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Short Cırcuıt Analysıs and Management of Mıcrogrıd System by Usıng Statcom

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ABSTRACT: The dynamic response of the grid to any change in its transmission power is always fluctuating. In the past, only thermal power plants were used to supply the power required by the demand, but nowadays renewable energy resources have taken a significant share. Due to the inherent intermittent of this type of renewable energies, the dynamic responses of the network have also become more intense, and therefore it is necessary to use special equipment and control strategy to improve stability and maintain normal condition in generating the required power, especially in the fault conditions. In this project, a microgrid including a wind power plant with a capacity of 2 MW is used, which is connected to the main grid. To maintain the stability of the microgrid, a device called STATCOM is used, which can maintain the voltage level of the network at the desired value by injecting reactive power. In order to evaluate the efficiency of the proposed system, four different operating conditions including normal status, single phase to ground fault, two phase to ground fault and three phase to ground fault are modeled and the obtained results show that the use of STATCOM can play a major role in improving the stability level of the network.

KEY WORDS: Static Compensator (STATCOM), Grid Stability, Wind Farm, Short Circuit.

INTRODUCTİON

In recent years, in order to improve the capacity of the transmission system with the lowest possible cost, the technology of flexible AC transmission systems (FACTS) have been used. FACTS devices technology consist of power electronic equipments that include a number of controllers. Among the advantages of using them, we can mention the improvement of dynamics and transient stability of the grid, voltage stability, line reactive power compensation, improvement of power factor, optimal adjustment of voltage profile, and minimization of losses. The stability of the power system is actually defined as the ability of the system to reaction when disturbances occur and to recover it to normal conditions (Khan et al. 2016). Usually, voltage stability in power systems occurs due to the lack of reactive power demand (Razavi & Elmi, 2020).

FACTS controllers have an inherent ability to absorb or inject reactive power at the appropriate time in order to maintain voltage stability (Narain & Gyugyi, 2000). In fact, the purpose of participation of FACTS devices in the power system lines is to create more flexibility in addition to improving the active power transmission capacity and preventing the occurrence of subsynchronous resonances and damping network fluctuations (Yuma & Kusakana, 2012). The performance of such devices has been widely studied in numerous articles (Salim & Maika, 2016).

After a permanent fault occurs in the microgrid (power lines or transformers), protective equipments disconnect the damaged part from the microgrid in order to quickly clear the fault. The absence of the faulty unit has led to the weakness, which is usually accompanied by a voltage drop at the load terminals in the damaged section (Eurostage package. 2010, Amin & Elmi, 2021). This phenomenon usually occurs on microgrids with low short-circuit inertia and relatively high demand. In this situation, a device called STATCOM can be used. In fact, SATACOM maintains the voltage level and by injecting power leads to supplying the required load, which can simultaneously inject or absorb both active and reactive power into the microgrid (Borhan et al. 2023). In this regard, the main contributions of the proposed approach are as follows:

- Maintaining the stability level of the microgrid under severe fault conditions
- Controlling the operation of STATCOM to recover voltage level to normal status after short circuit occuring
- Evaluating the performance of proposed approach under different states of short circuit faults

METHODOLOGY

Static synchronous compensator (STATCOM) is a type of FACTS controller with parallel connection that operates based on a voltage source or current source converter (Chansareewittaya & Jirapong, 2010). This controller is able to absorb or inject reactive power into the system at the required time. STATCOM is used together with energy storage sources to improve the dynamic characteristics of the power system. It can also be used as an active harmonic filter. Figure 1 shows the schematic of STATCOM structure. In this situation, the STATCOM measures the desired bus voltage level and corrects the reactive power exchange in order to maintain the voltage at its standard value. When the voltage level is lower than its rated value, the STATCOM injects reactive power into the microgrid, and in the situations of increasing the voltage level from the nominal state, it helps to maintain the voltage level by absorbing the reactive power. In the control approach, by converting the three-phase model to the rotary two-phase (dq) model, the desired parameters are controlled independently. (Independent control of active and reactive power is considered here). According to which flux is chosen for orientation, the vector control method used is implemented in three ways.

- Rotor flux orientation
- Stator flux orientation
- Magnetizing flux orientation

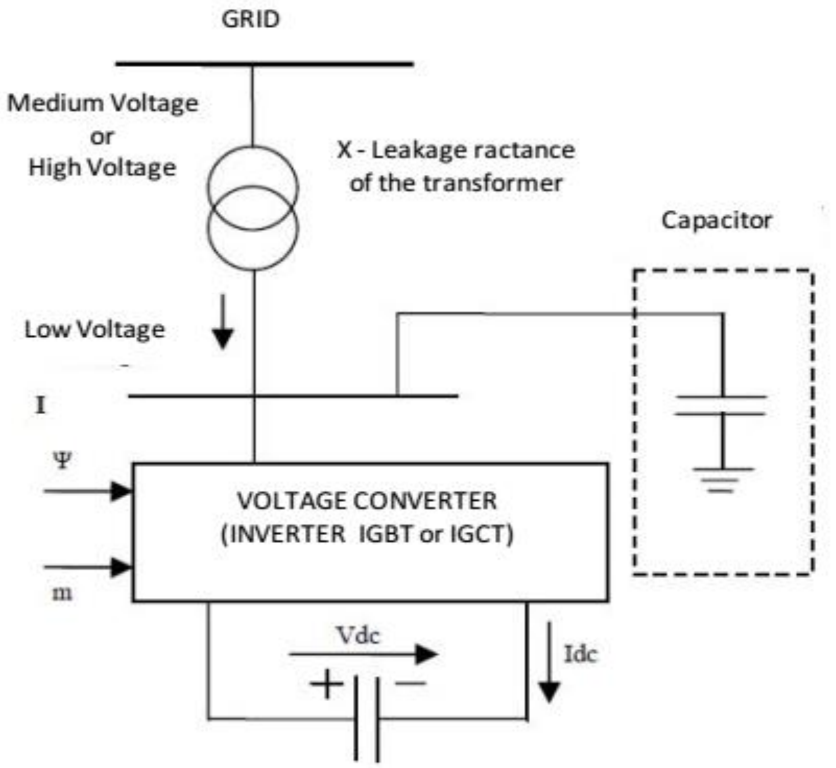

Figure 1. Schematic of STATCOM structure (Eurostage package, 2010)

Each of these methods has its own characteristics. In this article, the stator flux orientation method is used, because it is less sensitive to the generator parameters and its isolating circuit is also simple. To connect the doubly fed induction generators (DFIG) to microgrid, three steps must be implemented. The first step is to synchronize the stator voltage with the microgrid voltage, which is used as a reference. The second step is connecting the stator to the grid, and in the last step, the power transfer conditions between the DFIG and the network are applied in a reference frame dq, which is the same speed as the stator flux. Equations 1 and 2 are obtained by setting the quadratic quantities of the stator flux equal to zero. In the following, it is assumed that the microgrid is stable. In this condition, the voltage V_s is proportional to the constant stator flux ϕ_s. (Equation 3 and 4)

$$\varphi_s = \varphi_{ds} \tag{1}$$

$$\varphi_{qs} = 0 \tag{2}$$

$$V_{ds} = 0 \tag{3}$$

$$V_{qs} = V_s \approx \omega_s \varphi_s \tag{4}$$

φ_s : Stator Flux
φ_{ds} : d-axis flux
φ_{qs} : q-axis flux
V_s : Amplitude of stator voltage

In the following, the resistance of the stator phases is neglected, which is a realistic approximation for electrical power machines used in wind farms. As a result, the stator voltage vector has a quadratic increase compared to the stator flux vector. So, the rotor voltages can be calculated by Equations 5 and 6. According to these relations, d-axis and q-axis of flux can be obtained by Equation 7 and 8.

$$v_{dr} = \sigma L_r \frac{di_{dr}}{dt} + R_r i_{dr} - \sigma L_r \omega_r i_{qr} + \frac{M}{L_s}\frac{d\varphi_{ds}}{dt} \tag{5}$$

$$v_{qr} = \sigma L_r \frac{di_{qr}}{dt} + R_r i_{qr} - \sigma L_r \omega_r i_{dr} + \frac{M}{L_s} V_s \tag{6}$$

$$\varphi_{ds} = L_s i_{ds} + M i_{dr} \tag{7}$$

$$\varphi_{qs} = L_s i_{qs} + M i_{qr} = 0 \tag{8}$$

V_{dr} : d-axis voltage
V_{qr} : q-axis voltage

L_r : Rotor inductance
L_s : Stator inductance
ω_r : Angular speed of rotor

Generally, the real and reactive power of stator can be presented by Equations 9 and 10, respectively. In this situation, active and reactive power can be controlled independently. In fact, i_{qr} is used to control active power (Equation 11) and i_{dr} is used to control the reactive power (Equation 12). Also, in this approach, the field orientation method is used and active and reactive power are considered as variables.

$$P_s = v_{ds} i_{ds} + v_{qs} i_{qs} \tag{9}$$

$$Q_s = v_{qs} i_{ds} - v_{ds} i_{qs} \tag{10}$$

$$P_s = -V_s \frac{M}{L_s} i_{qr} \tag{11}$$

$$Q_s = \frac{v_s^2}{\omega_s L_s} - V_s \frac{M}{L_s} i_{dr} \tag{12}$$

Microgrid Modelling

Figure 2 shows the single-line diagram of the power system under study, which is used for analysis and simulation. The required power of the network is provided via the connection to the main grid and to a DFIG wind turbine with a rated power of 2 MW. The low voltage distribution grid is considered as 600V and 25kV is determined for medium voltage level. Also, the total length of the grid is considered equal to 23 km. Since in real conditions, the microgrid voltage is not constant, therefore, in the time period from 0 to 0.4 seconds, the magnitude of voltage is supposed as 1.06 P.U. at t = 0.2s and 0.94 P.U. at t = 0.3s. In order to evaluate the operation of the STATCOM when a fault occurs, simulations have been carried out in 4 different conditions consist of normal state, single-phase to ground fault, two-phase to ground fault and symmetrical three-phase fault. The characteristics of STATCOM are presented in Table 1. The simulation has been done in the Simulink environment of MATLAB software. The time step is equla to $20\mu s$ so that it is sufficiently smaller than the time period of the power system and the obtained numerical solutions have high accuracy. In the system under study, it is assumed that during the occurrence of the fault and transient analysis of the system (Max. 5s), the wind speed is constant and does not change significantly.

Table 1: Characteristics of STATCOM

Parameter	Value	Parameter	Value
Extra capacitor capacitance (P.U.)	1	Short circuit reactance of Trans. (P.U.)	0.06
Internal capacitor capacitance (P.U.)	0.00005	Overload coefficient of Inverter	2.3
Rated power of STATCOM (P.U.)	1	Winding inductance (P.U.)	347.22
Max. Active power	0.037	Desired initial active power point (P.U.)	0.037
Max. Winding current (P.U.)	0.0125	Max. Range of DC voltage regulation (P.U.)	1
Min. Winding current (P.U.)	0.00399	Min. Range of DC voltage regulation (P.U.)	-1
Internal Coefficient of inverter (k)	0.225	Desired DC voltage (P.U.)	6.25
Integral coefficient of active power fault (k_2)	-200	Time constant coefficient for DC voltage fault	160

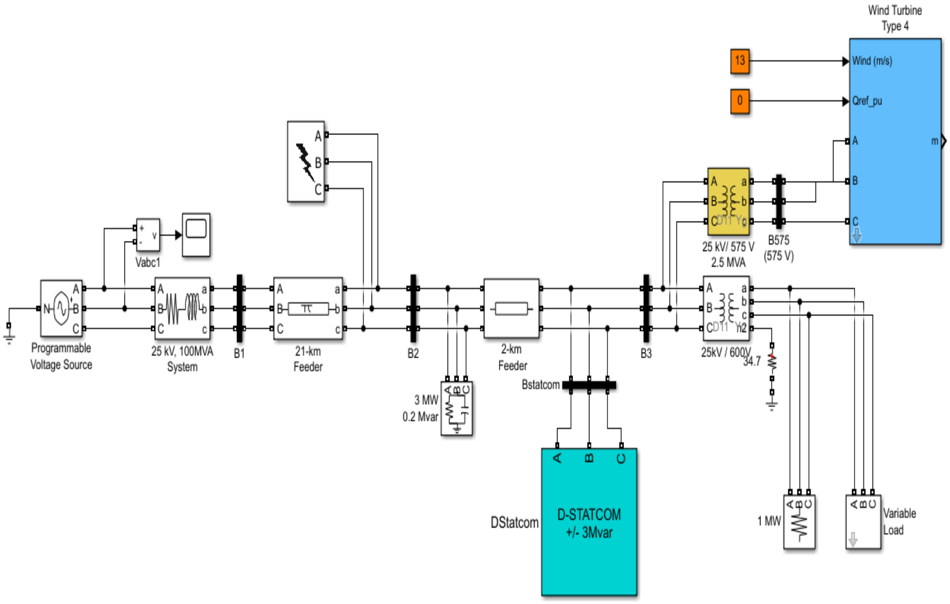

Figure 2. Simulated under study microgrid

Simulation results

Scenario 1: Normal status

In this case, it is assumed that no fault occurred in the microgrid. In Figure 3, two graphs are drawn, that the top figure shows the voltage and current of phase a and the bottom figure shows the voltage level of the inverter. In Figure 4, first in the upper graph, the q-axis output current values in the STATCOM is shown in two states (real and desired), and then in the lower graph, the active/reactive power injected into the microgrid are displayed. It should be noted that all the simulations were done with Simulink part of MATLAB software.

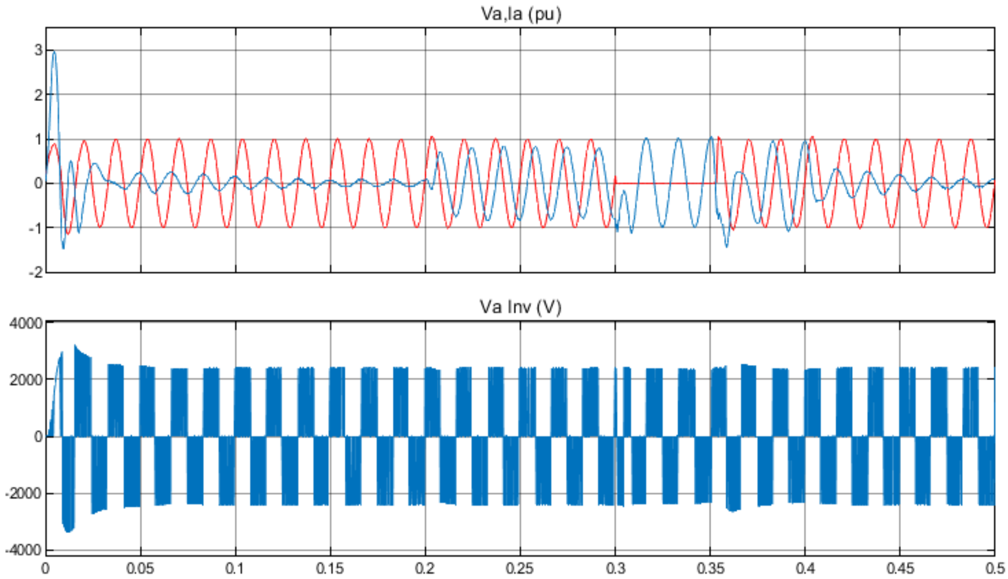

Figure 3. Top: voltage/current of phase a - Bottom: inverter output voltage (normal state)

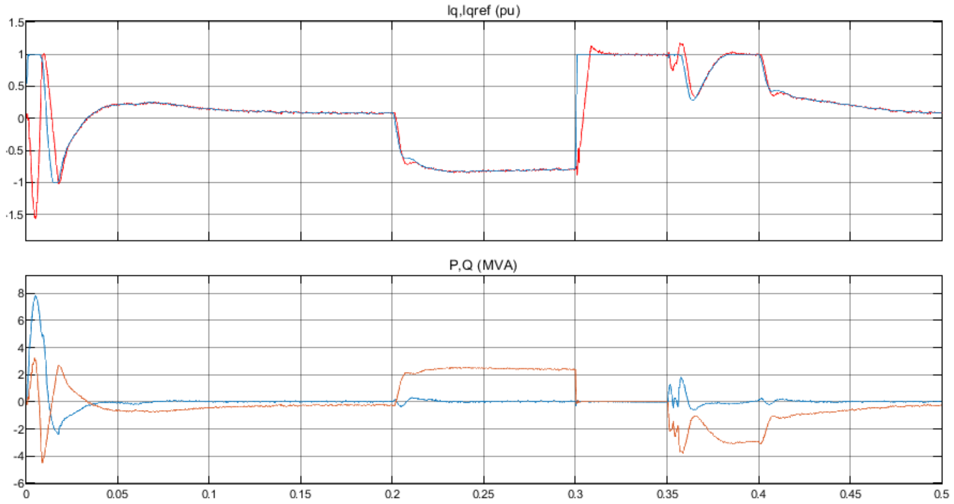

Figure 4. Top: q-axis current (real vs. desire) - Bottom: output active & reactive power (normal state)

Scenario 2: Single-phase to ground fault

In this case, it is assumed that a single-phase to ground fault occurred in phase a of bus B2, so that the fault was occured at t = 0.3s and was cleared at t = 0.35s. As can be seen in the top graph of Figure 5, the voltage is zero (red line) and the current has a rapid increasing rate (blue line). By adjusting the inverter voltage of the STATCOM (bottom diagram of Figure 5), the stability of the microgrid is guaranteed in this condition. The q-axis current values in two states (real and desired) are shown in the top diagram of Figure 6, and the variations of active/reactive power are shown in the bottom diagram of Figure 6.

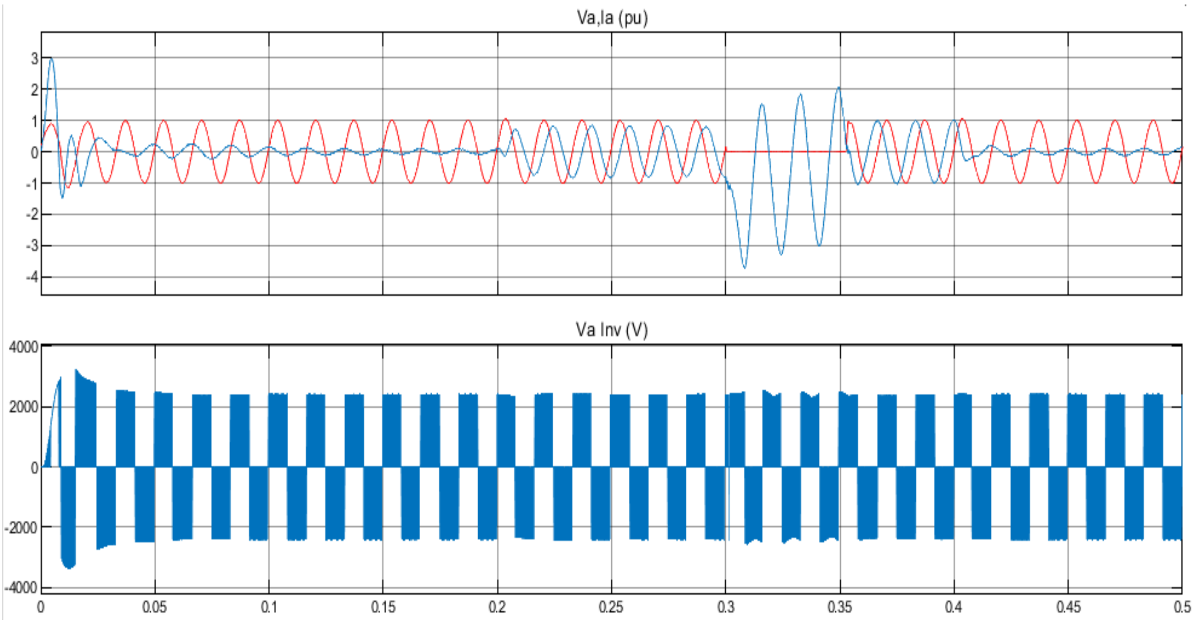

Figure 5. Top: voltage/current of phase a - Bottom: inverter output voltage (single phase to ground fault)

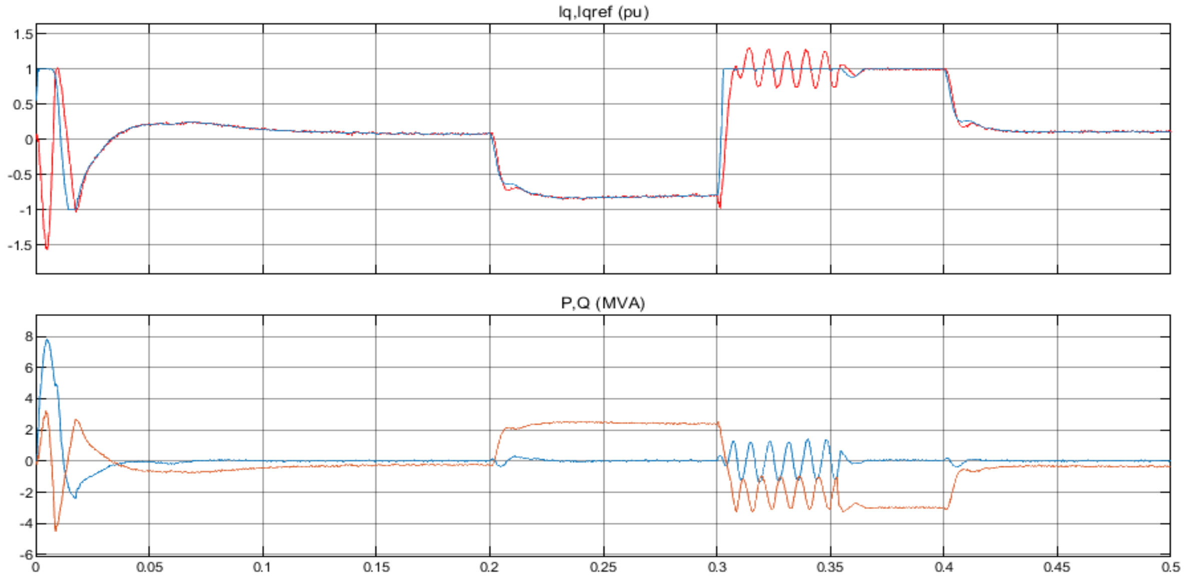

Figure 6. Top: q-axis current (real vs. desire) - Bottom: output active & reactive power (single phase to ground fault)

Scenario 3: Two phases to ground fault

In this case, it is assumed that there is a short circuit between phases a & b to the ground. The results obtained in this condition are shown in Figures 7 and 8. As can be seen, although the disturbance was more severe than the previous scenario, the stability of the network is still maintained.

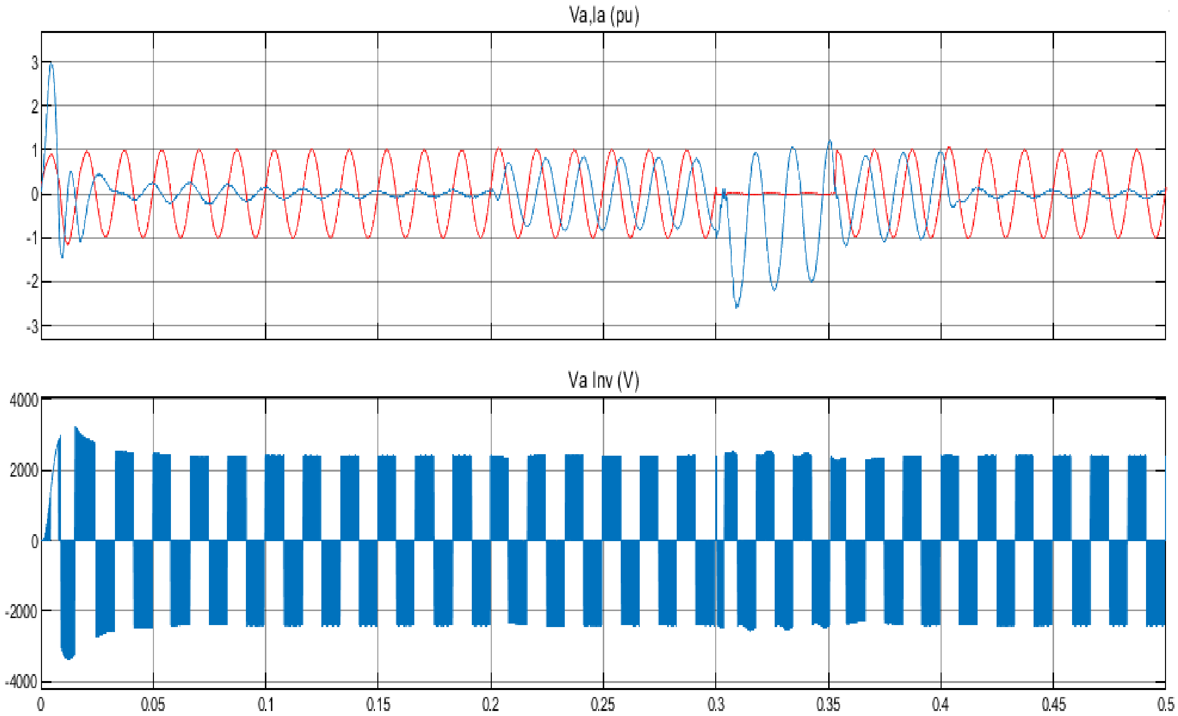

Figure 7. Top: voltage/current of phase a - Bottom: inverter output voltage (Two phases to ground fault)

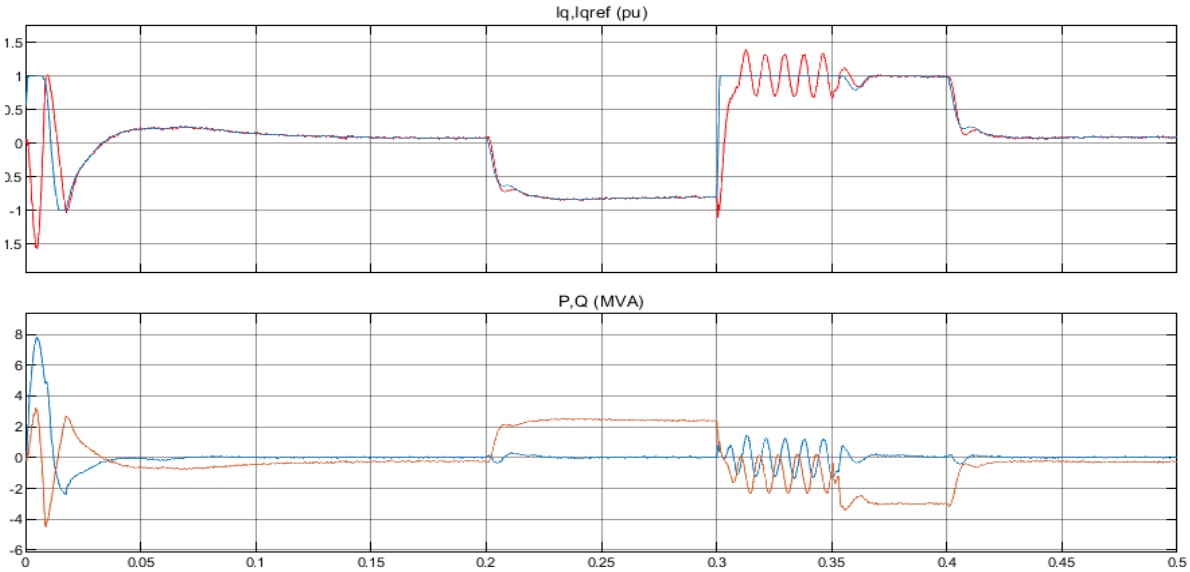

Figure 8. Top: q-axis current (real vs. desire) - Bottom: output active & reactive power (Two phases to ground fault)

Scenario 4: Three phases to ground fault

This type of fault has been considered as the most severe type of possible fault in the power system, which affects the stability of the microgrid, significantly. In this regard, it is assumed that there is a short circuit between phases a, b and c with the ground. The results obtained in this scenario are shown in Figures 9 and 10.

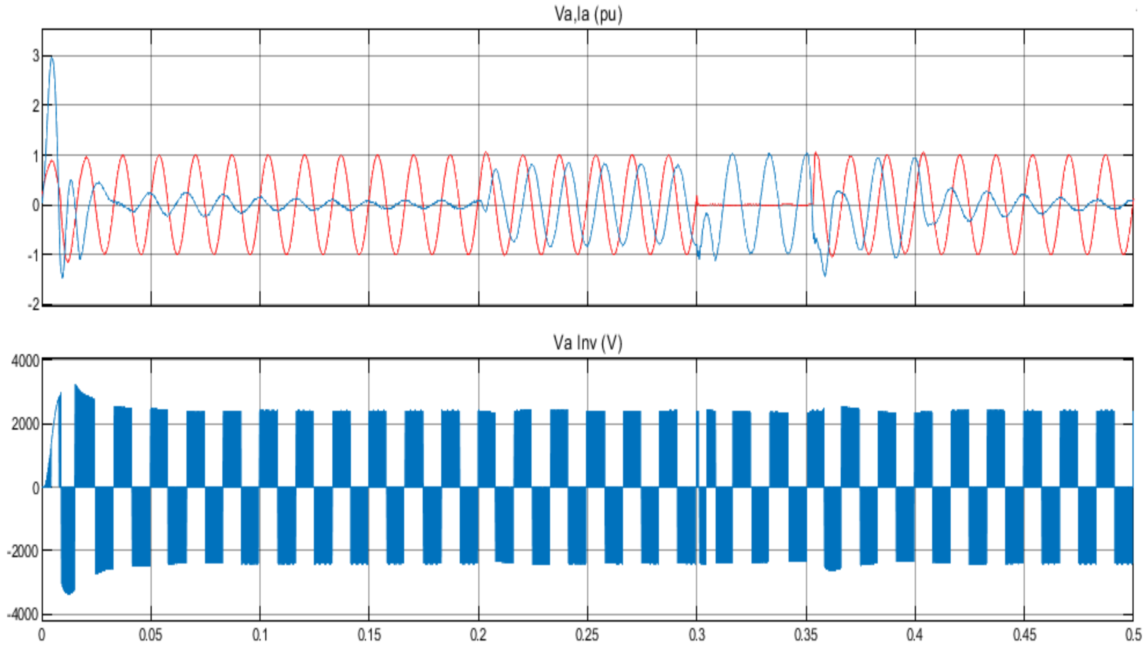

Figure 9. Top: voltage/current of phase a - Bottom: inverter output voltage (Three phases to ground fault)

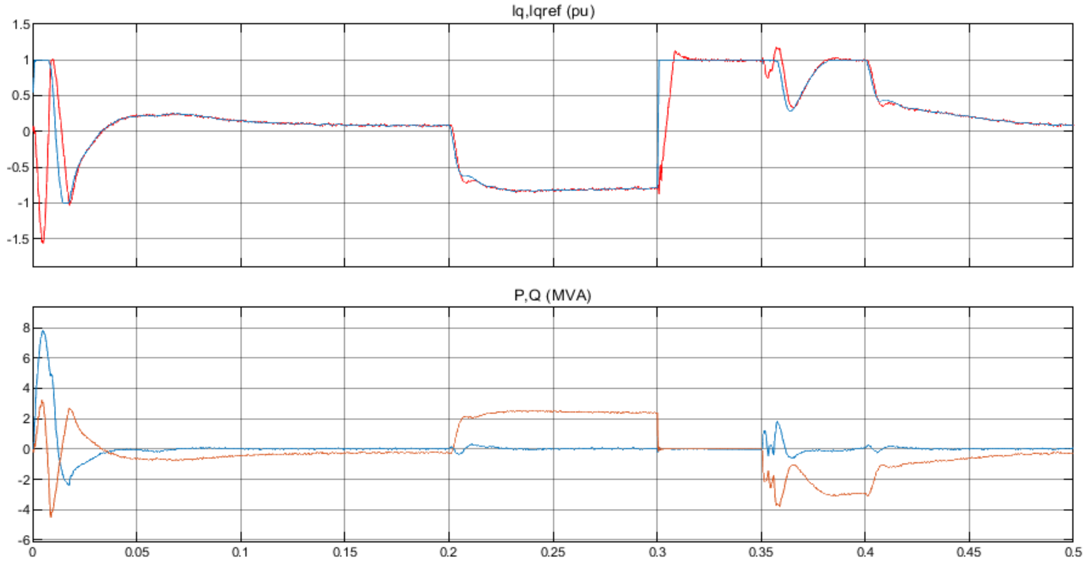

Figure 10. Top: q-axis current (real vs. desire) - Bottom: output active & reactive power (Three phases to ground fault)

CONCLUSİON

Connecting wind turbines on a large scale to the main grid due to the inherent fluctuations in wind speed can cause serious problems for the stability level of the grid. Therefore, several methods have been proposed to solve these challenges. One of the most common solutions from an economic point of view is the use of reactive power compensating devices. So, in this project, the reactive power static compensator (STATCOM) has been used in order to maintain the network stability conditions despite the high level penetration of wind power resources. In order to evaluate and ensure the performance of the proposed approach, various types of faults such as single-phase short circuit to ground, two-phase short circuit to ground and three-phase short circuit to ground have been modeled. In addition, the microgrid voltage varies between 0.94 PU. and 1.06 P.U. in the fault time duration. Comparing the obtained results with the normal state of the microgrid guarantees the optimal performance of the presented approach.

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