EARTHQUAKE EARLY WARNING SYSTEM FOR GEOTHERMAL BINARY POWER PLANT IN INDONESIA

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ABSTRACT

The operational safety and reliability of geothermal binary power plants is an essential aspect for the successful application of this technology. Besides the technology itself, external causes can also influence the reliability of the plants. Many geothermally used areas have an increased seismic activity which can lead to the failure of geothermal power plants. Damages can be prevented by a timely shutdown of the plant or parts of the plant, such as the turbine and thus can increase the plant reliability. We establish, test and further develop an independent early warning system at the site of the geothermal binary demonstration power plant in Pangolombian-Lahendong, (Indonesia). The density of seismic events is high enough in this area and up to now the demonstration power plant had two turbine bearing damages because of earthquakes located in the area of Northern Molucca islands.
The early warning system consists of 10 Raspberry Shakes, which are Raspberry Pi based geophones and one central computer. Each Raspberry Shake is equipped with its own data processing unit and is able to send data to a central computer via mobile communication. Based on this data, operationally relevant signals for the power plant are generated such as “turbine trip” or “plant shut down” in order to prevent it from damages.
Such an early warning system is not only important for geothermal power plants, it is of general relevance for sensitive infrastructure that has to be protected against damages caused by earthquakes. The most important challenge is to detect seismic events early enough and to determine their intensity fast enough in order to bring the plant into a save operating mode.
Within this contribution we will present the motivation, the technical concept and the integration of the earthquake early-warning system into the power plant control system.

1 INTRODUCTION

Indonesia is known for its huge geothermal potential, which is dominated by wet steam fields. The prevailing plant type in Indonesia is currently the single-flash which directly uses the vapor part from the produced vapor-liquid-mixture to drive the turbine. Binary plants which transfer the geothermal heat to a separate working fluid are not yet an established technology at Indonesian sites. The first commercial binary units have been commissioned at Sarulla field in North Sumatra just in 2017 (Wolf & Gabbay 2015, Richter 2018b). Due to their adaptability they could however be implemented at much more sites and help to increase the geothermal capacity in Indonesia.
In order to successfully demonstrate geothermal binary power plant technology at an Indonesian site and to intensify the know-how transfer in this technology field a German-Indonesian collaboration

project has been initiated in 2013 involving GFZ Potsdam (Germany), the Agency for the Assessment and Application of Technology in Indonesia (BPPT) and PT Pertamina Geothermal Energy (PGE).
The demonstration plant is located in the Lahendong geothermal area close to the village Pangolombian in the northern part of the island Sulawesi and is in operation since September 2017. In January 2019 the demonstration plant was handed over to the Indonesian consortium.
Indonesia is located in a seismically very active zone. Several hundred earthquakes with a magnitude higher than 4 are registered every year and in 2020 approximately 70 events showed a magnitude >5. The area of northern Sulawesi also experiences many earthquakes every year. Some of the earthquakes in recent years reach a magnitude that causes high ground accelerations in the area of the demonstration plant and as a consequence with a higher risk for turbo generator bearing damage.
This paper describes the technical concept of an erthquake early warning system for the demonstration plant and their integration in the operating concept of the plant.

2 MOTIVATION

An earthquake, on 3/24/2019 in the area of the Northern Molucca Sea caused ground movements at the site of the binary demonstration power plant, resulting in turbo generator bearing damage. The earthquake had a magnitude of 6.1 and the epicentre was about 200 km away at a depth of about 10 km. A first analysis of the data showed that about 30 seconds after the earthquake, high vibrations were measured at the acceleration sensor of the turbo generator. The vibrations led to the damage of the turbo generator bearing. The time span between the time of the earthquake and the high accelerations at the earth's surface could be sufficient to minimise or prevent the bearing damage. Since there are several earthquakes a year with similar location and magnitude we decided to develop and test together with partners a smart earthquake early warning system which can also be significant for other industrial or constructional infrastructure.

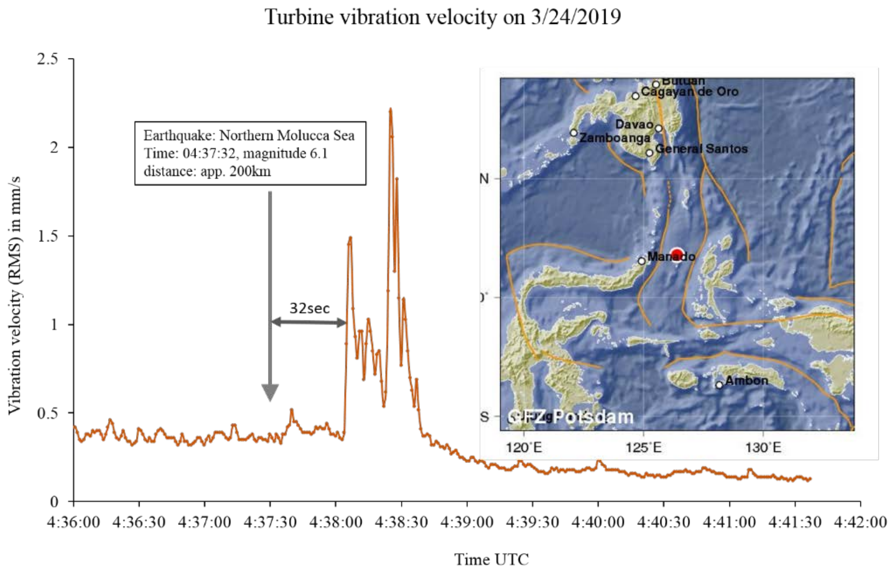

Figure 1: Position of earthquake leading to turbo generator damage: time: 2019-03-24-37-32 UTC, Northern Molucca Sea, magnitude 6.1, depth 10 km (source GEOFON) and measured turbo generator vibration velocity

3 PLANT DESIGN AND OPERATION

3.1 Binary power plant design

The demonstration plant has been integrated at the Lahendong geothermal field close to the village Pangolombian where geothermal brine with a temperature of about 170°C is available. The plant has an electrical capacity of 500 kWel and the working fluid is n-pentane. The whole plant concept consists of three separate cycles, the hot water cycle, the working fluid cycle and the cooling water cycle.

During operation, the heat of the brine is transferred to the hot water cycle in the primary heat exchanger. By means of the intermediate hot water cycle, the working fluid in the ORC preheater and evaporator is then heated up and evaporated. The hot water is continuously circulated and the pressure in the hot water cycle is maintained with an expansion vessel with nitrogen cushion. In the ORC-unit the working fluid vapour drives the turbine-generator-unit. After the turbine, the superheated working fluid vapour is flowing through a recuperator register before entering the water-cooled condenser tube bundle. The recuperator and condenser tube bundles are arranged together in one vessel. The heat removal in the cooling water cycle is realized with a dry cooler consisting of 6 units.
Using the hot water cycle, it is possible to operate, shut-down and start-up the binary plant without changing the existing operational regime of the brine supply. Furthermore, it minimises the impact on the geothermal field operation in case of sudden plant shut down because of grid blackouts or future earthquake warnings. More information about the plant concept and operational experience can be found in Frick *et al*. (2019).

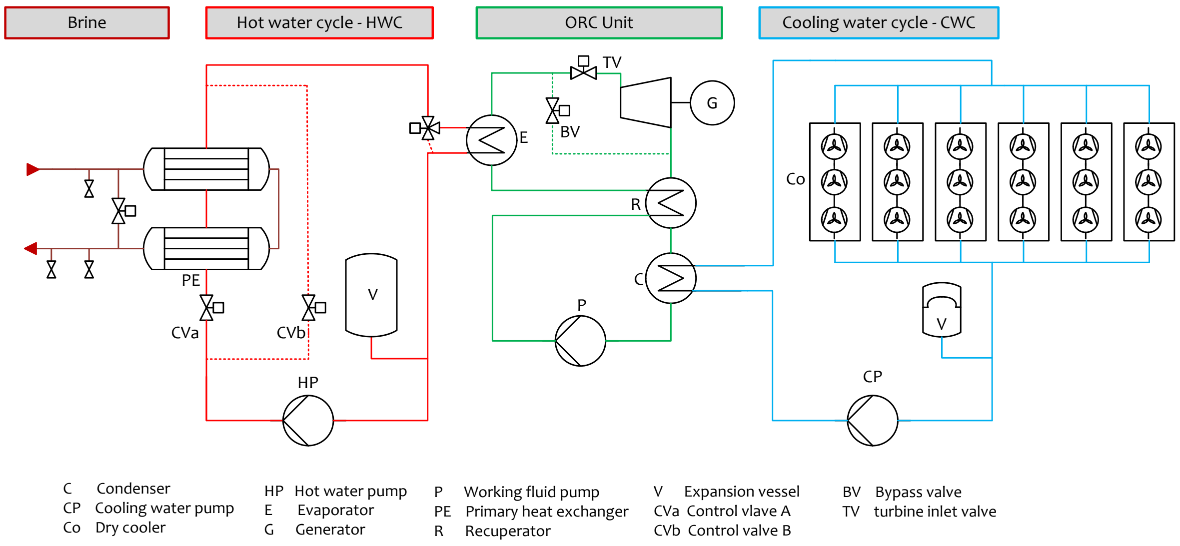

Figure 2: Flow chart of the binary demonstration plant (based on Frick et al. 2019)

3.2 Turbo generator design and operational aspects

The turbine and the generator (turbo generator) are integrated in one housing without an external coupling and without any rotating gaskets. The turbo generator unit has two plain bearings, the front bearing, close to the turbine wheel and the rear bearing. The front bearing is a radial bearing and the rear bearing is of the radial-axial type.

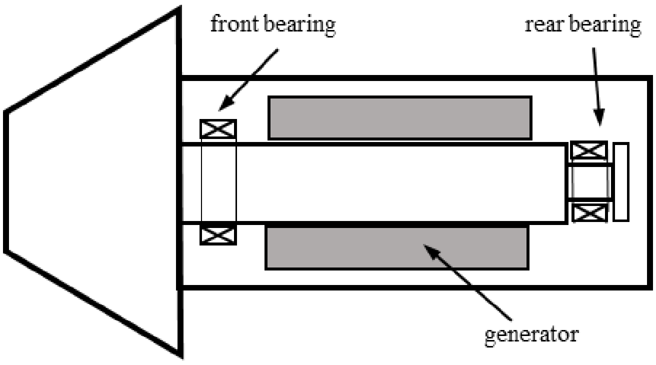

Figure 3: Schematic turbo generator design with indicated bearings

In case of an earthquake such as mentioned in chapter 2, the surface accelerations caused by the earthquake led to a turbo generator shaft movement far out of the normal position.
As a consequence, the axial bearing surfaces of the rear bearing had direct contact to each other and the lubrication of the bearing was disturbed and finally completely interrupted. Without a bearing lubrication, there is direct friction between the bearing surfaces and abrasive material removal.
The damaged rear bearing (left) and the new installed bearing (right) is shown in Figure 4.

Figure 4: left: damaged turbo generator rear bearing showing completely removed lubricating channels, right: new installed bearing with lubricating channels

In Figure 1 is shown, that the time span between the event of an earthquake and arrival of the destructive seismic waves at the power plant site is 32 seconds. This is also the time available for the complete shutdown of the turbo generator. The time that is needed to reduce the rotational speed of the turbo-generator from 100% to 0% is shown in Figure 5 and is approximately 30 seconds.
The shut down time could be further reduced by using an additional breaking system.

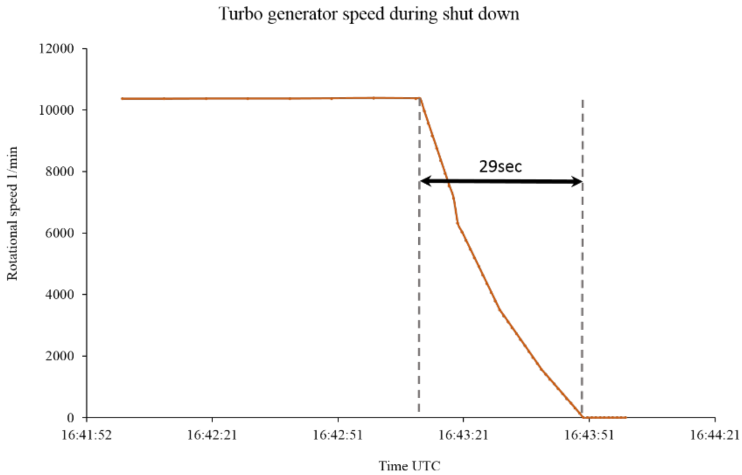

Figure 5: Time required to reduce the rotational speed of the turbo generator from 100% to 0%

4 CONCEPT OF EARLY WARNING SYSTEM

The concept of the early-warning system is based on the fact that different waves are generated during an earthquake and that they propagate at different velocities. The most important waves are the P- (primary) and S- (secondary) waves. P- and S-waves are body waves that propagate inside the earth. The P-waves are compressional waves or longitudinal waves, which can propagate in all type of material (solid, liquid and gas) and they reach velocities of approx. 6 km/s in the area of northern Sulawesi. P-waves rarely cause destruction on the earth's surface (non-destructive waves). The secondary wave is a shear wave that propagates transversely and can only travel in solid material, since liquids and gases cannot transmit shear forces. S-waves are responsible for destruction on the earth's surface because of their high vertical and horizontal amplitudes. They reach velocities of about

3.5 km/s (about 60% of the P-wave velocity).

The velocity difference between this two types of waves is used in early warning systems, as P-waves can be detected very well by seismic sensors (geophones). Depending on the distance of the earthquake, the time difference between P-wave and S-wave arrival can range from several seconds to minutes. This time difference can be used as reaction time, for example, to shut down a turbine.

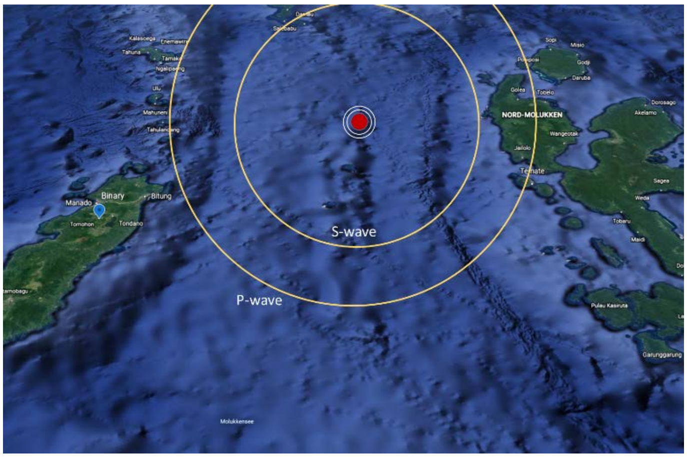

Figure 6: Figure illustrating different arrival times of P-waves and S-waves

4.1 Technical design of early warning system

The planned early warning system consists of 10 seismic sensors, called Raspberry Shake 4D, combining weak and strong motion monitoring (Figure 7), and a server for fast processing of the data and for data storage as well as a communication interface to the control system of the binary power plant.

Figure 7: Seismic sensor: Raspberry Shake 4D, Size 190x60x60 mm (raspberryshake.org)

The 10 seismic sensors are distributed around North Sulawesi as shown in Figure 8. Four sensors are located in the immediate vicinity of the power plant and six sensors are located in surrounding areas (max. radius of 300 km) with a high probability of being close to the epicenter of earthquakes that may have an impact on the geothermal power plant site.

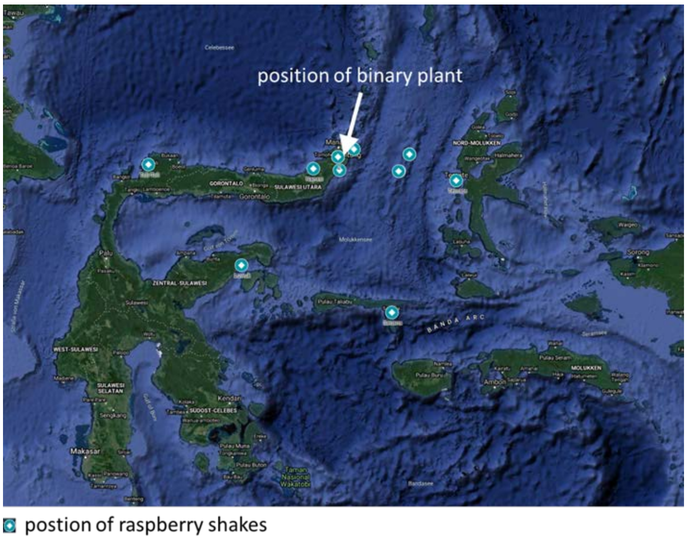

Figure 8: Position of seismic sensors considered for the early warning system in the area of North Sulawesi (source: Google Earth)

With this 10 installed sensors, two approaches are being pursued in the development and testing of the early warning system: **on-site early-warning**, for which the sensors directly at the power plant site are used, and **regional early warning**, for which the remotely installed sensors are important.

With on-site early warning, the faster and earlier arriving P-waves at the power plant site, are recorded and evaluated. The evaluation leads to an expected ground acceleration, which can be caused by the following slower S-waves. In general, only one seismic sensor is necessary for on-site early warning. More installed sensors lead to redundancy and increase the reliability of the system.

In the case of regional early warning, the P-waves near the epicentre are recorded and used to calculate the location and the magnitude of the earthquake as well as to determine the ground acceleration expected at the target location. At least 4 sensors are required for regional early warning.

Depending on the number of stations nearby the epicentre, regional early warning might be more accurate as more stations are available and an earthquake can be clearly identified as a source for ground movements. But the applicability and reliability depends on data transfer infrastructure and needs a stable internet connection.
On-site early warning is less accurate, as high seismic amplitudes can also be caused by a local construction site where no destructive seismic S-waves follow. Therefore, the probability of a false alarm is higher. On the other hand, it is stand alone, might be more cost effective and there are no dependencies on internet communication.

The basic set up of the early warning system and the flow of information/data are shown in Figure 9. In case of an earthquake, the P-waves are registered by the sensors. The data is then sent from each sensor via UMTS to the data server. At the server, the data is analysed using special algorithms which are adapted to the local wave propagation conditions. The result of this analysis will an expected ground acceleration at the power plant site. This acceleration value is transferred to the power plant control system and the turbo generator is switched off, if the expected value exceeds the permissible limit for the turbo generator.

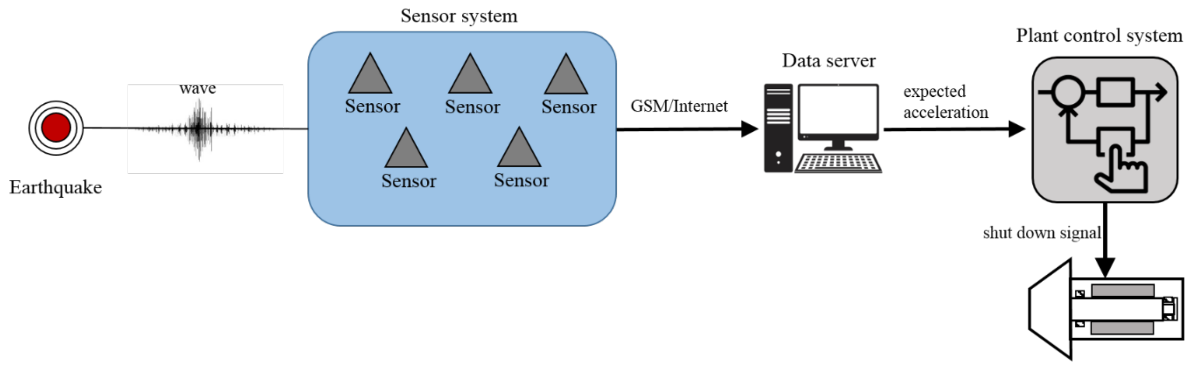

Figure 9: Basic set up of the early warning system (gempa GmbH/GFZ)

4.2 Turbo generator shut down procedure

In case of an earthquake, only the turbo generator is to be taken off the grid and brought to a standstill. The working fluid cycle, the brine supply and the hot and cooling water cycles continue to operate, so that the turbo generator can be restarted quickly. In case of an early warning, the turbine inlet valve (TV) is closed and the bypass valve (BV) is opened, thus the pentane vapour is bypassed to the turbine and directly led into the regenerator/condenser. Simultaneously, the heat input into the pentane cycle is reduced by lowering the hot water inlet temperature at the evaporator by means of the two control valves (CVa and CVb) in the hot water cycle, thus introducing a bypass over the primary heat exchanger (PE). As soon as the turbo generator release is possible again, the hot water temperature is increased via a predefined ramp and the standard turbo generator release procedure is followed until the normal operation mode is reached. (Figure 2)

4.3 Technical research aspects

The main challenge for the proposed early warning system, is to minimize the time span between an earthquake event and the turbine has reached a non-critical speed at which a bearing damage is prevented. This is to be achieved by adaption and optimisation of data recording, processing and evaluation. Furthermore it is important to predict the expected ground acceleration at the plant site and to determine the critical ground acceleration at which the turbine could be damaged.
A measurement and test period of about one year is planned in order to have enough events for evaluation and calibration. Finally, the early warning system has to be implemented into the binary control system to test and optimise the shutdown and restart procedure for the turbine.

5 CONCLUSION AND OUTLOOK

At the geothermal binary demonstration power plant in Lahendong, Indonesia, an earthquake in the Northern Molucca Sea region caused strong ground movements at the power plant site and, as a result, turbo generator bearing damage. As there are several earthquakes with a magnitude >5 in the North Sulawesi area, we develop and test an adapted and cost-effective early warning system together with partners. The early warning system should enable a timely shutdown of the turbo generator in case of an earthquake. The challenge is to generate a fast and effective early warning signal, to integrate it into the process control system and to develop a suitable turbine shut down procedure that enables a fast restart.

The current status of the project is significantly behind schedule due to the global pandemic restrictions. At the moment, the locations for the seismic sensors have been identified, but the commissioning could not be carried out yet. After commissioning, a one year test phase is planned without direct turbo generator shutdown. The test phase is used to adapt the early warning algorithms and to determine the ground acceleration limits for the turbine. After the test phase has been completed, the early warning system will be directly integrated into the power plant control.

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GEOFON: https://geofon.gfz-potsdam.de/

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