# OPERATION OF WIND FARMS TO DEFECTS IN THE MEDIUM VOLTAGE GRID

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**Keywords: Wind Farm, Medium Voltage**

**Abstract***: Integrating wind power in medium voltage networks raise problems both economic and technical. The article presents a wind power plant integration in a medium voltage network and its operation in case of fault on other section than the line that wind power plant inject power. In the wind power plant is connected and compensator STATCOM for reactive power compensation. The wind power plant is equipped with squirrel cage induction generators.*

## 1. INTRODUCTION

Connecting wind farms to electricity grids requires solving a large number of technical problems to achieve safe operation of these sources in the electricity system presence and maintaining the system into operation in their presence.[1]

Power groups used in the wind power plants are of two categories, depending on the speed control: Fixed speed and variable speed. Fixed speed turbine is the oldest type of turbine. Train squirrel cage induction generator that connects directly to the grid.[1]

*Wind turbine with fixed speed*

This configuration is known as the "Danish concept" that uses a squirrel cage induction generator (GARS) to convert mechanical energy into electrical energy. Because of the difference between the turbine rotor speed and rotor speed asynchronous generator is necessary to use a multiplier (gearbox) that perform the necessary harmony between these two speeds. Slipping asynchronous generator varies little as the generated power increases, without being kept constant. Since the electric machine speed variations are less than 1%, this turbine is considered to operate at a constant speed or fixed speed [2,3].

The turbine fixed speed is now fitted with brake active aerodynamics (stall control) even though they were designed and turbine systems with fixed speed and adjusting the angle of attack, asynchronous generator with squirrel-cage rotor is connected to the grid through an transformer. Because of voltage fluctuations, asynchronous generator absorbs reactive power from the grid. This is why using a capacitor battery with the role of reactive power compensator. Connecting to the network is achieved through a soft starter having the role to prevent inrush currents when the coupling conditions along the two power sources (asynchronous generator and network) are not satisfied.[4,2]

Whatever the method to control power generated, it should be noted that fluctuations of wind speed are transformed into mechanical power fluctuations and as a consequence into electrical power fluctuations. For a small grid, these electrical power fluctuations give rise to variations in the voltage at the point of grid connection. The main disadvantage of this configuration is that it requires a system of control (adjustment) of the speed, a strong grid, and must be able to withstand considerable mechanical stress [4.2].

In almost all cases, the internal networks of medium voltage or high voltage of wind power and photovoltaic and in some cases even power lines connecting these central power system are made of electrical cables that generate significant quantities of reactive power which influences power factor into PCC. In these circumstances it is necessary compensation of reactive power for voltage at the PCC and reactive power exchange with the grid of the power system to meet the requirements of technical codes electricity transmission grid or distribution of electricity [5].

Modern solutions for rapid and automatic voltage control and fluctuations of energy use electronic control systems for reactive power flow. Systems FACTS (Flexible Alternating Current Transmission System) built based on power electronic circuits, ensure state control of electrical quantities to achieve the necessary transfer of power in electricity grids. [5]

### 1.1. Static synchronous compensator shunt (STATCOM)

It is a device that uses power electronics with forced commutation (eg GTO - Gate turn-off thyristor, IGBT - insulated gate bipolar transistors) to control voltage and power flow, and improving the transient stability into electricity grids. STATCOM uses a voltage source converter to absorb or inject in nodes grid is connected amount of reactive power to control voltage in node connection or flow control reactive on power line connection at the power system [6].

STATCOM is the most efficient synchronous compensator shunt, his answer is the same as the synchronous compensators (rotating) and, moreover, has no mechanical inertia. The three-phase schematic diagram is shown in Figure 1 [6].

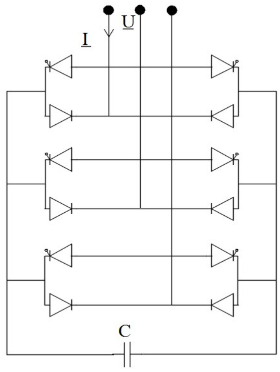


*Fig.1- Three-phase scheme of STATCOM*

A STATCOM can be used in two ways [7]

a) *The voltage control mode connection.*

STATCOM regulates voltage into the mains connection point by controlling the reactive power absorbed or injected into the power grid through a converter VSC. Reactive power absorbed or injected into the grid by this device depends on the voltage amplitude in the connection point. When the voltage amplitude into the connection point is higher than the reference value (Uref), STATCOM absorbs reactive power from the grid and thus reduce the tension in the connecting node (comparison inductive STATCOM). When the voltage amplitude into their grid connection point is lower than the reference value (Uref), STATCOM inject reactive power into the power grid and thus there is an increase in tension in the node grid connection (comparison capacitive STATCOM)

b) *Reactive power control mode in the connection node*

In this mode of operation is controlled STATCOM reactive power output, independent of other parameters of grid.

### 1.2. Protection of medium voltage grid

The primary aim of energy system is to generate, transport and distribute electricity to consumers. Reaching the goal requires both appropriate equipment reliability primary and secondary protective equipment and automation taking economic factors into account.

Ensuring uninterrupted operation of the electrical system is of great importance, both because the consequences can be serious disruptions in operation, and that electrical installations are more exposed to disturbances than other types of installations. The gravity of the consequences derived primarily from the fact that - part electrical installations generally a complex energy system - a fault appeared in a place disturbing normal functioning of the whole system; Second, the severity of defects in electrical installations due to very high energies that interfere into their development, leading to extremely high destructive effects.. Knowing the methods of intervention and detection of these defects have developed various protective equipment to cover most conditions from damages that may arise in their functioning.

In general, medium voltage lines are fitted with the following types of protection:[8]

a) Timed overcurrent protection against phase defects

$$I_{maxII}=k_{sig}\cdot I_{sarc.max} \quad (1)$$

In which:

- $I_{sarc.max}$ it is the maximum current that can be carried by a medium voltage line limited by the diameter or type current transformer existing supply end;
- $K_{sig}$ is a safety factor equal to 1,25 ÷ 1,3

b) Instantaneu overcurrent protection (cutoff current)

$$I_{maxI}=k_{sig}\cdot I_{scc.max} \quad (2)$$

In which: - $I_{scc.max}$ is three phase short-circuit current calculated at the end of the line for which the adjustment protection;

- $K_{sig}$ is a safety factor equal to 1,25 ÷ 1,3

c) Timed current homopolar protection

$$I_{hII}=k_{sig}\cdot \varepsilon\%/100\cdot I_{nTC} \quad (3)$$

In which:

- $I_{nTC}$ is the nominal primary current of the transformer current with which is made Holmgren the filter
- $K_{sig}$ is a safety factor equal to $k_{sig}$=1,5

### 1.3 Wind farm protections

To protect wind power plant, against defects that might arise in their grid and beyond, wind power plants must be equipped with a minimum of protection [9]:

- Instantaneu overcurrent protection (cutoff current)
- Timed overcurrent protection against phase defects
- minimum frequency protection
- maxim frequency protection
- minim voltage protection
- maxim voltage protection
- protection against phase asymmetry..

As noted they represent a minimum and may be supplemented with other protection according to the specific network which supplies.

1. *Minimum and maximum frequency protections*

Minimum and maximum frequency protections are designed to protect wind farm against isolated operation and so as not cause defects aggravation of the grid are connected.

Recommendations standards in force for minimum and maximum frequency protections are:

$$f_{min} = 47\text{Hz}, t = 0.5\text{s} \tag{4}$$

$$f_{max} = 52\text{Hz}, t = 0.5\text{s} \tag{5}$$

*1. Minimum and maximum voltage protections*

The purpose of this protection is to protect generator against minimum / maximum voltage that could occur, and protect network against overvoltage created by the wind power plants. Protection can be used as short circuit protection because fault current increases during what has the effect of lowering the minimum voltage and starting minim voltage protection of generator, and after the set time the control tripping protected equipment

To have clarity on the parameters (voltage) so protection is supplied from groups as the bars of medium voltage point of common coupling. Minimum and maximum voltage protections have two stages:

a) step of signaling

$$U_{max} = +6\%, t < 60\text{s} \tag{6}$$

$$U_{min} = -6\%, t < 60\text{s} \tag{7}$$

b) tripping stage

$$U_{max} > +10\%, t \leq 0.3\text{s} \tag{8}$$

$$U_{min} < -10\%, t \leq 0.3\text{s} \tag{9}$$

*2. Overcurrent protection*

Protection as a value adjustment has two steps:

a) Delayed step – against overcurrent occurring in connecting wind groups with a lower power and greater control over.

b) Rapid step – current cutoff – against short circuits in the internal grid of the wind farm with a higher current value and time t = 0s

Setting values for the two steps, to meet current standards must be set so fast maximum protection to eliminate defects in the 0s, the recommended value is $I_{max\,I} = 10 \cdot I_{nom}, t = 0\text{s}$, and timed overcurrent protection is sufficiently sensitive against overloads caused by the connection groups, but at the same time, selective to allow groups to remain in service to transient grid faults., recommended value is $I_{max\,II} = 1.1 \cdot I_{nom}, t \leq 1.5\text{s}$

*3. Protection against asymmetries between phase and earth*

Protection has a simple operating principle verifying increased or decreased voltage on phase is also adjusted in two steps, one signal and another tripping.

a) *Asymmetries* $<\pm 5\%$ , t=10s - signalization

b) *Asymmetries* $\geq\pm 5\%$ , t=1s - trip

## 2. SIMULATION AND DISCUSSION

Simulations were performed using Matlab - Simulink. The proposed grid simulation is composed of a wind power plant with an installed power of P = 9 MW, which supplies by a 20 kV line, with a length of 5 km, into substation St.A.

St. A. is composed of a transformer Un=110/20 kV, Sn = 25 MVA. Short circuit power Sk, on the 110 kV bar is Sk=2000 MVA. On the line connecting the wind power plant and substation St.A. is connected a line that supplies the consumer with a power of P = 500 kW.

The wind power plant is composed of 6 units of 1.5 MW each. The wind power plant is equipped with squirrel cage induction generators and synchronous compensator shunt STATCOM 3MVAR

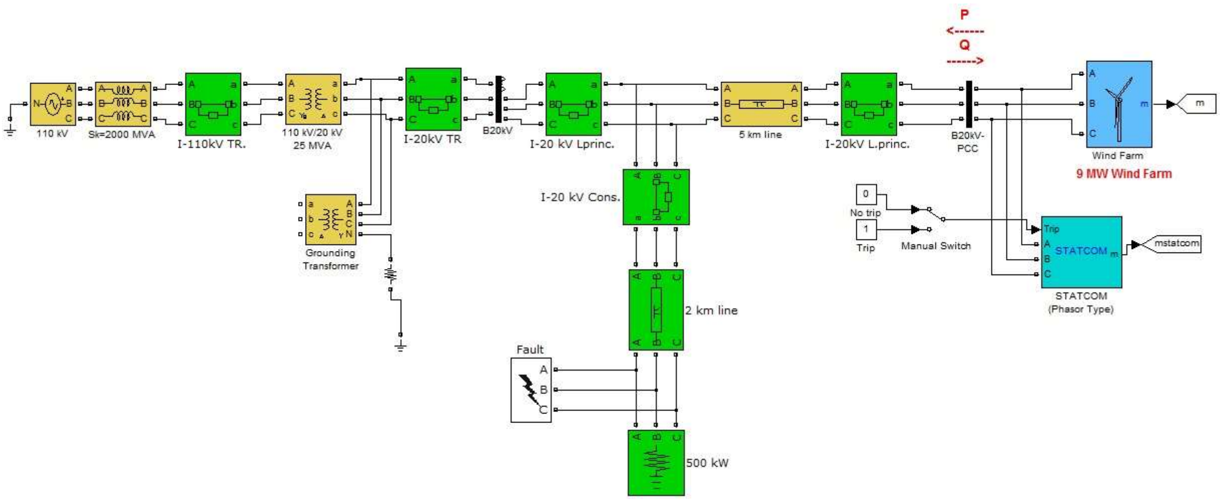


*Fig.2 – The proposed grid simulation*

### A. Determination protections settings.

For simulated grid were adjusted the protections:

**L 20 kV –principal**

a) *Instantaneu overcurrent protection*

$$I_{maxI} = k_{sig} \cdot I_{sccmax} = 1.1 \cdot 3555A = 4000A - t = 0.2s$$

b) *Timed overcurrent protection*

$$I_{maxII} = k_{sig} \cdot I_{sarc.max} = 1.2 \cdot 325 = 390A - t = 1s$$

Where: $I_{sarc..max}$ – is the maximum current that can be transported safely on line (Imax = 325 A- limited by conductor cross section OL-Al 95 mm$^2$)

c) *Homopolar current protection*

$$I_{hII} = k_{sig} \cdot \frac{\varepsilon\%}{100} I_{nTC} = 1.5 \cdot \frac{5}{100} \cdot 400 = 30A - t = 0.2s$$

**L 20 kV – The consumer 1**

*a) Instantaneu overcurrent protection*

$$I_{\max I} = 1000 - t = 0s$$

*b) Timed overcurrent protection*

$$I_{\max II} = 100A - t = 0.5s$$

*c) Homopolar current protection*

$$I_{hII} = 20A - t = 0s$$

**Wind power plant**

Adjusted values respectively measures for protection of minimum and maximum voltage of 20kV bar from point of common coupling are expressed on a per unit. So it is necessary to choose a basic voltage Ub and voltage that wind power works at one time called the current value and noted with $U_C$:

$$U_b = 21kV\,;\, U_C = 21kV\,;\, U_{u.r.} = \frac{U_C}{U_b} = \frac{21}{21} = 1u.r.$$

a) Instantaneu overcurrent protection directed towards the wind farm

$$I_{\max I} = 10 \cdot I_{nom} = 10 \cdot 260 = 2600A - t = 0s$$

b) Timed overcurrent protection directed towards the wind farm

$$I_{\max II} = 1.4 \cdot I_{nom} = 1{,}4 \cdot 260 = 360A - t = 1.5s$$

c) Minimum voltage protection

$$U_{\min} = 0.7p.u. = 0.7 \cdot 21 = 14.7kV \text{ -for line voltage}$$

$$U_{\min} = 0.7p.u. = 0.7 \cdot 12 = 8.4kV \text{ - for phase voltage}$$

d) Maxim voltage protection

$$U_{\max} = 1.1p.u. = 1.1 \cdot 21 = 23.1kV \text{ - For line voltage}$$

$$U_{\max} = 1.1p.u. = 1.1 \cdot 12 = 13.2kV \text{ - For phase voltage}$$

e) Protection against voltage asymmetry 5% - t=1s

f) Protection of minimum frequency

$$f_{\min} = 47Hz - t = 0.5s$$

a) Protection of maxim frequency

$$f_{\max} = 52Hz - t = 0.5s$$

**B. Making simulation**

It will simulate the operation of the grid in normal operating conditions without any fault on the grid and without connecting consumer 1-500 kW.

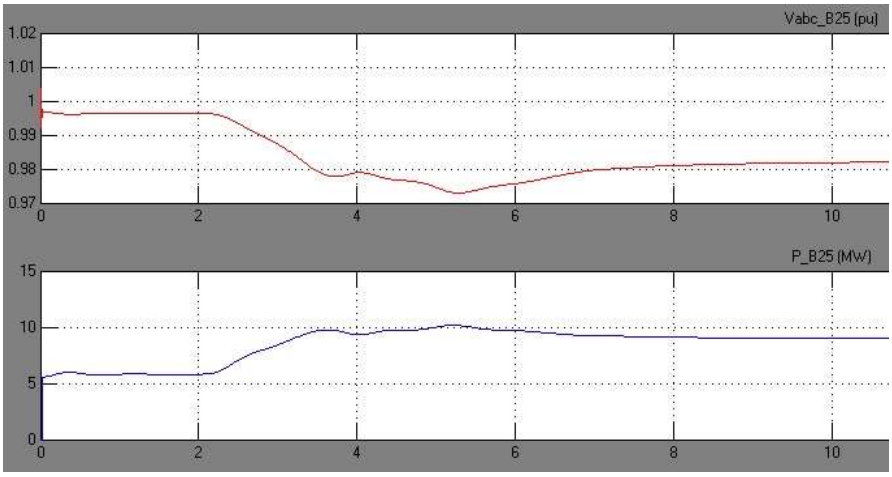


*Fig.3 – Functioning of the grid with STATCOM connected*

As you can see in Figure 3 with static compensator shunt - STATCOM connected voltage on bar 20 kV in the wind power plant (V_B25) has a value of 0.98 pu - 11.99 kV (20.75 kV), active power (P_B25) amounts to 9 MW.

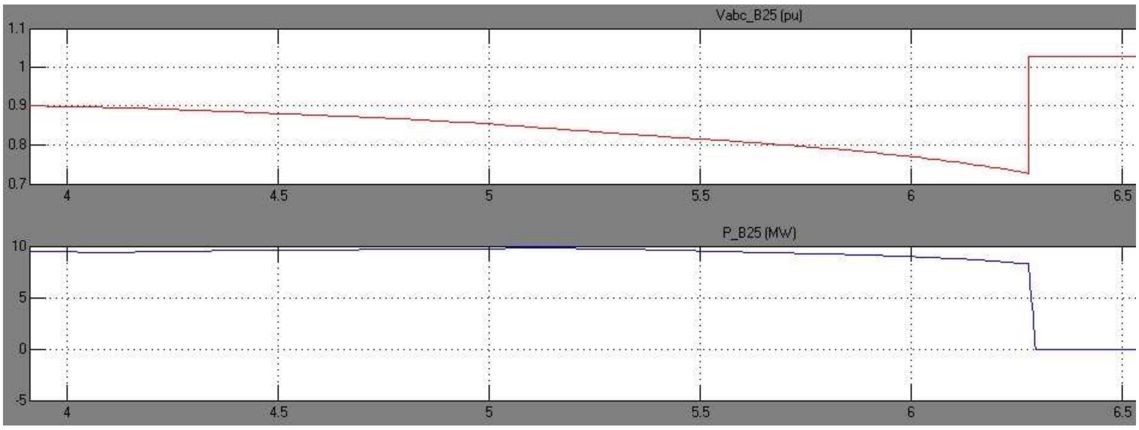


*Fig.4 – Functioning of the grid with STATCOM disconnected*

If disconnection static compensator shunt - STATCOM, a part of the reactive power required asynchronous generators is produced locally by capacitor banks' own plant, while the remaining reactive power required producing full active power assets by groups wind is consumed from the 20 kV grid. Increased consumption of reactive power from grid has the effect of lowering of voltage bar 20 kV corresponding point of common coupling (PCC) - the measure Vabc_25 (pu) under value with adjustment for the protection of minimum voltage of wind units (Umin = 0,7p.u -8.4 kV t = 0.1s) which has the effect of tripping all groups of wind power by 0.1s at the time t = 6,3s. Once tripping the wind groups, voltage on bar 20 kV corresponding PCC returns to the value of 0.988 p.u., the bar remaining energized, fed from 20 kV grid.

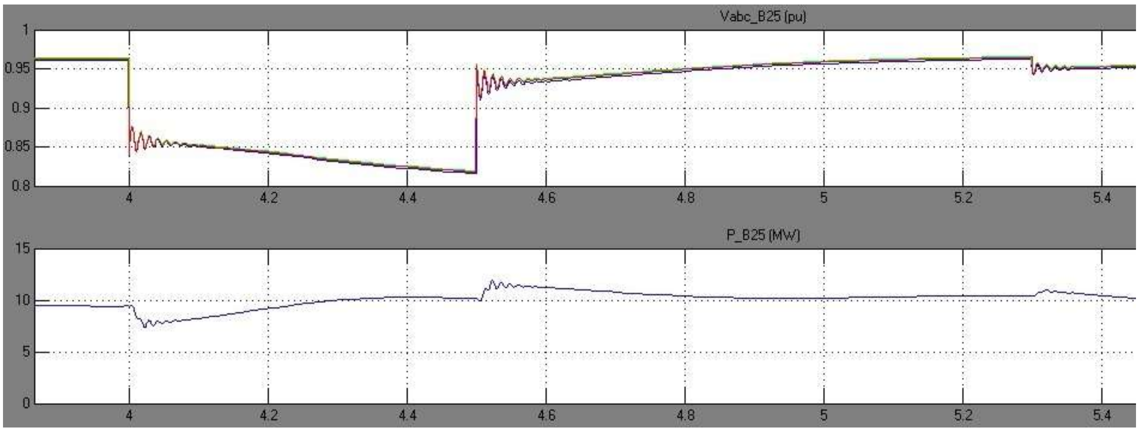


*Fig.5 – Three phase fault on the line that supplies consumer 1-500 kW*

At time t = 4s there is a three phase fault in the L- 20 kV which supplies the consumer 1. When the fault occurred which lasts 0.7s, whose value is approximately 700A, starts timed overcurrent protection corresponding consumer 1, after 0.5s (4,5s) give the command to trip I-20kV which supplies consumer 1. The fault is removed by tripping I 20 kV which supplies consumer 1. In RAR pause (0,8s) the arc extinguishes and after tripping, 0,8s connects at I 20kV for the consumer 1 (5,3s). It can be seen that the emergence fault, the voltage on bar 20 kV corresponding wind farm (B_25) decreases the value 0,976pu - 11.85 kV (20.5 kV) to the value of 0.83 p.u. - 10.1 kV (17.43 kV - 4,5s), but wind power plant remains connected because value required and setting for the minim voltage protection of wind turbine voltage is

0.7 pu - 8.4 kV (14.7 kV).

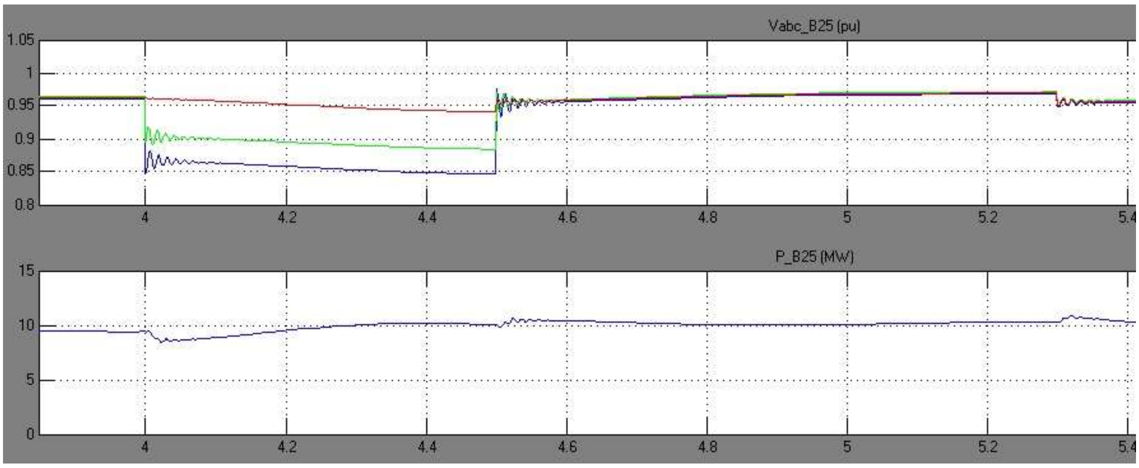


*Fig.6 – Phase to phase fault on the line that supplies consumer 1-500 kW*

Was simulate a phase-phase short circuit R-S, with a current of 600 A, fault notified by the overcurrent protection of consumer timed 1.

At t = 4s take place phase to phase fault R-S, with a value of I = 600 A. Started timed overcurrent protection after 0.5s and tripping the switch of the Consumer 1 (tripping all three phases). The defect is removed, the voltage 20 kV bar corresponding PCC increase to an amount above 0,95p.u. After 0,8s from the eliminate defects by tripping breaker for the consumer, RAR automation connects the switch and the consumer1 continues to be powered.

## 3. CONCLUSIONS

Choosing right protections settings in medium voltage grid is very important. Defects which were not removed from the sections where defects have taken place may tripping the upstream elements and has the effect of tripping line that debits the wind power plant. In case of squirrel cage asynchronous generators, it is very important that the entire reactive power needed to be produced locally. Disconnection STATCOM device of wind power plant has the effect of tripping groups by under voltage protection. Squirrel cage induction generators of wind power plant consumes reactive power from the grid that has as effect on lowering voltage on the medium voltage bar below setting of minimum voltage protections groups. For any defect appeared radial section and removed the protections own defective equipment, wind power plant remains in operation.


## *ACNOWLEDGMENT*

This paper is supported by the Sectoral Operational Programme Human Resources Development POSDRU/159/1.5/S/137516 financed from the European Social Fund and by the Romanian Government


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