Paragraph IV presents the statistical processing of the collected data and the results and discussion are reported in Paragraph V.

2 Italian Electric Power Grid

Italy has electric generation capacity of 69 million kilowatts. In 2001, the country generated 203.4 billion kilowatt hours (bkWh) and consumed 289.1 bkWh. The generation is mostly from thermal sources (78%) - oil, gas, and coal. The mix of thermal power is shifting away from oil toward natural gas, such that natural gas should be the dominant fuel source for electricity generation by the end of the decade. Non-hydro renewable electricity generation (mostly solar and geothermal) almost doubled in the 1990s, and now over 2% of Italian electricity is produced from renewable sources.

Italy's extensive electricity network is linked to its neighbor's countries. Electricity imports come mostly from France, Switzerland and a small percentage from Slovenia. In the summer of 2002, Italy and Greece completed the construction of a new 163-kilometer (102-mile), 400-kilovolt underwater cable to link Italy and Greece. The cable will allow Greece to transfer electricity to the EU, as well as serve as a back-up source for Italy [10].

Italy is a large consumer and a net importer of electricity power generation in Italy holds natural gas its main production source, counting for about 46% of overall generation. As regards wind and solar, despite having had a steep increase in their shares in the last few years, they still amount only to 3.1% and 0.6% each in the overall generation share [11]. In more detail, the net national energy production (284.8 billion kWh) dropped by 2.3% compared to 2011; however, photovoltaic production increased by an impressive 71.8%. In December 2012 alone, photovoltaic systems produced 749 GWh of energy, providing 2.81% of the month's energy demand [12].

Italy is endowed with renewable energy sources that could be captured and utilized. Due to the high levels of sunshine that reach Italy's land surface, the Italian government has made solar energy technologies its top priority. Italy also is studying the potential of biomass and wind energy. The focus of the National Program on Renewable Energy from Biomass is to examine genetic varieties of plants that will maximize the energy obtained from combustion. Funding for research in harvesting wind energy is small compared with programs examining solar and biomass. Italy's major wind energy programs focus on the feasibility of constructing wind farms in Apulia and Sicily, both in the South where wind resources are greatest. Italy also is one of the largest producers of geothermal energy in the world, behind the United States, the Philippines, Mexico and Japan. In 1997, Italy has had an installed geothermal capacity of 550 MW.

Italy can be divided in different zones grouping more geographic regions, in specific:

- North, that includes the regions of the North-West (Liguria, Lombardy, Piedmont, Aosta Valley) and the North-East (Emilia-Romagna, Friuli-Venezia Giulia, Trentino-Alto Adige, Veneto).
- Center, that includes the regions of Lazio, Marche, Tuscany and Umbria.
- South, that includes the regions of South Italy (Abruzzo, Basilicata, Calabria, Campania, Molise, Apulia) and those of Insular Italy (Sardinia, Sicily).

Figure 1 shows the electric distribution grid for the three Italian zones (North, Center and South) above presented.Please, leave two blank lines between successive sections as here.

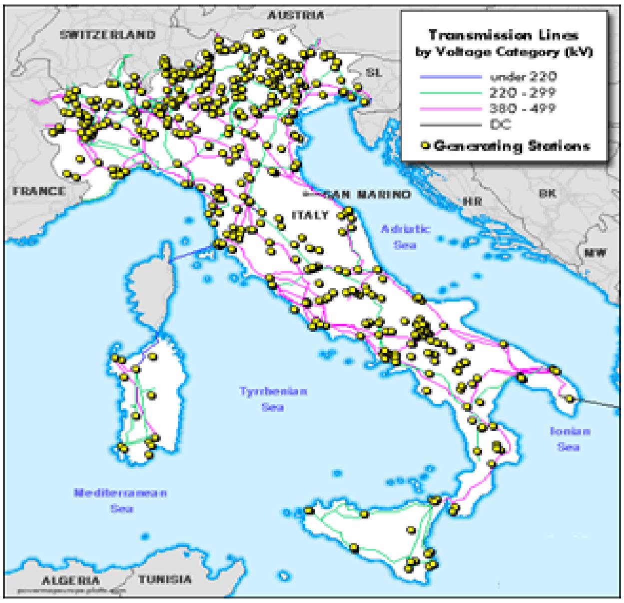


Fig. 1. Italian transmission high voltage grid.

3 Data collection method on the Italian Grid

This paragraph wants to group different information on the Italian grid, in particular the distribution of the voltage dips and the diffusion of the photovoltaic systems and wind farms in all Italian regions from 2009 to 2012 in order to perform a correlation among their values. This survey has been carried out considering the data available from different websites, and specifically:

- The 'QuEEN' site [13] that is the Italian system for power quality monitoring of MV distribution networks. This site allowed the identification of the number of voltage dips in all Italian regions.
- The 'ATLASOLE' site [14] that is the geographic information system that identifies the photovoltaic systems installed in the Italian grid. This allows interactive viewing of the PV installations at Region, Province and District levels; where the update takes place on a daily basis. In particular ATLASOLE shows photovoltaic systems grouped by power classes (1 - 3 kW, 3 - 20 kW, 20 - 200 kW, 200 - 1000 kW, 1000 - 5000 kW, greater than 5000 kW) and/or number of installed plants.
- The 'ATLAVENTO' site [15] allows the interactive viewing of wind farms in Italy, classifying them into national, regional and provincial levels, into number of installed wind systems, into their power (MW) and into their production (GWh).
- The TERNA site [16]. TERNA is the Italian Transmission System Operator (TSO) that manages electricity transmission in Italy guaranteeing its safety, quality and affordability over time. It ensures equal access conditions to all grid users. Moreover, it develops market activities and new business opportunities with the experience and technical skills gained in managing complex systems.

3.1 Voltage Sags

The number of voltage sags has been recorded from the Italian power quality monitoring system considering the 400 most important HV/MV substations and referring to the years from 2009 to 2012. This survey has been conducted for all Italian regions. Subsequently, these data are grouped evaluating the sum of voltage sags for different years. The analysis method and the classification of the voltage sags in terms of deepness and duration are reported in [17].

Figure 2 shows an example of the voltage sags number in Sicily region for each year.

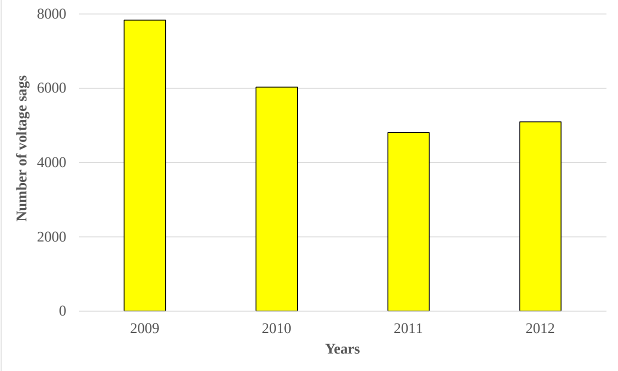


Fig. 2. Distribution Voltage dips for different years in Sicily.

3.2 Photovoltaic Systems

The incentive policies carried out in Italy for several years have led to the development and spread of several photovoltaic installations throughout the nation. In particular, much progress in installed power can be seen starting from 2009, as depicted in Fig. 3.

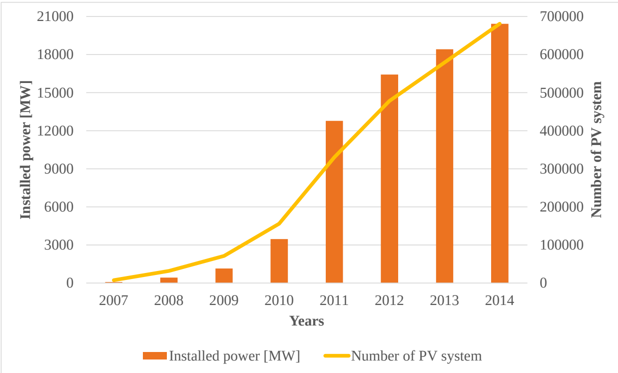


Fig. 3. PV power plant number and total PV installed power in Italy.

The development of renewable energy and photovoltaic systems has radically transformed the electricity generation system in Italy. In a few years, it moved from a system that relied on a limited number of large conventional power plants to a system that includes many small and medium-sized distributed generators, usually based on renewable energy sources.

However, the distribution of the installed power and the number of photovoltaic systems in Italian regions is not homogeneous. In fact, the North of Italy, especially Lombardy and Veneto, is characterized by many small size power plants. Instead, the South of Italy, due to its highest radiation, is distinguished for high power systems installations.

3.3 Wind Farm

The conditions for wind energy production in Italy are not favorable in every region of the country, because of the long and narrow shape of the territory and the presence of high reliefs, such as the Alps, that constitute an obstacle to the wind.
For this reason, the most promising sites are located in the central and southern regions of Italy, particularly along the Apennines and the Adriatic and Tyrrhenian islands.
At the end of 2012, Italy has installed more than 1,000 wind turbines. In particular, the 2012 was an important year for wind power in Italy in terms of new installations: more than 1,200 MW was installed in twelve months, as shown in Fig. 4.

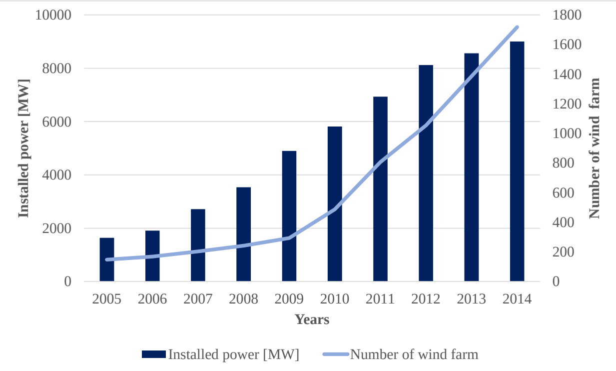


Fig. 4. Wind power plant number and total installed wind power in Italy.

3.4 Primary Substations

In this work, it has been assumed that the robustness or the weakness of the transmission grid is proportional to the number of high voltage (HV) substations. Figure 5 shows the development of the Italian transmission grid during the last years.

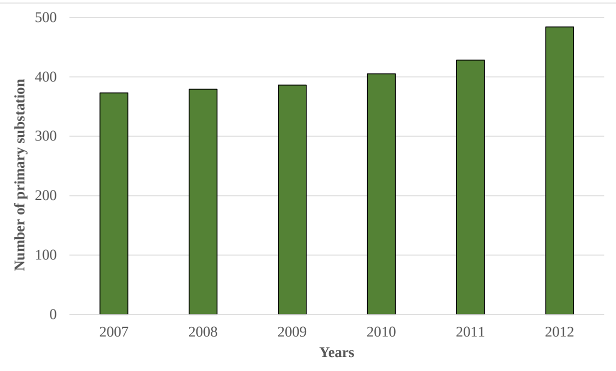


Fig. 5. Number of primary substations installed in Italy.

4 Statistical Processing of the Collected Data

All the data collected in the survey previously described have been processed in a statistical way, to find possible correlation between PV and wind installation and the number of primary substation with the delivered power quality in terms of voltage sags.
The comparison have been carried out among the 20 Italian regions that have different characteristics regarding the above items.
In order to facilitate the comparison of the delivered power quality as a function of the grid robustness and the renewable energy installation, the collected data have been normalized considering the following variables, parameters, quantities and indexes:

- PV_{region}: installed PV power in a specific region of Italy;
- $WIND_{region}$: installed wind power in a specific region of Italy;
- P_{gen}: total installed power in Italy equal to 128 GW;
- $N_{sub\text{-}region}$: number of the primary substation in a specific region;
- N_{sub}: total number of the primary substation in Italy in 2012 equal to 484;
- $N_{VS\text{-}region}$: number of the voltage sags in a specific region;
- $N_{VS\text{-}ref}$: reference number of the voltage sags (assuming the maximum recorded number equal to 8000)
- $PV^{*}_{region} = {PV_{region}}/{P_{gen}}$: normalized installed PV power in a specific region of Italy;
- $WIND^{*}_{region} = {WIND_{region}}/{P_{gen}}$: normalized installed wind power in a specific region of Italy;
- $N^{*}_{sub-region} = {N_{sub-region}}/{N_{sub}}$: normalized number of the primary substation in a specific region;
- ROS: index (Renewable On Substations)

$$ROS = {\left(PV^{*}_{region} + WIND^{*}_{region}\right)}/{N^{*}_{sub-region}}$$

- $N^{*}_{VS-region} = {N_{VS-region}}/{N_{VS-ref}}$: normalized number of the voltage sags in a specific region.

To better understand the possible correlation between the normalized voltage sags and the PV and wind installations, summarized through the ROS index, the Pearson index has been used. This index represents the correlation between two variables and it gives also the quality of their relation. It describes the linear correlation (dependence) between two variables (X and Y), where in this case X represents the ROS index whereas Y is the normalized voltage sags. It is widely used in the sciences as a measure of the degree of linear dependence between two variables. The correlation coefficients $\rho X,Y$ of the analyzed population between two variables (X, Y) with expected values μX and μY and standard deviations σX and σY is defined as in the formula:

$$\rho_{X,Y} = corr(X,Y) = \frac{\text{cov}(X,Y)}{\sigma_X \sigma_Y} = \frac{E[(X-\mu_X)(Y-\mu_Y)]}{\sigma_X \sigma_Y} \quad (1)$$

where E is the expected value operator, cov means covariance and corr is used as alternative notation for the correlation coefficient. The possibile value obtained can be in the range (−1, +1), where 1 is total positive correlation (direct proportionality), 0 means no correlation, and −1 refers to a negative correlation (inverse proportionality).

5 Results and Discussion

The data presented in Paragraph III and the normalized values and ROS indexes described in Paragraph IV are collected from 2009 to 2012 for each region and reported in Fig. 6.
As it is possible to note the characteristics for the various regions are not homogeneous. In fact, each region can be assumed as representative case of the combination of these variables:

- percentage of PV installation;
- percentage of wind installation;
- robustness or weakness of the electric grid;
- ROS index;
- quality of the power (voltage sags number)

The first step of this analysis is the evaluation of the correlations between ROS indexes and the normalized voltage sags $N^*_{VS-region}$. The obtained results are reported in Table 1.

Table 1 Correlation between the ROS index and the normalized voltage sags.

Region	$corr(ROS, N^*_{VS-region})$	**Correlation typology**
Abruzzo	0.073	No correlation
Apulia	0.107	Positive very weak
Aosta Valley	-0.934	Negative very strong
Basilicata	-0.932	Negative very strong
Calabria	-0.882	Negative very strong
Campania	-0.821	Negative strong
Emilia R.	-0.953	Negative very strong
Friuli V. G.	-0.834	Negative strong
Lazio	-0.738	Negative strong
Liguria	-0.862	Negative strong
Lombardy	-0.586	Negative weak
Marche	-0.596	Negative weak
Molise	-0.241	Negative very weak
Piedmont	-0.795	Negative strong
Sardinia	0.725	Positive strong
Sicily	-0.896	Negative very strong
Trentino A. A.	-0.903	Negative very strong
Tuscany	0.439	Positive weak
Umbria	-0.611	Negative
Veneto	-0.861	Negative strong

From Fig. 6, it is possible to observe that a high presence of photovoltaic generation does not substantially cause a degradation of the delivered power quality in terms of number of voltage sags. In fact, in more than half regions (Aosta Valley, Emilia R., Friuli V. G., Lazio, Liguria, Lombardy, Marche, Piedmont, Trentino A. A., Tuscany, Umbria, Veneto) characterized by only PV installations, the total number of voltage sags remains quite low and does not significantly vary with the PV installed power. Moreover, the correlation between *ROS* index and $N^*_{VS-region}$ for these regions is not homogeneous because it mostly depends by the robustness of the electric grid ($N^*_{sub-region}$).

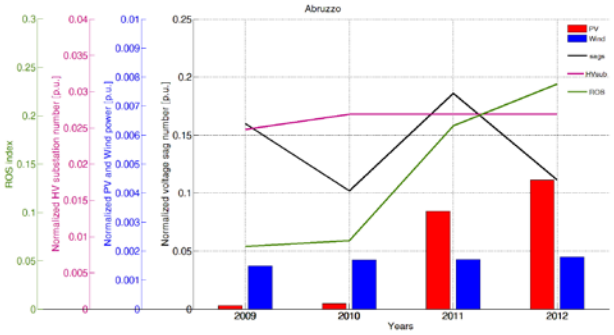
Different considerations arise for those regions where wind power is installed.

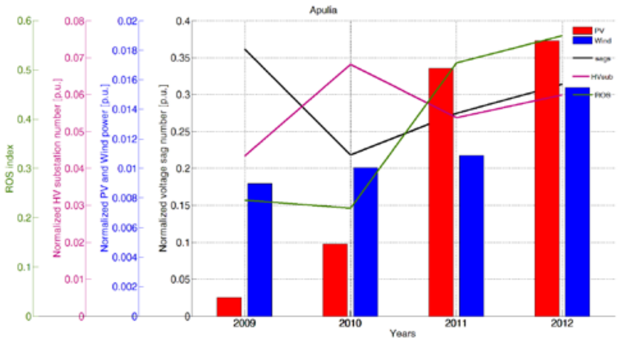
In case of a moderate percentage of wind power, as in Abruzzo, Basilicata and Molise, the number of voltage sags is not correlated to the presence of this source. Instead, in those regions with a significant amount of wind power (Apulia, Calabria, Campania, Sardinia and Sicily) it is possible to observe that the quality of the delivered power is largely worse compared to the other regions.

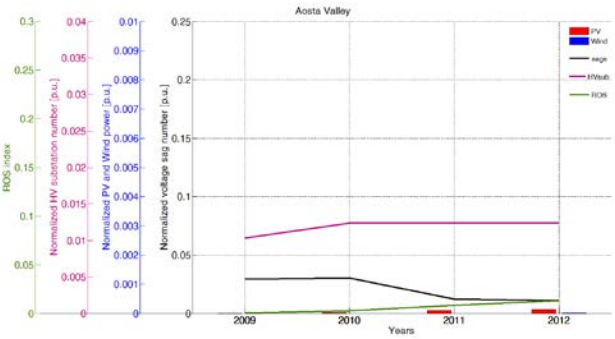
However, there is a trend of improvement where there is a substantial reinforcement of the transmission grid after new wind power installation as in Calabria, Campania and Sicily.

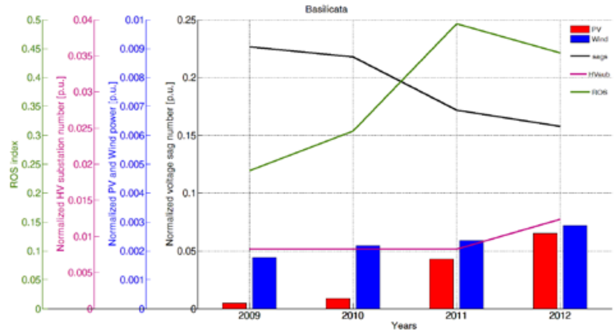
On the contrary, if the connection of new wind power is not followed by an adequate reinforcement of the transmission grid, it is not possible to experience any PQ improvement as highlight in Sardinia, or even a PQ deterioration can arise as shown for Apulia.

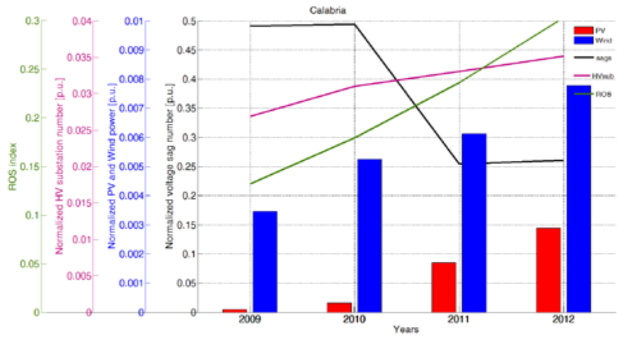
It has to be noticed that two islands, Sardinia and Sicily, both characterized by a high amount of wind power, have a different behavior considering the different robustness of the grid.

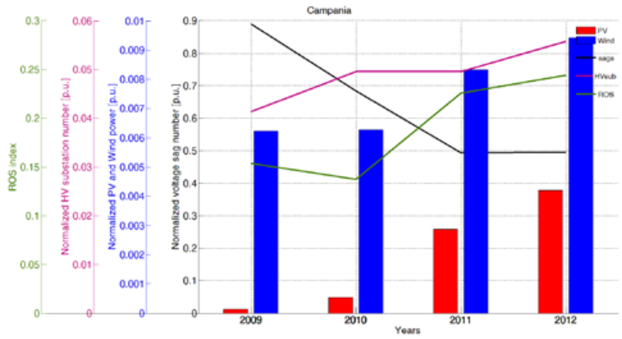


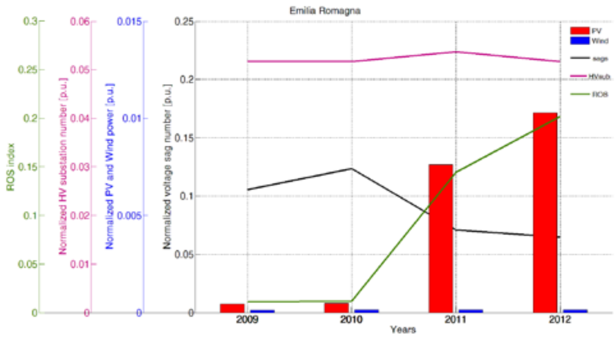


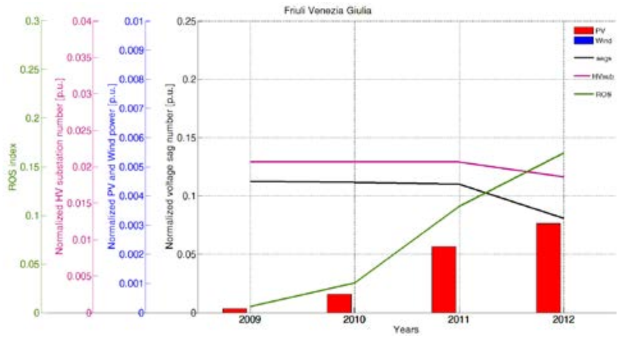


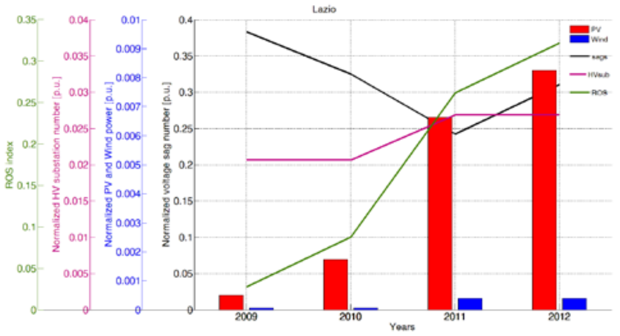











Lazio
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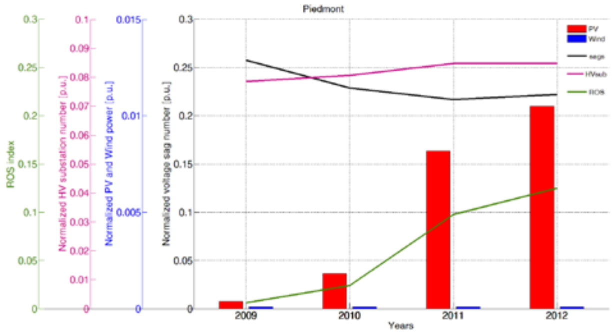
Piedmont
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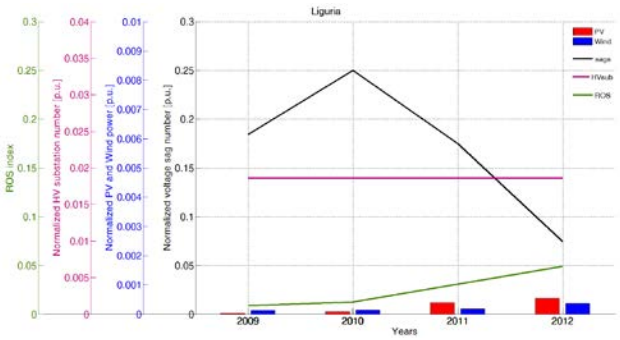
Liguria
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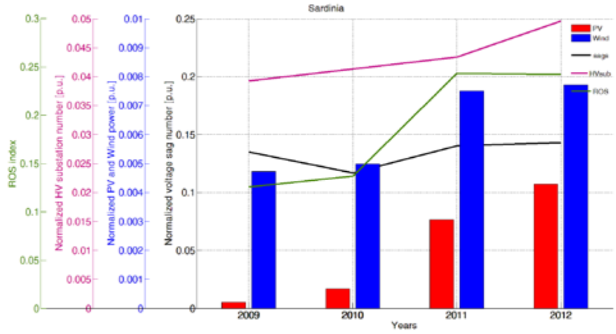
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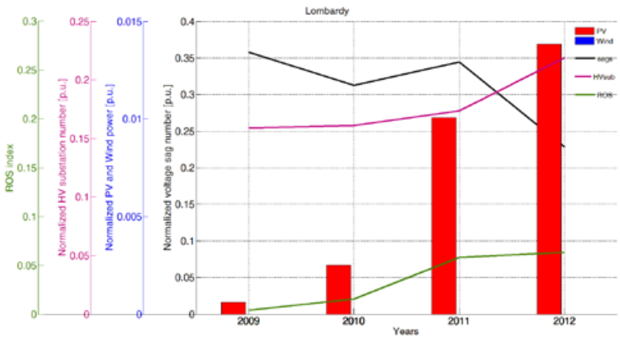
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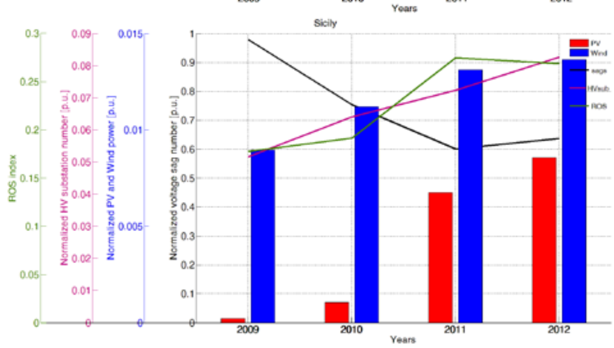
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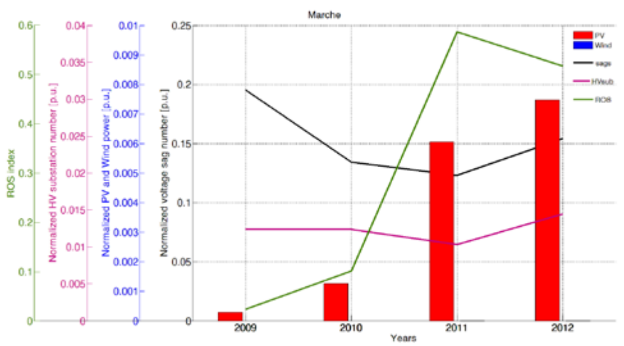
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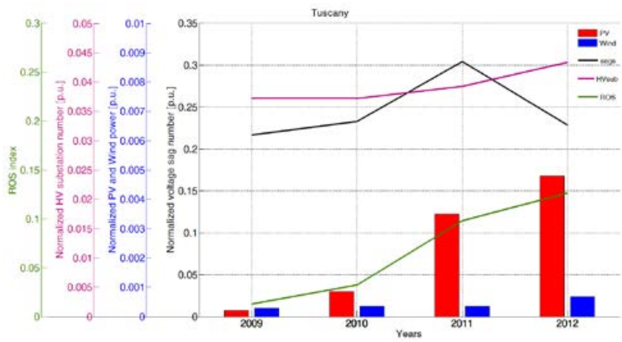
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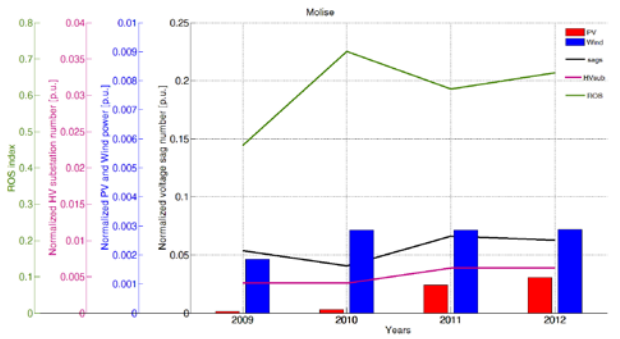
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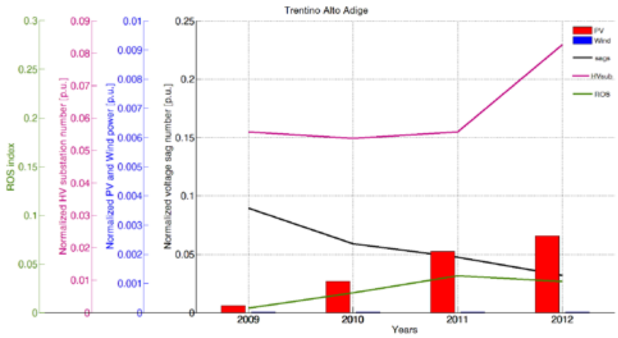
Trentino Alto Adige
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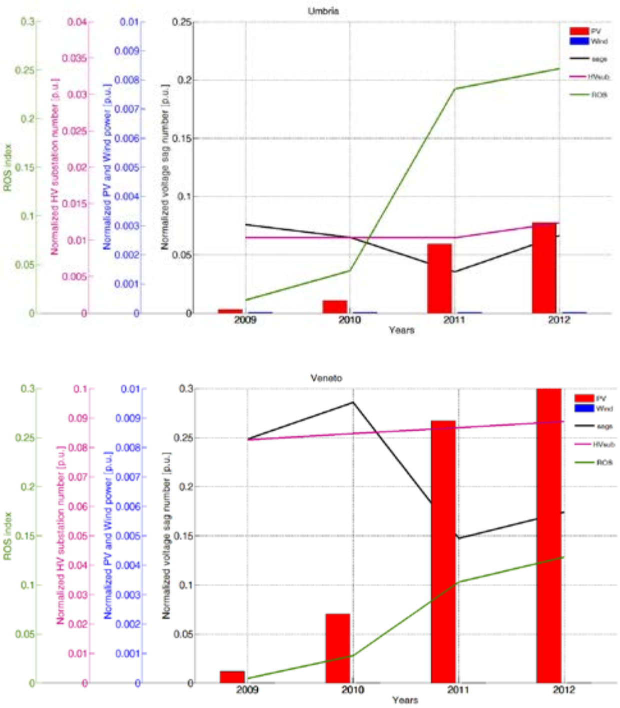

Fig. 6. Details of all Italy's regions indicating Voltage dips, Photovoltaic Systems and Wind Farms.

6 Conclusion

In this paper the correlation between voltage sags and the spread of renewable energy, in particular photovoltaic systems and wind farm, has been analyzed. The analyzed period considers four years, from 2009 to 2012. The study has been carried out for the 20 Italian regions, each as a representative case of a particular combination of PV, wind and robustness of the grid.

The obtained results show that in general the integration of photovoltaic systems, also in the case of strong percentage of the total installed power, does not affect the quality of the delivered power in terms of voltage sags.

Instead, different considerations can be done for those regions where wind power is installed.

In case of a moderate percentage of wind power, the number of voltage sags is not significantly correlated to the presence of this source. Vice versa, in those regions with a substantial amount of wind power, a worse quality of the delivered power compared to the other regions was noticed.

However, an improvement trend can be observed where the transmission grid is reinforced after new wind power installation.

Instead, if the connection of new wind power is not followed by an adequate enhancement of the transmission grid, it is not possible to note any PQ improvement, or even a PQ deterioration can be observed.

Therefore, it is possible to conclude that renewable sources interfaced to the grid through electronic converters, as PV systems, do not affect the quality of power, and they can be connected without any particular adaptation. On the contrary, renewables such as wind energy, mainly based on doubly-fed induction machines for the analyzed period, can cause some PQ deterioration if their installation is not followed by a grid reinforcement. New wind systems based on full load converters and permanent magnet synchronous generators (PMSG) can provide ancillary services that are able to prevent these problems [18].

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