IMPACT OF RENEWABLE ENERGY GENERATION TECHNOLOGIES ON THE POWER QUALITY OF THE ELECTRICAL POWER SYSTEMS

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ABSTRACT

The impact of the PQ problems found in the test network in case of large amounts of RE integration has been analysed. The analyses discussed in this study will demonstrate how the integration of RE generation systems can have a positive and at the same time a negative impact on the PQ of the system. It has been demonstrated how a clever integration can define the future behaviour of the system. Results obtained allowed to conclude that the impact of the RE generation technologies depends in a big part of penetration level, configuration of the system and the type of RE technology.

INTRODUCTION

Environmental and economic affairs lead to changes in the power generation system. As consequence massive efforts have been made to motivate the development of RE (Renewable Energy) resources. Distributed Generation (DG) together with renewable Distributed Energy Resources (DER) units has been emerging in the landscape. DG leads to fundamental changes in the power generation system. Conventional centralized structures are now being converted to DG systems, where unidirectional power flows are now reversed under the influence of DER units feeding in to the distributed system. With the increasing share of RE technologies, fundamental issues such as Power Quality (PQ) come into view all over again. PQ in particular receives much interest due to an increasing sensibility of customers and because of the fear that the quality and reliability of electricity supply may be at risk with a higher share of new renewable generation technologies. The sharp electricity generation increase from RE resources creates a necessity for different studies to analyse the PQ impact of the integration of this technology into the power system, as well as an evaluation of the resulting consequences in order to make the required adjustments. The main objective of this work was to investigate the impact of RE generation system technologies on the network PQ. This has been accomplished with the design of an accurate test model of 380 kV and 110 kV power systems with MV and LV distribution networks. Detailed models of a wind turbine, Photo Voltaic (PV) generator and a microturbine have been set up. Experimental study cases, where RE generation technologies were integrated into the system to evaluate, compare and analyse the PQ of the test power system model, have been created. Methods to evaluate the voltage sags, flickers and harmonics in the test model have been studied and implemented.

POWER SYSTEMS MODEL

To study the impact of renewable sources on the PQ of the system, two different networks, "the basic 380 kV transmission system" and "the basic 110 kV transmission system", have been modelled. These two voltage transmission levels where selected as they represent the more usual transmission voltage levels used in Germany.

The 380 kV Transmission Systems

The 380 kV transmission system is a balanced EHV network with 850-km three-phase overhead lines, a connection to one external grid and four different power plants connected through step-up transformers. The subsystems, 110 kV – HV system, 10 kV - MV system and 0.4 kV - LV system, are fed from this grid as illustrated in Figure 1. Three load blocks, which represent the load centres, have been designed. The total load of the system is about 1000 MVA. Each load block has a different configuration, in order to test different concepts.

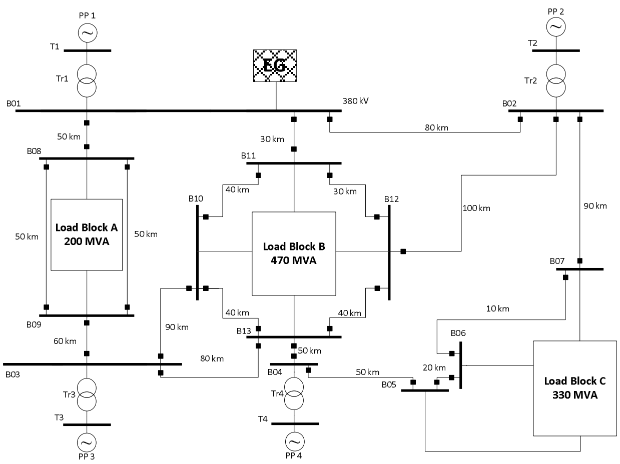

Figure 1: The 380 kV transmission system

The Basic 110 kV Transmission System

The 110 kV transmission system is a balanced centralized power system network with about 650 km three-phase overhead lines, into which three power plant will be connected Figure 2. The installed capacity of the whole generation is 750 MVA. The network has a connection with a 380 kV external grid and with the MV and LV subsystems, 10 kV and 0.4 kV respectively. In the distribution systems, four load blocks, which represent the load centres, have been designed. The total load of the system is 520 MVA. Each load block has a different configuration, as it was address before, in order to examine different configurations.

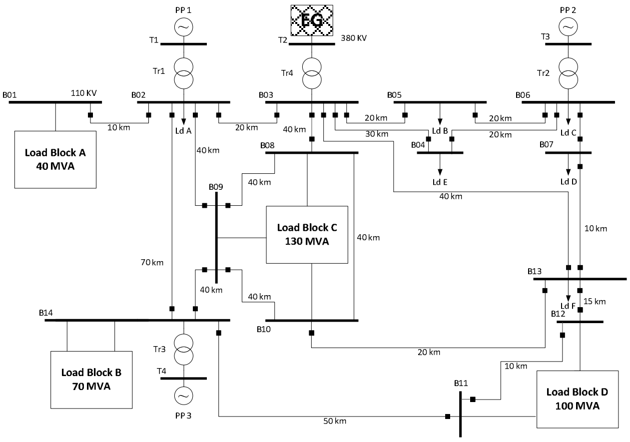

Figure 2: The 110 kV transmission system

INTEGRATION OF RENEWABLE ENERGY GENERATION TECHNOLOGIES IN THE POWER SYSTEM

This study takes special attention in wind turbines, specifically the Doubly-Fed Induction Generator (DFIG) wind turbines, as well as Photo Voltaics (PV) units, and the split-shaft microturbines model. Some of these units are used as power plants and as DER unit's technologies. Models of DER units tested and experimentally validated by various authors [1-3] have been used for this simulation. Here they are adapted and represented in a unified form, which is easy to read, to understand and to implement.

Three study projects where wind farm power plants and DER units, as DG, were integrated into the power system, as well as the different experimental study cases taken into consideration for the further PQ analysis.

Project 1: Wind Energy Integration into the Transmission System - Impact on Power Quality of Medium- and Low- Voltage Networks.

The goal of this study is to examine the PQ behaviour of the MV and LV network in case of integration of different amounts of wind energy at different locations of the 110 kV and 380 kV transmission systems. In order to analyse the impact of wind energy integration on the network's PQ, 2 base cases "the 380 kV transmission system" and "the 110 kV transmission system", have been modelled and aggregated wind farm models modelled and integrated.

For the PQ analysis of "the 380 kV and 110 kV transmission system", several scenarios where the location and number of wind farms in different busbars of the system and the amount of wind energy dispatch from 1% until 100% were changed, have been simulated. From this simulation 5 different scenarios have been produced. These scenarios have distinct configuration and were analysed according to Table 1 and 2 respectively:

Study case 1: Wind energy integration into the 380 kV transmission system.

Table 1: Project 1 - Study case 1

	The 380 kV substations – WE Generator connected to the busbars			
Scenarios	SS B01	SS B02	SS B03	SS B04
Base Case	PP1: 250 MVA	PP2: 250 MVA	PP3: 250 MVA	PP4: 250 MVA
12.5% WE	PP1: 125 MVA WF1: 125 MVA	PP2: 250 MVA	PP3: 250 MVA	PP4: 250 MVA
25% WE	PP1: 125 MVA WF1: 125 MVA	PP2: 250 MVA	PP3: 250 MVA	PP4: 125 MVA WF4: 125 MVA
37.5% WE	PP1: 125 MVA WF1: 125 MVA	PP2: 125 MVA WF2: 125 MVA	PP3: 250 MVA	PP4: 125 MVA WF4: 125 MVA
50% WE	PP1: 125 MVA WF1: 125 MVA	PP2: 125 MVA WF2: 125 MVA	PP3: 125 MVA WF3: 125 MVA	PP4: 125 MVA WF4: 125 MVA
Legend SS: Sub Station, TS: Transmission System, PP: Power Plants, WF: Wind Farm, WE: Wind Energy				

Study case 2: Wind energy integration into the 110 kV transmission system.

Table 2: Project 1 - Study case 2

	The 110 kV substations - Generator connecting to the busbars					
Scenarios	SS B01	SS B02	SS B05	SS B06	SS B14	SS B10
Base Case: The 110 kV TS		PP 1, 250 MVA		PP 2, 250 MVA	PP 3, 250 MVA	
Scenario 1: SC2-WFA: 16.6% WE	WF 1, 125 MVA	PP 1, 125 MVA		PP 2, 250 MVA	PP 3, 250 MVA	
Scenario 2: SC2-WFB: 33.3% WE	WF 1, 125 MVA	PP 1, 125 MVA	WF 2, 125 MVA	PP 2, 125 MVA	PP 3, 250 MVA	
Scenario 3: SC2-WFC: 50% WE	WF 1, 125 MVA	PP 1, 125 MVA	WF 2, 125 MVA	PP 2, 125 MVA	PP 3, 125 MVA	WF 3, 125 MVA
Scenario 4: SC2-WFD: 66.6% WE	WF 1, 125 MVA	PP 1, 62.5 MVA	WF 2, 125 MVA	PP 2, 125 MVA WF 4, 125 MVA	PP 3, 62.5 MVA	WF 3, 125 MVA
Legend SS: Sub Station, TS: Transmission System, PP: Power Plants, WF: Wind Farm, WE: Wind Energy						

Project 2: Distributed Energy Resources (DER) Systems Integration into Medium- and Low- Voltage Networks - Impact on PQ of the System

The goal of this study is to examine the effect of the integration of DER units at the system and to analyze the impact on the PQ on the network. In this study cases, in order to test the system PQ in case of DG integration, the DER units Model is connected in the MV and LV system. The amount of integrated RE DER units is varied. The following scenarios are pursued Table 3 and 4 respectively.

The study case 1: DG concept in the distribution system on the 380 kV transmission system model.

Table 3: Project 2 - Study case 1

	DER Units connected to the Load Blocks								
Scenarios	Load Block A [200 MVA]			Load Block B [470 MVA]			Load Block [330 MVA]		
	PV 5 kW	MT 55 kW	WT 10 kW 50 kW	PV 5 kW	MT 55 kW	WT 10 kW 50 kW	PV 5 kW	MT 55 kW	WT 10 kW 50 kW
Base Case	-	-	-	-	-	-	-	-	-
10% RE	20 MVA			50 MVA			30 MVA		
20% RE	40 MVA			100 MVA			60 MVA		
30% RE	80 MVA			130 MVA			90 MVA		
Legend TS: Transmission System, DG: Distributed Generation, RE: Renewable Energy, PV: Photovoltaic WT: Wind Turbine, MT: Microturbine, DER: Distributed Energy Resource									

The study case 2: DG concept in the distribution system on the 110 kV transmission system model

Table 4: Project 2 - Study case 2

	The 110 kV substations - Generator connecting to the Load Block											
Scenarios	Load Block A [40MVA]			Load Block B [70MVA]			Load Block C [130MVA]			Load Block D [100MVA]		
	PV 5 kW	MT 55 kW	WT 10 kW 50 kW	PV 5 kW	MT 55 kW	WT 10 kW 50 kW	PV 5 kW	MT 55 kW	WT 10 kW 50 kW	PV 5 kW	MT 55 kW	WT 10 kW 50 kW
Base Case: The 110 kV TS	-			-			-			-		
Scenario 1: SC2-DGA: 10% RE	1% DER Units (7.5 MVA) [18.75%] Load Block A			2% DER Units (15 MVA) [21.42%] Load Block B			4% DER Units (30 MVA) [23.07%] Load Block C			3% DER Units (22.5 MVA) [22.5%] Load Block D		
Scenario 2: SC2-DGB: 20% RE	2% DER Units (15 MVA) [37.5%] Load Block A			4% DER Units (30 MVA) [42.85%] Load Block B			8% DER Units (60 MVA) [46.15%] Load Block C			6% DER Units (45 MVA) [45%] Load Block D		
Scenario 3: SC2-DGC: 30% RE	3% DER Units (22.5 MVA) [56.25%] Load Block A			6% DER Units (45 MVA) [64.28%] Load Block B			12% DER Units (90 MVA) [69.23%] Load Block C			9% DER Units (67.5 MVA) [67.5%] Load Block D		
Legend TS: Transmission System, DG: Distributed Generation, RE: Renewable Energy, PV: Photovoltaic WT: Wind Turbine, MT: Microturbine, DER: Distributed Energy Resource -												

Project 3: Combination of Project 1 and Project 2

In order to evaluate the PQ of the system, scenarios with a large amount of RE generation technology have been tested. This is achieved through a combination of "Project 1: Wind Energy Integration into the Transmission System - Impact on PQ of MV and LV Networks" and "Project 2: Distributed Energy Resources (DER) Systems Integration into MV and LV Networks - Impact on PQ of the System". The scenarios of the 2 study cases are combined as explained in the following matrixes:

Study case 1: Integration on the 380 kV transmission system.

Table 5: Project 3 - Study case 1

	Scenario 1: "SC1_DGA": 10%	Scenario 2: "SC1_DGB": 20%	Scenario 3 "SC1_DGC": 30%
Scenario 1: "SC1-WFA": 12.5%	Scenario 1.1: 22.5% RET	Scenario 1.2: 32.5% RET	Scenario 1.3: 42.5% RET
Scenario 2: "SC1-WFB": 25%	Scenario 2.1: 35% RET	Scenario 2.2: 45% RET	Scenario 2.3: 55% RET
Scenario 3: "SC1-WFC": 37.5%	Scenario 3.1: 47.5% RET	Scenario 3.2: 57.5% RET	Scenario 3.3: 67.5% RET
Scenario 4: "SC1-WFd": 50%	Scenario 4.1: 60% RET	Scenario 4.2: 70% RET	Scenario 4.3: 80% RET

Study case 2: Integration on the 110 kV transmission system

Table 6: Project 3 - Study case 2

	Scenario 1: "SC2_DGA": 10%	Scenario 2: "SC2_DGB":20%	Scenario 3 "SC2_DGC":30%
Scenario 1 "SC2_WFA": 16.6%	Scenario 1.1: 26.6% RET	Scenario 1.2: 36.6% RET	Scenario 1.3: 46.6% RET
Scenario 2: "SC2_WFB": 33.3%	Scenario 2.1: 43.3% RET	Scenario 2.2: 53.3% RET	Scenario 2.3: 63.3% RET
Scenario 3 "SC2_WFC": 50%	Scenario 3.1: 60% RET	Scenario 3.2: 70% RET	Scenario 3.3: 80% RET
Scenario 4 "SC2_WFD": 66.6%	Scenario 4.1: 76.6% RET	Scenario 4.2: 86.6% RET	Scenario 4.3: 96.6% RET

POWER QUALITY ANALISYS

Voltage Sag Analysis

Voltage sag is one of the most important PQ problems affecting the sensitive customers. In this work the voltage sag frequency in the system is predicted. A methodology to perform voltage sags analysis is proposed in [4]. The method of fault position is adopted to predict the number of voltage sags deeper than a prefixed threshold. It consists basically in 4 steps: Load flow, voltage sags calculation (faults evaluation), Voltage sags occurrence calculation (based in statistics data) and study of result of sags analysis (mode of display result graphs). For the voltage sags analysis a voltage sag improved failure rate model is developed to be used as origin of input data to analysis. In this study the results shows the annual frequency of voltage sags occurrence in the busbars in analysis. The effect of RE capacity and location on voltage sags enhancement of the experimental study cases, where the RE generation technologies where integrated to the system is evaluated. The analysis is carried out by evaluating the value of the annual frequency of voltage sags occurrence. The results will be discussed for each PCC of the Loads Blocks of the power system.

Voltage sag analysis study result

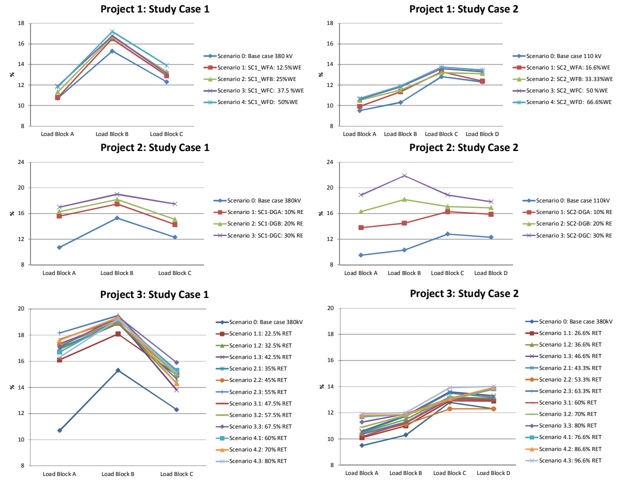

Figure 3: Total annual frequency of voltage sag occurrence

Flicker Analysis

This study is used to evaluate the flicker propagation behaviour with the integration of RE generation units in the system. This study estimates the maximum value of flicker emission shares at different customer's PCC. Flickers are quantified through the "short-term flicker severity" (Pst) and the "long-term flicker severity" (Plt). It is required to consider RE generation technologies as a potential source of voltage flicker. Flicker level evaluation should be determined indirectly, based on a simulated voltage on the power system models with an appropriate short-circuit power and for different network impedance phase angles. A method consisting of a motor start-up simulation is used for the flicker analysis. The motor-start simulation is done in the power system models, an induction motor model is used as a flicker generating source at the customer's terminal in the different Load Blocks. The instantaneous voltages during the motor switching operations are recorded and are fed to the flickermeter model to calculate flicker level (Pst) at different bars. For that purpose, the instantaneous voltage variations during motor start-ups are recorded and provided to the flickermeter for analysis. The flickermeter is developed with DPL from DIgSILENT. The flickermeter architecture is outlined in accordance with [5,6].

Figure 4 illustrates the results obtained in the simulation, which indicate that the Pst values at different LV points increase slightly when more induction motors are connected in the LV network. The flicker level depends on the size and angle of the grid impedance. Here, it is found that the Pst value at two different points of the system with the same type of disturbing loads may be higher. This is because the network impedance at one point is relatively higher than at the other point.

Flicker analysis study result

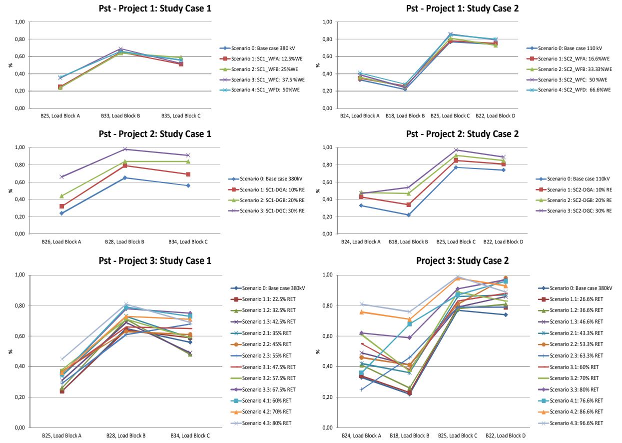

Figure 4: Short-term flicker severity level (Pst)

The simulation indicate that Pst values in the network marginally increase when the amount of induction motors are connected in the LV network. When the wind farms are connected to the system the behaviour of the flicker assessment remains almost equal. Furthermore, the results show the sharp rise of the Pst in presence of DER units, depending of the DER unit technology and position.

Harmonics Analysis

The harmonic analysis is performed using as base the harmonic analysis studies from the IEEE Brown Book [7]. To perform harmonics analysis, harmonics sources are introduced to the system. This is called the current injection method. In this method, nonlinear loads are modeled as ideal harmonic current sources. In this work, the harmonic sources are modeled in some loads in the different Load Blocks of the two base cases and in the converters used in the renewable energy generation resources integrated to the two base cases. To evaluate the behavior of the harmonics in the system the HD% and the THD% on the HV (110kV), MV (10 kV) and LV (0.4 kV) is analyzed at this point.

Harmonics analysis study result

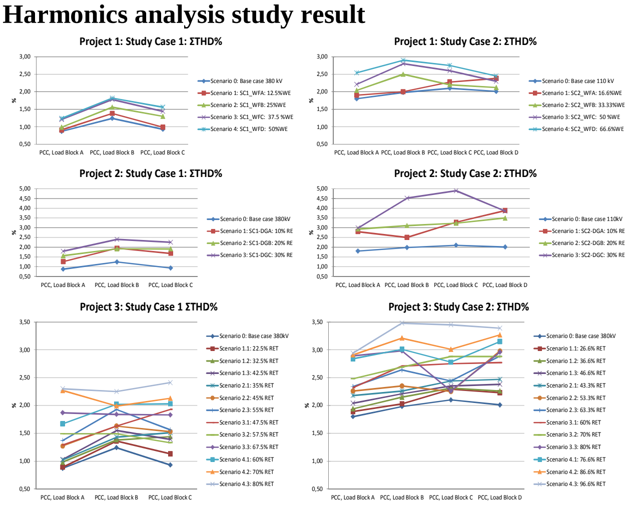

Figure 5: ΣTHD%, Total Harmonic Distortion

Figure 6 shows an increase of the THD% when more wind energy is integrated. It is proven that inclusive with 100% wind energy integration the system is working within the allowed limits since the maximum THD percentage stays below the limit of 1.5% established in [8].

CONCLUSION

The impact of the PQ problems found in the test network in case of large amounts of RE integration was analysed. The total annual frequency of voltage sag occurrence increases in the 380 kV system and decreases in the 110 kV system improving the PQ for this experimental test network. The Pst behaviour in the 380 kV network slightly decreases and in the 110 kV network increases depending of the loads and changes in a stochastic behaviour and has a negative influence on the PQ of system. The THD% in the 380 kV network shows almost the same occurrence and in the 110kV network slightly increases and makes the system vulnerable to PQ issues. The analyses demonstrate how the integration of RE generation systems can have a positive and at the same time a negative impact on the PQ of the system. This depends mainly on penetration level, configuration of the system and the type of RE technology implemented. If the RE generation technologies are adequately located, sized and selected in terms of technology and system configuration, this can clearly provide a benefit to the PQ of the system.

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