FROM FUEL BASED GENERATION TO SMART RENEWABLE GENERATION: PRELIMINARY DESIGN FOR AN ISLANDED SYSTEM. PART I: TECHNICAL ISSUES AND FUTURE SCENARIOS

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ABSTRACT

The subject addressed in this paper is the analytical study of the transition of the energy generation system for a real MV/LV distribution system from a 'fuel based' one to a distributed and smart 'renewables based' one. The paper outlines the technical issues related to such transition from one type of system to the other. The study is carried out for a real islanded MV/LV distribution network located in the Island of Pantelleria. The economical issues regarding the above transition are focused in a companion paper.

INTRODUCTION

The most important challenge in the near future in the electrical power systems field, mostly for Medium and Low voltage distribution systems, consists of a complete integration of Distributed Generation. Considering the objectives fixed in the European union for 2020 (reduction of 20% of greenhouse gases and increase of 20%, compared to the gross internal consumption, of electrical Energy produced from renewable sources), the most easy way to attain these objectives is that of a considerable increase of DG within electrical systems, thus allowing the exploitation of the different renewable energy sources available on the territory, otherwise not usable. Nevertheless the ever increasing penetration of DG in distribution systems encourages the rethink of all the design criteria, development, protection, control and management of resources in the transition from passive to active systems.At national and international level, such necessary evolution will lead to the development of the so called smart grids, calling with this term strongly automated systems and characterized by the presence of dispersed generators, loads, storage systems and by control and management strategies that make use of Information Communication Technologies.Within this framework, it is particularly important to perform studies and perspective researches aiming at the evaluation of DG over the networks, else than in technical terms, also through economic analysis. The Department of Electrical, Electronics and Telecommunications Engineering (D.I.E.E.T.) of the University of Palermo, in cooperation with ENEA (Italian National agency for new technologies, energy and sustainable economic development), has performed, within the National research project (Ricerca di Sistema supported by the Ministry of Economics), the technical economical feasibility study and the preliminary design of a demonstrator of a distribution electrical system for the transition towards active networks. Aim of this activity, carried out on the isolated MV grid of the Island of Pantelleria (a little physical island in the Mediterranean Sea), is to contribute to the process of identification of new reference modes and to the standardization of the relevant solutions. After a general description of the area above mentioned, in which the current features of the electrical system under investigation are reported, mainly in terms of production and consumption of electrical energy, articulation and consistency of the network, and data needed to identify the initial or reference scenario, in a following section the detailed analysis on the main aspects of feasibility of the interventions finalized to the integration of distributed generation systems based on renewable and to the demand control is shown, identifying five possible growth scenarios. Then, the results of the simulations executed in NEPLAN environment with reference to the normal working and some particular fault conditions that are most meaningful both for the actual scenario and for one of future scenarios, are reported.

DESCRIPTION OF THE SYSTEM

Electrical System characterization

The electrical system supplying the island of Pantelleria is islanded and is characterized by a thermal power plant for the production of electrical energy, by an MV radial distribution network with 150 load nodes operated at the rated voltage of 10,5 kV. More in detail, else than the generation bus, it is possible to identify 133 substations, 2 switching substations and 15 supply buses for MV. The thermal power station is made of 8 diesel groups, with a total power of about 20 MW. From the power station 4 lines (aerial and cable) spread out , all supplying at MV the above reported substations and indicated with progressive indices (Line 1 ÷ Line 4). Each line is equipped at the start of the line with maximum current and ground fault protection systems. The electrical distribution system, even if it is normally radially operated, shows different points where it is possible to radially counter- supply the lines or where it is possible to create a meshed configuration, both inside certain substations that are today remotely controllable, and from other points of the network.

Fig. 1 shows the simplified scheme of the MV distribution system where the four mail supply lines are evidenced and the substations where have been recently implemented remote control logics and faulted feeder detection.

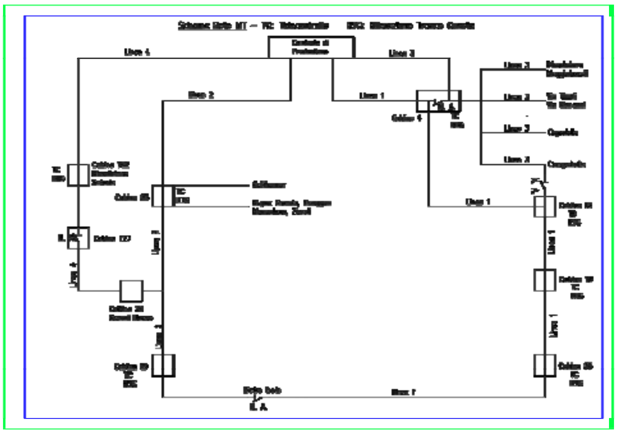

Figure 1 – Simplified scheme of the MV system.

Electrical Energy Load

The island of Pantelleria, currently, is totally dependent from external sources, except for some small photovoltaic plant that is already installed. The current supply system is mostly composed of diesel, but also from oil and GPL. The power plant is composed of eight groups, for a total power installed of about 20 MW, with a loading factor of 0,18, as an effect of the alternate use of the different sections of the power plant. The yearly energy need indeed is of about 44 GWh. Half the yearly consumption of energy by liquid fuel, both those for transportation and those for the energy production, takes place in the time between June and September. In 2000 the need for liquid fuel was of about 10.2 MTEP (7.7 MTEP for the power plant) of which 4.8 MTEP employed during summer (3.4 MTEP from the power plant). The analysis of the load diagrams shows that the peaks are registered in August during the evening (around 9 p.m.) and vary between 7 MW and slightly more than 10 MW (Fig.2). the minimum loading can be registered during winter (January) at 3 p.m. and is of about 3.1 MW. The average power is of about 6.2 MW during summer and about 4.6 MW during winter. The energy consumption in 2008 was of about 43.7 GWh, of which 21.1 GWh during summer (56%) (Fig.3).

FEASIBILITY STUDY

With reference to the feasibility study for the integration of distributed generation systems based on renewables and of demand control, a detailed study about the potential of the site was carried out. Considering not only the availability of energy resources that can be fruitfully exploited, but also taking into account all the other main aspects (constraints, availability of spaces, impact issues, territorial and functional specificity, etc.), that the real implementation requires, among the different renewable sources, it is considered to employ the solar resource through photovoltaic conversion and thermal solar, as well as the wind source, the geothermal one and urban waste.

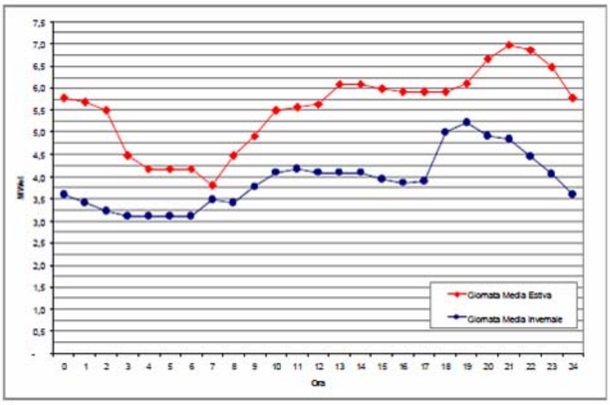

Figure 2 – Average hourly electrical power for the standard work day (summer 2009).

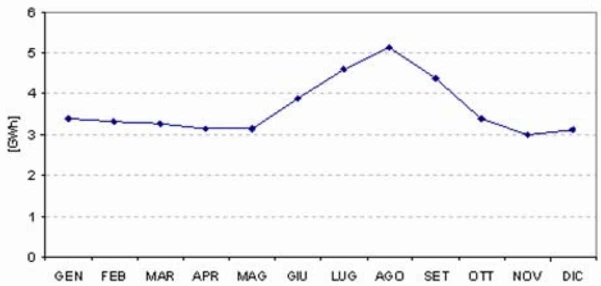

Figure 3 – Monthly electrical energy consumptions (2008).

Electrical generation from solar source through photovoltaic conversion

The Island of Pantelleria is characterized by a soalr radiation of 1.69 MWh/m^2/year, with a minimum of 1.90 kWh/m^2/day in January and a maximum value of 7.2 kWh/m^2/day in July [1]. Considering the particular environmental and architectural features of the island and taking in account of the really available surfaces, it is possible to think the installation of photovoltaic systems only in some specific areas with the following power and related energy capacity (for an equivalent number of hour of generation of 2007 hrs/year):

- urban city (in the North): P_{PV}=750 kWp – E_{PV}= 1.17 GWh/year;
- industrial area: P_{PV}=300 kWp – E_{PV}=0,45 GWh/year;
- airport P_{PV}=50 kWp – E_{PV}= 0.08GWh/year.

Considering the contributions of all photovoltaic systems, it is possible to have a total power of 1.1 MWp, with a related electric energy capacity production of 1.7GWh.

Electrical generation from wind source

An accurate analysis of the site has put into evidence a possible limited use of the wind resource, above all due to the effect of the environmental impact. It is thus hypothesized to install at most two wind generators with a total rated power of 1.2 MW. Considering a unitary energy production of 3000 MWh/MW [2], the expected production of electrical energy can be evaluated in 3600MWh/year.

Electrical generation from geothermal source

In past years many studies have been carried out in the Island of Pantelleria aiming at the use of geothermal source. On the basis of these studies, it is possible to consider the realization of a little geothermal power plant of 2.5 MW in the South-West part of the island. Considering a system functioning of 8000 hours/year, the obtainable energy is 20000 MWh/year (about 46% of total energy consumption of the island).

Electrical generation from urban waste

On the basis of executed studies, the refusal production is about 1405 kg/day/inhabitant. Considering the number of inhabitants (about 7700), the population increase due to summer tourist flows and the value of waste-not recycling (about 78%), in figure 4 the daily average waste-not recycling production is reported [3], [4].

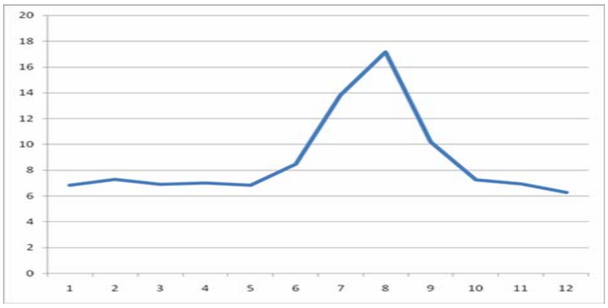

Figure 4 – Esteem of the average daily waste not recycling production for each month [t] .

On the basis of these data, it is possible to assume the installation of a urban waste electric generator near the rubbish dump in the South-East part of the island.
The generator size, determined on the basis of the daily refusals production, is 365 kWe. Assuming an heat of combustion about 4000 kcal/kg, for each refusals ton it is possible to have an energetic potential of 4600 kWh. Considering system performance and auto consumptions, the electrical energy that can be supplied to electrical system is 1070 kWh/t for each hour; assuming to supply the generator by means 5 t of refusals for day and a systems functioning of 300 days/year, the energy really supplied to the electrical system is about1620 MWh/year [5].

Solar thermal source

The hot water needs can be calculated in according with [6] or [7]. The application of the two methodologies determine an electric energy consumption of 1380 kWh/year for each family. Assuming that about 75% of the island families (2200) can use solar thermal systems and that these systems can satisfy 75% of hot water needs, the electrical load of the entire island can be reduced about 2.13 GWh. Considering that the equivalent number of hours/years of functioning of solar thermal systems is about 2007, the average power related to the yearly energy saved is about 1.06 MW.

POSSIBILE SCENARIOS

On the basis of the average electro-energetic needs of the Pantelleria Island (44 GWh/year), five scenarios, reported in Table I, have been hypothesized; in each of them a part of the energetic needs is obtained from renewables.

Table I Future Scenarios

Scen.	*Source*	*[%] compared to max. power*	*ELECT. POWER [MW]*	*ENERGY PROD. [GWh/year]*	*TOTAL ENERGY PROD. [GWh/year]*
	PV	60	0.66	1.02	
	Wind	50	0.6	1.80	
10.1	*Geoth.*	0	0	0	4.524
	Waste	0	0	0	
	Th.	80	0.848	1.704	
	PV	60	0.66	1.02	
	Wind	0	0	0	
10.2	*Geoth.*	0	0	0	4.324
	Waste	100	0.365	1.6	
	Th.	80	0.848	1.704	
	PV	100	1.1	1.7	
	Wind	100	1.2	3.6	
20	*Geoth.*	0	0	0	9.03
	Waste	100	0.365	1.6	
	Th.	100	1.06	2.13	
	PV	30	0.33	0.51	
	Wind	0	0	0	
50.1	*Geoth.*	100	2.5	20	23.175
	Waste	100	0.365	1.6	
	Th.	50	0.53	1.065	
	PV	60	0.66	1.02	
	Wind	0	0	0	
50.2	*Geoth.*	100	2.5	20	22.724
	Waste	0	0	0	
	Th.	80	0.848	1.704	

Among the scenarios above reported, a technical-economical study has been carried out related to the scenario named 50.1, which is characterized by a cover of

50% of energetic needs by means renewables.

SIMULATION AND RESULTS

Based on the executed characterization, a model of the network has been implemented using Neplan simulation software. The model, validated through a comparison with the data coming from the output data of the initial or reference scenario (passive system), has been used for the load-flow analysis (in particular working conditions) and of short circuit (for three phase faults in different nodes of the system) both for the initial scenario (passive), and for the above indicated scenario of active network (with DG), with the aim of evaluating the system's performance. Among the different working conditions, three extreme ones have been simulated:

- A: maximum load, August 14, 9.00 pm, P_{load}= 10.6 MW;
- B: maximum photovoltaic production, August 14, 12.00 am, P_{load}= 7.8 MW;
- C: minimum load, January 14, 3.00 am, P_{load}=3.1 MW.

About system topology, among all possible points, four principal ones have been considered to create meshes: the tie-switch near MV-LV station n.127; the tie-switch in bus 70; the tie-switch in bus 10; the tie-switch between line 1 and line 2 (airport connection). Four possible configurations of interest have been considered: 1) the base passive radial system configuration; 2) the active radial one; 3) the totally meshed one (four above mentioned tie-switches closed); 4) the minimum meshed one (only a tie-switch closed). In Fig. 5 the simulations results are reported.

Conf	Load. Cond	Pcar MW	Qcar MVAR	Pg MW	Qg MVAR	PgRes MW	QgRes MVAR	ΔPTot MW	ΔQTot MVAR	Num. viol.
	A	10.6	6.273	11.404	7.03	0	0	0.804	0.757	119
1	B	7.8	4.616	8.193	4.814	0	0	0.393	0.198	35
	C	3.056	1.82	3.089	1.1519	0	0	0.033	-0.30	0
	A	9.799	6.273	7.615	5.325	2.574	1.229	0.39	0.282	37
2	B	7.41	4.385	4.748	4.314	2.897	0.059	0.235	-0.01	0
	C	3.056	1.82	0.639	0.635	2.574	0.957	0.157	-0.23	0
	A	9.799	6.273	7.496	3.36	2.574	3.027	0.271	0.114	0
3	B	7.41	4.385	4.628	3.274	2.897	0.963	0.115	-0.15	0
	C	3.056	1.82	0.542	0.541	2.574	0.957	0.06	-0.32	0
	A	9.799	6.273	7.547	3.789	2.574	2.659	0.322	0.174	0
4	B	7.41	4.385	4.652	3.445	2.897	0.827	0.139	-0.11	0
	C	3.056	1.82	0.555	0.554	2.574	0.957	0.073	-0.31	0

Figure 5 – Load-flow simulations results.

In maximum load condition (A), the base passive system (1) presents an high number of violations in voltage values. The power injections, in particular those coming out from geothermal and waste generators, not only reduce the number of voltage violations (about three times), but also halve real power losses. The active configurations (3-totally meshed and 4- minimum meshed) determine further improvements eliminating voltage violations and reducing power losses. In all studied working conditions, it is easy to note a great reduction of the power (both real and reactive) supplied from diesel oil plant. The voltage profiles analysis put into evidence as the two active configurations (3-totally meshed and 4- minimum meshed) present the best features of regularity in all the electrical systems buses, (see Fig.6).

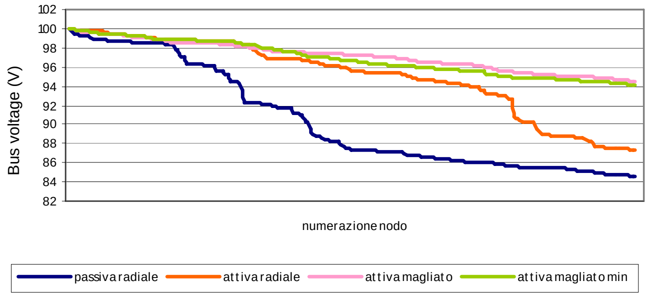

Figure 6 – Voltage profiles for the four configurations in maximum load conditions.

For the short circuit analysis, a three phase fault has been simulated in the following buses: diesel-oil plant bus-bar (G); geothermal plant bus-bar (125); waste generator bus-bar (129); bus n.127; bus n. 70; MV bus-bar of MV/LV station (87). The analysis of the results gained from simulations put into evidence high variations both in short-circuit currents and in power flows directions. Therefore, the connection of new generators needs a strong change in the present choice related to the characterization and dimensioning of protection systems.

CONCLUSIONS

In this paper an analytical study has been presented, concerning the transition of the energy generation system for a real MV/LV distribution system from a 'fuel based' one to a distributed and smart 'renewables based' one. The real power system studied is located in the Island of Pantelleria. The attention was focused on the technical issues related to such transition. In particular a technical analysis has been carried out for a specific scenario characterized by renewables really usable. Results gained from simulations put into evidence the benefits due to the evolution of the present electrical system in an active one both in terms of losses reduction and of quality of the energy supply. Nevertheless a real implementation of future evolutionary scenarios of the present system needs strongly structural and control modifications.

REFERENCES

[1] Norma UNI 10349, "Riscaldamento e raffrescamento degli edifici. Dati climatici"
[2] CESI, "Atlante Eolico dell'Italia", Novembre 2002 - http://www.rse-web.it
[3] http://www.istat.it
[4] F. Attura, S. Cassani, F. Monteleone, *Le Isole Minori*, ENEA, 2009, http://www.enea.it.
[5] http://www.pyromex.com
[6] EN 50440, "Efficiency of domestic electrical storage water-heaters"
[7] UNI/TS 11300-2, "Prestazioni energetiche degli edifici – Parte 2: Determinazione del fabbisogno di energia primaria e dei rendimenti per la climatizzazione invernale e per la produzione di acqua calda sanitaria"