Optimizing Geothermal Power Plants Using Artificial Intelligence

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ABSTRACT

The conventional methods of electricity production have significant side effects on global climate, due to which renewable sources of energy pose as a viable solution, with several benefits like low carbon emission and limitless supply. With an increase in public awareness towards renewable sources of energy along-with progress in technology, geothermal energy sector has seen dramatic boost in terms of production, and in an attempt to provide novel artificial intelligence (AI) equipped solutions for optimization of several aspects of geothermal plants, a substantial amount of research work has been done in the last two years. Therefore, this paper provides an outline of major AI allied applications pertaining to geothermal power-plants, followed by discussion and examination of research work conducted in this domain to tackle the emerging set of problems. Various challenges and limitations, as observed from the works, are then cited and given thoughts upon. The findings and literature work is consistently portrayed in figurative manner for clear comprehension and finally, the feasibility of AI (as a whole) in geothermal plants' optimization (in general) is discussed.

1. INTRODUCTION

Geothermal energy is a renewable resource that has no bounds in terms of quantity, and possesses inherent advantages compared to traditional energy resources that are used to generate energy for our daily use (Shah et al., 2019; Shah et al., 2020). Some of the major benefits of geothermal energy include limitless availability, low greenhouse emission and trivial production costs (Olkkonen et al., 2018; Zakeri et al., 2018; Khosravi et al., 2018a,b,c,d,e). It has several advantages over other renewable resources (like solar and wind energy) as they are sporadic in terms of time of the day (day or night) and location (high plain fields or concourse of buildings) (He et al., 2018; Cetin et al., 2019; Li et al., 2018; Vargas Payera, 2018).

Geothermal plants utilizes this energy, by circulating the hot steam from underground geothermal systems into turbine, which create pressure and spin them, which in turn generate electricity. There are several geothermal plants around the world located near hotspots of geothermal energy, that try to make the most out of this limitless source of energy. However, various hurdles along the way restrict the widespread implementation of geothermal plants, which include efficiency deficiency and sustainability issues. For instance, the highest recorded conversion efficiency is approximately 20.7% at Darajat in Indonesia (Ibrahim et al., 2005; Kaya et al., 2011), while the world average stands at 12% (Zarrouk and Moon, 2014). Therefore, the designing of plants to make sure that the efficiency is maximized and long lifespan of machinery is ensured is the need of the hour (Shah et al., 2019; Prajapati et al., 2021).

This is the point where Artificial Intelligence (AI) makes a notable difference (Talaviya et al., 2020; Patel et al., 2020; Gupta et al., 2020). AI is a field of computer science that deals with mimicking human behavior by making decision on its own, when given ample amount of data to learn from (Jha et al., 2020; Pathan et al., 2020; Kakkad et al., 2020). It takes a set of parameters and data points as input, and produces output(s) based on learning with certain accuracy (that has been low for geothermal plants) as portrayed in Figure 1 (Zarrouk and Moon, 2014). It has brought dramatic advancements in several domains, and can pose as a viable solution for optimizing geothermal plants to produce higher efficiency and have longer lifespan.

2. ADVANCEMENTS

The last decade has seen a wide array of changes and advancements in renewable energy sector as well as the domain of artificial intelligence. The public sentiment on sustainability has increased, which puts more emphasis on renewable sources of energy, and has resulted in an increase of renewable energy's production by governments and private organizations (Weinand et al., 2019; Ibrahim et al., 2005). For instance, developed nations and unions like EU (European Union) have decided to produce 20% of their total energy requirements though renewable resources by 2020 (and 27% by 2030) (Jha et al., 2017). Other small nations have pledged to go green as well, reaching renewable production up-to 94.5% (of total production) in Uruguay and 98% in Norway (Jha et al., 2017)! The contribution of renewables in electricity production in various countries is summarized in Figure 2 (Jha et al., 2017). In such a scenario, geothermal energy seems to be in the limelight due to its non-dependency on several factors like time and weather conditions, portrayed in number of publications over the years in Figure 3 (Jha et al., 2017).
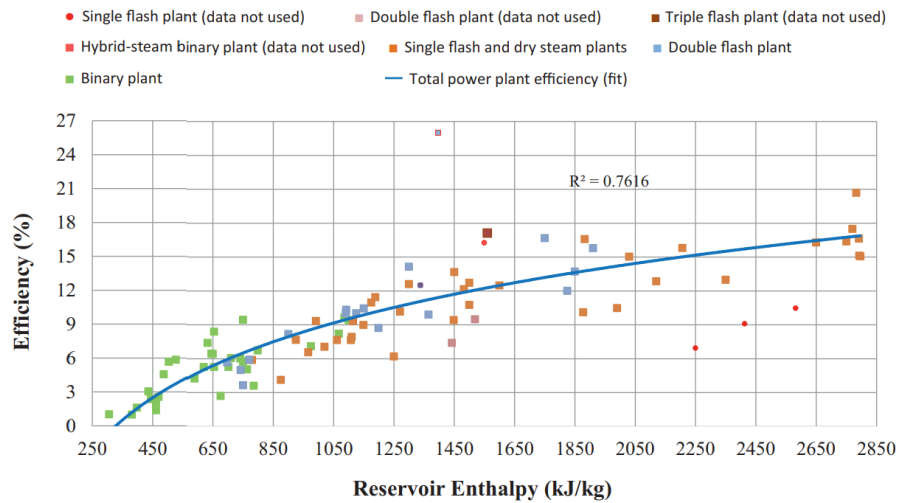
Figure 1. Geothermal power plant (generic) efficiency

The drastic advancements in the computational power and numerical optimization have made the applications of AI more widespread and economically viable for implementation. For instance, the performance of microprocessors have increased by 50% every year from 1986 to 2002, and 20% annually thereafter (Pacheco, 2011)! The computational capabilities have improved to great extent while being publically accessible due to reduced hardware costs, enabling the operation of simulation and optimization techniques into large scale problems like geothermal plant optimization (Lee et al., 2018). The penetration of internet into our daily lives also makes its usage cheap and practical, which in turn results in better accessibility of knowledge to researchers and engineers who need to fabricate specific models and process for a particular application. This leads to better ML models, along-with reduced training time and high accuracy, making the employment of AI in various field a viable and practical thing to execute.

Furthermore, such advancements in public sentiment and institutional acceptance of geothermal energy production, along-with boost in feasibility of AI implementation, result into a near perfect scenario where AI can be operated to optimize geothermal plants in order to tackle several challenges pertaining to prevalent usage of geothermal plants (including plant design, energy conversion accuracy and plant lifespan).

3. APPLICATIONS

The advancements in computational power and increased awareness about sustainable sources of energy, mentioned earlier, have resulted in a substantial increase of research work in geothermal energy sector. The chief focus of most research work tends to be on improvement of geothermal plants, to make them more operationally feasible, using AI or ML (subset of AI). These proposition provide a certain extent of innovative direction on working, designing or maintaining the energy production system of geothermal plants in order to tackle some of the hurdles that limit their widespread implementation. Some of the major applications in the domain since 2019 are hereby mentioned.
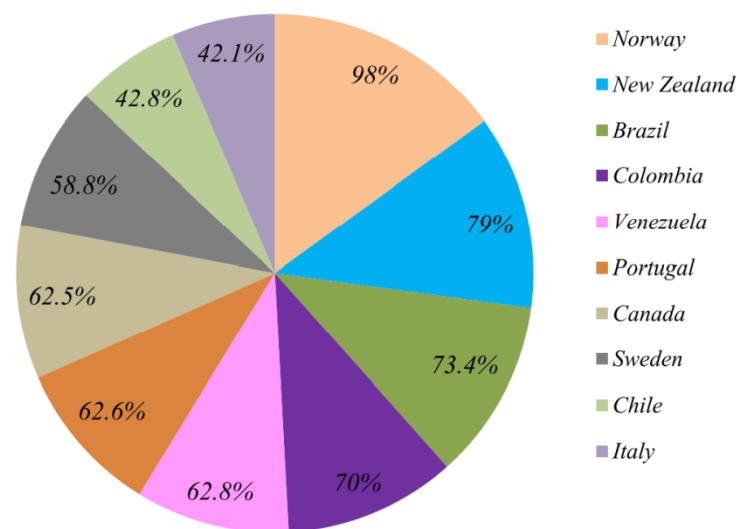
Figure 2. Contribution of renewable energy in electricity production [2014]
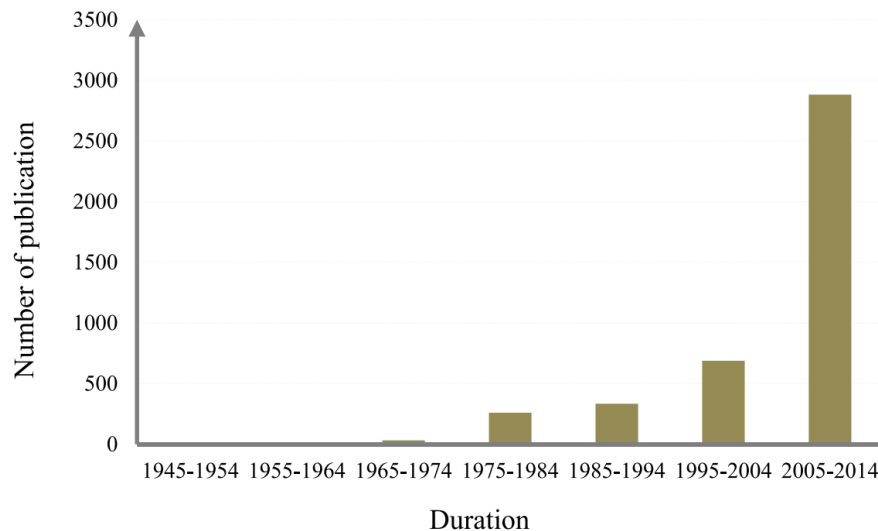
Figure 3. Published scientific reports of geothermal energy research

Tut Haklidir et al. (2019) presented a machine learning approach for prediction of reservoir temperatures using Hydrogeo-chemical data (consisting of parameters like EC, Na+, K+, boron, Cl and silica content). Geothermal plants' working is based on the conversion of geothermal fluids into electricity, which is carried out by employing the pressure of fluid to turbines, which in turn generate electricity. The efficiency and/or output of the geothermal plant, thus, is dependent on the level of pressure that fluid can generate, which is directly proportional to the temperature of the fluid. Therefore, the setup of a power-plant requires detailed and rigorous exploration of viable regions or geothermal hotspots. As the operational costs of power-plants is substantially high, this exploration phase is crucial and of utmost importance. However, manual exploration can be remarkably difficult and exceptionally expensive. Hence, this study developed a deep learning model to predict the geothermal reservoir temperatures that can drastically reduce human effort and expenses in discovering a viable site for locating power-plant. The model was compared against two traditional ML approaches, namely, linear regression (LR) and linear SVM (LSVM). DNN model outperformed both the approaches with mean absolute error (MAE) and RMSE of 6.54 and 8.29 (respectively), compared to LR's 14.05 & 21.13 and LSVM's 13.35 & 18.94 (respectively). Thus, the study successfully devised a methodology to help find viable location site by analyzing geothermal reservoir temperature, resulting in reduced human effort, costs and discovery time (Tut Haklidir et al., 2019).

Another study by Khosravi et al. (2019) employed AI for modelling Geothermal Organic Rankin Cycle (GORC) equipped with solar thermal unit, in geothermal plant. They utilized the capability of AI models to precisely simulate the processes pertaining to renewable energy system, and developed two intelligent methods for thermodynamic modelling of the plant. They are adaptive neuro-fuzzy inference system optimized with particle swarm optimization algorithm (ANFIS-PSO) and multilayer perceptron neural network optimized with PSO algorithm (MLP-PSO), and comprise of standard design parameters of a geothermal system, namely, turbine output pressure, well temperature, preheater inlet pressure, solar radiation, solar collector surface area and working fluid mass flow rate. These parameters are taken by the models as input variable to prove predicted values that include energy efficiency, exergy efficiency, levelized cost of energy (LCOE) and net power output of the GORC. Thereafter, evaluation of the models was carried out that proved the capability of the systems to predict the target accurately, where ANFIS-PSO performed better than MLP-PSO, with the former producing root mean square error (RMSE) for prediction of power generation, energy efficiency, exergy efficiency and LCOE of 12.023 (kW), 3.587e-04, 3.278e-04 and 1.332e-04, respectively. Thus, the study was able to find the optimum design parameters and operating conditions for developing sophisticated thermodynamic models, which are helpful in optimizing geothermal plants (Khosravi et al., 2019).

Zulkarnain et al. (2019) worked on the application of machine learning algorithms in making fault detection classification models employed upon critical engines of geothermal power-plants. They put effort in tackling two major challenges pertaining to manual fault detection in geothermal plant operation, namely, errors in determination of engine conditions and delays related to knowing alerts. The algorithm used was basic classifier and ensemble classifier for comparing algorithms to figure out the one(s) with the best classification indicators. Upon experimentation, support vector machine (SVM) provided the best accuracy of 96.28%, followed by artificial neural network (ANN) with 95.45% and finally XGBoost with 78.51%. The recall values were 100% for ANN & XGBoost, and 99.30% for SVM; while precision was 95.00%, 93.30% and 75% for SVM, ANN and XGBoost, respectively. The study was accurately able to resolve issues like manual determination of critical machines' condition and automatic failure detection, which significantly aids in determining machine state condition and reliability, upon which operators can take quick and constructive actions (Zulkarnain et al., 2019).

Geothermal fluids used in power-plants consist of hot water, steam and gases; that contain several dissolved elements like sodium, potassium, calcium, silica, bicarbonate, carbonate, chlorine, sulphate, boron, fluorine, lithium, iron, arsenic, mercury and bromine. Few of these elements exhibit toxic nature to living organisms on the ground, while being a vital part of several industrial processes (and hence possessing economic value). Therefore, Tut Haklidir et al. (2020) proposed a deep learning approach for prediction of geothermal originated boron contamination for aforementioned purposes. They collected data regarding temperature, pH, electrical conductivity and Na+, K+, Li+, Cl– ions & SiO2 concentrations of geothermal fluids from thermal springs, geothermal wells and several springs across geothermal systems in Western Anatolia (Turkey). In total, they gathered dataset of 80 water samples (with aforesaid parameters), out of which 64 were used for training and 16 for testing the proposed deep learning DNN model. Upon

predictive analysis, DNN outperformed two traditional ML approaches (LR and LSVM) with RMSE and MAE score of 11.05 and 8.49, respectively (compared to LR's 17.15 & 14.58 and LSVM's 18.35 & 15.04, respectively). Hence, their proposed model was successful in better predicting the boron contamination level, which in turn could help authorities make better decisions pertaining to location of power-plant, quality of geothermal fluid and proper discharge & economic value of waste-water (Tut Haklidir et al., 2020).

As perceived through all successful applications in various aspects of geothermal plants thus far, it is evident AI plays a huge role in optimizing almost every aspect of power-plants, ranging from location discovery to plant designing. The inherent property of AI to make accurate predictions at fraction of time and resources makes it a preferred strategy tool for enhancing geothermal plants' viability and practical feasibility in the contemporary world.

4. CHALLENGES AND FUTURE SCOPE

Following the unprecedented applications of AI in geothermal power-plants, almost in every aspect, this field has bloomed as a major area of research. Although there has been several obstacles and barriers along the way that restrict the successful and widespread execution of AI's full potential. Figure 4 condenses the main challenges for the implementation of data mining in financial world.

One core hurdle for AI's implementation has always been its extensive hardware and computational needs. These requirements, although have gradually decreased throughout the years, still results in economical restrictions to small scale researchers and businesses. Therefore, a flawless decision making process is generally required for balancing computational needs and model accuracy of the research work (as both are inversely proportional to each other). As almost all research work, especially in developing nations with few geothermal hotspots, have limitations in terms of resources available to them and hence, this aspect is of a major concern.

Besides, as inferred from almost all applications in the previous section, there's a firm deficiency of data pertaining to geothermal sector. Most of the research work required collection of fluid samples from geothermal hotspots and analyzing them, in order to generate datasets to be fed to AI. The collected data might not be up-to standard requirements due to limited resources as well. Hence, insufficient data and its poor quality pose a restriction to effective implementation of AI in geothermal sector as a whole.
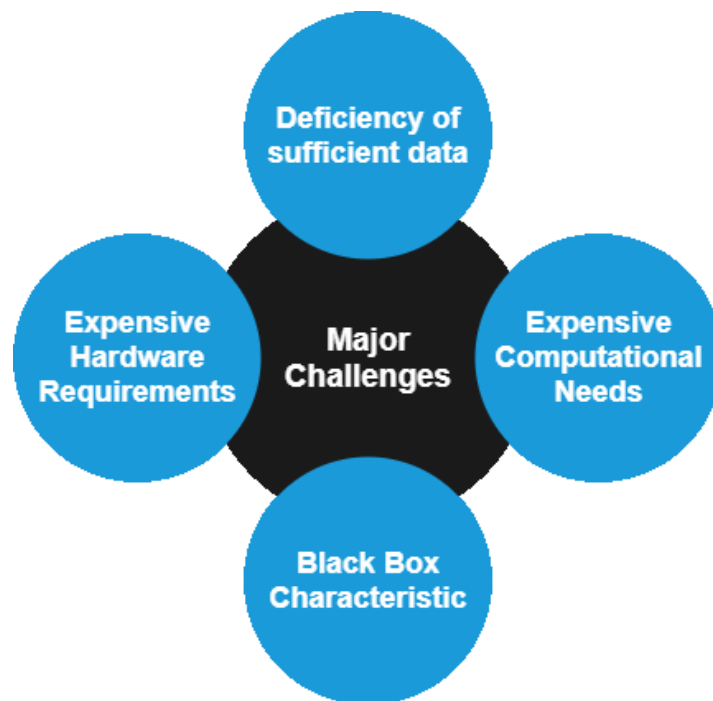
Figure 4. Major challenges pertaining to AI's implementation in geothermal plants

Furthermore, almost every AI model possesses 'black box characteristic' that puts confinement to its prevalent operation. It essentially refers to a system that doesn't portray its internal working, and can only be assessed in terms of input and output values. AI models learn on their own through data fed to them, and don't provide a proper explanation on as to how they learned and gave output. Therefore, in case of any mishap or incorrect prediction, there's no means of understanding its root cause. This becomes a major issue while working on expensive projects like geothermal plants.

However, despite of the existence of such challenges, the future scope of AI's mainstream implementation in geothermal sector, especially power-plants, is enormous. There's room for development and advancement in almost every aspect of power-plants, and the impending research work must focus on resolving the current shortcomings. Geothermal power-plants have the potential to make geothermal energy production as a major part of renewable energy production in any country, and AI can help it bring forward into its full glory by predicting optimum locations, optimizing power-plants, and increasing viability of its energy production.

5. CONCLUSION

This paper has focused on determining the feasibility of Artificial Intelligence's application in the optimizing geothermal power-plants in various aspects. The advancements in the domain, including computational innovations and public sentiment, have been thoroughly discussed (along-with their impact on geothermal plants). Upon holistic review and analysis of several papers and articles published in the last two years, the advancements in the technical domain prove to be substantial and their influence in geothermal and renewable energy sector seems dominant. Moreover, while the stated approaches produce feasible results and outcomes, few challenges including insufficient data, expensive computational needs and black-box characteristic are also presented that hinder the real world applicability of Artificial Intelligence to its full potential. Keeping that in mind, it is thereby noted that AI has commendable reach, importance and influence in geothermal power-plants' optimization process; and has vibrant future scope for research that must tackle challenges to the previously mentioned challenges.

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