Analysis of Power System Transient Stability Due to Increased Integration of Geothermal Power

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Abstract

Today, there are postulations of increasing global climate change which have sparked interest in the use of alternative green energy sources including geothermal. Currently, hydro power accounts for over 60 percent of the installed capacity in Kenya and is sourced from various Hydro power plant (HEPs) stations spread around the Tana River, Turkwel and Sondu Miriu and the rest comes from geothermal energy, thermal and wind. To meet the growing demand for electric energy, Kenya though the Vision 2030 medium industrialized country blue print, the nation plans to build numerous geothermal plants in coming years for the 5530 MW from geothermal energy alone. The optimum solution indicates that geothermal capacity should be increased from the current 198MW to 5,530 MW in the planning period, equivalent to 26% of the system peak demand by 2031. The system expansion plan over the 20 year plan period indicates that 26% of the total installed capacity will be obtained from geothermal, 19% from Nuclear Plants, 13% from coal plants and 8% from imports. Wind and Hydro plants will provide 9% and 5% respectively while Medium Speed Diesel (MSD) and Gas Turbines (GTs) will provide 9% and 11% of the total capacity respectively. This will immensely increase the proportion of geothermal energy of the total generated energy in the power system. This addition of geothermal power will change the power system dynamics especially power system stability.

This research proposal aims to carry out an impact assessment by analyzing power system transient stability due to increased Integration of geothermal power in the Kenya. The research on transient stability is motivated by the large number of GPPs to be integrated to the system, geothermal resources being in volcanic area and uncontrolled load connectivity. As the large numbers of geothermal power plants are connected to the Kenyan power system, their impact/ effect on system transient, small signal, and frequency and voltage stabilities need to be interrogated by transmission operators, power system engineers and scholars. Thus, this research will develop and simulate geothermal plants power plants dynamic condition, as GPPs penetration increases with emphasis on variable inertia constant and load location from generators and at the same time, perform an impact assessment study of geothermal for purposes of establishing transient stability margins as integration of geothermal continues to rise. Impact assessment of system transient stability analysis of the power system with steady increase in geothermal penetration, with system supplying an equally increasing composite load, under system fault will eventually be evaluated. The research will be based on model in power system simulation software like MATLAB, DigSILENT or other comparable software.

1. INTRODUCTION

Geothermal energy resources are abundant in Kenya. They are located within the Rift Valley with an estimated potential of between 7,000 MWe to 10,000 MWe spread over 14 prospective sites. When an increasing number of geothermal power plants are connected to the Kenyan power system, their effect on the power system is put to perspective as critical issues come up for transmission operators and power system engineers to deal with. Key among these issues is transient stability. The study of interconnection of several synchronous generators for GPPs and other power plants is important because of the power system stability, load demand variations and economic reasons.

1.1 Geothermal Power Plants

1.1.1 Direct Dry Steam

Steam plants use hydrothermal fluids that are primarily steam. The steam goes directly to a turbine, which drives a generator that produces electricity. The steam eliminates the need to burn fossil fuels to run the turbine. This is the oldest type of geothermal power plant. It was first used at Larderello in Italy in 1904. Steam technology is used today at The Geysers in northern California, the world's largest single source of geothermal electricity. These plants emit only excess steam and very minor amounts of gases. Flashed steam/dry steam condensing system; resource temperature range from about 320°C to some 230°C (Mwangi, 2006) (Tripple, et al., 2012).

1.1.2 Flash and Double Flash Cycle

Hydrothermal fluids above 360°F (182°C) can be used in flash plants to make electricity. Fluid is sprayed into a tank held at a much lower pressure than the fluid, causing some of the fluid to rapidly vaporize, or "flash." The vapor then drives a turbine, which drives a generator. If any liquid remains in the tank, it can be flashed again in a second tank (double flash) to extract even more energy. Flashed steam back pressure system; resource temperature range from about 320°C to some 200°C.For instance in Olkaria

GPP, the plant works on single flash plant cycle with a steam consumption of 7.5 t/h/MW. The turbines are single flow six stages condensing with direct contact spray jet condenser1. (Mwangi, 2006) (Tripple, et al., 2012).

1.1.3 Binary Cycle

Most geothermal areas contain moderate-temperature water (below 400°F). Energy is extracted from these fluids in binary-cycle power plants. The Hot geothermal fluid and a secondary (hence, "binary") fluid with a much lower boiling point than water pass through a heat exchanger for steam generate steam . Heat from the geothermal fluid causes the secondary fluid to flash to vapor, which then drives the turbines. Because this is a closed-loop system, virtually nothing is emitted to the atmosphere. Moderate-temperature water is by far the more common geothermal resource, and most geothermal power plants in the future will be binary-cycle-plants.(Mwangi,2006)(,Tripple,etal.2012).

2. BACKGROUND

Energy is consumed by all sectors of the economy and therefore growth in the economy of any country leads to a consistent rise in the quantity of energy consumed. While the Kenya is experiencing significant growth in energy demand, energy supply appears to have stagnated or dwindled. The security of energy supply especially electricity generation in Kenya seems to be threatened by climate change induced phenomenon, chief among them, drought. Inadequate electricity generation capacity and high power bills have been perennial problems for Kenyan consumers prompting the Government to explore various ways of tackling the glitches. Currently, a lot of effort is geared at geothermal power, which experts opine is environmental friendly and more affordable to run compared to other sources of energy like fossil fuel. A major shift to geothermal power will also insulate the country against the effects of drought, which often interferes with hydroelectric power. A major percentage of our installed capacity of power plants has historically been powered by hydroelectric sources with diesel plants also accounting for a significant portion of the total energy demand. Sutter, Kipyego, Mutai (2012).

The reliance on diesel to supplement increasing demand is unhealthy, as it has helped push the average cost of production of electricity and made it expensive for consumers. Making geothermal Kenya's major source of energy would allow for a complete stop to the usage or reallocation of price-volatile fossil fuels, such as diesel, which otherwise would have been needed for electricity generation. By reducing the component of our energy mix that is dependent on the price of fossil fuels – and increasing geothermal power use, which in the long term will guarantee stability – takes away fossil risks. Sutter, Kipyego, Mutai (2012).

Kenyan power system has persistently been operating under strained environment due to heavy loading, long transmission lines with uncontrolled buses at the receiving end, radial transmission lines, and shortage of local reactive power, intrinsic factors and small generation reserve margins. This has yielded very narrow limits for power system stability. Stress due to increased load exposes the system to oscillations that can severely restrict system operations by requiring curtailment of power transfer from one area as an operational measure. It is therefore crucial to accurately model the new generating units and understand dynamic load behavior of the system with integration of different sources apart from the traditional HEP. Various generating systems also affect the stability at various points on the power system. For the reasons above, transient stability analysis is the focus of this research study.

2.1 Kenya's geothermal power system modeling situation

At present there are no assessment studies done on geothermal power generation for the Kenyan power system network. Thus, it is difficult to predict the behavior of the system when other sources of power are integrated especially now that more geothermal power is being harnessed. The current installed capacity in Kenya's Olkaria Geothermal field is 198 MW. Sutter, Kipyego, Mutai (2012). This trend is expected to give rise to increased geothermal power plants connected to grid and in effect several power system issues come up with the increase. These issues are:

1. Effects to the power system when geothermal plants connected to the transmission grid continue to increase with consideration on variable inertia constant and load location from generator
2. The variation in the power system transient stability behavior after each increment these plants
3. Dynamic behavior of the system when geothermal power feeds a major load.
4. Voltage levels at various points of the system with majorly geothermal power system.

Recent studies have shown that, under disturbance power system is more stable when geothermal plants are used to meet the power demand of the load. This is so because the inertia of geothermal power plants is higher than for HEP plants since a smaller inertia decreases the critical clearing time. The reason is that the smaller the H constant the smaller P_{max}. A smaller P_{max} constrains a machine to swing through a smaller angle from its original position before it reaches the critical clearing angle. Therefore, smaller H constant decreases the critical clearing time and lowers the probability of the system to maintain stability. Ólöf Helgadóttir (2008).

2.2 Need for the Study

This study is motivated by the need to carry out an impact assessment by analyzing power system transient stability due to increased integration of geothermal power in the Kenyan grid by developing and estimating the effect of GPPs on transient stability. There are no studies for the present Kenyan system hence there is need to develop such to guide the integration of other sources. The uniqueness of the Kenyan system is the location of geothermal resources being restricted to the rift valley, heavily loaded power system and the varying distance of GPPs from the load center. The current installed geothermal power capacity in the country is 198 MW with 150 MW operated by KenGen and 48 MW by Or Power 4, both in the Olkaria Block. An additional 280 MW under development is scheduled for commissioning in 2013. In the Menengai Field with a potential of 1,600MW drilling is ongoing at Phase I for development for 400 MW. The first exploratory well in Menengai has been successfully completed with a capacity to generate more than 8MW. Initial project development activities have also commenced for the development of 800 MW in the Bogoria – Silali Block. This is geared towards meeting the 2030 Medium Term target of 1,600 MW by 2016 and eventually

5,530 MW by 2030.This signals the point that the geothermal power development is on the rise and Government is committed in tapping into this line of electric power generation in the near future. . To realize the evacuation of the 5530MW from geothermal, implementation plan has been put forward to construct 10,345Km in transmission projects to be undertaken by Kenya Electricity Transmission Company (KETRACO) by 2030. Sutter, Kipyego, Mutai (2012)

2.3 Extend of the Study

Sources of Electric Power are varied and include HEP, geothermal, wind, solar and tidal. This study will identify and analyze parameters of the increased GPPs by carrying out an impact assessment on system transient stability. This will be realized through analyzing the power system transient stability due to increased Integration of geothermal power in the Kenyan grid with emphasis on variable inertia constant and load location from GPPs purposes of defining system stability margins and dynamics. The geothermal projects aim to provide 5530 MW of geothermal electricity to the Kenyan national grid by 2030. This is going to make GPPs the largest installed electricity generating source of electricity. The Project is of significant strategic benefit to Kenya in solving the hydroelectric power dependent economy. With this optimistic project it is therefore important to carry out a research focusing on its impact assessment on known existing system.

3. PREVIOUS STUDIES

Research on geothermal power plants is gaining momentum amongst countries with this resource. Past research tends to be more focused on geothermal heat and its applications, fluid thermodynamics and environmental factors rather than on electrical properties of a geothermal system. There are few stability studies published comparing the stability performance of geothermal power plants with other generation technologies. Ólöf Helgadóttir (2008).

A research study on the Dynamic Behavior of Geothermal Power Plants Located at a Weak Point of Icelandic Transmission System, where a new 250 MW aluminum smelter in northern Iceland is planned and its power demand is met by both geothermal and hydro power plants, established that geothermal power plants to be installed have larger inertia than the power hydro plants they substitute. Therefore, the system is more likely to maintain stability under transient conditions when the new load is supplied from geothermal plants. Other interesting questions arise for system operators when an increasing number of geothermal power plants are connected to the power system. Next step in future work would be to address the issues appertaining to the role of geothermal power plants in taking part in regulation and operation of the system, in the same way as other power plants like hydro do in most countries including Kenya and the possibility to use this GPPs to start-up an energy intensive factory, like the aluminum smelters and other large power loads, with only geothermal electricity feeding it. This model developed was for single point in the system and was used to give the best source of power to the load considering the proximity of the both HEPs and GPPs to the smelter. To take care of variedly located GPPs, both from each other and load center, the model of a power system has to be expanded and modified to take of more GPPs enabling long-term stability studies including transient stability. Ólöf Helgadóttir (2008).

Another research on integration of geothermal energy into the Australian transmission network focused mainly on voltage stability and outlines its effects on the system. Voltage stability studies on Australian South East 14 generators test system show that bipolar HVDC transmission lines are more stable compared to HVAC. Also in this study, it has been demonstrated that stability of the HVDC interconnection is not deteriorated when the length of the line increases. On the other hand, the stability margin of HVAC interconnection decreases proportionally when the length of the interconnection increases. Inter-area oscillations are caused by interactions among large groups of generators at two ends of an interconnection and improve the transient stability; the research is limited has it proposes supplementary control for current source converter HVDC; the integration does not provide the dynamic transient behavior of the system as GPPs rise. Mehdi and Tapan (2011)

Further still, in the research on Impact of Widespread Penetrations of Renewable Generation on Distribution System Stability, these penetrations make transmission/distribution system more dynamic. The results show that with increasing penetration of solar energy, loadability improves, whereas it decreases with increased wind penetration. The increased penetration of wind power may limit the loadability due to Hopf bifurcation phenomenon. Grid loss has been found to increase after certain level of renewable penetration. Damping of low frequency oscillations improves as the wind and solar penetration increases. Also, transient stability improves with an increase penetration of renewable energy resources .Notably missing is the effect of penetration of geothermal power, also a renewable resource, hence there's need to carry out its study. Tareq Aziz (2010)

In the research on Modeling and Stability Analysis of Berlin Geothermal Power Plant (CGB) in El Salvador, This project present a local area model of the CGB and the surrounding grid, and it can be extended to add more units in the surroundings to make dynamics studies. The inter-area mode is not vividly explored in this study. Lopez and Alonso (2013)

Eigenvectors plots shows that the oscillation mode for this research study is local mode or Machine system mode, because all the units of CGB swing together with respect to the rest of the power system. By extending the model and having different locations of GPPs while including more of the surrounding grid and other power plants, there is an assumption that there will be additional oscillation modes or inter-area modes. The developed model is, however, very well suited for studying local phenomena. This research, thus recommended that the phenomenon be investigated, due its flexibility for systems with varied locations of GPPs (separated by large distances from each and the load center) as this was limited to local area oscillations. There is need to extend the study to include inter-area mode of oscillations. Lopez and Alonso (2013)

Because of difference in geothermal resource potential in other countries, unique physical location of Kenya's resources, heavy/strenuous loading on the system and varying distance from between GPPs and load center approach, the system dynamics differs from other countries endowed with the same. In this regard, Kenya intends to make it the leading source of electricity by 2030, thus calling for impact assessment for this unique source of electricity. This calls for stability studies, amongst them transient stability on the system to deduce the dynamic behavior as the GPPs continue to rise.

4. REVIEW OF POWER SYSTEM STABILITY INVOLVING DIFFERENT SYNCHRONOUS MACHINES

4.1 Classification of Power System Stability

To achieve a better overview and structure of stability analyses of power systems, it is of great help to classify possible power system stability. The classification to be introduced here is based on the physical mechanism being the main driving force in the development of the associated instability. It could be either the active or the reactive power that is the important quantity. Kundur, Paserba, Ajjarapu, and Andersson (2004)

A common characteristic of the instabilities to be discussed here is that they have their origin in too large an imbalance of active or reactive power in the system, locally or globally. This imbalance can then develop in different ways and cause unstable behavior depending on system characteristics. Power system stability is that property of a power system that enables it to remain in a state of equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to a disturbance. Figure 2.1 shows the classifications of power system stability. Kundur, Paserba, Ajjarapu, and Andersson (2004)
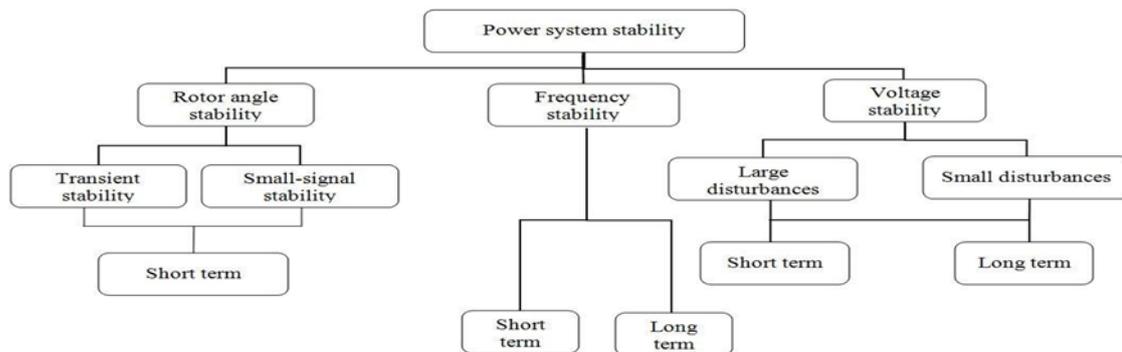

Figure 2.1: Classification of power system stability. Kundur, Paserba, Ajjarapu, and Andersson (2004)

4.2 Rotor Angle Stability

Rotor angle stability refers to the ability of synchronous machines of an interconnected power system to remain in synchronism after being subjected to a disturbance Kundur, Paserba, Ajjarapu, and Andersson (2004). It can be categorized into the following subcategories:

4.2.1 Transient Stability

This is the ability of the power system to maintain synchronism after a large disturbance e.g. loss of a generator or major load, system faults. In transient stability analysis the action of governors and AVRs is not considered and the time frame of interest is usually 3 to 5 seconds following the disturbance. It may extend to 10 to 20 seconds for very large systems with dominant inter-area swings. Kundur, Paserba, Ajjarapu, and Andersson (2004)

4.2.2 Steady State Stability

This is the ability of the power system to maintain synchronism when the system is subjected to slow gradual disturbances such as gradual power changes. Glover, Sarma, and Overbye (2009).It is basically concerned with the determination of the upper limit of the machine loading before losing synchronism provided the loading is increasing gradually. Glover, Sarma, and Overbye (2009)

4.2.3 Dynamic Stability

This is the ability of the power system to maintain synchronism after a small disturbance lasting for a long time after the action of with the inclusion of voltage regulators and turbine governors. Dynamic stability analysis covers longer intervals of 5 to 10 seconds and occasionally up to 30 seconds. Glover, Sarma, and Overbye (2009)

4.2.4 Voltage Stability

This can be defined as the ability of a power system to maintain steady voltages at all buses in the system under normal operating conditions, and after being subjected to a disturbance. The main factor causing voltage instability is the inability of the power system to meet the reactive power demand. Machowski, Bialek, and Bumby (1997)

4.2.5 Frequency Stability

This refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load. The main factor causing frequency instability is the inability of the power system to meet the real power demanded by the load. Machowski, Bialek, and Bumby (1997)

4.3 Synchronous Machines Parameters Operating Principle

In the synchronous machines, a magnetized rotor creates a rotating magnetic field in the air gap. If the rotor field is ideally sinusoidal and if the rotor rotates at constant speed, this will induce ideally sinusoidal voltages in the stator windings. If the machine terminals are connected, the currents flowing in the stator windings create a second rotating magnetic field which causes a torque on the rotor. In a synchronous motor, this torque drives a mechanical load; in a synchronous generator, the magnetic torque opposes the mechanical driving torque of the prime mover (e.g. a turbine). Under balanced, a steady-state condition the magnetic torque is equals the mechanical torque, and so the rotor continues to rotate at constant speed. These machines use either round rotor or salient pole rotors. Sridhara, Sasidhara and Vasudevan (2013)

Round Rotor   Round rotors are used with high-speed turbines such as steam or gas turbines; also called turbo generators. Salient pole rotors are used with low-speed hydro turbines. In order to obtain the appropriate frequency in spite of the low rotor speed, salient pole rotors typically have multiple pole pairs. For run-of-river power stations the numbers of poles can be as high as p = 200.Such rotors have very large diameters and short lengths. Sridhara, Sasidhara and Vasudevan (2013)

4.3.1 Stationary Operation of Synchronous Machines

With the losses neglected, the total impedance of the generator as seen from the stator is modeled with a single lumped inductance X_d. This is strictly only valid for the turbo generator with its homogeneous air gap. In the salient pole generator, the same effects that give rise to the reluctance torque which causes the active part of the stator current see a smaller reactance Xq than the reactive part, for which the reactance X_d is effective[8, 21]. Typical values for X_d and Xq are listed in Table 2.1

	Round Rotor	Salient Pole Rotor
Xd (p.u.)	1.0 – 2.3	0.6 – 1.5
Xq (p.u.)	1.0 – 2.3	0.4 – 1.0

Table 2.1 Typical values of reactances for synchronous machines. Sridhara, Sasidhara and Vasudevan (2013)

4.3.2 Dynamic Operation of Synchronous Machines

During network transients, the reactance of the synchronous generator is not constant. For symmetrical transients, on short circuits of synchronous machines, the machine reactance itself undergoes transient changes as the machine passes through the sub-transient, transient, and steady-state stages. The rotor of a synchronous machine rotates with synchronous speed in steady state. An important parameter in the analysis of rotor oscillations is the total moment of inertia of the synchronous machine J. This is the sum of all moments of inertia of all rotating parts of the synchronous machine, i.e. the sum of the moments of inertia of the rotor, turbines, shafts and other devices on the shaft system, e.g. generator feeding the field winding. As for electrical quantities it is practical to express J in a suitable p.u. Base hence the inertia constant of the synchronous machine H is defined as:

$$H = 0.5J\ddot{\omega}^2_{mo}/ S \qquad\qquad (4.1)$$

Where S is MVA rating of the machine and $\ddot{\omega}$ is rotor angular velocity. The numerator is an expression for the total kinetic energy stored in the synchronous machine in steady state and the unit for H is thus seconds. The inertia constant states how much time it would take to bring the machine from synchronous speed to standstill if rated power is extracted from it while no mechanical power is fed into it. The value of the inertia constant will vary within a much smaller range than the value of J for different machines. Table 2.2 shows typical values of H for different types of synchronous machines. Sridhara, Sasidhara and Vasudevan (2013)

Type of Synchronous Machine	Inertia Constant H (s)
Thermal Power	
• Steam Turbine	4 – 9
• Gas Turbine	7 – 10

Hydro Power	
• Slow (< 200 min−1) • Fast (≥ 200 min−1)	2 − 3 2 − 4
Synchronous Compensators	1 − 1.5
Synchronous Motors	≈ 2

Table 2.2 Typical values of H for different types of synchronous machines. Sridhara, Sasidhara and Vasudevan (2013)

It's evident that the H value is higher for thermal units as compared with hydro units. In line with this, electrical power system is more stable when geothermal plants are used to meet the power demand of the load. This is so because the inertia of geothermal power plants is higher than for hydro plants. A smaller inertia decreases the critical clearing time. The reason is that the smaller the H constant the smaller P_{max}. A smaller P_{max} constrains a machine to swing through a smaller angle from its original position before it reaches the critical clearing angle. Therefore, smaller H constant decreases the critical clearing time and lowers the probability of the system to maintain stability. Thirty to sixty per cent of the total inertia of a steam turbo-generator unit is that of the prime mover, whereas only 4-15% of the inertia of a hydroelectric generating unit is that of the waterwheel, including water.

5.0 DISCUSSION

At the end of this study, it is expected that the impacts of integrating geothermal power on the transient stability of the Kenyan power system will be determined. These results will help those involved in the project area along the geothermal project areas in the Rift valley resources' bed to be able to know what is expected when the project will be finally completed. The result will also help the Kenyan power system operators put necessary measures to demystify the impacts that might come as a result of the integration. In the analysis of stability of the power system it is essential to understand the behavior of the GPPs under steady state and dynamic conditions. The system dynamics and their characteristics under normal operation and under faults conditions will be identified.

6.0 CONCLUSION

It's evident that the H value is higher for geothermal power plants as compared with hydro units. In line with this, electrical power system is more stable when geothermal plants are used to meet the power demand of the load. This is so because the inertia of geothermal power plants is higher than for hydro plants. This study will give the extended and better transient stability margins as geothermal are integrated into a power system.

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