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GEOCLAD: A Software Platform for the Multiphase Analysis and Design of Geothermal Power Systems

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ABSTRACT

Most fluid dynamics models currently used on geothermal networks are applied in a mono-component version. The strong difference in temperature, pressure and chemical composition of geothermal fluids flowing from a geothermal reservoir to the surface equipment requires detailed models. The latter can improve economic benefits and reduce environmental impact. A predictive capability of the multiphase flow behaviour on wells, pipes and other components requires complex analysis to help the design process and the management of plant operations. GEOCLAD (GEOthermal power system cLoud computing Aided Design) is a new software tool under development for the design and management of geothermal powerplants. The numerical code simulating the multiphase dynamics can control and predict the performance of the process and the specifications of the geothermal plant. The code has been validated on both data available in the literature and real-world test cases. The back-end of the platform is based on a cloud computing concept, and it enables users to manage input data, simulation process, and results from any remote device, through a web user interface. It allows us to carry out both design activities and monitoring the geothermal plant's production, also optimising different operational solutions.

1. INTRODUCTION

Research carried out by U.S EIA demonstrated the quite high cost of geothermal operation, higher than nuclear plants (141 $/kW/y), and Sanyal (2004) showed how the most viable way to reduce geothermal energy costs is to reduce the operational costs. This high operational cost is also due to the large amount of work on analyzing a plant with conventional approaches based on several specific tools, valid only for a single component, to be coupled and integrated by hand by engineers. Since these costs include plant management, HSE analysis and optimization of performances, geothermal plant requires tools to reduce the effort on these activities, as already adopted by the oil & gas and nuclear industries (https://www.relap.com/, https://www.software.slb.com/products/olga), by integrating engineering design and plant compliance with safety and environmental impact regulations.

An efficient and robust design tool to exploit geothermal resources, ensuring engineering solutions which are consistent with both economic and environmental and safety constraints is required, but still unavailable (see for instance the Software Market Report from Reportlinker). This need is demonstrated by the tentative use of tools originated in other fields (oil & gas, nuclear) in the geothermal field, with unsatisfactory results (Verma, 2013). This lack of technology is also impacting the develop the new "zero emissions" geothermal plants (in Italy, for instance). Conversely, the positive impact of the Industry 4.0 paradigm to geothermal industry (namely industrial automation and digital integration of working conditions) leads to an increase in productivity and product quality in the geothermal plant (Huanga et al., 2017).

This picture reveals a series of challenges and related market opportunities (ETIP-DG, 2018): in this framework, the GEOCLAD (GEOthermal power system cLoud computing Aided Design) project has been proposed for cofunding by companies TEA SISTEMI and COTESA, in 2018, and granted by the EUEKA-EUROSTARS funding programme (EUREKA-EUROSTARS, 2019). The activities started in November 2018, and they follow a 2-year workplan. This paper illustrates the main features of the project, whose main innovation consists of integrating advanced modelling, a cloud infrastructure for data management, and an interface from a WEB GIS application. GEOCLAD will be suitable for design purposes (for engineers), for planning activities (managers) and information actions (decision-makers), sharing of input data, hypotheses and methodologies. The ultimate purpose of the software is to obtain results in line with economic resources and with the legislative requirements concerning the environment and health. This goal can be smoothly achieved thanks to the coupling of design with management activities (Fig. 1). This is the innovative approach of GEOCLAD, reached through the following key features:

- Tailored: it is specifically designed for power plants and urban districts geothermal energy development.
- Integrated: the product integrate a design engineering tool, a system operational optimization tool and a management tool.
- Predictive: the network/geothermal plant behavior is predicted along the time;
- Reliable, being based on well-known technologies, and made by a consortium with demonstrated high level of knowhow on required project fields;

- Simple: a single application for design, prediction and information allowing both engineers, operators and external consultants to use the same platform with same data, previous results and all the optimizations performed through the design phase, minimizing implementation or analysis errors and increase design accuracy.

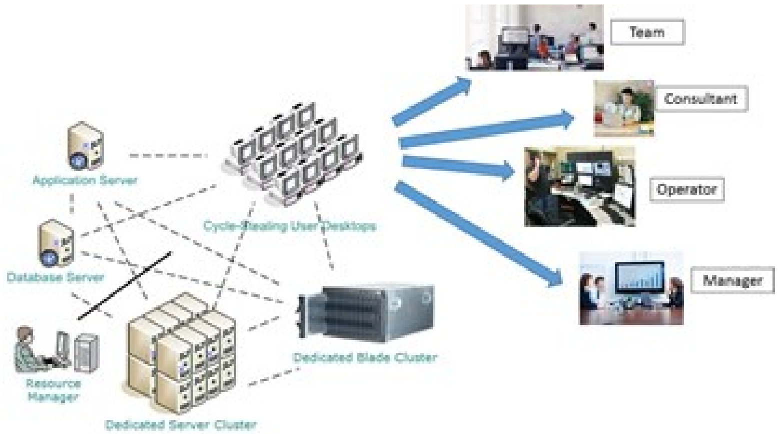

Figure 1. Schematic of a GEOCLAD-aided working model for designing and planning stages.

The modelling pillar underpinning this integrated design tool is the flow simulator MAST (Multiphase Flow Analysis and Simulation of Transitions), developed since 2005 by TEA SISTEMI, validated and used by the company to deliver consulting services in the energy field.

In Section 2 the modelling activities already applied to achieve the project goals are described, as well as the design of the software architecture implemented to start the development of backend, middleware and frontend of GEOCLAD tool. In the last section, the current and future activities are presented, to show the workflow and objectives of the second half of the project.

2. METHODS AND MATERIALS

2.1 MAST Code

The flow of a multiphase stream is a complex phenomenon and applies to process components and to transport systems as well, with several order of magnitude difference in scale. Over the years, many studies have been conducted on modelling mass and heat flow during fluid transport from the reservoir to surface, considering both one-dimensional and multidimensional approaches. Some of them are developed only in stationary conditions, others are parallelized computational models. The latter have an appropriate computational capability but are designed for fields not applicable to geothermal power exploitation. On the other hand, there are models for the analysis of multiphase systems in different areas, which are however designed mainly for the analysis of processes typical of power generation plants, with low degree of applicability to the development of a geothermal field.

From a modelling point of view, the objective of GEOCLAD project is to cover this lack by applying a customized version of the numerical code MAST - Multiphase Flow Analysis and Simulation of Transitions, developed since 2005 by TEA SISTEMI SpA (Bonizzi et al., 2009). MAST is a transient one-dimensional multiphase flow simulator, which is based on dynamic pattern recognition capabilities, whereby the prediction of the relevant flow regimes which generate along the line is automatically captured, provided that fine enough computational grids are utilized (of the order of some pipe diameters). All relevant flow patterns are described, namely the stratified, annular-dispersed, slug and bubbly flows. The mathematical modeling is based on a multi-field approach, whereby separate transport (i.e. conservation) equations are written for each relevant field (i.e. continuous and dispersed); from a numerical view point, MAST adopts a first-order upwind scheme for the discretization of the convective (i.e. spatial) terms, and a fully explicit scheme for the integration of the terms over time. The only equation which is semi-implicitly solved is the pressure equation, which is derived from a pressure-velocity coupling algorithm. A remarkable feature of the simulator is that the user has the possibility to select, from an internal library, some constitutive (i.e. closure) laws, such as the equations used for the calculation of the friction factors. The relevant simulation capabilities of the software can be summarized as below:

1. Simulation of 2(gas-liquid)/3(gas-oil-water)/4(gas-oil-water-dense fluid/foam) phase flows.
2. Simulation of multiphase flows with:
    a. prescribed bulk properties;
    b. single and multi-component fluids Operational modules: pigging, multi-pigging, foam-pig modules are available;
    c. simulation of steady and transient conditions;
    d. process equipment: valves, check valves, PID/manual/emergency/pressure safety valve/ controllers, flow mixer, multiphase, ESP pumps, simplified centrifugal pumps, booster pump, gravitational horizontal gas-oil-water separator;
    e. network module for three-phase and four-phase flow systems; which allows solving for both distributing (i.e. diverging) and gathering (i.e. converging) systems.

During GEOCLAD project, MAST has been modified to be applied on scenarios typical of geothermal plants and networks. In particular, the main modification concerned the identification of the phase transitions of the component. As a matter of fact, the main difference between a mono-component fluid and a multicomponent fluid is that in the first case the phase transition occurs, for each given temperature, to one and only one pressure value. Hence, from a thermodynamic point of view, while in the multicomponent case the sole fluid PT (pressure-temperature) diagram is sufficient to determine the gas phase volume fraction, in the single-component case the PT diagram can be used only to identify the limit between the possible liquid states sub-cooled, superheated steam, or saturation condition, but it is not a sufficient condition to determine the title of the phase. Therefore, in the single-component version of the model, the PH (pressure-enthalpy) plane is used in order to characterize not only the specific thermodynamic state under which the fluid is located, but (in case of saturated water), to quantify the volume fraction of vapor at a given instant. This aspect is crucial for the resolution of the model, since the instant knowledge of the vapor content is of fundamental importance for the calculation of the evaporation/condensation rates, which in turn represents a well/source term in the equations describing the mass balance. During the project activity this modification has been tested and validated using synthetic cases, selected ad hoc to verify the effectiveness and efficiency of the code.

Since 2017 TEA SISTEMI has developed an API (Application Programming Interface), named *PyMast*, written in Python language (Python 2019) to manage MAST simulations. PyMast is able to create input files for MAST code, run simulations and manage the post-processing of results in terms of plots and additional calculations (Fig. 2 and 3). PyMast will be used in the development of GEOCLAD backend, to link MAST code to the other part of the software system, as describe in Section 2.2.

Figure 2. An example of using PyMast to get plots of pressure and temperature profile along a pipeline (at a given time).

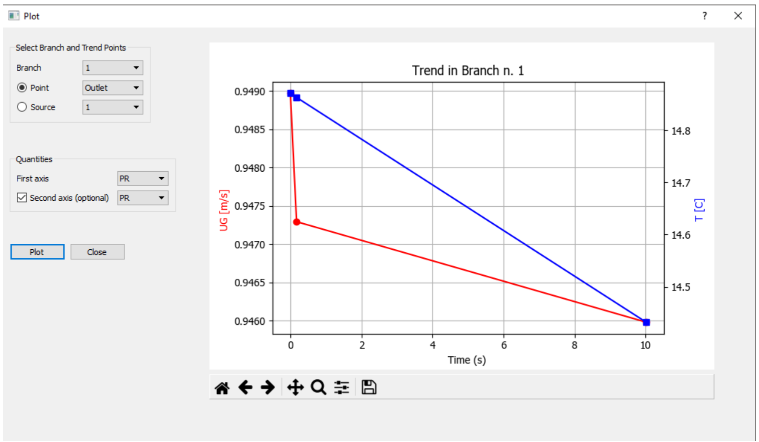

Figure 3. An example of using PyMast to get plots of gas velocity and temperature trends vs time (at a fixed position).

2.2 Design of GEOCLAD software architecture.

MAST is already a working component that performs most of the functionalities envisaged for the final software tool. The code will be automated in a distributed and parallel framework. To address this issue, the parallel version of MAST (implemented using the APIs of OpenMP) will be applied. Since MAST uses only one machine per job, the model will be distributed as unique processes, using several CPUs. The GEOCLAD backend will implement the business model needed to support the foreseen operations and the User interface, according to the diagram depicted in Fig. 4. The backend will provide the outputs in a way that can be rendered fast in the user interface (i.e. to get a responsive interface). The aforementioned API PyMast will be exploited to read and write MAST-compliant text files, to manage both input and output data.

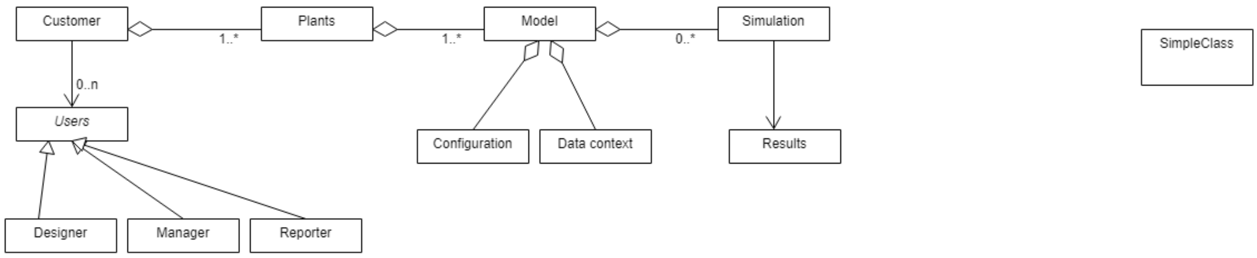

Figure 4. A schematic of GEOCLAD backend.

GEOCLAD Web User Interface (WUI) should support two main levels of abstraction of a model. This approach follows the natural way of designing and monitoring a geothermal plant, namely:

a) CAD-style: commonly used in the initial design phase and in tracking tasks. Georeferencing is not important for this stage, while the logical links between components and parametrization will be addressed and managed. The different parts of the plant will be selected from a library of predefined components (pipes, sources, valves, pumps, controllers, functional blocks, etc.).
b) GIS-style: used to deploy the system on the field. This part will be used to define real-world dimensions (lengths and depths) of spatial components.

This interface will act as a client of the backend to be used as pre- and post-processor for simulations executed through the GEOCLAD backend. The workflow to fully define a simulation is the object of the SimulationContext, structured as the integration of: (i) pre-processor, defined as a combination of input data and simulation parameters; (ii) manager of simulation jobs, which makes use of input data and a set of metadata about scheduling, priority, authoring, ownership, notification, conditions, etc.; (iii) post-processor, managing material produced by the simulation job and attached to the original simulation context. These results are stored by the backend until some maintenance and cleanup order is given.

The WUI will be designed to be user-oriented, in a modular way, e.g. setting different capabilities according to the level of User's privileges, and/or according to the level of accuracy the User wants to achieve.

Further to be used as pre- and post-processor for MAST simulations, the GEOCLAD WUI will allow comparing different scenarios with dashboards. The comparison will be made by graphing trends (i.e. variable(s) vs time) or profiles (variable(s) vs length) of different simulation results. This user interface will be carefully designed to limit the objectives and to allow an easy application.

3. CONCLUSIONS

Currently (June 2019), GEOCLAD project has achieved the main milestones expected for the first nine months of project activities, namely the modification of MAST code, its testing and the design of the software architecture. The project timeline (ending in October 2020) foresees the complete development of the software tools and a deep testing phase. The latter will be made on real-world geothermal projects, taking the advantage of involving project stakeholders, mainly consulting companies in the energy sector, in Italy and abroad. This project task will ensure a good feasibility of using GEOCLAD as effective tool in geothermal plant design and management.

ACKNOWLEDGEMENTS

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