Static Synchronous Compensator (STATCOM) Performance for Grid – Connected Wind Turbines

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Abstract-The principle aim for using SATATCOM is reactive power control for regulation and reduction of unbalance cases which happen in the electrical grid. When connected the wind farm to the power system, it appears two fundamental issues; stability and control. A thorough study is needed to identify the potential problems and to develop measures to mitigate them. Although the connection of wind farm into an existing transmission system does not require a major redesign, it necessitates additional control and compensating equipment to enable recovery from severe system disturbance.

This paper investigates the use of a Static Synchronous Compensator (STATCOM) along with wind farm for the purpose of stabilizing the grid voltage after, grid side disturbances such as a three phase or two phase short circuit fault, sudden load changes (increasing or decreasing) and temporary trip of a wind turbine or wind farm (in our case). This paper is focusing on fundamental grid operational requirement which are connected with wind farm to maintain nominal voltages at the point of common coupling by regular voltage and show the results with and without the STATCOM.

I. INTRODUCTION

Human activities, the most important of which are the burning of fossil fuels such as coal, oil and gas, cause severe damage to the environment [1]. Climate change has become a significant problem for the young and the big and one of the most important problems affecting the national growth of any country [2]. The consumption of fossil fuels has doubled in recent years due to the increase in population across the globe [3]. The fluctuation of oil prices caused economic disasters both for producing and importing countries [4].

The world has to turn to clean, renewable and environmentally friendly alternatives such as solar, wind and geothermal energy [5, 6]. Solar energy has gone a long way and solar power plants are now available in most parts of the world. They can also be generated at the house level and are connected to the network or unrelated [7, 8].

The use of wind energy in electrical systems has been increased in all over the world in the recent years. Many new problems have appeared which developed a demand for treating these problems related to making the electrical system stable. This system naturally has variable energy resources as steam plants, gas, atomic, hydraulic, photovoltaic and wind energy [9].

In the past, the wind energy share in the electricity system was representing a tiny part. However, the increased and continuous connection of huge wind farms to the electricity grid (which wasn't representing any fear in the past). In recent days, the connection of wind farms to the grid plays a major role in achieving the required power for the subjected load including the disturbance conditions in the grid [10].

The connection requirements with the grid are standards that are being legislated by controlling agencies to control the homogenous work between the wind farms and the electrical grids. These standards vary from one country to another and the wind farms systems have to manage these requirements to be able to connect to the grid [11].

One of the primary issues related to connecting the wind farm to the grid is the stability of the voltage of electrical system when a fault or disturbance happens in the grid. At this stage, the electrical system will be not able to satisfy the load requirements due to voltage reduction exists because of these faults, heavy load conditions, or the sudden stop of one of the generating units. The static synchronous compensating system (STATCOM) is used widely in electrical systems because of its ability to control the elastic power flow that helps the grid in insuring stability in the natural operation or in fouling cases or other transferring conditions [12].

The reason for using STATCOM in the wind farms is its ability to provide a supporting voltage for the bar in case of voltage bar's reduction or absorbing the additional reactive power from the electrical system due to loads reduction and preserve the voltage at its nominal value.

Most of the wind generators installed in the past were inductive generators which consume reactive power from the system even in natural operation conditions. In the last years, high numbers of wind turbines with variable speeds with doubled fed induction generators. In the normal condition, the generator operates with power factor near one. The inductive generator may need reactive power during its facing for some disturbances as three phase fault near the wind farm. For satisfying the grid requirement without stopping the wind turbines during the fault existence, the farms with reactive generators has to use a capacitors group to introduce a supporting reactive power for the grid in its normal and abnormal operation.

The flexible AC transmission systems (FACTS) were used to control the power flow and to damping the electrical system frequencies. This technology can be used to increase the power of the transmission lines, control the frequency, provide a passing frequency to support the system and protect it from collapse. The FACTS equipment can be used practically in wind farms to enhance the passing and
dynamic stability for the general electrical system. STATCOM as one of the FACTS equipment can be used in wind farms to support the passing frequency conditions and to prevent the system from collapsing. The FACTS equipment can support for the stable and dynamic conditions and can improve the dynamic and passing stability.

In this investigation, the focus was concentrated on making the wind farms to provide reactive power in the normal operation conditions. In addition to the conditions where the system frequency are not in the required levels. In this study, of the STATCOM performance will be checked using Matlab/Simulink program. The study was conducted to evaluate the important effect of STATCOM on the stability of grid's frequency after disturbances happened in the grid due to the existence of sharp defect in the system, or sudden variation in the system's load (increase or decrease) or the one of the wind turbines or farms stopping for a temporary period [13].

II. STATIC SYNCHRONOUS COMPENSATOR (STATCOM) DESCRIPTION

STATCOM is one of the FACTS equipment which uses the power electronics to control the power flow and improve the passing stability in the electricity systems. It controls the frequency in the side stations as it controls the reactive power injection or absorbing it from the electrical system. When the systems' frequency is low the STATCOM injects capacitive power. And when the system frequency is high then it absorbs the inductive power. Figure (1) represents a schematic diagram for the STATCOM compounds where elements from power electronics can be us like IGBTs or IGCTs. The STATCOM basically consists of two parts, the power and control. The power circuit consists of Transistor Bridge (6 transistors) and three coils works as a frequency increaser, and a capacitor with high storage capacity for storing and injection the capacitive power. The bridge control circuit consists of a group controlling the pulse width and inspection and measuring current and frequency group. The current is controlled by internal circuit that reforming it. The outer circuit measures the frequency and generates pulses so it can maneuver in the power capacitive in the three phases. This power sometimes it is being stored and in other cases it is injected during very little times according the net frequency wave and makes the current wave as the frequency wave, and then the power factor is improved to achieve the almost unit value. The general figure of the system is used in many applications. These applications vary according to the leading and inspection system. It can be used to omit the fittings in the general net and improve the power parameter where it can control the system and work as the system requirements. In other words, it works in storing and injecting the current according to the subjected error. This system can be operated as branch active filter operates directly with the grid. Also, it can be used as an AC/DC converter operates at unit power factor [12, 13].

III. OPERATING PRINCIPLES OF THE STATCOM

Figure (1) represents the operating principles of the STATCOM through which the reactive and inactive power flow between the sources V1 and V2. V1 represents the controlled system frequency while V2 the resulted frequency in VSC. In steady state case, the resulted V2 frequency from VSC is in the same phase with V1, and the angle equals zero. The power flow depends on the frequency, if V1>V2 , then the reactive power flow (Q) flows fromV1 toV2 while the STATCOM absorbs the reactive power. The power value can be calculated by [14]:

\[ Q = \frac{V_10(1-V_2)}{X} \] (1)

The capacitor is connected on the direct current side (DC) of the VSC and acts as continuous frequency source. In steady state case, V2 must have a small phase difference from V1 to compensate the transforming waste of the VSC and preserve the capacitor charged. The capacitors, in general, connected to the constant speed wind turbines to improve the system's frequency as it is the source of reactive power. Fixed discharge capacitors can improve strained stability of the system but is not sensitive to frequency changes. Constant capacitor cannot act as a single source to compensate for reactive power. One of the main benefits of using STATCOM is that the compensated power is not dependent on the level of frequency in the contact point, which means that the compensated current does not decline. The wind farm productivity varies as well as the total load all the day. Compensating the reactive power is required to preserve the frequency levels steady in the electrical system. The unbalance of the reactive power can affect seriously on the grid frequency. This effect can be reduced by using STATCOM as it can contribute in the requirements of low voltage during default or disturbance occurrence in the grid [15, 16].

IV. STATCOM MODEL:

Figure (2) shows the basic configuration, equivalent circuit and model for the STATCOM connected to AC electrical system bar by a coupling transformer. In this STATCOM the maximum current compensator is independent of the system's voltage. Hence, it operates in its full power all time even in low voltages. The characteristics of the STATCOM are:

- Its elastic abilities to control voltage to improve the electric quality.
- Quick response.
- It can be used with heavy variable loads.

The output of control system is proportional to with voltage difference (Vc-V), as in the equation:

\[ Q_c = \frac{V(V_c - V)}{X} \] (2)
The basic components of the STATCOM are the shunt inverter and the convertor. The control system is used to make the voltage capacity in the bar constant. The STATCOM evaluation depends on many parameters which are controlled by the reactive power value that needed by the system to recover or bypass the faults occur in the electrical system. The final evaluation of the STATCOM determined by the system economic, where the STATCOM capacity must be selected to satisfy in the minimum limits to make it stable after the temporary disturbances the system exposed to. The faults expected to happen and the ability of the system to get rid of them also determines the size of the type [17].

V. LOCATION OF THE STATCOM

The STATCOM must be fixed nearest the load bar for many reasons: The source of the support reactive power must be as near as possible to the point that needs support. Another reason for the studied system, the location of the STATCOM is better on the load bar as it is high sensitive for voltage in this point. The main characteristic for using it in the system is to reduce the losses and to increase the maximum transporting ability. The location is selected to be in a suitable location which needs compensated reactive power. The attachment of the STATCOM on the load bar reduces the reactive power flow through transporting lines. Thus, the line current reduces as well as the losses (IR). For this reason, the compensating sources are always as near as possible from load [18, 19].

VI. THE SUGGESTED SYSTEM

To evaluate the STATCOM in this research, the STATCOM was used by connecting it on one of the grid bars and studying the support reactive power, which introduce it to the electrical system. Three-phase electrical system was suggested as shown in Figure (3). This system consisted of a traditional electricity plant that contains synchronous generator with 30 MVA power and three wind turbines. These turbines have double fed induction generators (DFIG) each generator's power is of 3 MW. These turbine are connected to a common bus bar (B1). The system total resistive load is 4 MW, and the inductive load is 2Mvar connected to bus bar No. 6 which is the load bar. The system voltage is 20kV, and the transport lines length is 10 km, and each line has a reluctance of 0.06+j0.6 Ω.

The system is connected to an external grid with a short circuit power of 50 MVA [20, 21]. As there is no wind farms in Iraq a wind farm was suggested and connected to virtual grid. This system was simulated using a Matlab/Simulink program as shown in Figure (4). The transient cases of the system performance which were simulated by Matlab/Simulink are:

- To show the STATCOM performance during short cut of a three phase circuit that is considered the worst failure in the electrical grid. Variable STATCOM powers were used for this purpose.
- A sudden change in the load.
- Sudden stop of the wind turbines.

According to the above mentioned, a STATCOM connected to a load bar B6 was assumed, as well as capacitors with different capacities connected to the same bus bar. Synchronous generators respond immediately to the disturbances that occur in the system. While the double fed induction generators in the wind turbines difficult to have a quick response for the disturbances as same as the synchronous generators. For this reason, additional devices are needed to assist in keeping the electrical grid in its steady state during and after the disturbance. The proposed testing system has two kinds of generator, the first is synchronous and the other is induction type operated at normal operation. When the system is simulated by Matlab/Simulink the focus will be on monitoring the bus bar B6 voltage and how the STATCOM respond at trouble occurrence in this proposed grid. One of the main objectives of this study is to evaluate the system needs of a device to assist it to return back to stable state as soon as possible during the error or disturbance period. The reactive power of the STATCOM source is connected always near the point that needs compensating, and this case is the main incentive to connect the STATCOM on load bus bar. However, the main demand for the reactive power always changes which made it a must to put a compensating system to control the reactive power level in the system [22, 23].
VII. THE SIMULATION RESULTS

1- Three Phase Short Cut Case
1-1 Three Phase Short Cut Case With STATCOM

Three-phase circuit malfunction was tested on the load bus bar without the STATCOM. The fault was occurred on the bus bar B6 while the bar has resistive load of 4 MW and inductive load of 2 MVAR and the bar nominal voltage was 850 V/Line. When the error was occurred the voltage was dropped to 590 V. The voltage reduction to this value could cause a disconnection of the bus bar from the grid. The second case tested was using STATCOM with 5 MVAR powers which made the error voltage rose to 670 V. In the third case, 10 MVAR STATCOM was used which resulted in increasing the voltage drop to 730 V. The fourth case, a 12 MVAR STATCOM was used, and the voltage drop was raised to 750 V. The fifth case, a STATCOM of 15 MVAR was used to raise the voltage drop to 850 V. Figure (5) shows the results of all the tests conducted to indicate the STATCOM operation to fit its power to raise the drop voltages level [24, 25].

![Fig. 5 Performance of STATCOM in different power value during fault](image)

<table>
<thead>
<tr>
<th>STATCOM power</th>
<th>Voltage (before error) V</th>
<th>Voltage (during error) V</th>
<th>Voltage drop raise percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without using STATCOM</td>
<td>850</td>
<td>590</td>
<td>69.4</td>
</tr>
<tr>
<td>STATCOM (5 MVA)</td>
<td>850</td>
<td>660</td>
<td>77.6</td>
</tr>
<tr>
<td>STATCOM (10 MVA)</td>
<td>850</td>
<td>730</td>
<td>85.8</td>
</tr>
<tr>
<td>STATCOM (12 MVA)</td>
<td>850</td>
<td>750</td>
<td>88.2</td>
</tr>
<tr>
<td>STATCOM (15 MVA)</td>
<td>850</td>
<td>850</td>
<td>100</td>
</tr>
</tbody>
</table>

1-2 Short Circuit Error By Using Capacitors Bank As A Compensating Equipment

![Fig. 6 The relation between voltage and time with and without capacitors employment](image)

The error started at t=7 sec and ended at t=7.08 sec. The error was occurred on the load bar B6 while the bar was loaded with a resistive load 4 MW and inductive load 2 MVA. The voltage in this case was 850 V/Line. The system was tested at three variable operation cases. Figure (6) shows the voltage drop results during this case without and with capacitors bank. The figure shows the tested cases:
- The bar without any compensation equipment.
- The bar with capacitors of 500 kVA only.
- The bar with capacitors of 700 kVA only.

The figure result indicates that the capacitors use affect the nominal voltage before the short cut error occurrence (where the voltage was raised to 860 V on the nominal value 850V). The capacitors have an influence on raising the voltage drop during the error period when high capacitors' values were used but its effect was out the nominal grid voltage. When the STATCOM operation compared with the capacitors performance, the STATCOM has kept the voltage values constant and stable before, during, and after the error occurrence (when a 5 MVA STATCOM was used) [26].

![Fig. 7 The sudden load drop without STATCOM](image)

Figure 8 manifests the use of STATCOM effect on the voltage stability as it behaves as a spare bank for the reactive power that absorbs the excess reactive power and keeping the voltage at its nominal value [27].

![Fig. 8 The sudden load drop with STATCOM case](image)
Figure 9 clarifies a comparison between the electrical system disturbance case and the system stability case with the STATCOM and without it. In this case, a sudden load was added (50% increase in the inductive load and 25% of resistive load). The increment was started at t=7 sec and continued to t=7.2 sec. Fig 10 shows the voltage on the load bath bar in the case of no STATCOM, where the voltage reduced lower than its nominal value (850 V) to 832 V.

In the case of STATCOM availability, the response is fast where it worked on compensating the reactive power and met the additional load requirements and achieved the stability case for the electrical system and maintained the voltage nominal value stable, as shown in Figure 11.

3. When The Wind Farm Out Of Surface

The third studied case was when the wind farm (9 MW) was stopped at time t=7 sec and returned to operation at t=7.2 sec. The impact of this cut off on the voltage was studied. This cut off caused reduction in the voltage lower than the nominal value where its value reached in this case 841 V. The grid, here, was not loaded with its full load. This case represents an unstable voltage load case when there was no STATCOM. Figure 13 shows load voltage in the pre-mentioned case.

The figure results reveals that using STATCOM the voltage value stayed at its nominal value during the cutting off and restarting process.

Fig. 9 a comparison between the electrical system disturbance case and the system stability case

Fig. 10 Sudden increase in the load causes reduction in the voltage level (without STATCOM)

Fig. 11 Sudden increase in the load with STATCOM

Fig. 12 Comparison of voltage values on the load bar at the sudden increase of load with and without STATCOM

Fig. 13 the period of the wind farm cut off and its return to work with no SATATCOM used

Fig. 14 shows the voltage returned to its stable case with using STATCOM.
VIII. CONCLUSIONS

The electrical power produced from wind farm varies with wind speed in nature. For this reason we need efficient control of the wind farm when it is connected to the grid. The dynamic compensating of the reactive power is an efficient procedure to maintain the electricity quality and voltage stability. When a number of wind turbines which depend in its operation on inductive generators are connected to the grid, the grid become weaker and required adding control devices for this kind of generators that do not have the ability for improving as known in the synchronous generators. This study focused on the studding the normal and dynamic performance of wind turbines at and after the disturbance case.

The study results indicated that the connection of STATCOM to the wind turbines system supplies the system with efficient control. The suitable power STATCOM can supply necessary compensating reactive power in the case of error or grid disturbance. If the STATCOM was with higher power and volume, it can be used to control the system voltage and improves the grid reliability especially when faults or disturbance occurs.

REFERENCES