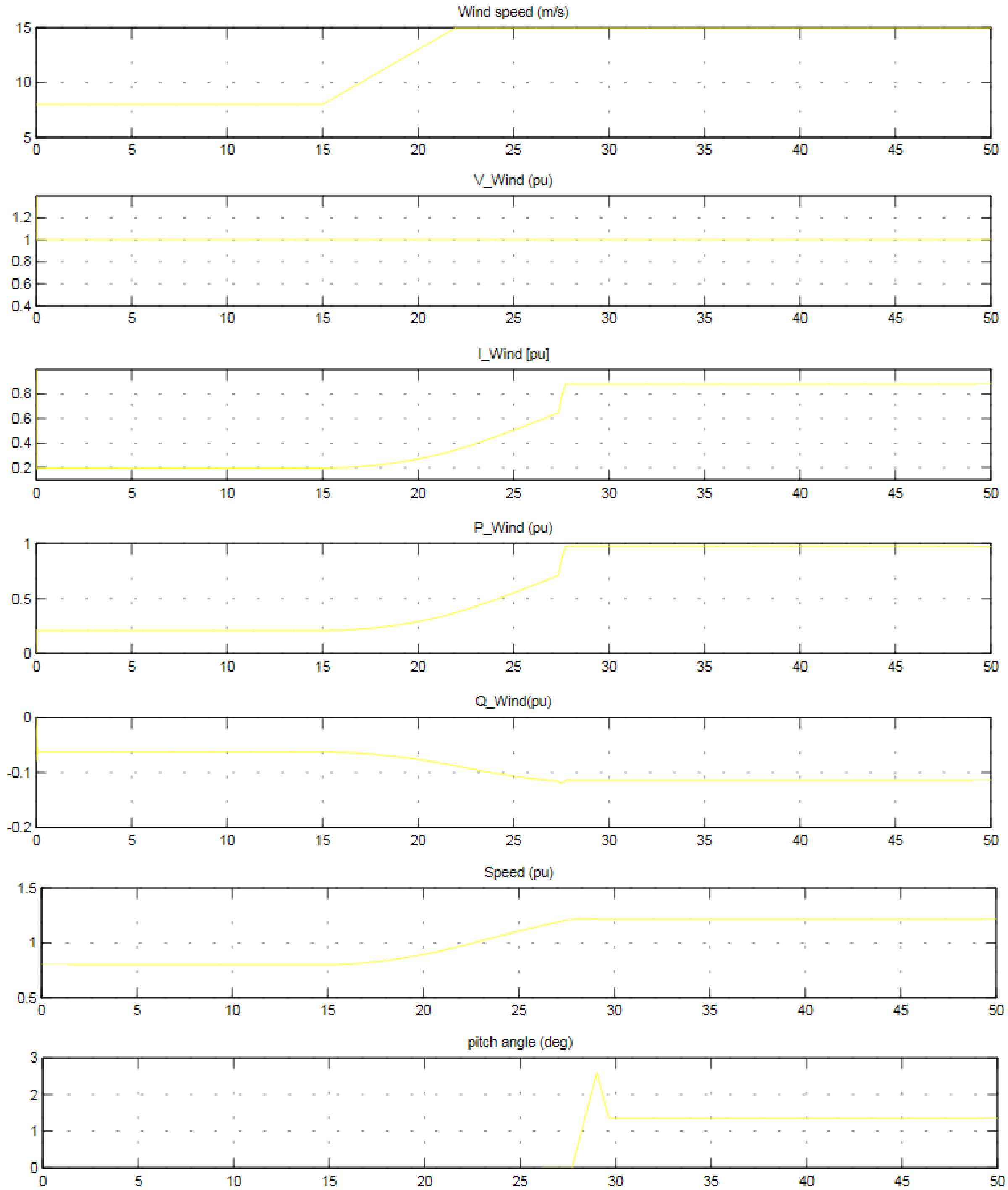
Simulation results listed in this report



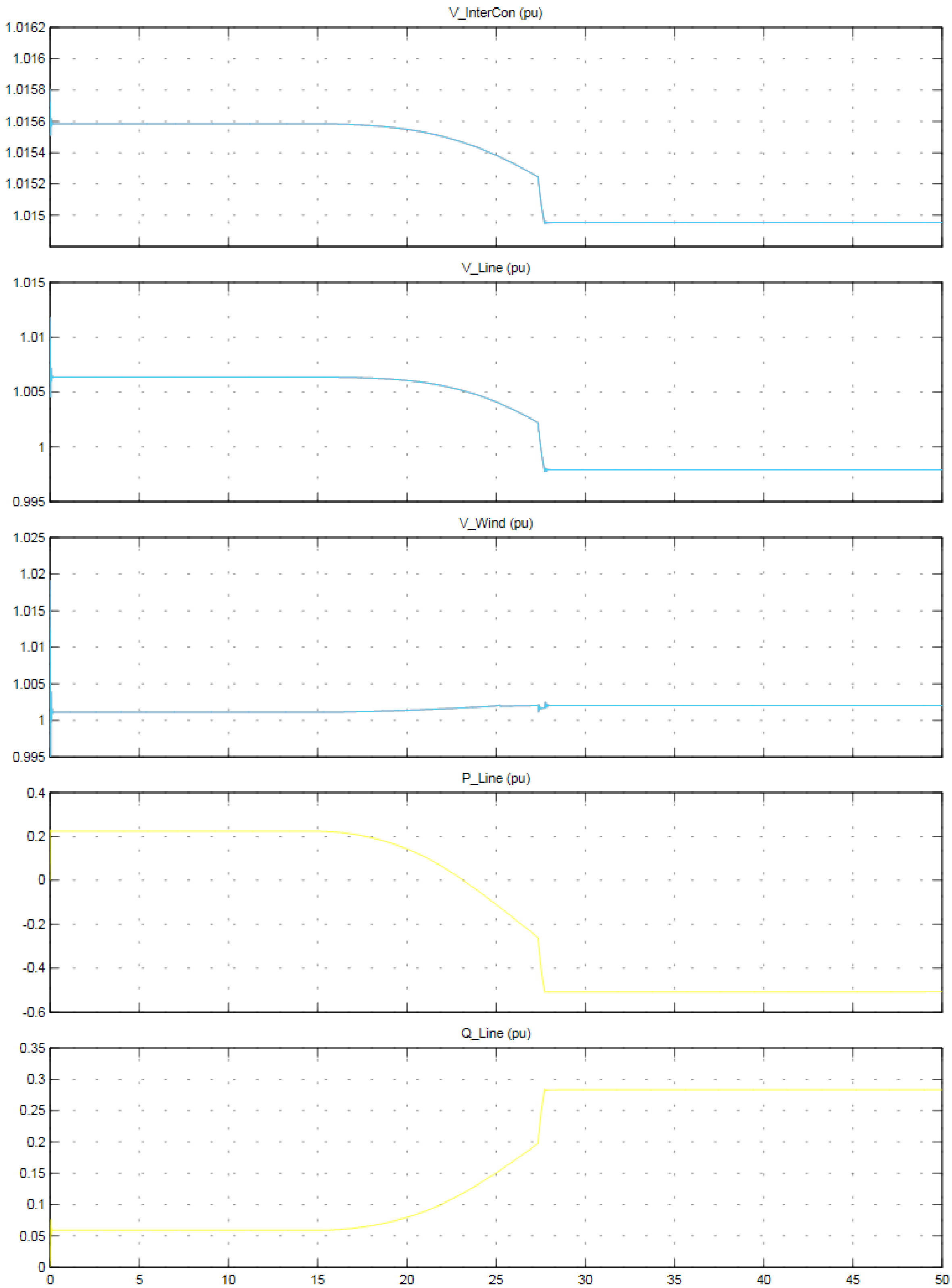
Wind speed (m/s), wind farm voltage (pu), current (pu), active power (pu), non-active power (pu), wind rotor speed (pu) and pitch angle (deg) for the replacement wind farm by **wind speed changing form 15 m/s to 8 m/s**



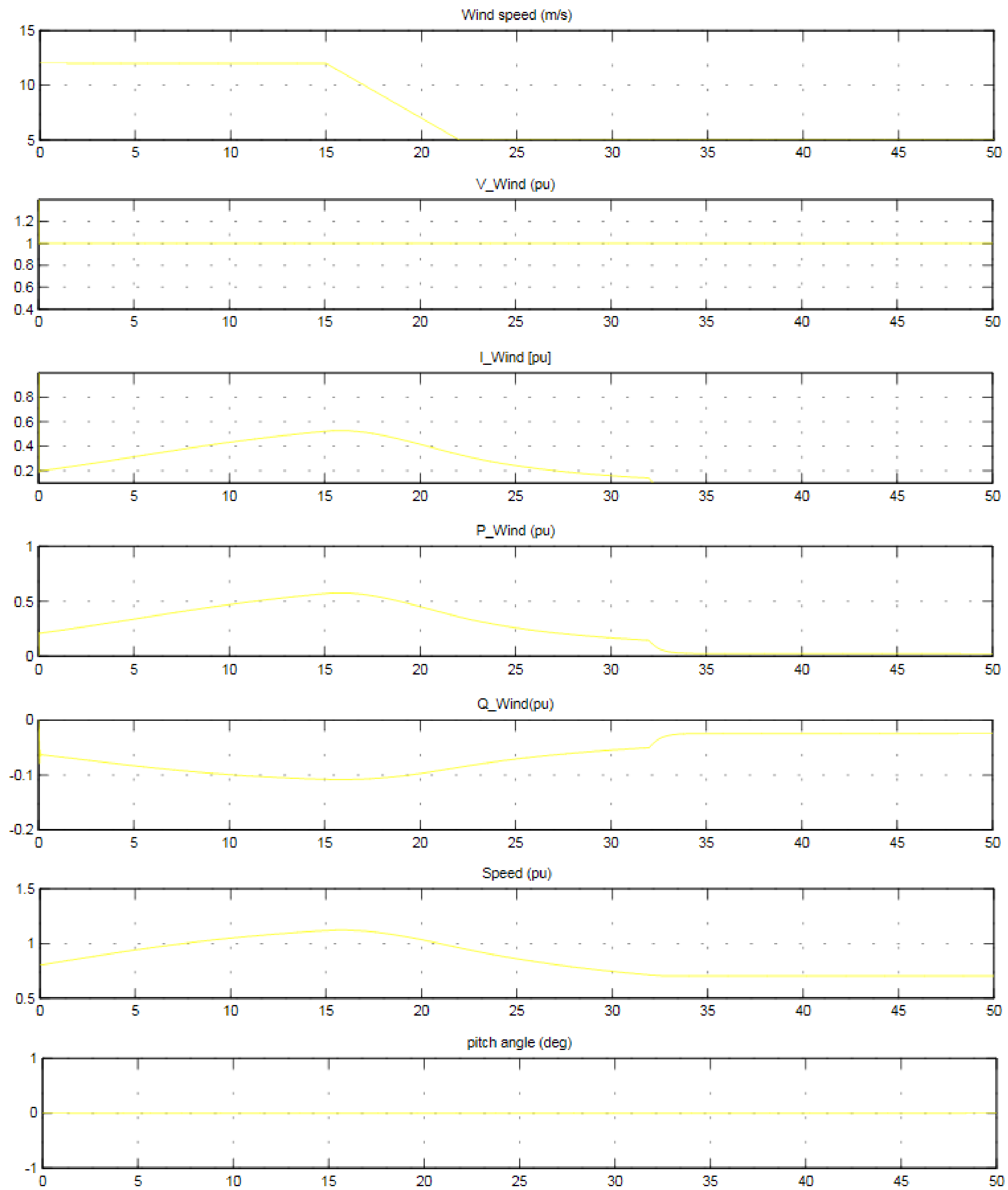
Voltage on Interconnector (pu), HV line (pu) and wind farm (pu) and active power (pu), non-active power (pu) in the line for the replacement wind farm by **wind speed changing form 15 m/s to 8 m/s**



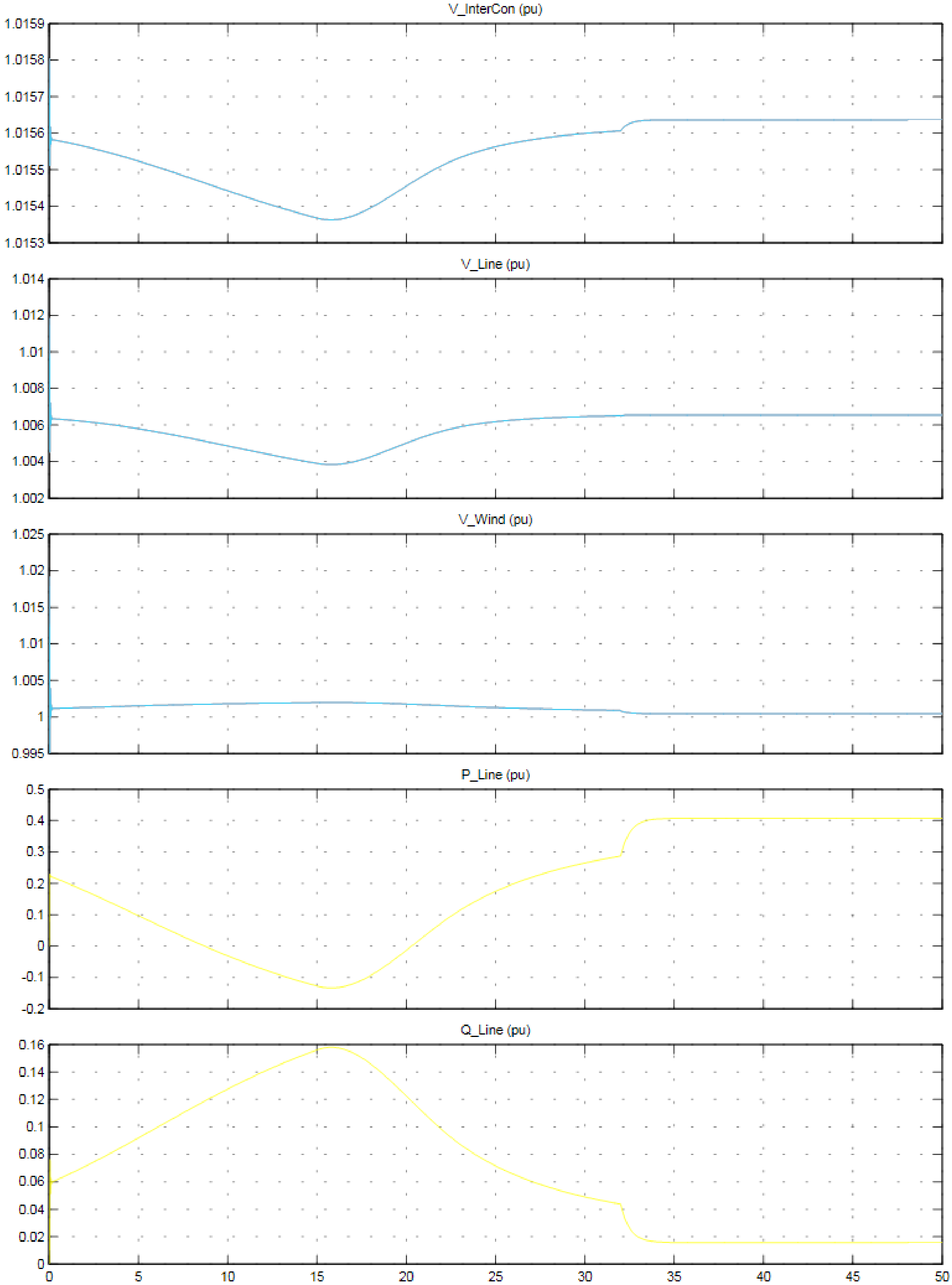
Wind speed (m/s), wind farm voltage (pu), current (pu), active power (pu), non-active power (pu), wind rotor speed (pu) and pitch angle (deg) for the replacement wind farm **by wind speed changing form 8 m/s to 15 m/s**



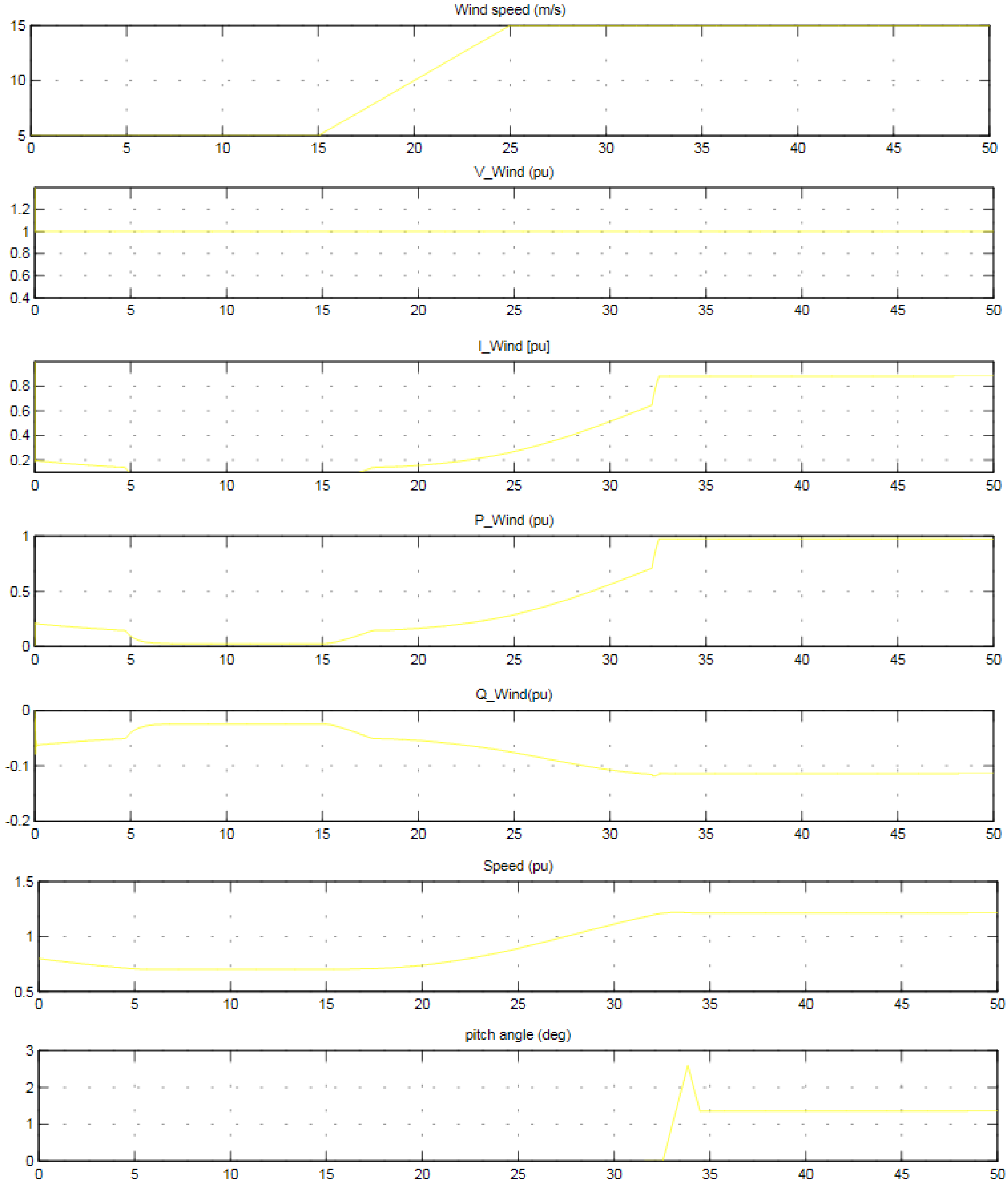
Voltage on Interconnector (pu), HV line (pu) and wind farm (pu) and active power (pu), non-active power (pu) in the line for the replacement wind farm by **wind speed changing form 8 m/s to 15 m/s**



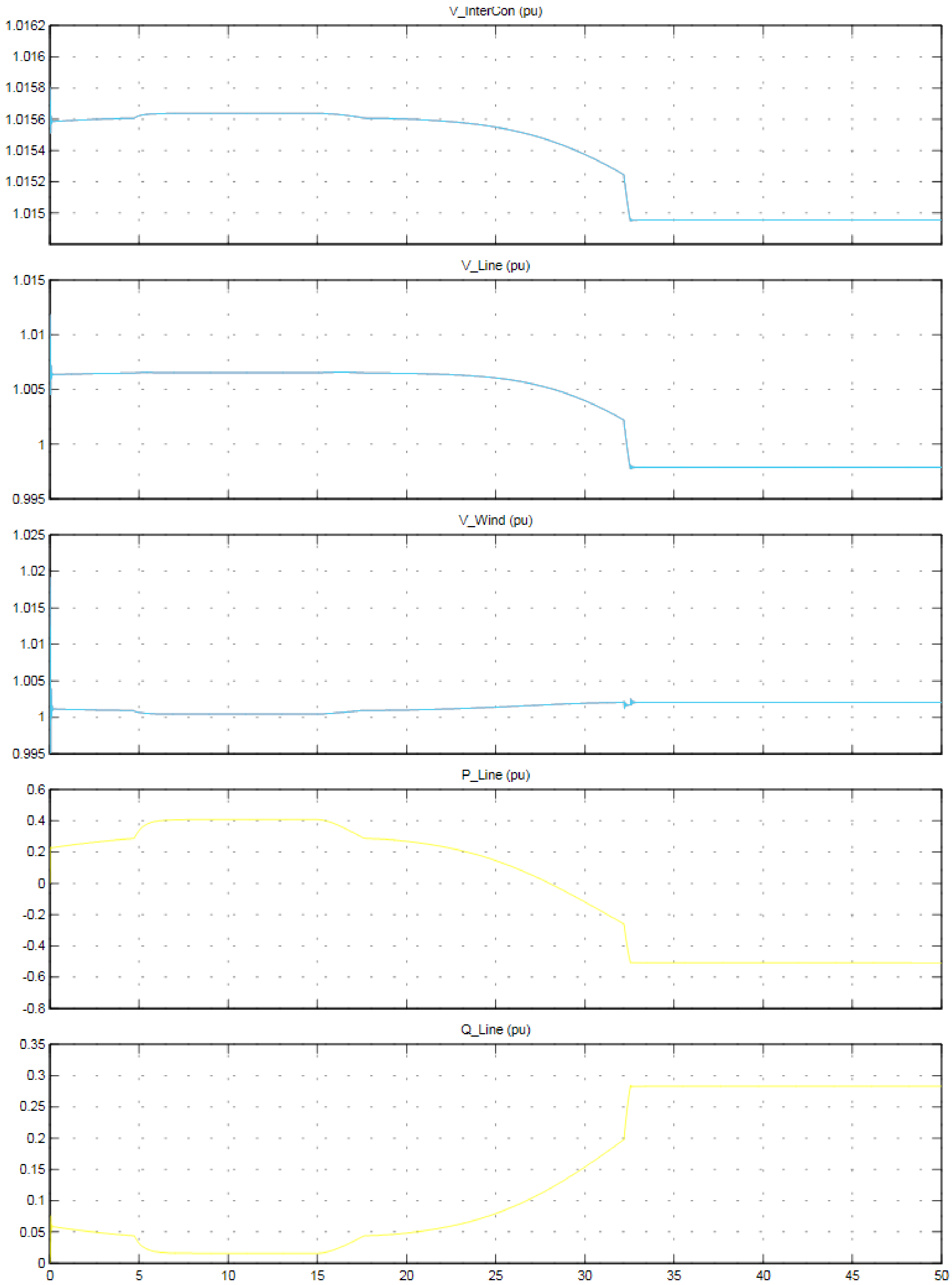
Wind speed (m/s), wind farm voltage (pu), current (pu), active power (pu), non-active power (pu), wind rotor speed (pu) and pitch angle (deg) for the replacement wind farm by **wind speed changing form 12 m/s to 5 m/s**



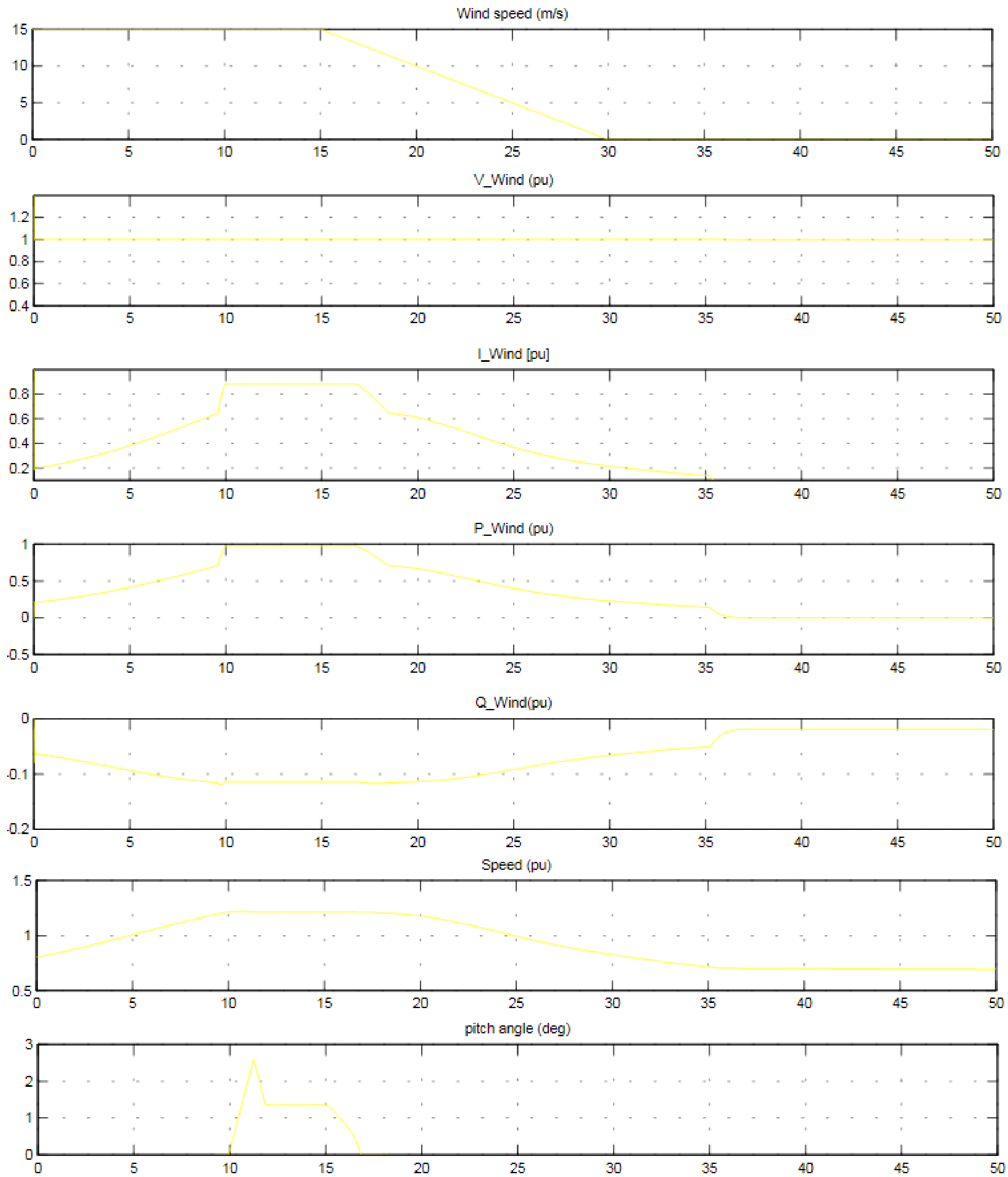
Voltage on Interconnector (pu), HV line (pu) and wind farm (pu) and active power (pu), non-active power (pu) in the line for the replacement wind farm by **wind speed changing form 12 m/s to 5 m/s**



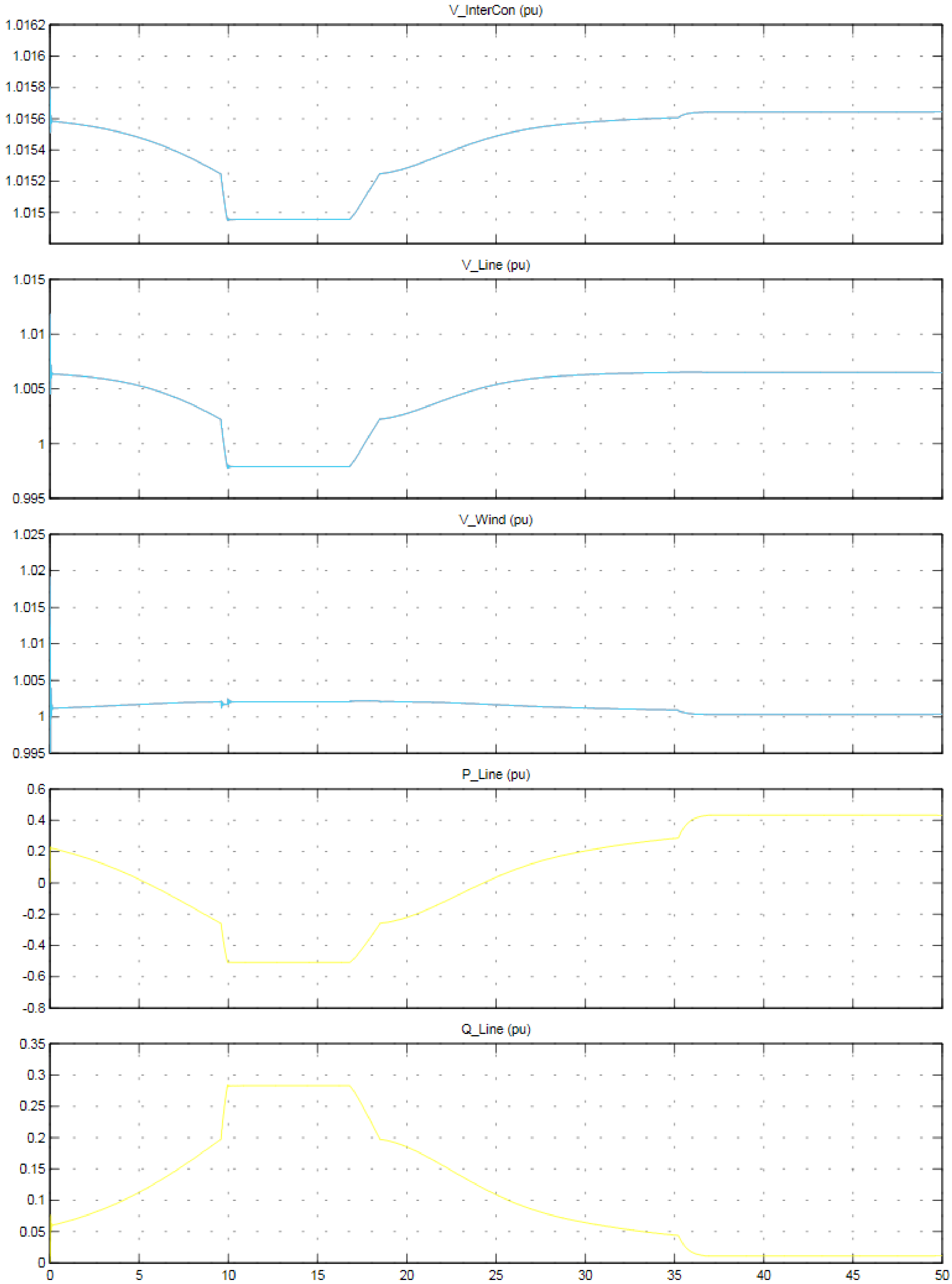
Wind speed (m/s), wind farm voltage (pu), current (pu), active power (pu), non-active power (pu), wind rotor speed (pu) and pitch angle (deg) for the replacement **wind farm by wind speed changing form 5 m/s to 15 m/s**



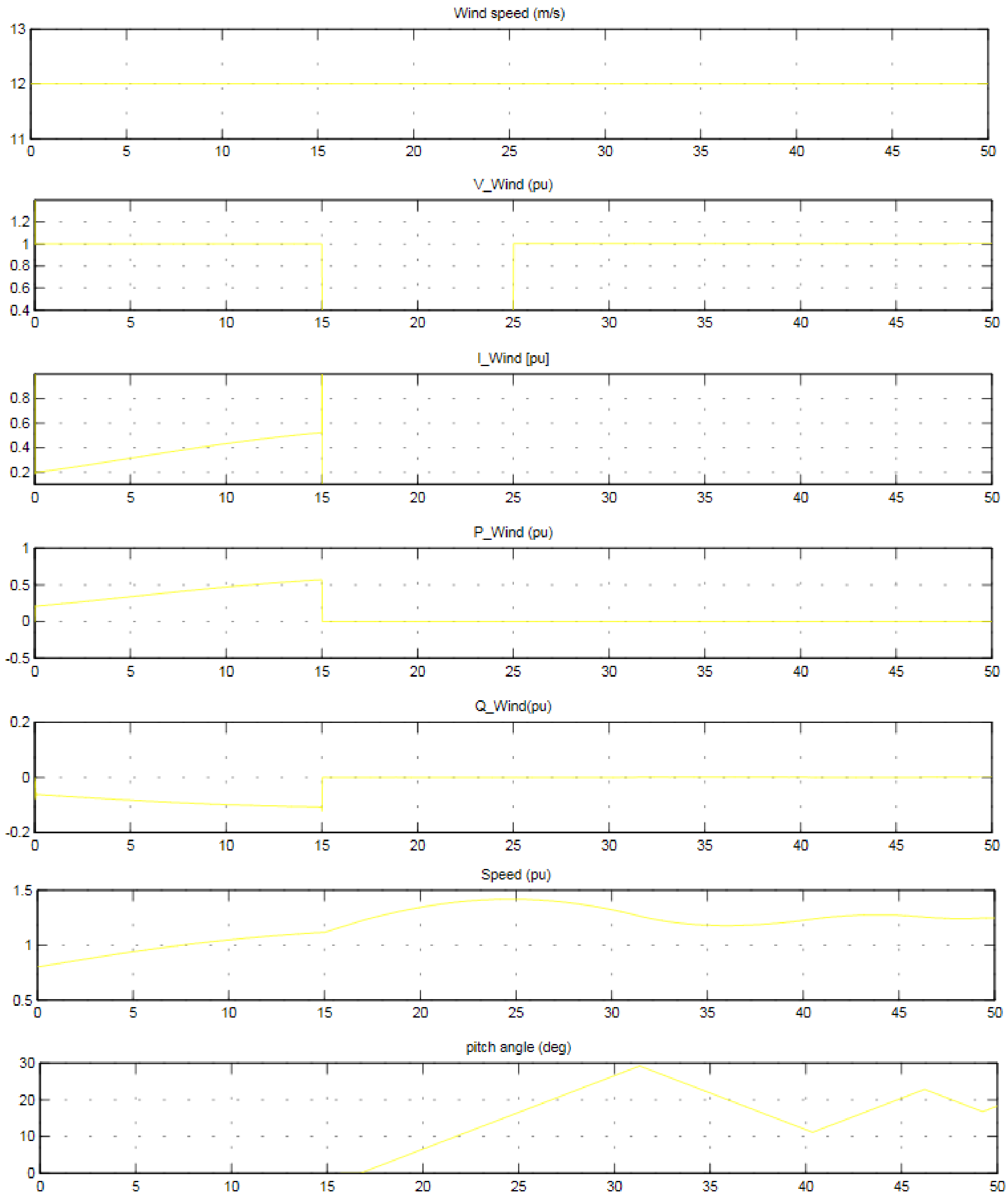
Voltage on Interconnector (pu), HV line (pu) and wind farm (pu) and active power (pu), non-active power (pu) in the line for the replacement wind farm by **wind speed changing form 5 m/s to 15 m/s**



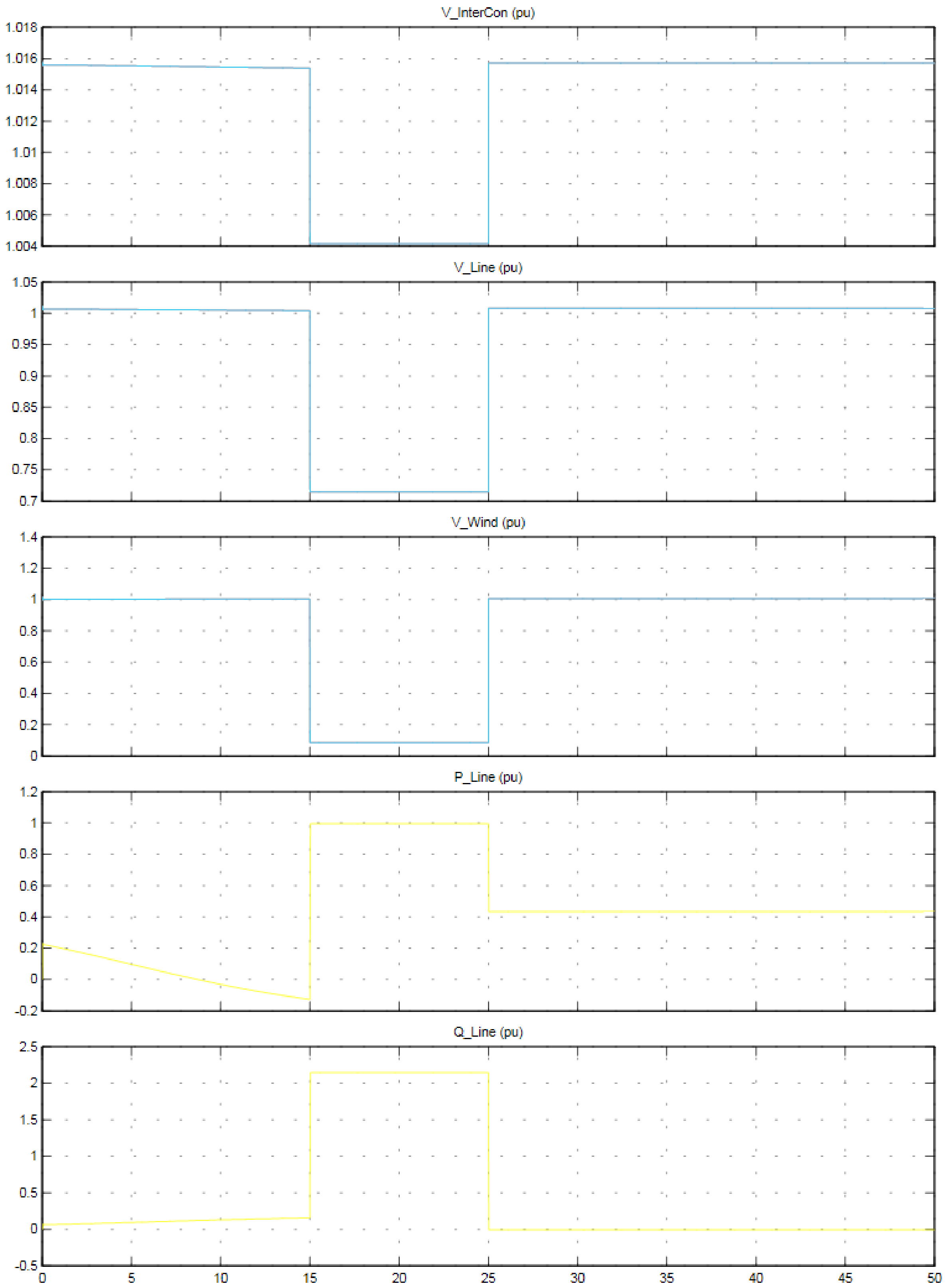
Wind speed (m/s), wind farm voltage (pu), current (pu), active power (pu), non-active power (pu), wind rotor speed (pu) and pitch angle (deg) for the replacement **wind farm by wind speed changing form 15 m/s to 0 m/s**



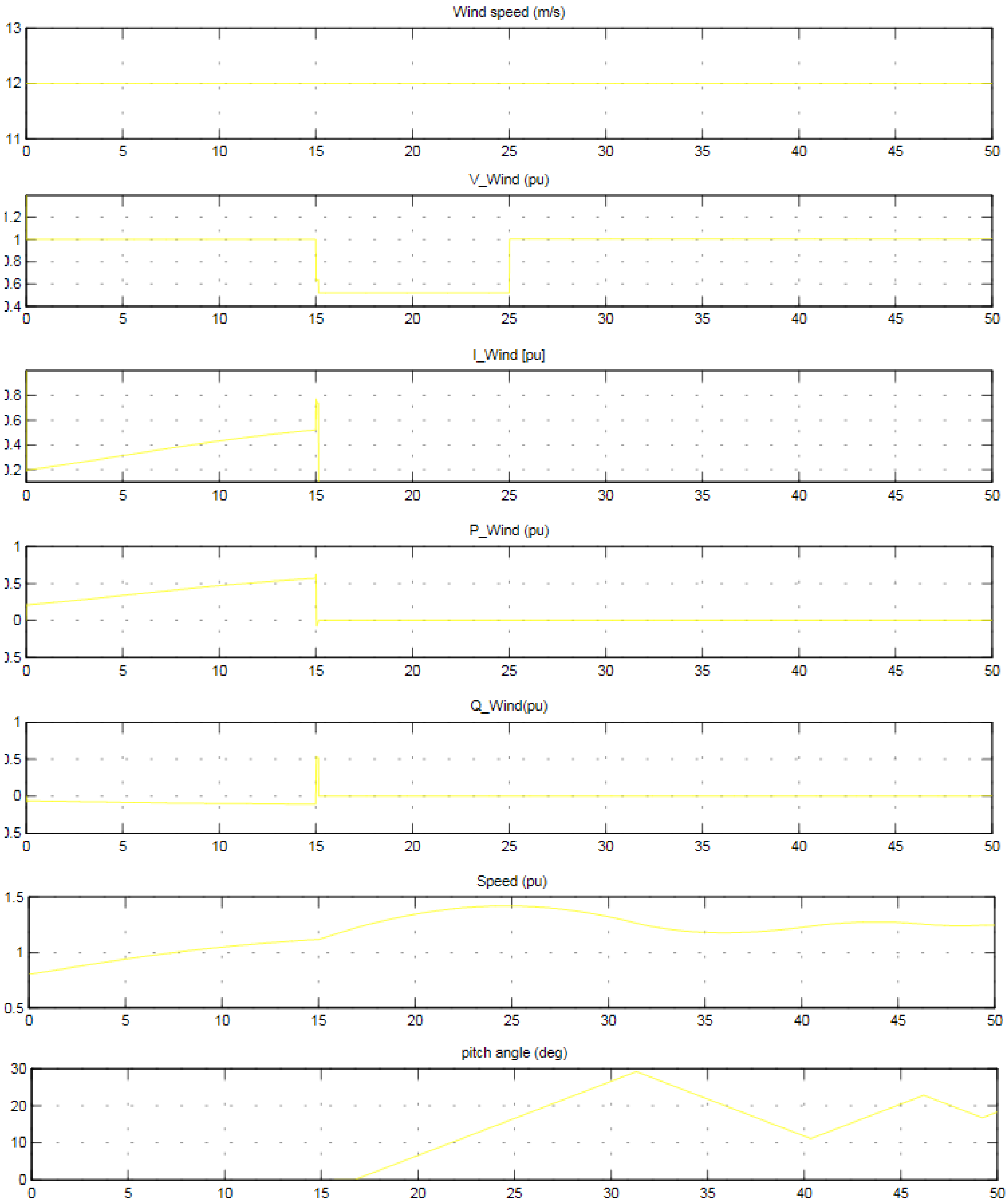
Voltage on Interconnector (pu), HV line (pu) and wind farm (pu) and active power (pu), non-active power (pu) in the line for the replacement wind farm by **wind speed changing form 15 m/s to 0 m/s**



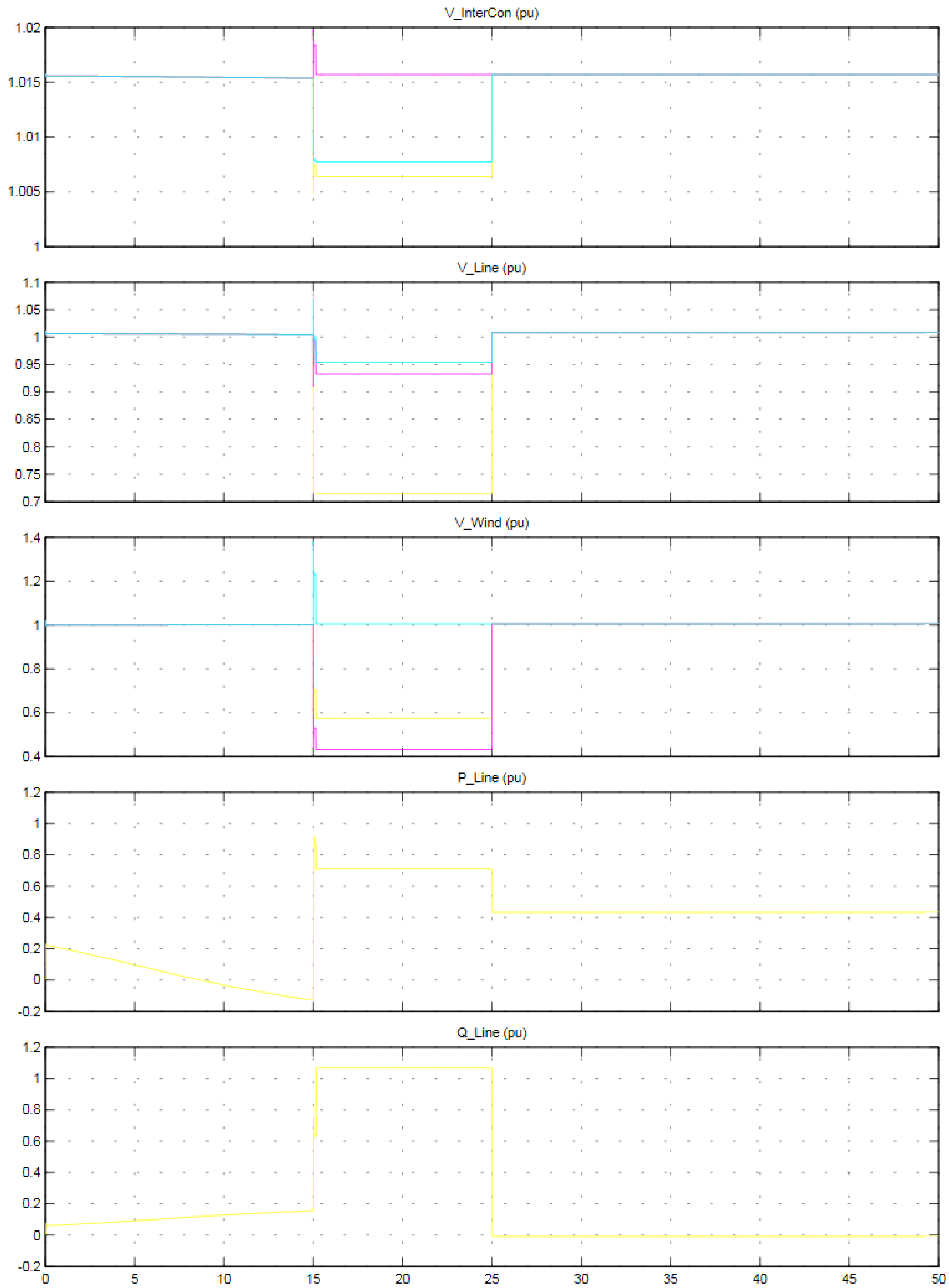
Wind speed (m/s), wind farm voltage (pu), current (pu), active power (pu), non-active power (pu), wind rotor speed (pu) and pitch angle (deg) for the replacement wind farm **by three-phase fault** near wind farm, wind speed 12 m/s, fault begin at 15 sec, fault end at 25 sec



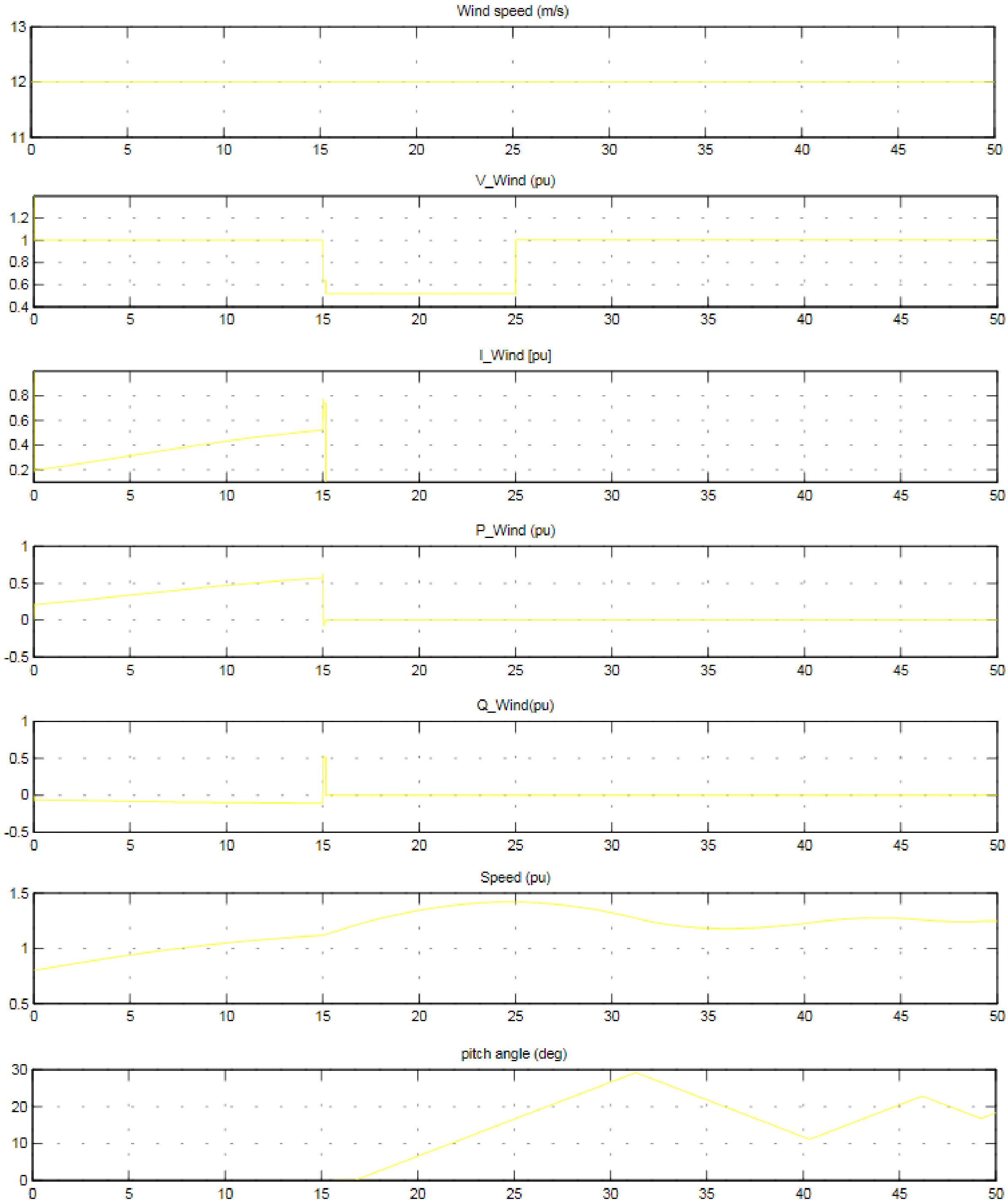
Voltage on Interconnector (pu), HV line (pu) and wind farm (pu) and active power (pu), non-active power (pu) in the line for the replacement wind farm **by three-phase fault** near wind farm, wind speed 12 m/s, fault begin after 15 sec, fault end at 25 sec



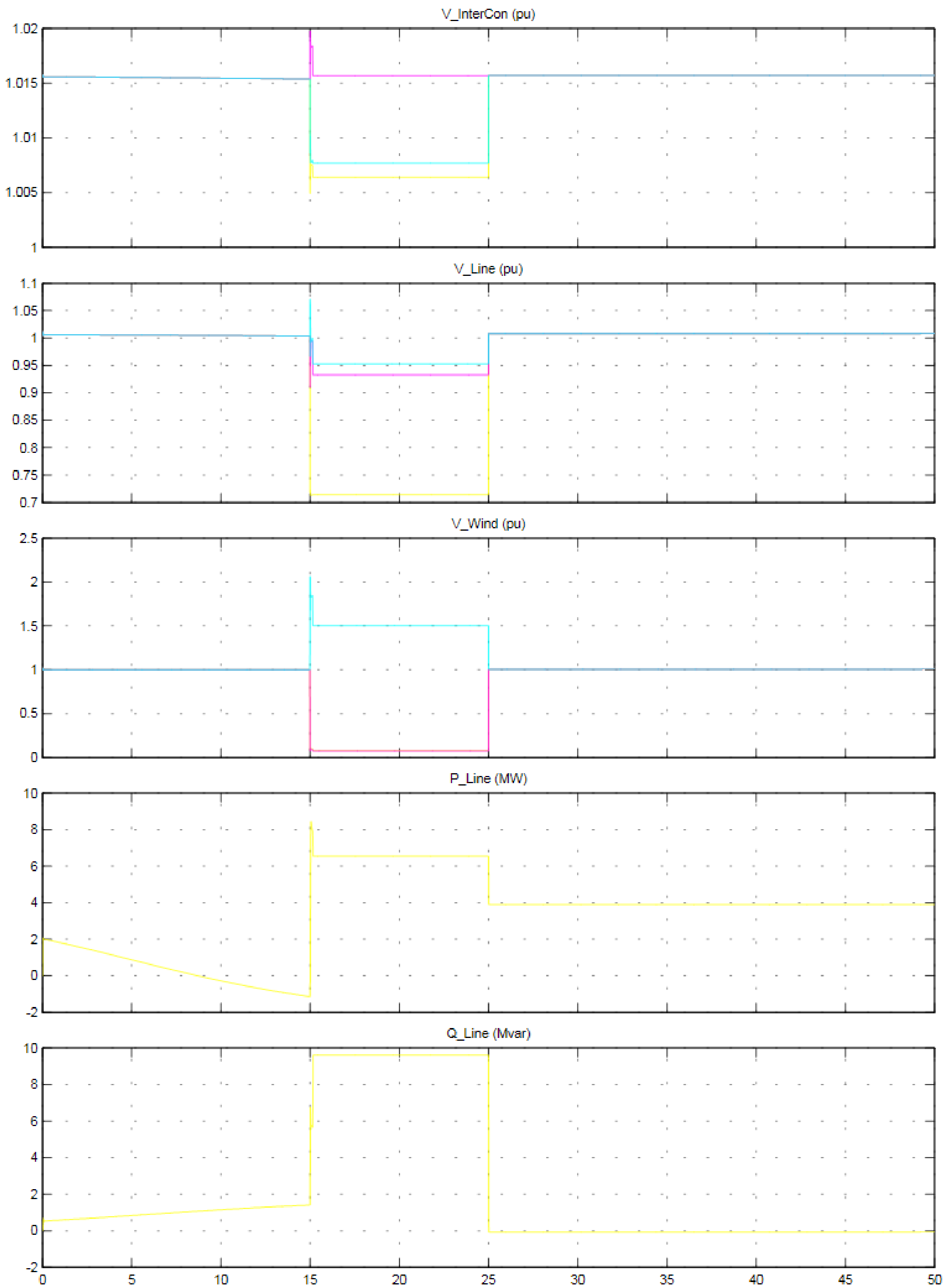
Wind speed (m/s), wind farm voltage (pu), current (pu), active power (pu), non-active power (pu), wind rotor speed (pu) and pitch angle (deg) for the replacement wind farm **by line-line short-circuit** near wind farm, wind speed 12 m/s, fault begin at 15 sec, fault end at 25 sec



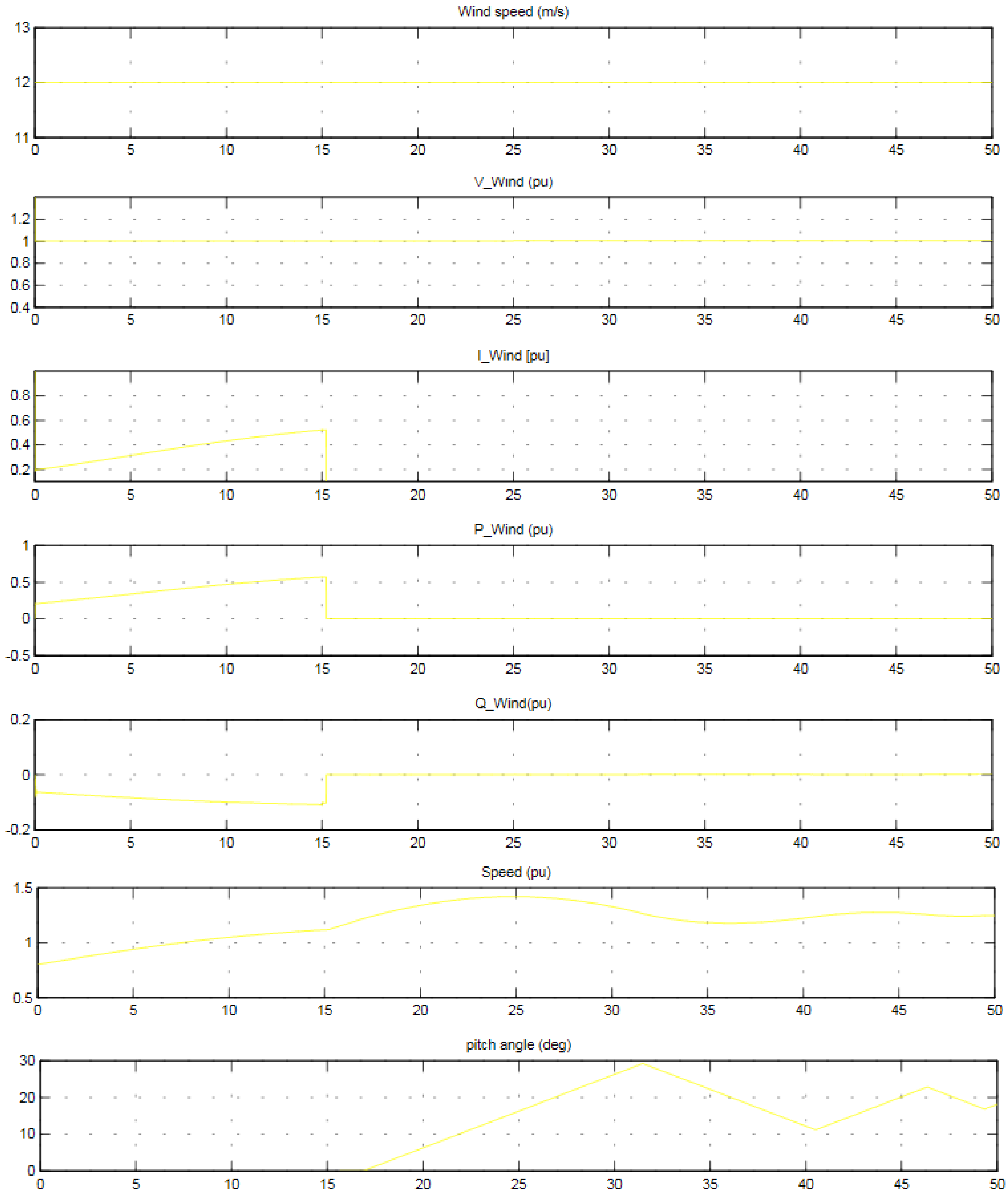
Voltage on Interconnector (pu), HV line (pu) and wind farm (pu) and active power (pu), non-active power (pu) in the line for the replacement wind farm **by line-line short-circuit** near wind farm, wind speed 12 m/s, fault begin after 15 sec, fault end at 25 sec



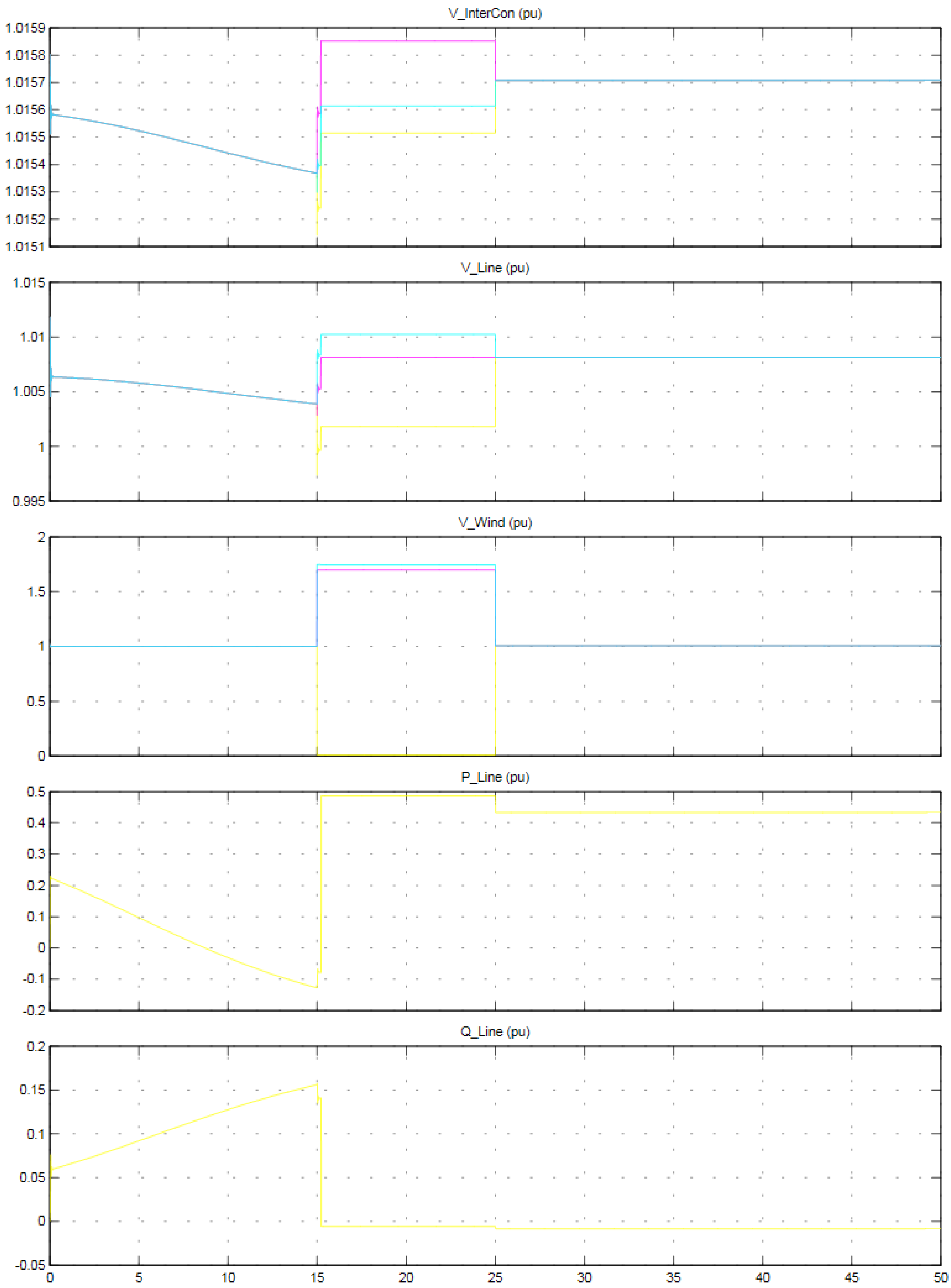
Wind speed (m/s), wind farm voltage (pu), current (pu), active power (pu), non-active power (pu), wind rotor speed (pu) and pitch angle (deg) for the replacement wind farm **by line-line grounded short-circuit** near wind farm, wind speed 12 m/s, fault begin at 15 sec, fault end at 25 sec



Voltage on Interconnector (pu), HV line (pu) and wind farm (pu) and active power (pu), non-active power (pu) in the line for the replacement wind farm **by line-line grounded short-circuit** near wind farm, wind speed 12 m/s, fault begin after 15 sec, fault end at 25 sec



Wind speed (m/s), wind farm voltage (pu), current (pu), active power (pu), non-active power (pu), wind rotor speed (pu) and pitch angle (deg) for the replacement wind farm **by line-ground short-circuit** near wind farm, wind speed 12 m/s, fault begin at 15 sec, fault end at 25 sec



Voltage on Interconnector (pu), HV line (pu) and wind farm (pu) and active power (pu), non-active power (pu) in the line for the replacement wind farm **by line-ground short-circuit** near wind farm, wind speed 12 m/s, fault begin after 15 sec, fault end at 25 sec

Results discussion and recommendation

- ✓ Incorporating of electrical energy from wind farm (10 % of energy consumption) into the Maltese grid addict the grid stability from the wind conditions
- ✓ Grid stability is depended from the interconnector power supply, loss of connection with simultaneously farm disconnecting (e.g. in the case of short-circuit of fault) results with blackout in the whole Maltese grid
- ✓ The new constructed wind farms should be provided with power electronic devices listed on the begin on this report in order to reduce short-time power fluctuation and reactive power compensation
- ✓ Grounded short-circuit and faults in the wind farm may impudence the correct operation of the grid protection system in the nearly located grid area
- ✓ Efforts should be made in order to the wind farm by faults, the same grid disconnected conditions should be apply as by conventional power station

✓ *Impact of Malta–Sicily HVAC submarine interconnector*

The Malta-Sicily Interconnector, inaugurated in April 2014, contributes to the achievement of a diversified mix of energy sources by providing the country with access to electricity generated through sources located in Sicily and other regions in mainland Europe.

The Interconnector comprises a 120 km HVAC system capable of bidirectional flow of electrical power, transferring 200 MW of electricity. In Sicily, the Interconnector is linked to the Italian network at 230 kV at the Terna substation in Ragusa. The submarine cable lands in Malta at Qalet Marku, Bahar ic-Caghaq and transmits electricity to the distribution network at 132 kV through a nearby Enemalta terminal station at Maghtab.

Maghtab Terminal Station

This terminal station is located a few hundred metres away from Qalet Marku Bay, where the submarine cable was pulled ashore in December 2013. At the Terminal Station, electricity from the submarine cable will be received at 220 kV and stepped down to 132 kV. It is then fed to the Maltese grid via cables passing through a purposely-built 6.5 km tunnel leading to the Kappara Distribution Centre. The cables connecting the Terminal Station to the Distribution Centre comprise three circuits, each with three single core cables in trefoil formation. At the other end of the terminal, the Interconnector cable heads towards Sicily through an 850 m underground culvert until it reaches Qalet Marku Bay, at Bahar ic-Caghaq.

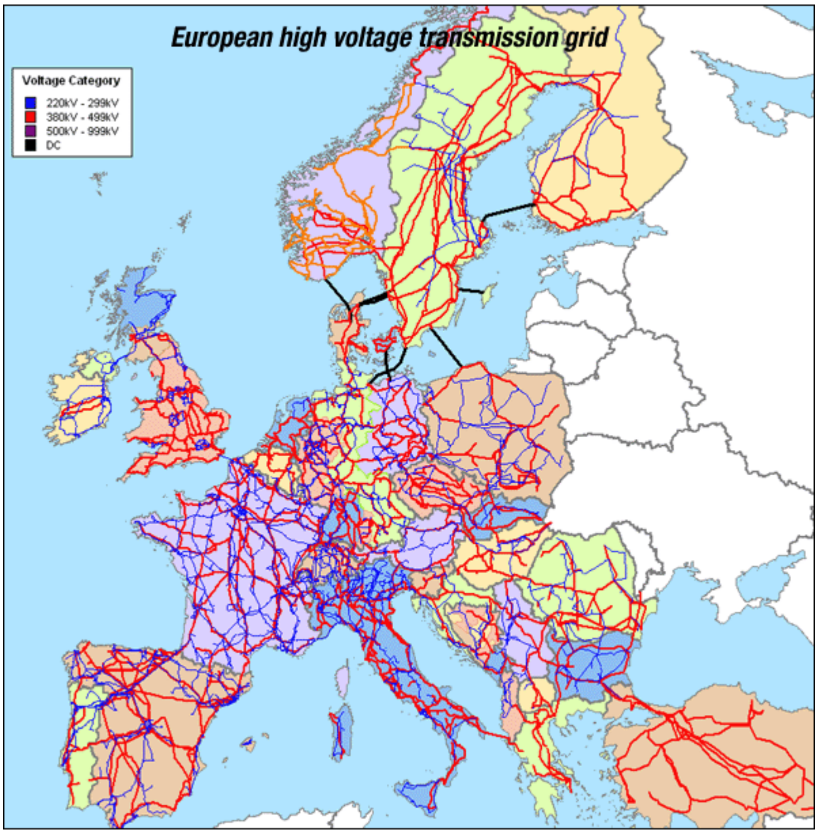
The submarine cable

The subsea circuit is approximately 98 km long. It was laid between December 2013 and March 2014 using the specialized cable laying vessel, the Nexans Skagerrak. Along most of the route, the submarine cable is buried in a trench beneath the seabed. In areas where the seabed was too hard to trench the cable is covered with a rock berm. The cable also crosses some Posidonia Oceanica meadows. To avoid damaging this listed plant’s habitat, the cable has not been buried or placed in a trench but wrapped in strong cast iron shells. At Qalet Marku, the submarine cable is pulled through a 220 m underwater micro tunnel reaching from the seabed in the middle of the bay to the culvert leading to the Maghtab Terminal. At Marina di Ragusa, the interconnector was pulled ashore through another micro tunnel and then jointed to the land cables leading to the Terna substation.

Submarine cable for interconnector Malta – Sicily (enemalta.com.mt)

Ragusa Substation

In Sicily, the Interconnector is linked to the Italian network at a Ragusa substation managed by Terna, the company that operates the electricity transmission grid in this region. At Marina di Ragusa a transition joint connects the submarine cable to the land cables. The 19.1 km stretch of cable from Marina di Ragusa to the Terna substation includes three single core cables placed in trefoil formation and buried in a trench mostly dug in public secondary roads. This circuit was laid in 19 stretches of cable, each one 1 km long.



European High Voltage transmission grid (geni.org)

With the interconnector Maltese power system obtained the possibility of energy exchange with European grid. This is very imported for the future in the case of eventually constriction and use of off-shore wind power, to ensure the supply of energy, in the absence of energy from wind farms and by wrong wind conditions.

The analyses made on the University of Malta performed for interaction of wind turbine rated at 100 MW and interconnector of 200 MW showed the key role of interconnector for grid stability in this case. The simulation took into account the switching of reactors used to absorb the highly capacitive nature of the submarine cable. On Sicily's side one 120 MVA reactor was placed, however on Malta's side two 60 MVA reactors will installed. The results show that the proposed capacitive interconnector generated 300 MVAr of reactive power and 5 MW are lost along its length in terms of real power losses when importing its maximum power capacity. In this condition the 120 MVA reactor on Sicily's side and the 60 MVA reactor on Malta's side need to be switched on for a distributed capacitive effect along the cable. In such operating conditions the increase in current required for the submarine cable's reactive power is equally shared allowing the maximum of the cable for real power transfer. However during minimum demands all availed reactors are suggested to be switched on to balance the amount of reactive power sent to Malta with that transferred to Sicily.

The transient analysis of being disconnected from mainland Europe due to a sudden three phase fault to ground was also carried out. Following the rapid changes of the busbar voltages, powers transferred and network frequency due to this fault will result in a complete shutdown of the local grid together with the disconnection of the wind farm from the grid.

The effect of the wind farm's operation with the grid is simulated. The simulation considers steady state analysis when disconnecting the wind farm at different power levels on the network. It was shown that for an importing scenario extreme changes in busbar voltages are experienced following disconnection of the wind farm. In the case of normal condition with network being supplied full power from Sicily, the loss of the wind farm resulted in the lowest voltage level, but in the case of loss of wind farm when interconnector was not supplying power to the local grid, this resulted in the highest busbar voltage. Similary export cases show the lowest and highest levels on the busbar after disconnecting wind farm from the winter network model. As simulated by the maximum summer load scenario and without the connection to the European grid the network failed to stabilize when the wind farm is disconnected. The sudden loss of the wind farm will eventually lead the whole system to run-away scenario for isolated network. Other faults simulated are a three phase to ground on the 132 kV cable and the disconnection of the largest local generation block. Such condition still managed to stabilize due to the fived connection to Sicily and the possibility to increase the power imported.

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