Proceedings, 7th African Rift Geothermal Conference
Kigali, Rwanda 31st October – 2nd November 2018

Generation While Drilling (GWD) strategy in geothermoelectric project development

Umberto Desideri[a], Franco Donatini[a], Luca Giannecchini[a], Renato Papale[b]

[a] University of Pisa, DESTEC, Largo Lucio Lazzarino, 56122 Pisa, Italy

[b] Steam Srl, via Ponte a Piglieri 8, 56121 Pisa, Italy

e-mail: renato@telodicopapale.it

Keywords

Scaling-up, cost mitigation, generation, drilling, social factors

ABSTRACT

Geothermal Energy has large possibilities and could promote a real economic growth in developing Countries, but it is currently exploited worldwide largely below its potential. The main problem that discourages investments is the high level of expenses in its first developing stages before the project feasibility assessment.

It could be noted that, after the surface and deep exploration phases, (geological and geophysical tests, drilling and well testing of typically 2 or 3 wells), the project cost reaches almost 25% of the total Capital Expenditure, while the risk still remains “moderate”, according to primary Investment Banks on the basis of their funding experience. To mitigate the economic risks linked to the technical uncertainness of the first phases, the Banks have developed several financial and insurance tools classified as “Geothermal Risk Mitigation Facilities” (GRMF). Actually, no tool is available on the market to reduce the “time to market” of the project and the residual costs linked to the “Development” phase (Drilling, Design, Construction, Start-Up), after the “Feasibility” one.

Small “pilot” plants (Well-Head Power Plant – WHPP) recently started to be used in order to mitigate costs and risks of large Geothermal Projects and produce revenues in their very early phase. Anyway, to date no one has experimented the possibility to exploit the geothermal resource from the first explorative wells, in order to produce energy for drilling and construction from a WHPP directly installed on the drilling yard.

«Generation While Drilling» means the possibility to operate the drilling rigs (and all the equipment of the Construction site) in an isolated grid, during the development of the larger Geothermoelectric Power Plant.

Particularly in regions relatively distant from populated areas and without electric grid, the main problem is to have enough energy for the construction phase and GWD could be the solution.

The present theoretical Study faces the technical problems that prevented this possibility to date, mainly due to the electric transient inducted by the Rig on the Grid. The simulation is based on real acquired data and on the characteristics of real generation Units.

It must be highlighted that overpassing these technical problems can be very advantageous for expansion of Geothermal, mainly in Developing Countries. These are the benefits of the GWD strategy:

- The installation of a small wellhead power plant on the platform of the first exploration wells, capable of producing energy in an "early" phase of the project, allows significant savings in terms of lower energy costs for internal consumption during drilling and development phase, and consequently a greater return of investment;
- Having the opportunity to evaluate the characteristics of loops of productive and re-injective wells much longer than usual, time-to-time as they are drilled, allows more accurate well-testing than normally, with an increased technical knowledge of the resource that gives a benefit in the design of the final plant, in terms of better long-time performances of the full project;
- The creation of a distribution network in the vicinity (isolated smart grid) allows to share with the local population the benefits of the project long before the construction of the final large plant; this can have a positive influence on the social acceptability of the investment.

1. Risk analysis of a Geothermal Project and benefits of GWD

As other renewable sources, also geothermal energy requires initial costs to estimate productivity. These are “at risk” investments, which are not guaranteed by confident future revenues.

Compared with other renewable sources, the initial costs required by geothermal energy are very high due to the techniques and the long time needed for the “feasibility”. All these conditions (long times, high costs and risks) heavily penalize the business plan and discourage private investments.

Figure 1 shows the classic curves of costs/risks trend during the geothermal project development timeframe, elaborated by primary investment banks, based on their experience.

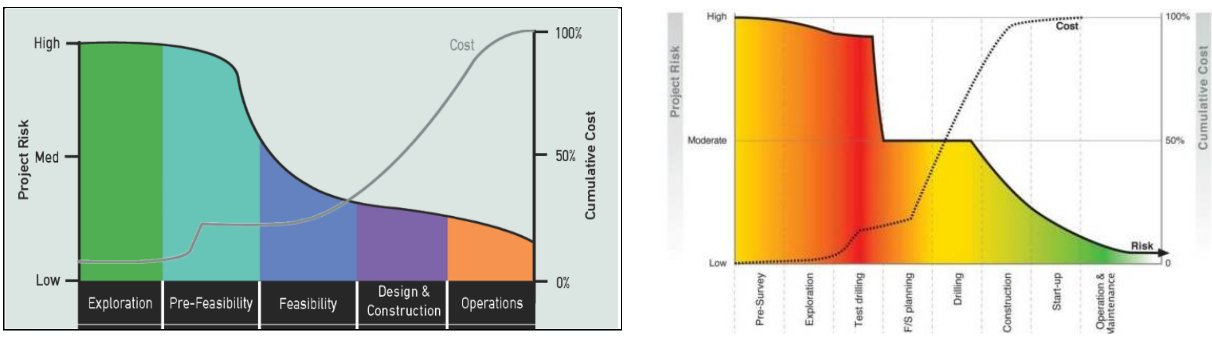

Figure 1: a) Source World Bank (WB), b) Source European Investment Bank (EIB)

The two curves, inevitably approximated, differ however a little. Both show that at the end of the "Deep Exploration" phase (which typically requires drilling and production/injection testing of at least two or three wells), with the achievement of the "Feasibility Study", the costs reach approximately 25% of the total investment, and risks still remain in the "Moderate" range.

For the purpose of the reduction of economic risks associated with the technical uncertainty of these initial phases, the banks have studied several financial and insurance instruments, commonly called "Geothermal Risk Mitigation Facilities" (GRMF). This is a good help, but, on the technical side, no tool is yet available on the market for investors to reduce time, residual risks and costs associated with the "Development" phase (Drilling, Design, Construction, Start-Up) that follows the "Feasibility".

Now, imagine the positive impact on the cost/revenues trend of the investment, if a small generation plant could be installed on the platform of the first exploration wells (so-called: Well-Head Power Plant – WHPP). It could generate energy in an early phase of the project, using the first wells already made during the "Deep Exploration" phase (in case of its positive result) giving early revenues.

WHPP strategy is not a new idea. This strategy begun to be adopted in different contexts, and massively in Kenya, where several new WHPPs have been inaugurated in 2017 (with a total capacity of more than 80 MW), and many other are under construction or in bidding phase, for an approximately additional 60 MW of power. Using this strategy, the electric energy produced during the "Development" phase (i.e. during Plant Construction) induces early revenues and then a reduced value of total financial exposure and consequently a better return of the investment in absolute and temporal terms. This plant family can fill the gap between the end of drilling and installation of the final Power Plant, at the end of the design and bidding process.

However, early-generation revenues by energy sales are possible only if a grid connection is available from the beginning. In case of a Project developed in remote areas, the proposed improvement of the business model still remains applicable if we can make allowance for the lower costs of the internal energy consumption during the "Development" phase. In this phase, the highest consumption is for the wells' drilling, which requires diesel fuel for the generators, and this could have a very relevant cost for the Project, mainly in remote areas.

Unfortunately, there is no experience in power supplying a drilling rig by a geothermal well-head plant, and this for a technical reason: the rapid and unexpected variations in charge, due to drilling activities, generate electrical transient on an isolated grid that a diesel generator can manage, and a small geothermal plant cannot do.

So, it is clear that a good effect for cost and time reduction of a Geothermal Project in remote areas (and consequently the improvement in its rentability) could be reached if it should be possible to suppress the transients that prevent to supply a drilling rig by a WHPP on an isolated grid.

The aim of this paper is to show the result of a study, based on a model fed by real acquired data, on how those transients can be suppressed, and how a small Geothermal WHPP can supply drilling rigs, making it possible to Generate while Drilling (GWD) to create early revenues and an improvement of a Geothermal Project in remote areas.

2. Simulating electrical problems for the supply of a drilling rig on an isolated grid

2.1 Generation side

To produce Electrical Energy from Geothermal, we're used to see two different technologies applied:

- Steam Turbine-Generators, directly using the geothermal steam;
- "Binary" Cycles, in which an intermediate fluid operates in the Turbine (or Expander); because an organic fluid is often used, the system is also known as ORC (Organic Rankine Cycle).

Both technologies (typically used in competition for WHPPs) have been evaluated. 4MW is the capacity of the geothermal unit that has been selected for this study, in case of the supply of two Rigs. In our model, real characteristics of Generator Control Systems have been used, as communicated by two Italian Manufacturers: FRANCO TOSI for the backpressure steam turbine and EXERGY for the ORC technology.

We did not consider another available possibility, that is the combination of the two cycles, named "Hybrid Cycle" or also commercially known as "GCCU" (Geothermal Combined Cycle Unit). This third solution has several advantages as better performances, total reinjection and, if requested, the possibility to have early installation of the backpressure steam turbine (in six months) then followed by the ORC (that requires longer time). Even if the GCCU is not yet widely used for early applications (but will start to be applied in Kenya in the near future), it could become a favorable alternative. Anyway, we think that the results of our study can be easily extended also to that case.

2.2 Load side

To have a clear idea on how fast the electrical charges can vary on the grid due to typical drilling activities, we must consider the heaviest and challenging ones, which are: a) a sudden torque variation during drilling; b) the lifting of the entire drilling rod battery; c) a sudden stop of rotation. Other activities, like mud pumping, normally are not affected by rapid variation of power demand, so aren't a possible source of transients. We've also simulated the possibility of up to two drilling Rigs supplied by the geothermal unit.

For the purpose of this study, in order to create the input for a theoretical model, the above listed three main causes of disturbances have not been estimated but, with the cooperation of the Italian Drilling Company PETREVEN, we used real data. In fact, for the purpose of this study, we had the opportunity to access to the entire data set that has been collected by their RIG, during all the phases of each well drilled in Chile, during the Cerro Pabellón Geothermal Project (one year of data acquisition), by the way, in a very challenging climate condition. For our purpose, we chose and took out the most significant trends from the data set, acquired in the heaviest situations.

From the real data, we created several time-based sequences, mathematically defined by a cubic "spline" interpolation to be imported in, and processed by, a MATLAB-Simulink Model.

The several cases simulate:

a. A Single RIG, during Normal Drilling phase;

b. A Single RIG, during Rods raising;

c. A Single RIG, with a sudden load rejection;

d. Two independent RIGs, Both in Normal Drilling phase, having a sudden stop at the end;

e. Two independent RIGs, Both in Rods raising phase (not synchronized);

f. Two independent RIGs, one in Normal Drilling while the other is raising rods.

Figure 2 shows the time-based curves of the power demand (in kW) for the cases *d*, *e*, and *f*.

Figure 3 shows the Simulink model that has been developed to describe the equipment, including the Generator Control System (of the two different Generation Systems), the Rigs, and the "mitigation system" (transient suppressor) that is discussed later.

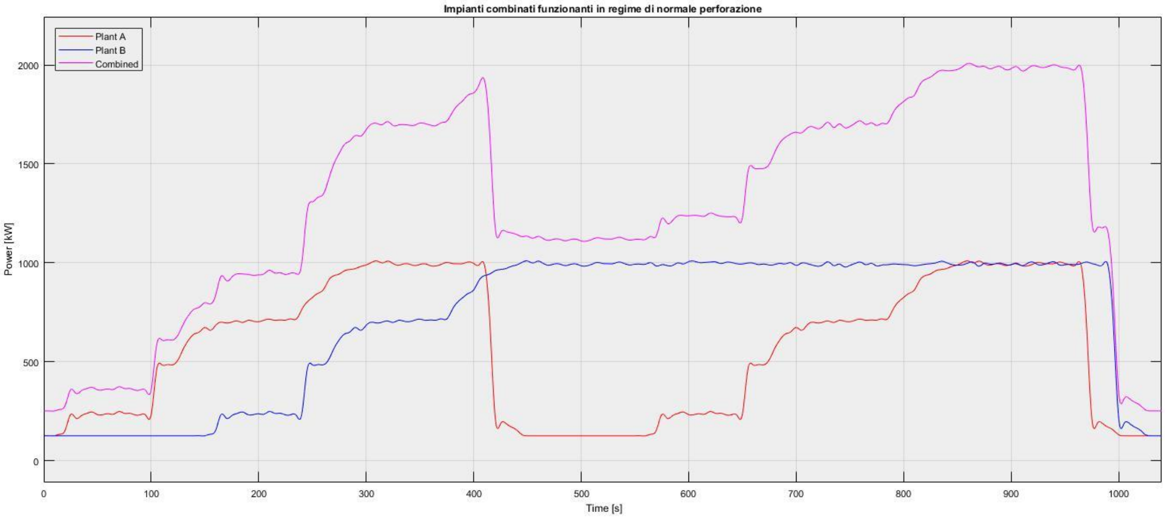

Figure 2, case d: Two independent RIGs, Both in Normal Drilling phase, with a sudden stop at the end

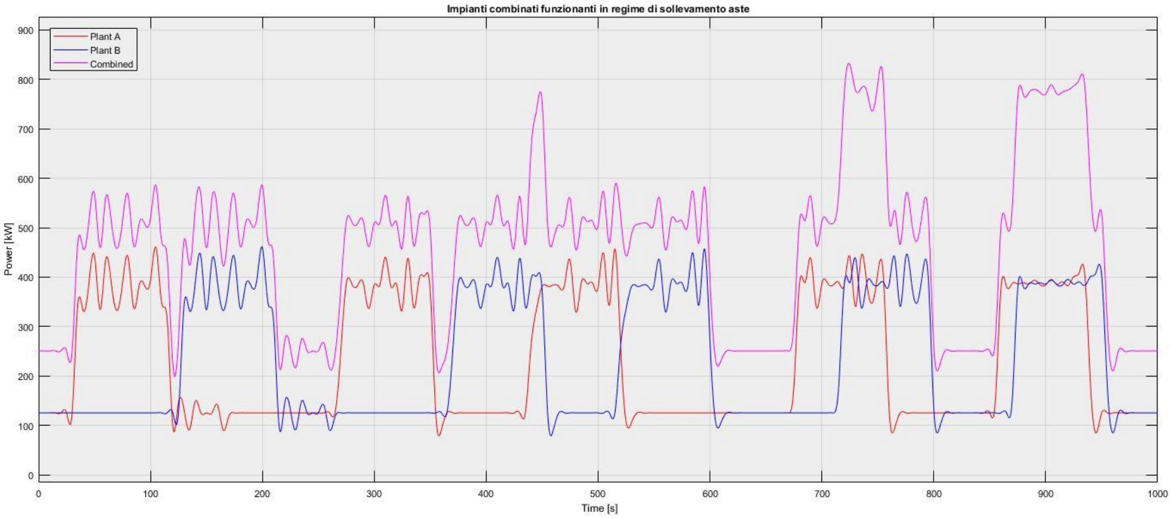

Figure 2, case e: Two independent RIGs, Both in Rods raising phase (not synchronized)

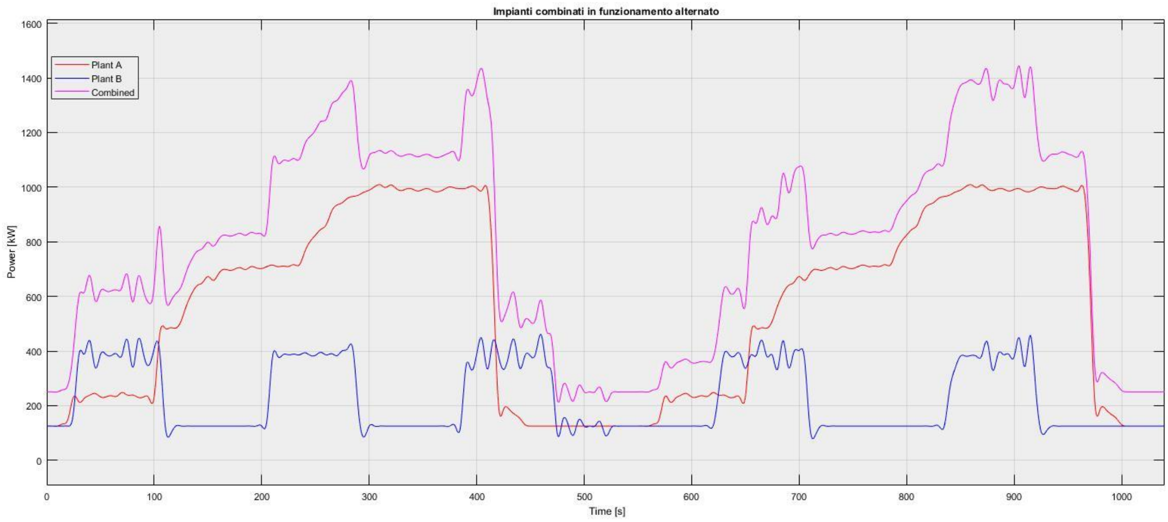

Figure 2, case f: two independent RIGs, one in Normal Drilling while the other is raising rods

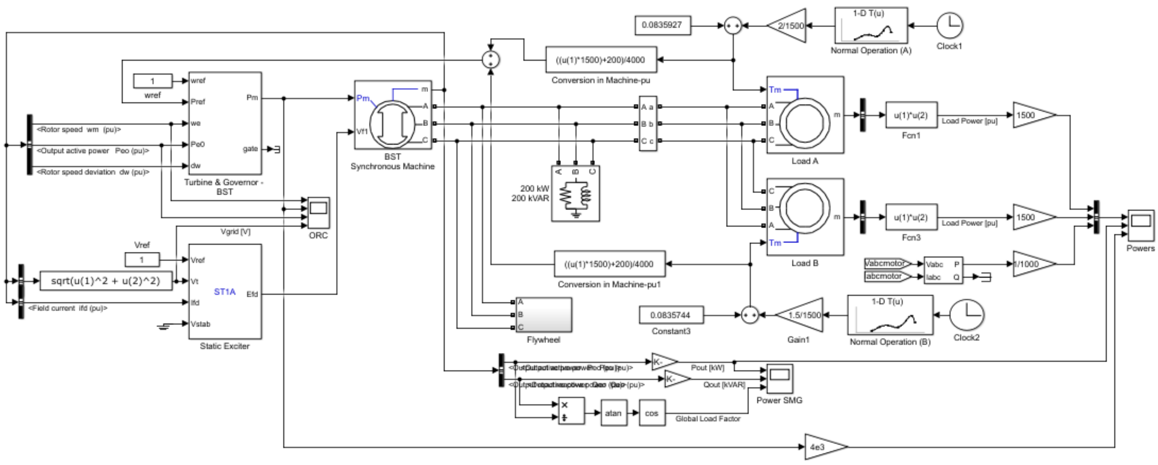

Figure 3: diagram of the Simulink model (backpressure steam turbine case)

The Model has been "tuned" by setting the parameters in order to align its behavior to the one measured in known basic conditions, separately for the Rigs and for the Generators. Then, the two models have been joined in one, and it has been used to investigate the transients that may occur at the given critical working conditions.

Finally, the feasibility of a "mitigation system" based on commercially available components, able to suppress the transient and limit the *V* and *f* variations in the grid, has been evaluated, as discussed later.

With regard to the data set, it must be highlighted that, as the most updated RIGs, that one used in Cerro Pabellón was equipped with hydraulically moved systems. This kind of equipment mechanically acts as a damper for the electric motor; so, what is here discussed cannot be applicable in case of Rigs equipped with directly-coupled electric motors, that we estimate can be affected by more complex transient phenomena.

3. Solving electrical problems on the isolated grid

The Model confirmed that in several of the cases we have studied, the Generator Control Systems of the Geothermal Units are not able to support the load variations, and so Voltage (*V*) and Frequency (*f*) variations on the grid could exceed the limit of ±5%. They can cause unexpected generator stops, even during normal operation, with interruption of the power supply to the Rigs with high risks for all the equipment, and consequently economic losses.

This behavior affects both the generator types, even if the ORC seems to be more flexible (probably due to the smaller rotating mass). A smarter control of bypass steam valves can increase the performances of the backpressure turbine, but we did not investigate.

The remediation adopted is based on an “energy storage” system (ESS) connected in parallel on the grid. We simulated to have it close to the Rigs (or, better, two halves of it, one on each well pad).

A previous study on a similar problem, solved for a lifting crane on isolated grid in the Livorno (Italy) Harbor, a super-capacitor set (with inverters) has been chosen as EES. For the present case, due to the size, the cost and other practical difficulties of the utilization of such a system in remote areas, we prefer to study a different ESS, this one based on a mechanical principle: it consists of spinning masses that accumulate kinetic energy at high speeds. The equipment is confined in a vacuum enclosure, rotates on magnetic bearings, is connected to an electrical apparatus and is available in several sizes, with the commercial name of "Flywheel Energy Storage System" (FESS).

According to the effective loads and imposing the condition that V and f cannot vary over ±3.5%, the optimal size of the FESS has been calculated and its characteristics have been simulated and inserted into the Model.

In *figure 4* are shown the time-based curves of the Frequency variations (relative; it means 1 = 100% of the nominal Frequency), the mechanical power on turbine shaft and the electric power on the grid (limited to the described loads) for the cases *d, e,* and *f.*

It could be seen that with a 1000 kW FESS, Frequency variations are limited to ±3.5%, and the Power variations are smoothed, with no peaks or spikes, so the load variations have been made compatible with the flexibility of the given characteristics of both the Generator Control Systems (in the figure, backpressure steam turbine case is plotted, but ORC case is similar, a little bit more stable) and transient suppressed.

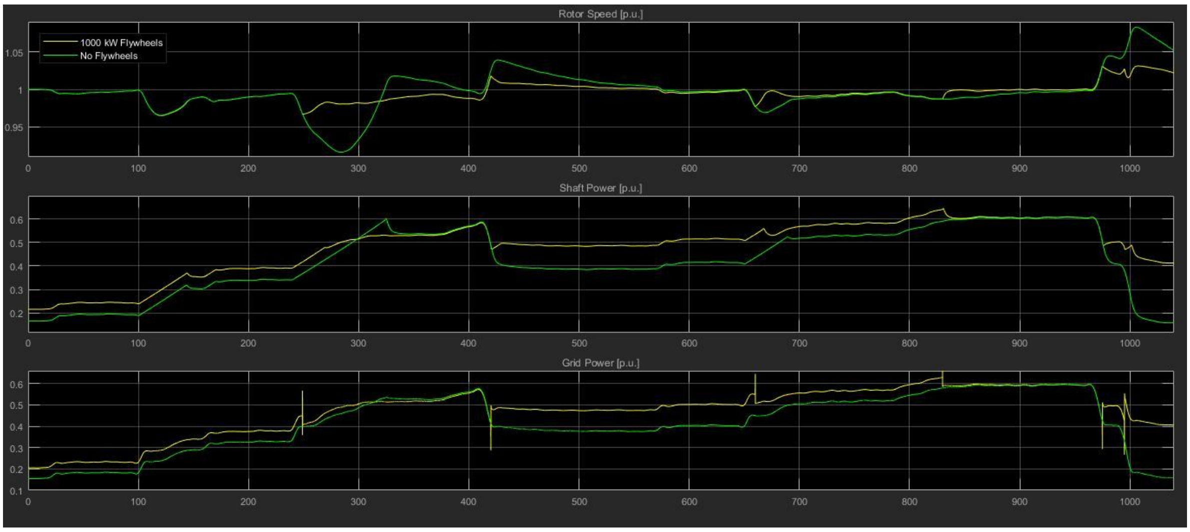

Figure 4, case d: Two independent RIGs, Both in Normal Drilling phase, with a sudden stop at the end

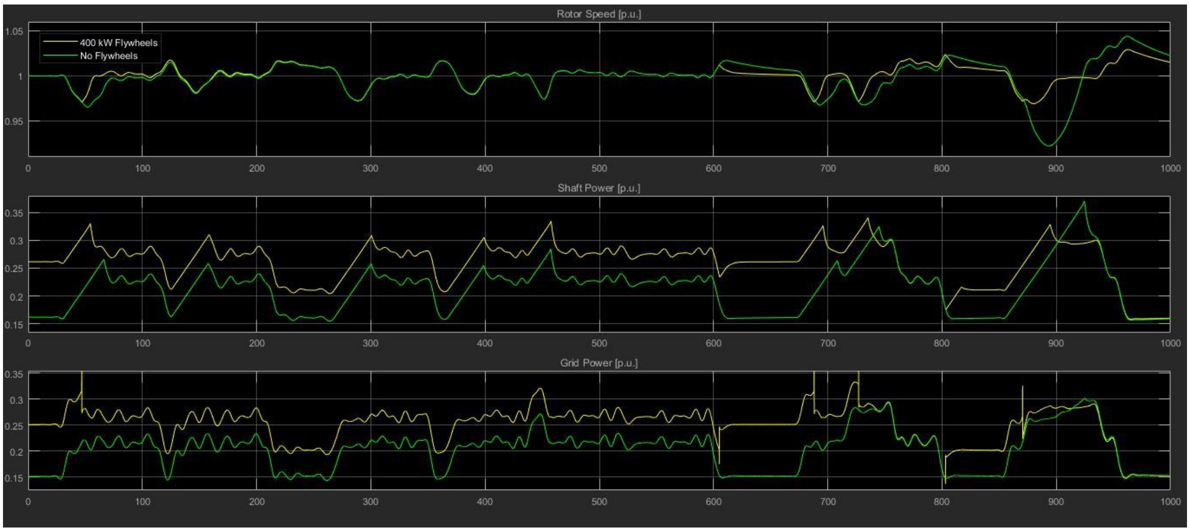

Figure 4, case e: Two independent RIGs, Both in Rods raising phase

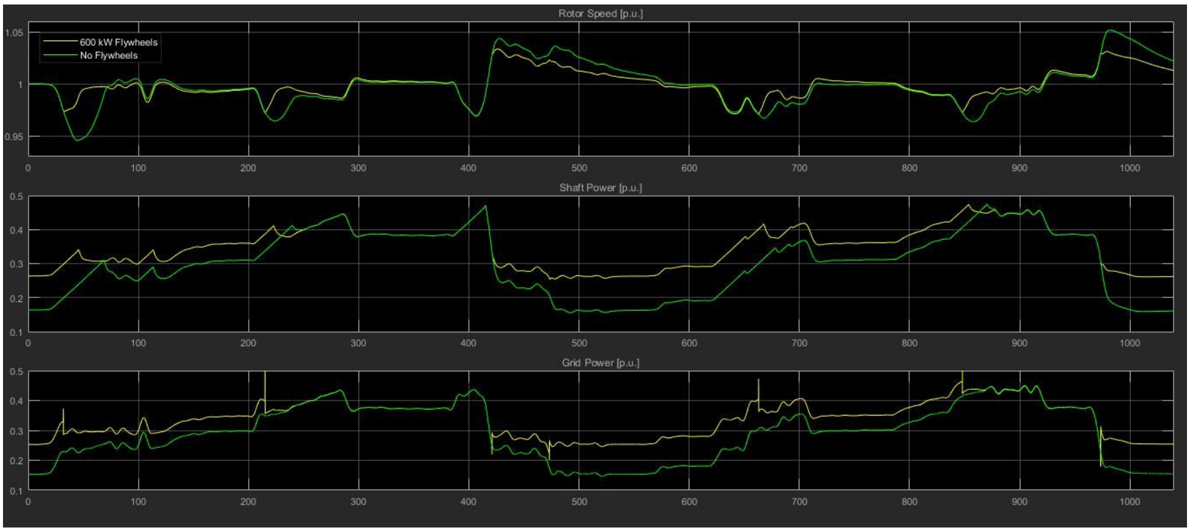

Figure 4, case f: Two independent RIGs, one in Normal Drilling while the other is raising rods

4. Economic evaluation and Conclusions

In this paper, for concision, many details of the Model have been omitted, besides some other technical information, i.e. the unique design of a well pad that makes possible the steam production from a well while drilling another one that could be in the same "cellar", 6 meters far from. Anyway, we are confident to have demonstrated that there are technical ways to make the GWD method feasible.

Let's now discuss a little about the economic aspects of the technique. Noticeably, the sooner is the WHPP installation, the greater is the economic benefit for the investment. For a complete analysis, it must be also evaluated the impact of the cost of the WHPP (and the FESS) on the Business Plan of the whole Geothermal Project. Using the cost information received from the Manufacturer and their evaluation for installation costs and time in remote areas, the Return Of Investment (ROI) time can vary between one year for the steam turbine, and less of two years, for the ORC.

These figures have been evaluated comparing the operative cost of diesel fuel consumption for the generators normally used with the Rigs, referring to the situation of Cerro Pabellón, at 4560m a.s.l., in the Andean Region. Obviously, this cost depends on the resources of the

Country and on how “remote” is the remote area; so, economic evaluations must be made case by case.

Anyway, an additional remark must be added. To evaluate the investment profitability of a geothermal project, it would make a large difference in case the WHPP is part of the investment (acquired by the owner, even if used for only three years during Development) or if it could be “moved” to other Projects when the large final Plant is commissioned, and so the cost is “shared” along its lifecycle by several projects.

So, we think that one more step to help the introduction of GWD method could come from the Investment Banks (in cooperation with Manufacturers) in case they can create a Financial Product for the access to leasing contracts for WHPP early installation. For example, a Contract for leasing included operation and maintenance, that after three years can be renovated for other three after overhaul or resolved with restitution of the equipment (to be used for other Project by different Employers) or, last alternative, concluded with its purchase.

In conclusion, we want to stress that GWD model has additional benefits for the development of a geothermal project than the financial ones:

- First of all, WHPP installation needs building and practice of a loop between productive and reinjection wells, with the possibility of evaluating the characteristic of wells for a longer period than the ones usually adopted for well-testing. In particular, if the WHPP is designed to guarantee high flexibility and adaptability to different conditions of pressure and admission rate, its operation (from time to time on the wells progressively drilled) allows to collect producibility and reinjection data much more accurately than compared to what is usually done. It originates a greater technical knowledge that can be used for a better design of the final plant, with a direct benefit on its expected performances.
- In addition, the creation of a power distribution network supplied by the WHPP allows sharing its benefits with the inhabitants of the surrounding area long time before the construction phase with the greater environmental and visual impact begins. This fact should positively influence the social acceptability of the overall geothermal investment by the land, which, as is often the case in remote but not unpopulated areas, has no previous industrial inclination.

This study has been conducted using the services of University of Pisa, Dept. DESTEC. The Authors want to thank the colleagues and students who cooperated to its progress.

A special thanks to the Companies PETREVEN, FRANCO TOSI and EXERGY and to their staff, who supplied the factual data for the Model and helped during its “tuning” phase.