DISTRIBUTED ENERGY RESOURCES (DER) IMPACTS ON THE PERFORMANCE OF SPECIAL PROTECTION SCHEMES (SPS)

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ABSTRACT

In this paper, the impacts of Distributed Energy Resource (DERs) on Special Protection Schemes (SPSs) from different aspects are investigated and remedial actions are proposed to maintain the integrity of the SPSs used. A sample system is considered and a moderate SPS is designed for the classical system; then the impact of DERs on the capability of the designed SPS is evaluated.

INTRODUCTION

Power system protection can be divided in two main categories: equipment protection and system protection. Equipment protection is needed in order not to destroy the components in the power system in case of faults. Protective actions have to be taken even in situations where no power system equipment is subject to be damaged is classified as system protection. Mitigation of wide area disturbances is performed by Special Protection Scheme (SPS), which is the common name used when the focus for the protection is on the power system supply capability rather than on specific equipment. SPS is also referred to as System Protection Scheme, i.e., the word "special" is replaced by "system", since it is more relevant to describe this type of protection [1].

SPS are often characterized of:

• Protections, which operate on selected rare contingencies, usually outside the design range of the equipments allowing control actions such as load and generation shedding which are not used in the secure operating state.

• Systems allowing taking greater operational risks with the likely consequences being outside capability of conventional protection.

• System wide protection, operating in multiple locations, with coordinated control of multiple signals.

Detection of abnormal system conditions and taking predetermined corrective action to preserve system integrity and provide acceptable system performance are performed by the sophistically-designed SPSs. SPS actions include among others, changes in load (e.g. load shedding), generation, or system configuration to maintain system stability and acceptable voltages or power flows. System wide protection operates in multiple locations with coordinated control of multiple signals.

SPS is normally applicable for loss of network integrity triggered by one or more of the network disturbances like transient angular instability, frequency instability, voltage instability, small signal instability or instability resulting from cascade line tripping.

In [1] designing SPS is introduced based on two main aspects:

- System studies for contingencies identification.
- Decision logic of the SPS to execute actions. The possible decisions can be:
  - Predetermined, based on the off-line simulation.
  - Intelligent, based on the on-line simulations. A special, usually simplified, power system model is needed which can run in real time.

The SPS operates from the detection of the contingence. This detection can be based either on the event itself (event based) or on the power system response to the event (response based). An example of the event based operation could be the loss of a critical line. An example of the response based operation could be the frequency drop below a certain threshold.

When designing SPS in networks comprising of Distributed Energy Resources (DERs), remarkable issues arise. One of them is related to the generation of the DERs, especially wind/solar types, since their outputs are not deterministic. In these circumstances, the designed SPSs based on deterministic scenarios are affected accordingly.

To the knowledge of the author, the publications in this area are limited. In [2] and [3], there are applications of SPS designed to allow the connection of wind generation in remote areas without compromising the stability of the network. For example, SPS can protect a corridor for the interconnection of wind power to the network. SPS detects the opening of one line of the corridor and disconnects the necessary amount of generation to maintain the operation within the transmission capacity. The generation to be shed is pessimistic when assuming generators operate at rate power, especially considering the intermittent nature of wind power.

The presence of DG generation [4]-[5] in the network increases the uncertainty regarding the load and generation conditions during the real contingencies. In order to compensate for this uncertainty, many SPSs are designed with pessimistic assumptions and consequently overreact. For example too much load could be shed in a specific network situation or disturbance. Additionally, the contingency studies need to be repeated periodically to account for the continuous development of the network. In this regard, there is high risk of actual DG levels not being adequately considered or updated.

The impact of the network uncertainty on the SPS operation depends on its complexity [2]. Real time SPSs have a more optimized reaction because they are based on the knowledge of the actual network condition. The acquisition of the real time information from the DGs represents a significant difficulty, especially with the high amount of dispersed generation connected to the distribution network.
An additional difficulty for the system studies is the modeling of the new generation technologies. While the models are well defined for conventional rotating machines, they are not sufficiently developed for power electronics based generators. It is particularly important to develop better models for wind turbines. Usually, the simplified models are used, which could affect the accuracy of the simulation and the resulting actions.
In this paper, the impacts of DERs on SPSs from different aspects are investigated and remedial actions are proposed to maintain the integrity of the SPSs used. A sample system is considered and a moderate SPS is designed for the classical system; then the impact of DERs on the capability of the designed SPS is evaluated.

SPS AND UNCERTAINTIES OF DERS

As quoted before, the design of SPS in the presence of DERs is made complex by the wide range of operating conditions and system characteristics that the protection must encompass. As a result of these uncertainties, the compromise between dependability and security may become delicate, and choices have to be made on the conservative side. Generally speaking, when parameters are known with more uncertainty, a less efficient design is resulted. Hence, extra effort should be done to shed light on the uncertain parameters, such as the seasonal composition of wind/sunshine. Provision should be made to update the settings of the SPS accordingly.
The designed SPS in the presence of DERs must be tested in a wide range of conditions. This can be done in a variety of ways, but some randomization in the selection of parameters (for example wind speed) is typically appropriate. To this purpose, uncertainty is modeled by treating the relevant parameters as sampled random variables. This applies to system parameters, topology, load level, generation scheme, availability of other countermeasures, the characteristics of the SPS itself, etc.
The simulation procedure must also include the ability to store various parameters characterizing the operating conditions and various performance measures characterizing the acceptability of each simulation (this includes cases where the SPS should not act). This leads to building a large database of scenarios.
Any SPS study should address the following issues:

- How accurate are the parameter values? Is it realistic to expect that we can further reduce uncertainty of modeling and data?
- How sensitive are the study results to these values?
- How to ascertain that all relevant phenomena and components are included in the model?

For some system components, especially DERs generation, there is generally a lack of data. Sensitivity analysis around guessed values is the least to be done. Uncertainty is also present in the system operating condition as well as in the triggering disturbance itself. This raises the following questions:

- Does the SPS function satisfactorily in the whole range of plausible system operating conditions (robustness)?
- Does the SPS function satisfactorily against the various disturbances that can cause instability (dependability)?
- Does it unduly operate in stable situations (security)?

In order to improve the knowledge on system security, a statistical approach can be defined to allow taking into account many uncertainties that influence the results: loads and dispersed generators behavior, power flows due to transactions, failure modes of existing SPS and possible interactions.

SIMULATION RESULTS

Figure 1 shows the single-line diagram of the sample system used for the study configured in MATLAB/Simulink environment [6].
A 9-MW wind farm consisting of six 1.5 MW wind turbines connected to a 25-kV distribution system exports power to a 120-kV grid through a 30-km, 25-kV feeder. A 2300V, 2-MVA plant consisting of a motor load (1.68 MW induction motor at 0.93 PF) and of a 200-kW resistive load is connected on the same feeder at bus B25. Both the wind turbine and the motor load have a protection system monitoring voltage, current and machine speed. The DC link voltage of the DFIG is also monitored.
Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter. The stator winding is connected directly to the 60 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind. The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the wind speed. For wind speeds lower than 10 m/s the rotor is running at sub-synchronous speed. At high wind speed it is running at hyper-synchronous speed. Figure 2 shows the turbine mechanical power as function of turbine speed for wind speeds ranging from 5 m/s to 16.2 m/s. The DFIG is controlled in order to follow the red curve. Turbine speed optimization is obtained between point B and point C on this curve. Another advantage of the DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as in the case of squirrel-cage induction generators [4]-[5].
The wind-turbine model is a phasor model that allows

transient stability type studies with long simulation times. In this simulation, the system is observed during 50 s.
The 6-wind-turbine farm is simulated by 6 wind-turbine block. Each wind-turbine has the parameters as follows:
1. The nominal wind turbine mechanical output: 1.5 MW;
2. The generator rated power: 1.5 MW at 0.9 PF;
3. The nominal DC bus capacitor: 10000 microfarads;
The power generation of the wind farm is transmitted by a 575V/25kV transformer and two 120kV transmission lines to the set-up power system.

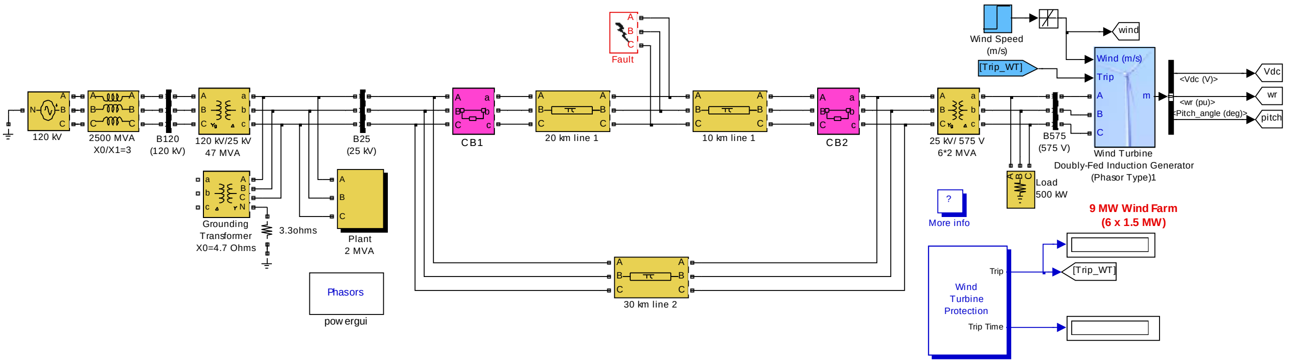

Figure 1: Sample system configuration in MATLAB/Simulink environment

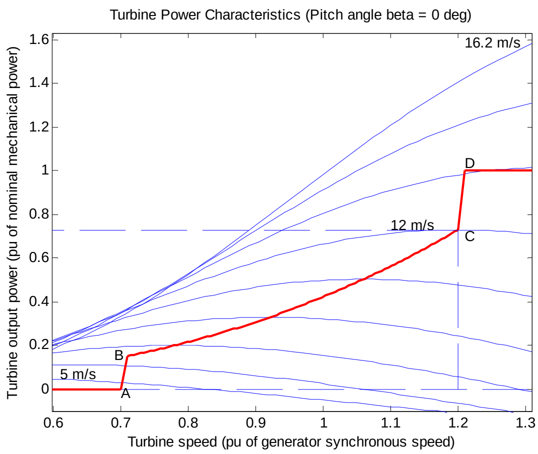

Figure 2: Wind turbine output power versus turbine speed for different wind speeds

In order to evaluate the wind farm power output for different wind speeds, especially for sudden changes in wind speed, initially, wind speed is set at 8 m/s, then at t = 50s, wind speed increases suddenly at 14 m/s. Figure 3 shows the active and reactive power generated by the wind farm. The generated active power is around 4MW for wind speed at 8 m/s, at t = 50 s, the wind speed is increased by a step change to 14 m/s. The generated active power starts increasing smoothly (together with the turbine speed) to reach its rated value of 11 MW in approximately 15 s. Over that time frame the turbine speed will have increased from 0.8 pu to 1.21 pu. Initially, the pitch angle of the turbine blades is zero degree and the turbine operating point follows the red curve of the turbine power characteristics up to point D. Then the pitch angle is increased from 0 deg to 0.76 deg in order to limit the mechanical power. The reactive power is controlled to maintain a 1 pu voltage. At nominal power, the wind turbine absorbs 0.68 Mvar (generated Q = -0.68 Mvar) to control voltage at 1pu. If the mode of operation is changed to "Var regulation" with the "Generated reactive power Qref" set to zero, it will be observed that voltage increases to 1.021 pu when the wind turbine generates its nominal power at unity power factor.

Designed SPS

The designed SPS monitors the transmission lines; by disconnection of any line, the SPS shed the pre-specified amount of wind generation to alleviate the overload of the remaining transmission line. The pre-specified generation to be shed is 5.5 MW; it is evaluated at the normal wind speed, 14 m/s. This value is half of the farm wind generation, i.e., 11MW.
Figure 4 shows a case with the normal speed 14 m/s. The wind farm generates 11 MW. At t=35s a single-phase fault occurs on Line I for 0.15s. Line 1 is tripped due to this fault and disconnected by opening the circuit breakers at the line ends. The load of Line 2 is increased to 11 Mw, and the SPS sheds 5.5 MW after 5s at t=40s. The line overload is mitigated by this SPS intervention.

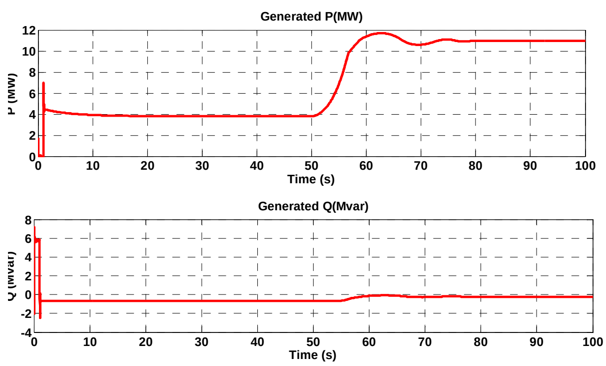

Figure 3: Generated P and Q of the wind farm for wind speed 8m/s up to 50s and 14 m/s afterwards.

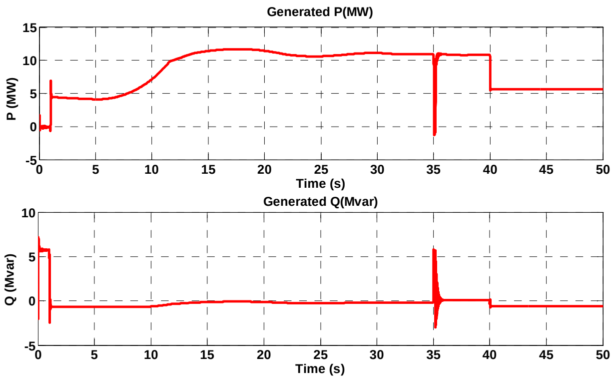

Figure 4: Generated P and Q for wind speed=14m/s. Line1 is disconnected at t=35s. SPS correctly reacts at t=40s to mitigate the Line 2 overloading.

Impact of DERs' Uncertainty on SPS

The wind speed is not fixed, so it is assumed that the wind speed is 10 m/s. This case is illustrated in Figure 5, as it is shown, the wind farm generation is 5.5 MW, when a single-phase fault occurs at t= 35s and Line 1 is disconnected at t=35.15 s. The loading of Line 2 is as 5.5 MW; hence there is no overload in reality. But, SPS falsely reacts to keep the second line in service by rejecting the wind farm generation to mitigate the line overloading. The pre-specified shed pattern is as before, hence the load is reduced to less than 2 MW. In other words, the SPS has overreacted.

Table 1 shows the simulation results in a quantitative style. As can be seen, the results of Figures 3, 4 and 5 are summarized in this Table. The last case of this Table shows the overreaction of the SPS due to the uncertainties caused from the unavailability of real data from the wind generation.

Remedial Actions

One of the remedial actions to cope with this problem is to develop communication infrastructure to have enough data of DERs applicable in the SPS decision taking. In this case, the conventional SPS could be transformed into smart SPS. Another solution could be the implementation of pre-prepared wind/sunshine patterns into the SPS reaction plan.

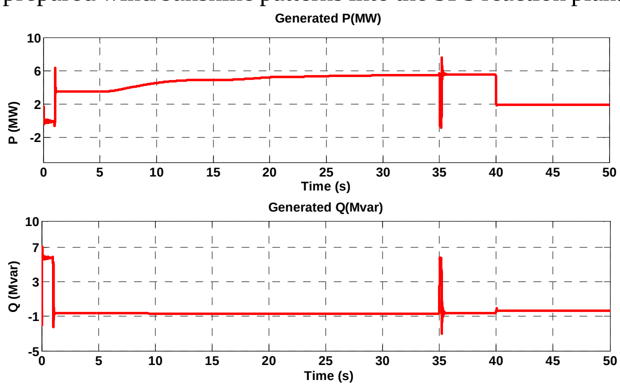

Figure 5: Generated P and Q for wind speed=10m/s. Line1 is disconnected at t=35s. SPS reacts at t=40s to mitigate the Line 2 overloading. The SPS overreacts.

Table 1: SPS Performance for Different Wind Farm Generation in Response to a Disturbance

Case No.	Line 1 Load (MW)	Line 2 Load (MW)	Wind Gen. (MW)	Wind Speed (m/s)	System Operation Status	Gen. Shed (MW)
1	2	2	4	8	Normal	0
2	5.5	5.5	11	14	Normal	0
3	Tripped	11	11	14	Line 2 Overloaded	0
4	Open	5.5	5.5	14	SPS Action Satisfactory	5.5
5	2.75	2.75	5.5	10	Normal	0
6	Tripped	5.5	5.5	10	Line 2 Normal	0
7	Open	2	2	10	SPS Overreacted	3.5

CONCLUSION

In this paper, the impact of DERs on the conventionally designed SPS is investigated. It is shown that the uncertainty embedded in the nature of renewable sources such as wind or sunshine can influence the performance of the SPS. Generally, it is assumed that the DERs are operating at their rated power output, so if real-time data from these sources are not available, then the SPS action to shed generation/load to alleviate overloading of the transmission lines is overrated. In order to improve the knowledge on system security, a statistical approach can be defined to allow engineers to study the behavior of power systems taking into account many uncertainties that influence the results.

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