RELAYING PROBLEMS IN THE CONNECTION OF A DISPERSED GENERATING PLANT TO THE 132kV NETWORK

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INTRODUCTION

Starting from 1991, with the adoption of the energy saving oriented laws N°9/91&N°10/91, new generating plants have been set up in Italy by Independent Power Producers to deliver the generated electric energy to the National Grid. According to these laws, the new plants had to make use mainly of renewable sources or waste fuel. In case of conventional thermal plants they had to be configured as co-generation plants, as high efficient use of primary fuel was requested. Several plants using high efficient gas turbines in combined cycle configuration have been connected to 132kV network when rated above 10MW.
As an aftermath of the recent liberalisation of electric energy market and the privatisation of generating field stated by the law N°79/99 of 16/3/99, which acknowledges the UE directive 96/92/CE, new power plants of different size and type will be connected to the National Transmission Grid in the next future. Great impact on network exploitation and protection philosophies is expected due to the presence of the new generating units dispersed on the network. As a consequence, appropriate technical regulations stating common rules for private producers and public system operators are essential to guarantee high levels of quality and availability of the supply to users. The National Transmission Grid Operator (GRTN "Gestore della Rete di Trasmissione Nazionale") is defining detailed technical regulations which make reference to the new national standard CEI 11-32, issued by the Italian Electrical Committee (CEI) in June 2000 as a revision of the previous one published in 1993 to take into account the laws 9&10/91.
The new dispersed generation will affect mainly the 132kV network, which had been planned in Italy as primary distribution system to supply large user plants and MV distribution network.
Different power flows, which may affect voltage profile and overload lines, are expected; fault duty can increase up to values exceeding the withstand level of existing components. Line protection settings and criteria will be re-analysed taking into account in-feed effect, possible power swings and generator out-of-step conditions. Moreover, automatic three-phase reclosing with short dead time (0.3s), which had been installed to improve the quality of supply to the loads, may cause generators out-of-phase reclosing: this will make necessary the installation of single-phase reclosing systems instead of three-phase ones.

The paper deals with specific relaying problems caused by the connection to the existing 132kV network of a private co-generation power plant, rated 140MW, and focuses the study performed to achieve a satisfactory co-ordination plan between new and existing protective relays and to minimise the replacement of existing protections.

SYSTEM CHARACTERISTICS

132kV Network

During the 70's and 80's, the Italian 132kV network was developed as a distribution system. The system, which is typically a meshed grid, is fed by the 380kV grid via 380/132kV main stations. Normal operation is performed by means of "load islands"; each island is made by a number of main lines ("arteries"), usually fed by two or three separate supplies; HV/MV distribution substations are connected to the lines via two-feed-through schemes.

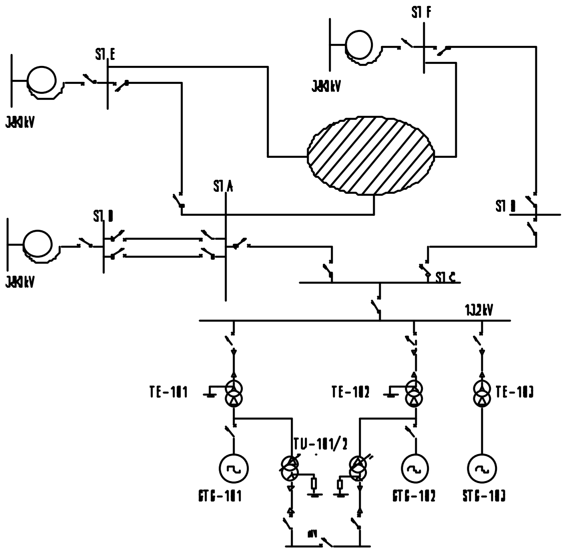

FIGURE 1. General one line diagram.

Lines are equipped with solid state distance relays, single system, four protection zones, without power swings blocking device; tripping characteristic is quadrilateral type, resistance and reactance can be set independently. As a rule, tele-protection schemes are not used, with the exception of multi-terminal and short

lines (<2km) that are fitted with permissive or blocking schemes. No specific station busbar protections exist. Fast automatic reclosure is three-pole type; circuit breakers are generally equipped with three-pole command. Breakers are closed without check of synchronism due to the passive nature of the system.
When in the early 90's new generating plants by Independent Power Producers began to be connected to the 132kV network, it became necessary to upgrade line switching devices and protective systems to make the network able to operate both as distribution and transmission system.
For the specific case described in the paper, the new power plant was connected to the 132kV network via a new "two-feed-through" station (Figure 1) on the AB line. D, E and F are the 380/132kV main stations; line AC is 1.3km long, whereas lines CB and BF are respectively 7km and 41km long. No other generating plants are connected to the system in the area.
The following problems were to be solved. To avoid the risk of damages to alternators due to rotor stress in case of three-phase reclosing, six circuit breakers and reclosing devices were replaced in stations A and B to substitute three-phase reclosing systems with single-phase ones (single-pole reclosing is required to achieve fast automatic service restoration in case of line transient single-phase-to-ground faults, that are about 70% of the whole network faults). Moreover, synchro-check devices were installed on all the circuit breakers on the "artery" DF (Figure 1) to allow parallel restoration between the system and the power plant after separate operation of the plant itself on some local loads. For what concerns line distance protections, their setting was revised to ensure, beyond selectivity, fault clearing times lower than generator critical clearing times and to prevent false tripping during electromechanical power swings following short circuit removal. Due to the short length of the AC line, tele-protections with overreach scheme were installed.

Power plant

The power plant, combined cycle type, is made of two gas turbine generators, (GTG-101 & GTG-102), Siemens V64.3 type, each with its relevant Heat Recovery Steam Generator (HRSG) and of one steam turbine generator (STG-103), Ansaldo A10 type, powered by the steam generated in the HRSGs. Three step-up transformers (TE-101, TE-102 & TE-103) connect generators to the 132kV substation, AIS type, to allow the delivery of generated power to the National Grid. The auxiliary services of the plant are fed at 6.0kV and 0.4kV via two unit auxiliary transformers (TU-101&TU-102). Two generator circuit breakers are connected to gas turbine generator terminals to allow the start-up of the plant via the step-up transformers and the unit auxiliary transformers (Figure 1). The main characteristics of generators and transformers are gathered in Table 1.
Table 2 shows the main characteristics of the 132kV system at the connection point.
Plant protections against external faults are shown in Figure 2, where only one bay is represented (the other bay protection systems are identical).
The 132kV circuit breaker E-Q52, which connects the plant to the station C ("interface" between the plant and the network), is tripped by a distance relay, microprocessor type, and by an overfrequency-underfrequency relay, with rate of rise function (ANSI code 81O/U). The distance relay is complete of power swing blocking function.

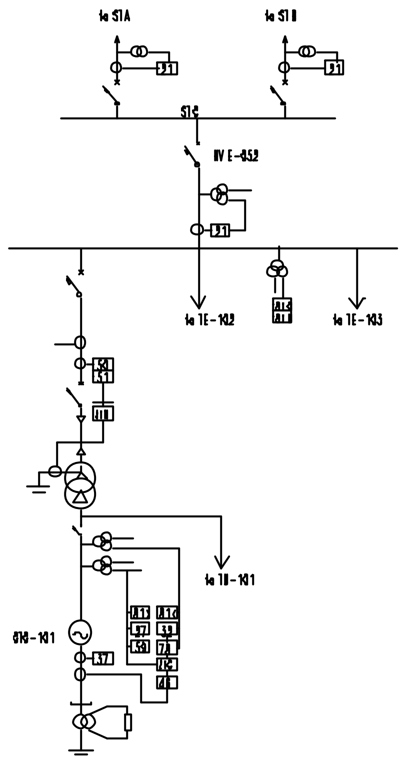

FIGURE 2. Protective relay one line diagram.

TABLE 1 - Plant main components characteristics.

GENERATORS	**GTG-101/2**	**STG 103**	**Unit**
Rated Power at 15°C	70	70	MVA
Rated Voltage	11.5	11.5	KV
Rated Power Factor	0.85	0.85	
Sub-trans.react./sh.circ.time const.	14.7/ 0.018	14.7/ 0.018	% / s
Trans. reactanc / sh. circ. time const.	21.3 / 0.77	21.3/ 0.77	% / s
Synchr.react./armat. sh.c.time const	183.0/ 0.49	183/0.49	% / s
Armature resistance per phase (75°C)	0.0033	0.0033	Ω
Zero seq. Resistance/zero seq. react.	0.13 / 8.8	0.13 / 8.8	% / %
Excitation type	Static	Static	
Turb.+generator.inertia const. (H)	4.98	*3.98*	S
STEP UP TRANSFORMERS	**TE-101/2**	**TE-103**	**Unit**
Rated Power ONAN/ONAF at 15°C	59/70	59/70	MVA
Rated voltage ratio	131/11.5	131/11.5	KV
Connection diagram (vector group)	Ynd11	Ynd11	
Impedance voltage at 75°C	8.3	8.3	%
No-load losses at rated voltage	29.4	29.4	KW
Load losses at 75°C (ref.to 70 MVA)	158.6	158.6	KW
UNIT AUX. TRANSFOERMERS	**TU-101**	**TU-102**	**Unit**
Rated Power ONAN/ONAF at 15°C	5.9/7.4	5.9/7.4	MVA
Rated voltage ratio	11.5/6.3	11.5/6.3	KV
Connection diagram (vector group)	Dyn1	Dyn1	
Off-load tap changer taps	±4*2%	±4*2%	
Impedance voltage at 75°C	8.3	8.3	%

TABLE 2 - Grid characteristics at connecting point.

Average voltage value	134	kV
Three-phase fault currents (min/max)	15 / 19	kA
Single-phase-to-ground fault curr. (min/max)	15 / 18.5	kA

When the HV.E-Q52 circuit breaker trips, the plant automatically switches to "island" operation and trips one gas turbine and the steam turbine generators; the second gas turbine generator, with speed governor automatically switched from droop to frequency control mode, remains in operation supplying the services of the plant.

TRANSIENT PERFORMANCE STUDY AND PROTECTIVE RELAY CO-ORDINATION

Due to the large size of generators (3x70MVA) and the specific characteristics of 132kV network, the setting of the existing protections required the analysis of power plant transient performance. Therefore, a stability study was performed with the following main goals:

– calculate critical clearing times for three-phase faults on 132kV network, in order to state the maximum fault clearing times consistent with generator stability;
– analyse transient trend of impedance and frequency necessary to set protective relays, in order to prevent false tripping of line distance relays on power swings and ensure selectivity between plant and network protections;
– verify the capability of the plant to switchover to island operation.

The software used for the study was "Cymestab" by CYME Inc.; generators with their governors and excitation systems, large induction motors of the plant, and the 132kV network around the plant were suitably modelled. Equivalent models of 380kV network and relevant generating plants were taken into account.

Several disturbances, of different type and location, were simulated, i.e.:

– three-phase faults at different points of incoming lines to station C, followed by fault clearing and faulted line disconnection;
– switch-over to island operation supplying a small part of the 132 kV network, as a result of sudden grid mesh breaking.

The analysis took into account the operation with the generators over and under-excited (corresponding respectively to daily and nightly operation), as well as normal and emergency network configurations (i.e. both the incoming lines in operation and one out of service for maintenance).

Due to the different source impedance values of stations A and F (about 5Ω and 20Ω), the loss of the AC line is the most critical case from a stability point of view: the equivalent transfer impedance of the plant increases and sustained power swing are to be expected in the post-fault period. Figure 3 represents the trend versus time of gas and steam turbine generators "torque rotor angle" (referred to the network equivalent generator) in case of three-phase fault at station A. Since no specific busbar protections exist, the fault is cleared by the AC line second zone distance relay installed in station C. Torque rotor angle oscillation amplitude is strictly dependent on fault clearing time and on generator load and excitation conditions. The resulting critical clearing times of generators are 0.35 – 0.4s (over-excited) and 0.25-0.3s (under-excited).

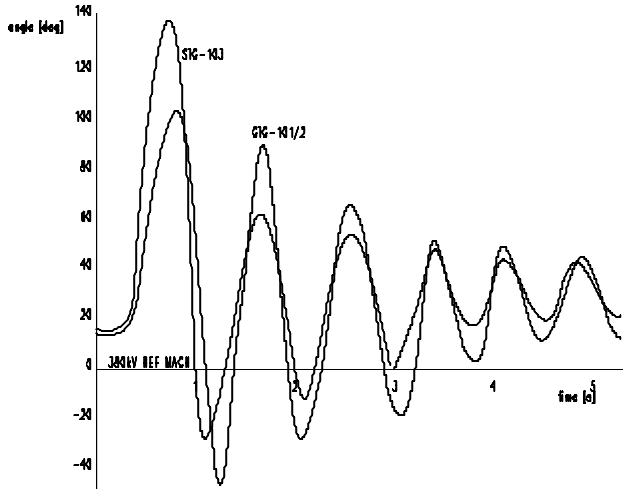

FIGURE 3. Generators torque rotor angle versus time (critical clearing time:0.35s).

PROTECTION SETTING

Distance relay setting

The impedance *locus* as seen by different protections was plotted in the X/R diagram to facilitate relay settings. Figure 4 shows the impedance loci seen by BF line protection installed in station B, in case of three-phase fault in station A cleared in 0.35s (refer to the transient of Figure 3).

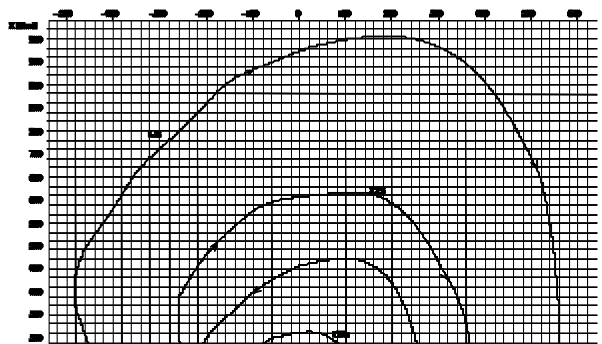

FIGURE 4. Station B (line BF) distance relay R,X diagram.

Figure 5 represents a zoom of the same *locus* and the quadrilateral operating characteristic of the protective relay in station B (first zone only). As during generator power swings the impedance *locus* enters the relay's existing operating area, it was necessary to reduce the resistive reach below 50Ω (previous setting) with a proper margin.

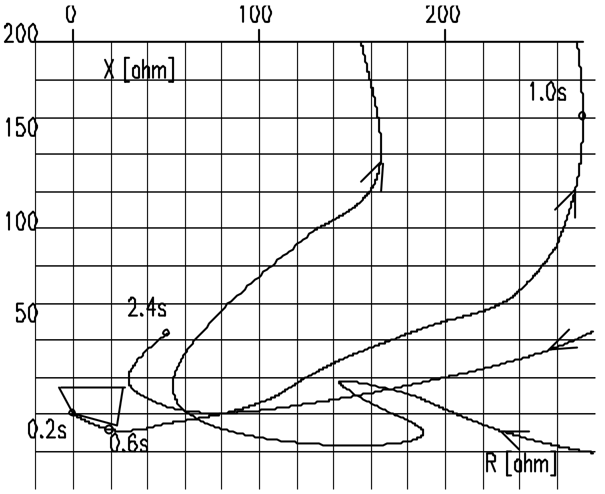

FIGURE 5. Station B (line BF) distance relay R,X diagram: a zoom around the zero.

Frequency relay setting

The power plant is requested to operate on restricted parts of the 132kV network to ensure supply continuity to the users in case of sudden mesh breaking. For the power plant, this situation corresponds to sudden load reductions, up to full load rejection in case of very small residual loads.

The transient performance study of the plant pointed out that in case of sudden load reduction greater that 75% of base load, motoring of gas turbines was to be expected as a consequence of different load sharing among the three generators, different inertia constant of the machines and different time-response of speed governors: gas turbine generators start to operate as synchronous motors fed by the steam turbine generator. This operating condition conflicts not only with turbine safe operation (the anti-motoring relay trips the machine), but also with process requirements (in combined cycle steam is obtained from recovery boilers fed by gas turbine exhausts).

Considered that it is not possible to detect the mesh breaking point *a priori*, the 132kV busbar over-frequency relay was set to prevent the above harmful situations in case of operation on very restricted network islands.

Several frequency trends versus time, corresponding to sudden switch-over of the plant to different restricted parts of the network, were analysed. The setting of over-frequency relay (f>=50.5Hz, df/dt=1.5Hz/s, t_R=0.2s) was stated on the basis of the results shown in Table 3.

TABLE 3 - Frequency trend for different load reduction.

DISTURBANCE	TIME TO REACH 50.5Hz	MAX FREQ. AND AVERAGE df/dt
100% (*) load reduction	0.17s	51.6Hz 3Hz/s
75% load reduction	0.17s	51.6Hz 2.2Hz/s
50% load reduction	0.5s	51.2Hz 1.2Hz/s

(*) With HV.E-Q52 tripping and consequent island sequence starting.

Whenever a sudden load reduction greater than 50% of plant base load is experienced, the HV.E-Q52 circuit breaker trips, thus starting the island automatic sequence that disconnects the steam turbine and one gas turbine and prevents gas turbine motoring (Figure 6).

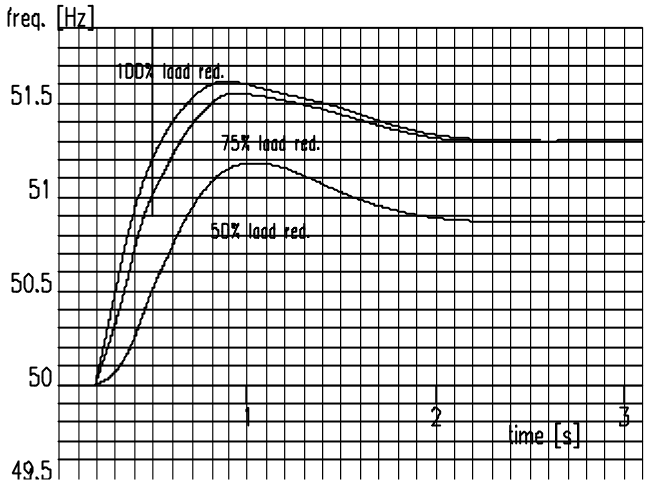

FIGURE 6. Plant frequency versus time (100%, 75%, 50% load reductions).

CONCLUSION

The problem of power swings as a consequence of transient performance of generators after fault removal is well known and easily faced if previously taken into account in the planning stage of a transmission network where large power plant are likely to be connected.

On the contrary, this may result a problem when power swings occur as a consequence of the connection of a power plant on a network planned to operate only supplying loads. False tripping of line distance relays is to be expected with the consequent risk of network separation in unexpected points, thus increasing the risk of network blackout.

The paper illustrated the benefits obtained from a stability study in the setting of line distance relays previously installed on a 132kV network, where a new power plant, 140MW, was set up.

The simulation of several disturbances allowed the setting of the existing distance relays without adding any power-swing blocking function.

The plant has been in operation for two years: few disturbances on the network have been experienced so far and no unwanted tripping of distance relays occurred.