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Towards a geothermal reservoir management system

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ABSTRACT

To exploit the deep geothermal resource in a sustainable way, Stadtwerke München (SWM), Innovative Energie für Pullach (IEP) and the Karlsruhe Institute of Technology (KIT) are designing a reservoir management system in the frame of the INSIDE project[1]. This system should indicate when and what operational parameters need to be adapted to mitigate risks of induced seismicity or ground deformation.

The reservoir management system consists of three main components that are linked and mutually interact: the database, the processing centre and the dashboard. The database contains monitoring observations taken in the field, associated results and numerical reservoir modelling projections. The processing centre digests this information or generate new one in order to feed the dashboard. This latter indicates, from selected key indicators, whether the exploitation is currently sustainable, otherwise it will automatically send an alert and propose alternative production scenario to be reviewed by the board of decision.

To assess the relevancy and practicality of the proposed concept, a prototype based on the partners' infrastructure, data and experience is developed and presented. It is hosted by the SWM cloud infrastructure, which can handle the big data amounts generated by the different monitoring devices used in the frame of the INSIDE project. Additionally, the cloud infrastructure offers its own processing capabilities, whose results can further feed the database and the dashboard. Parts of the prototype have been implemented technically; others will be tested with the help of a dummy dataset before integration of real data.

1. INTRODUCTION

Deep geothermal energy has been successfully harnessed in the greater Munich area (Germany) since the late 1990s (Dorsch & Pletl, 2012). Further and larger developments to exploit this resource is planned for supplying the city of Munich with CO2-neutral district heating by 2040. This goal requires careful management of each existing and future geothermal plant for long-term, efficient and sustainable exploitation of the underground resource in the Malm reservoir. One of its aspects concerns the mitigation of risks associated with the heat extraction and, in particular, the possible induced seismicity and ground deformation.

It is well-known that the development and exploitation of deep geothermal fields can induce seismicity (Zang et al., 2014) or ground deformation (Heimlich et al., 2015). Regarding induced seismicity, this is particularly true for enhanced geothermal systems (EGS), but also for hydrothermal systems, such as that exploited in Unterhaching and Poing, both in the suburb of Munich (Megies & Wassermann, 2014). Hence, such risks have to be minimized. This challenging task necessitates, at least, monitoring these phenomena using seismic and geodetic stations in order to anticipate any unexpected behaviour. Better, it should also integrate forecasts of such risks, which is a very active domain of current research, especially regarding induced seismicity (Gaucher et al., 2015).

Here, however, we are not focusing on the technical aspects of the seismic or deformation monitoring, nor on the approaches to model the reservoir behaviour and forecasting induced seismicity or ground deformation.

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[1] INSIDE abbreviation stands for: "Investigation into induced seismicity and ground deformation as interference aspects during the operation of geothermal plants in the Bavarian Molasse Basin".

We rather propose a concept to combine and use both types of information to help the geothermal field operator to manage the reservoir exploitation while mitigating the current and future associated risk. Such a system can be compared to an adaptive traffic light system to mitigate induced seismicity (Grigoli et al., 2017) that would additionally account for ground deformation and possibly integrate observed or forecasted thermo-hydro-mechanical parameters in the reservoir. Furthermore, if a risk is identified, the system would propose alternative production scenarios that would help the operator to take decisions. Hence, we talk about a reservoir management system (RMS). The main priorities guiding the RMS concept are: the use of geothermal operators' IT infrastructure, the integration of continuous monitoring and numerical modelling data, and the real-time applicability.

In the following, we first present the concept of the RMS. Then, we describe a prototype that is partly implemented and which needs further development and tests to assess the concept.

2. RESERVOIR MANAGEMENT SYSTEM

The objective of the RMS is to optimize the exploitation of the deep geothermal resource, while mitigating the risks of harmful induced seismicity and ground deformation. To do so, it needs to access and communicate with a database, which stores the monitoring observations acquired in the field, the associated results and the numerical reservoir modelling projections. Such an information serves as input for further analyses, whose goal is to extract a finite number of key indicators that may possibly lead to change the geothermal production schedule. This aspect constitutes the dashboard together with the decision centre that is another component of the system. Finally, a third component for the RMS is necessary to exploit all gathered data and to support the decision-making, it is the processing centre. Figure 1 shows schematically the different components of the RMS that are linked and interact together. They are described in more details in the following.

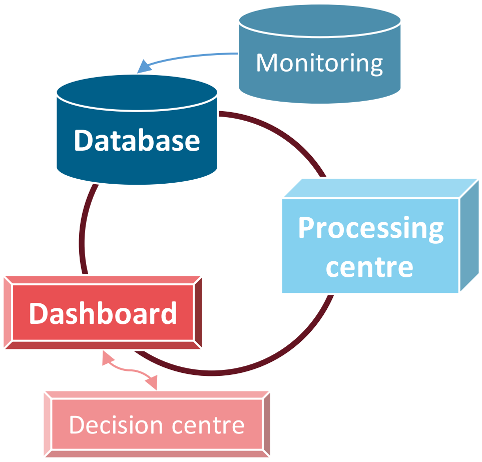

Figure 1: Schematic of the three main components, which constitute the RMS: Database, Processing centre and Dashboard.

2.1. The database

The database (DB) is a key component of the RMS that makes available information useful to the dashboard and the processing centre. Two types of data are stored in it: static data and dynamic data. As indicated by its name, the former type is expected to remain unchanged or being manually changed from time to time only. The latter, on the contrary, can be updated periodically or even continuously, in real-time. Typically, a velocity model to locate induced seismicity, ground-motion prediction equations, the structural geological model and the associated numerical mesh needed for numerical reservoir modelling could be considered as static data. In the dynamic dataset, the continuous seismological and geodetic data acquired by the monitoring devices in the field could be found as well as the geothermal production parameters (pressure, flow rate, temperature) or the forecasts of the numerical reservoir modelling in terms of temperature, pressure, deformation and seismicity.

The DB should be self-sufficient and contain all information that will eventually help, directly or indirectly, the decision makers to adapt the production parameters for sustainable exploitation of the geothermal resource.

2.2. The dashboard and decision centre

The purpose of the dashboard is twofold (Figure 2). First, it simplifies all observations provided by the sensors monitoring the geothermal exploitation and the results of the numerical reservoir modelling, which are stored in the DB. This is performed in the processing centre by a so-called “dashboard module”. Hence, a finite set of indicators that were identified previously as relevant for assessing the proper working order of the exploitation are displayed on the dashboard (left-hand side of Figure 2). The second purpose of the dashboard is to launch a reaction of the plant operator and ease the decision making (with other stakeholders) in case a risky event occurred or is forecasted. One would identify such a risky event from several safety indicators reaching pre-defined thresholds determined manually or automatically. Then, such an alert would be transmitted to the “decision centre” to persons who would later decide how the geothermal exploitation should be adapted to mitigate the foreseen risk, but also would launch a “production scenario module” (right-hand side of Figure 2). In this latter, several production scenarii would be simulated by the processing centre and the results transmitted, via the DB, to a mirror of the dashboard. The range of production scenarii should be determined in advance with the field operator, who can define which parameter could be adapted in practise (e.g. reinjection temperature, production rate, injection well(s), switching doublet…). Hence, it would be possible, like in the dashboard itself, to assess the relevancy of proposed scenarios to mitigate the identified risk. Eventually, the final decision of adapting the production parameters for sustainable geothermal exploitation would be taken by the decision board.

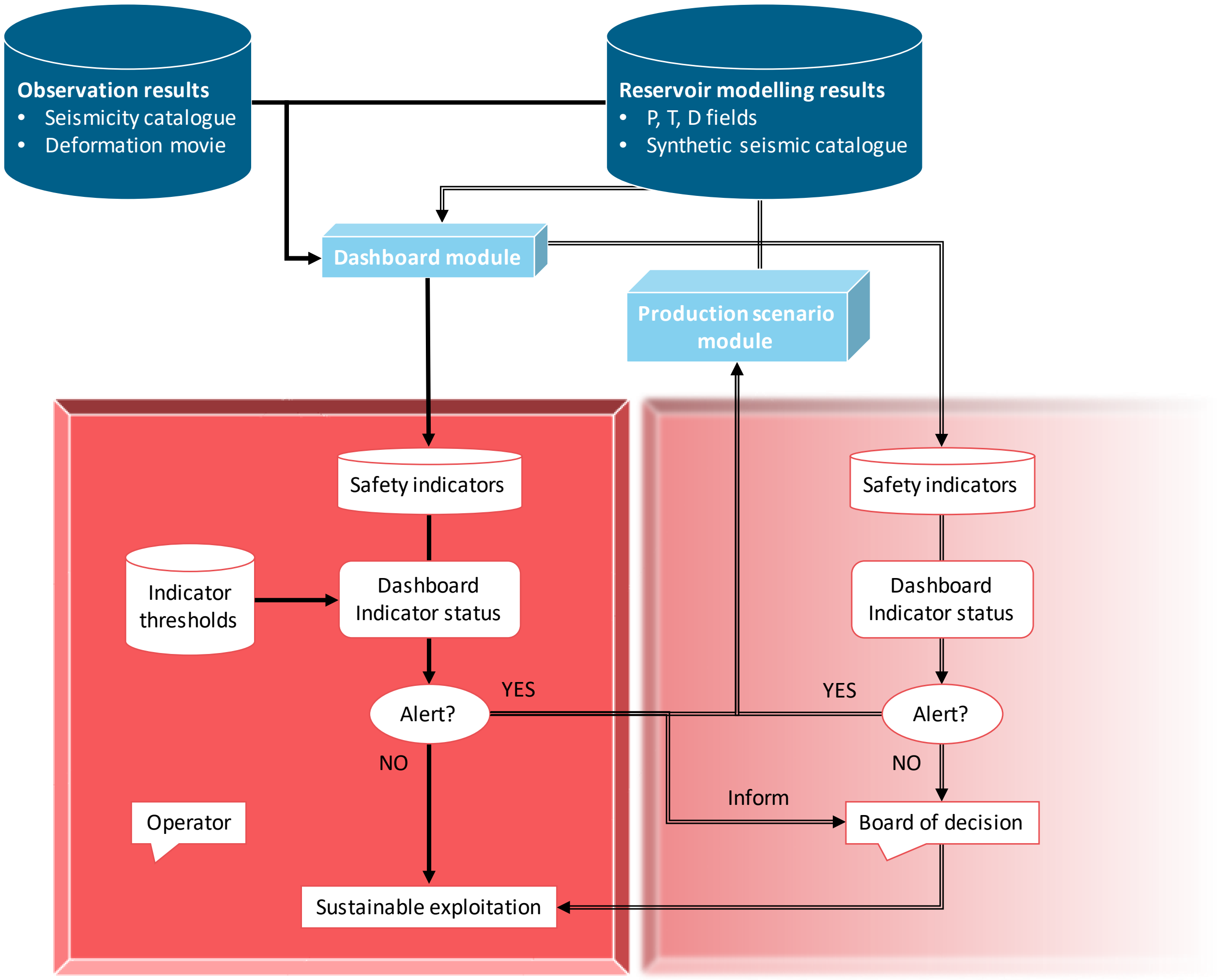

Figure 2: Schematic of the dashboard and decision-centre component of the RMS, which is interacting with the DB and the processing centre.

2.3. The processing centre

In this component, all processing tasks necessary to make the RMS running are performed. Accordingly, it hosts the dashboard module and the production scenario module described above. This can be the place where forecasts of induced seismicity and deformation may be run too. One could also find other modules dedicated to the processing of monitoring data, such as automatic detection, picking and location of induced seismicity on the continuous seismic data stream.

With the intent to forecast induced seismicity for example, the current RMS concept is not restricted to one specific approach but could include and merge several of them: physics-based, statistical-based or hybrid-based forecasts (Gaucher et al., 2015). As long as the results are delivered to the DB in a format later understandable by the dashboard module, this would be suitable.

One could also think the production scenario module as constantly running in order to be prepared prior to any alert rather than being activated only when the alert is given.

In the processing component, the application of open source codes that can be launched by command lines, i.e. without requiring operator manual assistance, is considered. This should increase its capabilities and flexibilities by giving access to many open source libraries easy to deploy and to run on many different types of computing platforms including cloud clusters.

The proposed concept for the RMS is relatively flexible. Indeed, separating the three main components allows independent development of each of them but also asynchronous implementation into the system. Nevertheless, this requires defining strict protocols and rules to exchange the data between the different components, e.g. input or output data types and formats. Eventually, the capabilities of the RMS depend strongly on the implementation of efficient communication bridges between the three components, not solely on the processing centre capacities.

3. PROTOTYPE

Prior to realizing such an RMS, it is decided to first assess the relevancy and practicality of the proposed concept. With partners from academia and from geothermal exploitation industry, the INSIDE project gives the opportunity to develop a prototype close to the reality of the field operations and in accordance with the management of the exploitation. SWM made its infrastructure available to host the prototype. A working environment has been chosen and several modules of the different components have been implemented. IEP will provide field and operational data to further test the RMS concept.

3.1. Technical implementation

The SWM Internet-of-Things (IoT) platform, which hosts the different components and modules developed for the prototype, is built within the Microsoft Azure™ cloud infrastructure. It can handle the big data amount generated by the different monitoring devices of the INSIDE project (GNSS, seismometers, distributed acoustic sensing, well hydraulic parameters, etc.). Figure 3 illustrates the infrastructure that was implemented to store in real-time and to process Distributed Acoustic Sensing (DAS) data acquired along the Th3 well of the Schäftlarnstraße (Sendling) geothermal plant. Indeed, a fibre optic cable (FOC) was cemented from surface to 700 m depth behind the casing of that well and can be connected to a DAS recorder installed in the operating room (left-hand side of Figure 3).

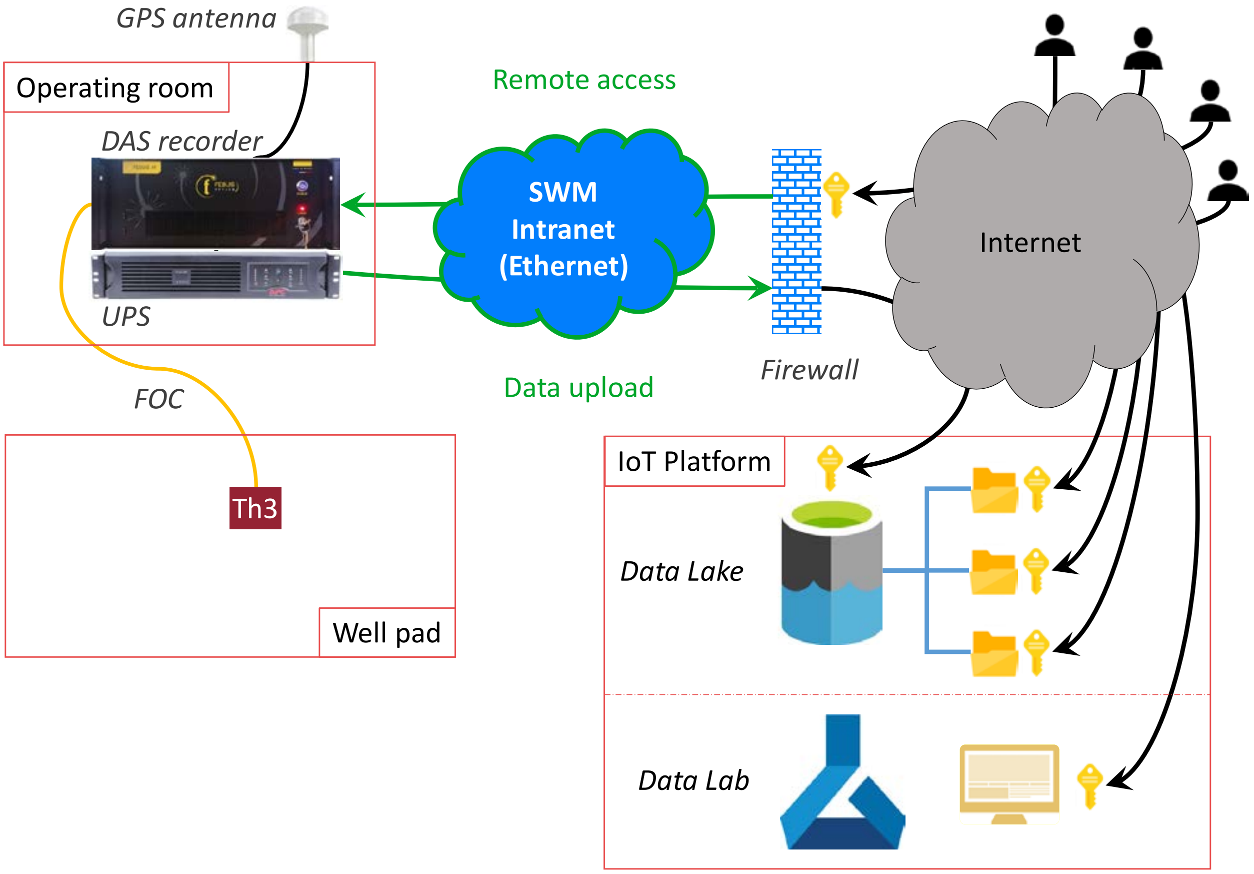

Figure 3: Infrastructure implemented to store and process Distributed Acoustic Sensing data acquired at the Schäftlarnstraße geothermal plant, which is operated by the Stadtwerke München (SWM).

This set-up allows DAS data acquired in the field at a rate of 12 Mbit/s to continuously migrate to a specific part of the DB called “Data Lake”. Such amount of data is not negligible – far larger than what all other devices are generating together – and requires efficient data transfer. Therefore, once generated on the SSD of the DAS recorder, which is connected to the SWM intranet, the data are securely pushed through internet and finally stored and backed-up in the Data Lake, given valid access keys were used. Only permitted users can access this data via the internet.

The platform also provides cloud-computing capabilities on the SWM “Data Lab”, the processing centre (bottom right of Figure 3). Hence, periodic DAS data processing is carried out to identify possible induced seismicity recorded by the FOC cemented in Th3. KIT developed the Python codes, hosted by and run on the Data Lab, to read the data landing in the Data Lake and to apply triggering and event detection methods on the DAS signal. Interestingly, the Data Lab offers computing instances whose capabilities can be adapted to the processing load (e.g. variable number of CPUs). As for the Data Lake, only permitted users can access the Data Lab (right-hand side of Figure 3). Once processed, the original data in the Data Lake are stored on a most appropriate tier, which provides cheaper long-term storage but larger access latency.

The described set-up, which is currently running, confirms that it is feasible to copy data acquired in the field to the DB and then run specific processing modules from the processing centre; all of this being implemented on an existing industrial platform accessible by authorized users.

3.2. Dummy dataset

To further develop the prototype and check other components and modules, a dummy dataset is under construction at the time of writing this manuscript. Data associated with the Pullach geothermal site, which is exploited by IEP since 2005, will be used. In particular, we are interested in assessing the dashboard component and its proposed structure.

The dummy dataset will contain typical results of the processing of seismic monitoring network as well as the results of thermo-hydro-mechanical (THM) modelling. Hence, the former will take the form of a regularly appended catalogue of seismic events (virtual or mimicking seismicity induced in similar context) combined with a working-state of the monitoring network; the latter will provide current and future temperature and pressure fields modelled numerically for a typical Molasse-Basin geothermal reservoir. Such a dataset will serve as input for the dashboard module (Figure 2), which will compute and deliver the safety indicators.

A series of safety indicators have been selected. For the seismic monitoring aspect, they are, as a function of time: the monitoring station status, in a given volume around the geothermal wells, the number of events, the seismicity rate, the magnitude range, the peak-ground velocity or acceleration. For the THM modelling results, they are, as a function of time (past, present and future), the temperature or pressure in a given volume around the production section of the geothermal wells. If the THM reservoir modelling is coupled to the modelling and, consequently, to the forecast of induced seismicity (one task of the INSIDE project actually focuses on this aspect), the corresponding results could be provided within a synthetic catalogue of seismic events. Then, such a catalogue could be processed, like the real catalogue, however, with the ability to look in the future (1 week, 1 month, one quarter…). The production parameters like pressure, temperature, flow rate at wells, total circulating volume could constitute additional indicators of interest.

The list of indicators is not fixed. It should be adapted to the type of geothermal site of interest and to the state of knowledge of the seismogenic behaviour. Such flexibility, however, necessitates categorising the indicators to ease their handling by the dashboard component. For example, whether it is a scalar value, a vector, function of time and/or space, must be determined, and would lead to dedicated post-processing options or display options, etc.

To ease the duty of the operator looking at the dashboard, it was decided to display the status of these indicators in the form of traffic lights. The status is determined by comparing the indicator value to predefined thresholds, to be adapted manually or automatically and to the site context. This approach would not prevent to obtain a more detailed view of the indicator itself, e.g. by clicking on the status light.

With the dummy dataset, the first step will be to generate an alert. This alert will have to be developed to launch specific actions, in our case, informing a group of stakeholders and starting automatically a reservoir-modelling instance (i.e. the production scenario module of Figure 2). With the latter, control from the dashboard of the Data Lab processing can be tested. Finally, feedback of the reservoir modelling results into the mirror of the dashboard will be checked. All these steps should lead to a relatively good level of verification of the viability and feasibility of the RMS.

4. CONCLUSIONS

A concept for a geothermal reservoir management system has been presented. Its goal is to allow sustainable exploitation of the geothermal resource, which involves, in addition to risk mitigation of induced seismicity and ground deformation, optimization of the production parameters.

The three main components of the RMS, namely the database, the processing centre and the dashboard are strongly linked. On the one hand, this requires clear rules to communicate between the different components, especially regarding the definition of the input and output data types and formats. On the other hand, this decomposition allows flexibility since each component can be developed, in the most appropriate way, independently of each other.

In the current state of the INSIDE project, we have been able to implement parts of the system on a cloud infrastructure commonly used by SWM. This consisted mainly in the transfer of the big data amounts generated by the different monitoring devices of the INSIDE project to the database and their processing by the processing centre. Soon, a dummy dataset will be used to further assess the concept, especially regarding the dashboard and its automatic actions.

We hope that the prototype of the RMS will serve as a proof-of-concept and will be a significant step towards full integration in IT infrastructures of geothermal field operators. Besides its structural aspect, to be efficient, the RMS calls for reliable tools to forecast induced seismicity and ground deformation that can be implemented in a practical way to be usable by the operators.

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