Research/Technical Note

Analysis of the Power Blackout in the Ethiopian Electric Power Grid

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Abstract: In recent years, with an increasing load demand for rural electrification and industrialization, the Ethiopian power system has faced more frequent, widely spread and long-lasting blackouts. To identify the impacts, analyzing and studying the reasons and the mechanisms of such blackouts would be the first step and so, the January 6th, 2016 blackout of the Ethiopian Electric Power (EEP) is reviewed based on the data that are available at the National Load Dispatch Center (NLDC) archive. The analysis is done by considering the sequential phases of the blackout: system condition prior to the power failure, initiating events, cascading events, the final state of the power system and its restoration. Computer simulations are then performed using DIgSILENT PowerFactory software to identify the root cause of the blackout and evaluate the initiating event that had triggered the sequence of events that followed. In doing so, two procedures are followed. Firstly, power flow simulation is run to analyze the system performance under steady state conditions to determine the voltage magnitude at critical buses and the loadings of lines and generators prior to the disturbance. Secondly, time domain simulations are performed to analyze the system performance under transient conditions for the specified initiating and cascading events. Above all the possible method is suggested for the prevention of such incidents.

Keywords: Cascading Events, Electricity Blackouts, Power Flow Simulation, Restoration, Steady State

1. Introduction

1.1. Blackouts in Electrical Power Systems

Blackouts are major incidents in the power systems. A blackout is described by its geographical scale, depth and duration [1]. The depth is related to the number of not supplied customers. The geographical scale and depth together determines whether the blackout is partial or a total blackout. The duration indicates the severity of the incident and its consequences, particularly in terms of cost. A blackout always results from an initiating event and worsening factors. Some of these initiating events and worsening factors are contact between line and tree, short circuit fault, equipment failure, heavy load, switching mistakes, etc... [2, 3]. Evaluation of worldwide disturbances show that protection systems have been involved in 70% of the blackout events [2].

Analyzing and studying the reasons and the mechanisms of blackouts would be the first step for blackout prevention. This paper presents the assessment of January 6, 2016 large scale incident in the Ethiopian Power Grid. The paper further attempts to draw recommendations for preventing future blackouts that will arise on the system. Moreover, the patterns of cascaded events in blackouts and the different defense mechanisms can be seen in the studies [4, 5].

1.2. Overview of the Ethiopian Electric Power System

The Ethiopian Electric Power (EEP) is a national company; operated and owned by the government of Ethiopia (GoE) and is responsible for constructing and maintaining generation plants, transmission lines and HV substations of the country. The main HV levels of the power transmission lines are 400 kV, 230 kV and 132 kV. Among them, the

400kV and 230kV transmission lines are the most important lines, responsible for the intra-power flows and for interconnecting the eight regional power systems: Northern, Northwestern, Northeastern, Southern, Southwestern, Western, Eastern, Central and Addis Ababa regions. The electrical network is extended to Djiboutian network on the east and the Sudanese network to the northwest and consists of 1071.76 km of 400 kV circuits, 5895.54 km of 230 kV circuits and 4666.79 km of 132 kV circuits [6]. The main HV transmission grid of the EEP system is shown in Figure 1.

Currently, the total installed generation capacity is reaching over 4300 MW and a peak load of 2164 MW has been registered.

Because of the high economic development tempo in Ethiopia in recent years, the total load has increased continuously and its power system has been extended accordingly. Nowadays, the Ethiopian power system has suffered wide area electricity blackouts [7]. This paper focuses on analyzing one serious blackout which happened on January 6, 2016.
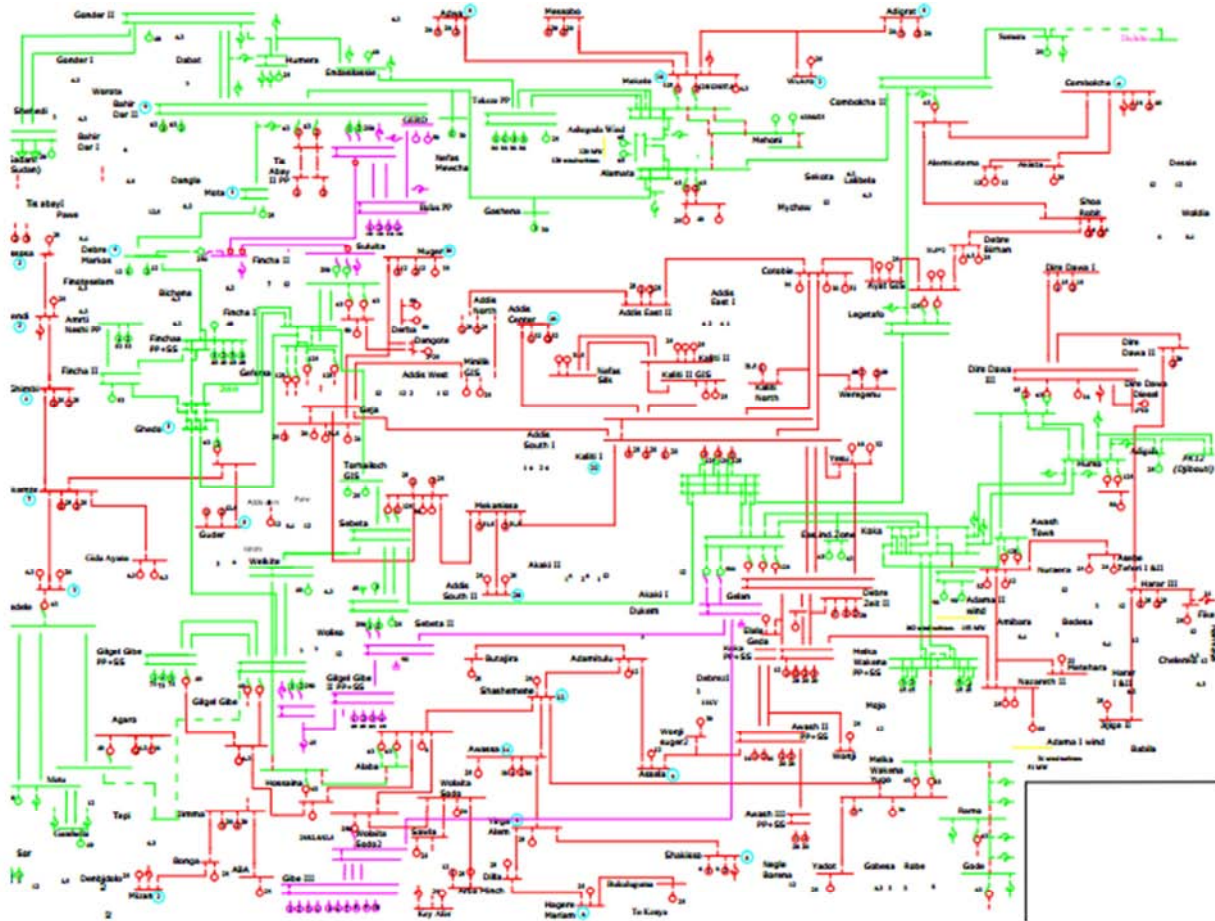
N623 - represents buses at Kality I 230/132 kV substation
N557 - buses at Gefersa 230/132 kV substation
N555 – bus at Bahir Dar II 230/132 kV substation
N420 – bus at Fincha 230/132 kV substation
AKA400 – bus at Akaki I 400/230 kV substation

BEL400 – bus at Beles 400 kV station
SEBII4 – bus at Sebeta II 400/230 kV substation
SEKO40- bus at Sekoru 400/230 kV substation
TEK230 – bus at Tekeze 230 kV station
GG I – synchronous generators at Gilgel Gibe I HPP

GG II – synchronous generators at Gilgel Gibe II HPP
GG III –synchronous generators at Gilgel Gibe III HPP
GGIII – synchronous generators at Gilgel Gibe III HPP

Figure 1. The main HV transmission grid of EEP [7].

2. Analysis of the January 6, 2016 Blackout

The last month of the year 2015 and the first month of the year 2016 were challenging times for EEP. In these two months only, four large scale blackouts happened on the EEP power network. This work however focuses on one particular blackout – January 6, 2016. In doing so, the following technical analyses have been carried out to investigate the system collapse by using DIgSILENT PowerFactory software package: power flow simulations to analyze system performance under steady state conditions. The analysis is made by considering the sequential phases of the blackout: system condition prior to collapse, initiating event, cascading events, final state of the system and its restoration.

2.1. System Condition Prior to Power Failure

On January 6, the peak demand at 16:00 hrs was about 1.24 GW, the weather condition was windy as well as rainy in the south western region of the country, around Gilgel Gibe II hydropower plant (GG II HPP). On the other parts of the country (northern and eastern parts), there was no

sufficient rainfall to feed the reservoirs of Awash III and II, Koka and Tekeze HPPs.

The voltages at critical substation buses such as, Kality I 230/132 kV, Sululta 400/230 kV, Sebeta I 230/132 kV, B/Dar II 400/230 kV, Akaki I 400/230 kV, Combolcha II 230/132 kV, and Ghedo 230/132kV showed increments from their nominal values as indicated in Figure 2, but it was still in the acceptable range and therefore, the system was at its normal state. The system frequency was at its nominal value, 50 Hz. The total generation was over 1300 MW at 16:00 hrs, which consisted of 1200 MW of hydropower plant production and the remaining 100 MW was from wind turbine production. The total transnational exchange was 15.8 MW which was exported to Djibouti. Ghedo_Gefersa 230kV transmission line I, which is the vital line for the intra-power flow among southwestern, western, and Central regions, was in a planned maintenance outage. With this information, power flow simulation is conducted to evaluate the steady state condition prior to disturbance. The results of this simulation are depicted in Figures 2, 3, and Table 1. the voltages at different buses that deviate (although the range is in the normal operating range) from the specified 1.0 pu are indicated in Figure 3. The bus voltages were within the steady state limits (the minimum being 0.98 pu at Kality I 230 kV bus and the maximum being 1.05 pu at Beles 400 kV bus).
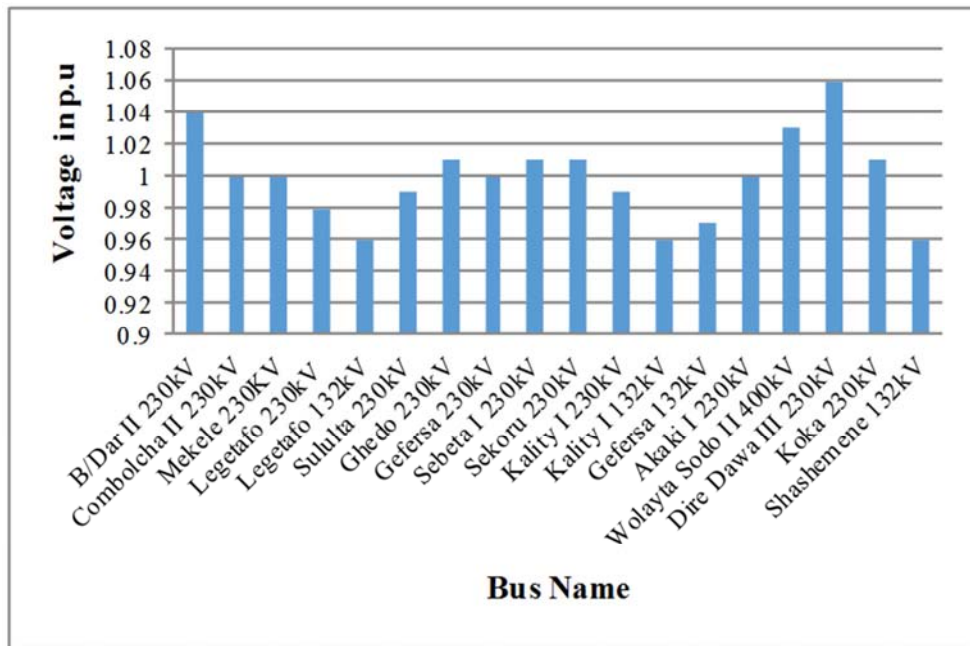

Figure 2. *Voltages at critical buses prior to disturbance.*
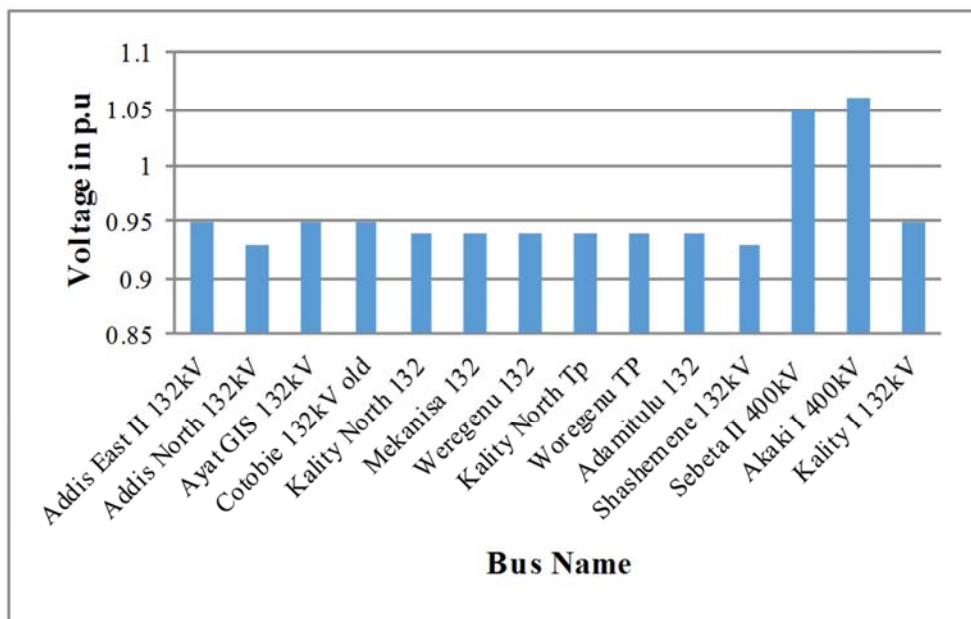

Figure 3. *Voltage profiles of buses with deviations by 5% or more.*

The power flow on important transmission lines is far below their ratings and is given in Table 1. The total grid loss is 34.89 MW.

Table 1. Power Flows on Important Lines before the Incident.

No.	Important Line (s)	MVA
1	B/Dar II_Alamata 230kV line	72 + j50
2	Sululta_D/Markos 400kV line	192 + j77
3	Suluta_Gefersa 230kV line I and II	84 + j35
4	Sebeta I_Kality I 230 kV line	170 + j65
5	Sebeta II_Gelan 400kV line	221 + j22
6	Sebeta II_Gilgel Gibe II 400kV line	326 + j7
7	Gefersa_Ghedo 230kV line II	70 + j2
8	B/Dar II_D/Markos 400kV line	209 + j59

From the company's point of view, the power system operation was normal and the voltage variations at the critical buses were acceptable.

2.2. Initiating Events

At 16:16 hrs, GG II_Sekoru 400kV line was tripped by zone I protection due to the occurrence of a three-phase to ground short circuit fault (LLL-G) at a distance of 7.8 km from Sekoru substation as indicated in Figure 4. To investigate the behavior of the system with this fault, a time domain simulation is run, and the speed, rotor angles, terminal voltages, the mechanical power input and electrical power output of power plant generators are considered for evaluation. In addition, the voltages at critical buses and their corresponding frequency deviations; the currents and voltages across GG II_Sebeta II 400 kV and GG I_Sekoru 230 kV lines before and immediately following the disturbance are considered.
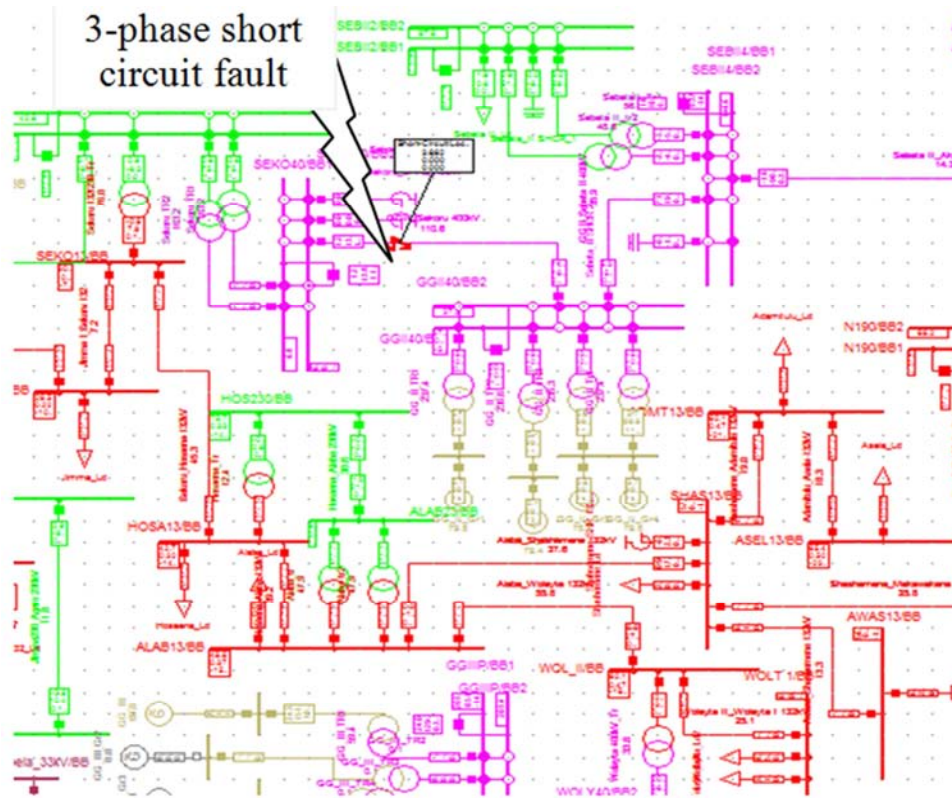

Figure 4. Initiating event of the January 6, 2016 blackout.

2.2.1. Before the Disturbance

The rotor angles of HPP generators prior to the the initiating event were at their steady values as shown in Table 2. The synchronous speed (ω_s) of all the HPP generators was 1.0 pu. The terminal voltage of each generator was also synchronised to 1.0 pu.

Table 2. Rotor Angles of HPP Generators Prior to the Disturbance.

Hydropower Plant Generators	δ_{i0} (radians)
Beles (Gr1, Gr2, Gr3, Gr4)	-0.32
Fincha (Gr1, Gr2, Gr3, Gr4)	-0.382
Gilgel Gibe (GG) III (Gr1)	-0.738
Gilgel Gibe II (Gr1, Gr2, Gr3, Gr4)	-0.738

Hydropower Plant Generators	δ_{i0} (radians)
Awash III (Gr2)	-1.491
Koka (Gr1, Gr2)	-1.041
Tekeze (Gr1)	-0.777
Gilgel Gibe I (Gr1, Gr2)	-0.635
Melkawakena (Gr4)	-0.911

The reactive powers supplied by generators at steady state along with the maximum and minimum reactive power limit were indicated in Table 3 and it is observed that all the generators' reactive power supplied/absorbed prior to the initiating event are within the acceptable ranges. The current through GG II_Sebeta II 400 kV line is 0.109 pu and the voltages across this line is around 1.037 pu; and the current

through GG I_Sekoru 230kV line is 0.114 pu and the corresponding voltage across this line is 1.010 pu.

The turbine power (P_{mi}) input and the electrical power (P_{ei})

output of each HPP generator is shown in Table 4 and there is no overloaded generator prior to the disturbance.

Table 3. *Reactive Power Supplied by each HPP Generator Prior to Disturbance.*

HPP Generators	Reactive Power Supplied by each Generator (MVAr)	Q_{min} (MVAr)	Q_{max} (MVAr)
Beles (all units)	-33.01	130	130
GG III (Gr1)	-75.56	-100	100
Tekeze (Gr1)	-13.16	-38	38
GG I (Gr1, Gr2)	-7.83	-21	21
Awash III (Gr2)	6.693	-15	13
GG II (all units)	-7.833	-50	50
Koka (Gr1, Gr2)	2.151	-12	11.6
Melekawakena (Gr4)	0.532	-45	45

Table 4. *Turbine Power Input and Electrical Power Output of HPP Generators Prior to the Disturbance.*

HPP Generators	Turbine Power (P_{mi}) in pu	Electrical Power (P_{ei}) in pu
Beles (all units)	0.796	0.796
Fincha (All units)	0.940	0.940
GG III (Gr1)	0.406	0.406
GG II (all units)	0.807	0.807
Koka (Gr1, Gr2)	0.654	0.654
Tekeze (Gr1)	0.521	0.521
Melkawakena (Gr4)	0.782	0.782

2.2.2. Immediately Following the Disturbance

The earth fault trip time for protective relays can be set from 0 to 10 seconds, depending on the network levels, fault types and characteristics according to [8]. For the three-phase to ground fault, the fault clearing time should not exceed 8 cycles (160ms) [9]. Hence, for our case, a 150 ms fault clearing time is taken to conduct a 10-seconds transient simulation. This time domain transient simulations over a period of 10-seconds after initiation of the disturbance are shown in Figures 5, 6 and 7. These simulations depict the dynamic performance of EEP system by representing profiles of generator rotor angles, speed and terminal voltages, etc...

After the fault has been cleared the speed of generators returned to the normal operating ranges with damped oscillations. The rotor angles of Beles, Fincha and Tekeze HPP generators were having their steady state values with little oscillations. The rotor angles of the remainning generators were transiently stable with sustained oscillations as dipicted in Figure 5.
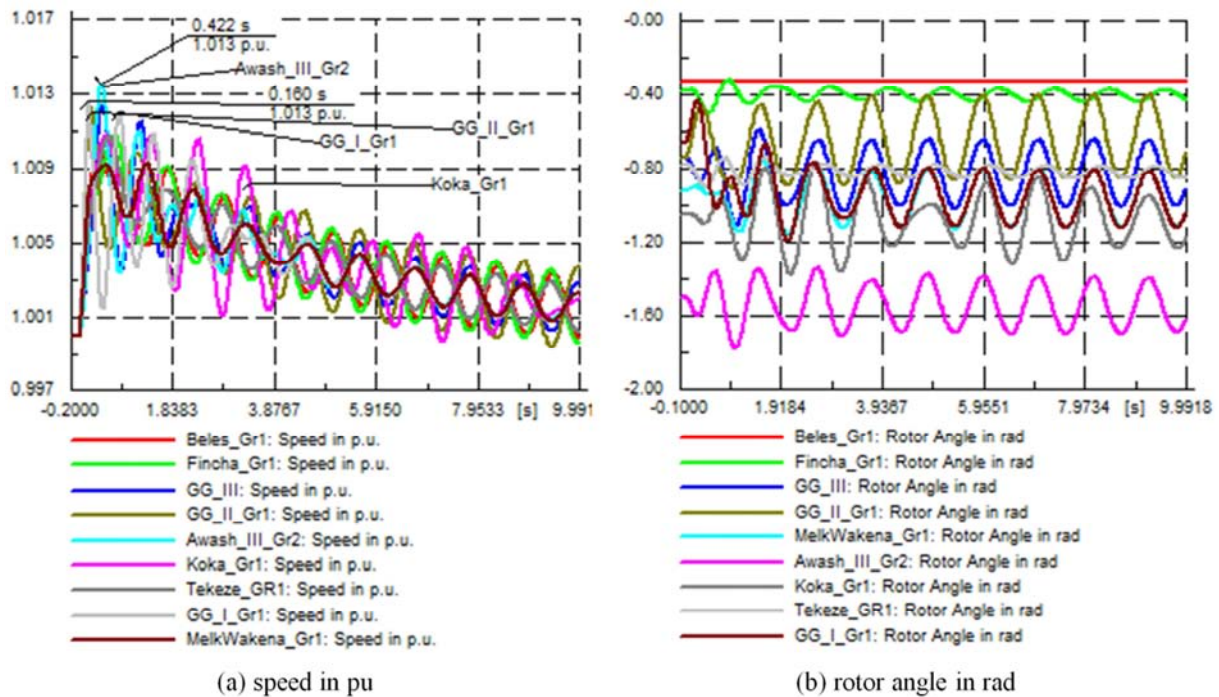

(a) speed in pu

(b) rotor angle in rad

Figure 5. *Speed and rotor angle profiles of HPP generators.*
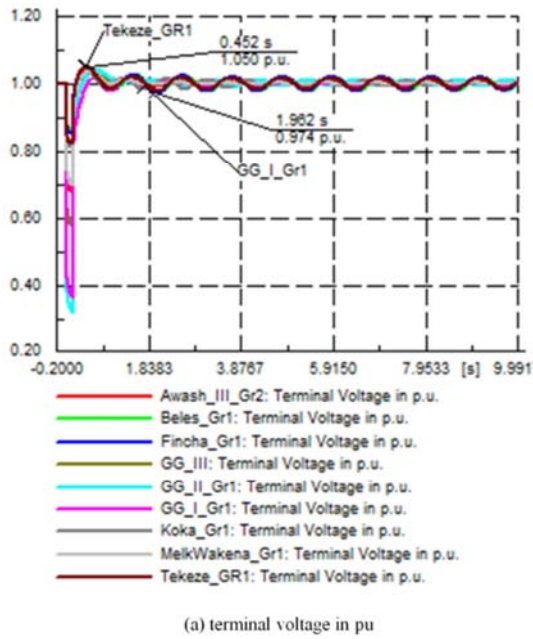
(a) terminal voltage in pu

Figure 6. Terminal voltage of HPP generators.

The terminal voltages of all the generators were recovered to well above 0.98 pu. The reactive power supplied by each generator was recovered to their steady state values. The other important characteristics observed on the generators' chracteristics was that as the terminal voltage was dipped, high reactive power was absorbed by their corresponding generators during the short circuit fault as indicated in Figure 6. The reason is that, during the short circuit fault, there is no load supplied by the generators. The electrical power output of these generators is almost collapsed during the fault.

In addition, the voltages at critical buses were also returned to the normal operating conditions range after the fault on the line has been cleared within 150 ms. The

frequency deviation observed on GG II 400 kV substation was 0.5 Hz and on other critical substations it was 0.4 Hz at 150 ms and later the frequency deviations were lowered to below 0.2 Hz. After the line fault has been cleared. Figure 7 depicts these conditions.

There was no overloaded component observed on the system and all the parameter of the power system were observed to be in the normal operating ranges.

Therefore, from the simulation results we can say that if the fault clearance time setting of the protective relays of Gigel Gibe II_Sekoru 400 kV line at both ends were 150 ms or shorter than this, the sequence of events observed on the SCADA would not be observed and hence, the blackout of January 6, 2016 would not have happened.
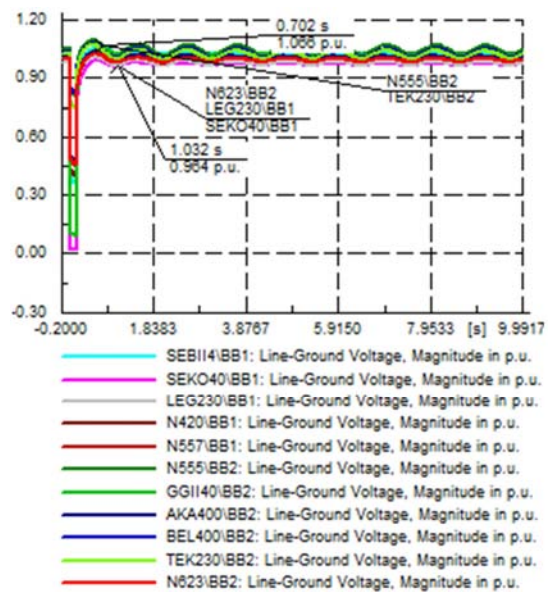

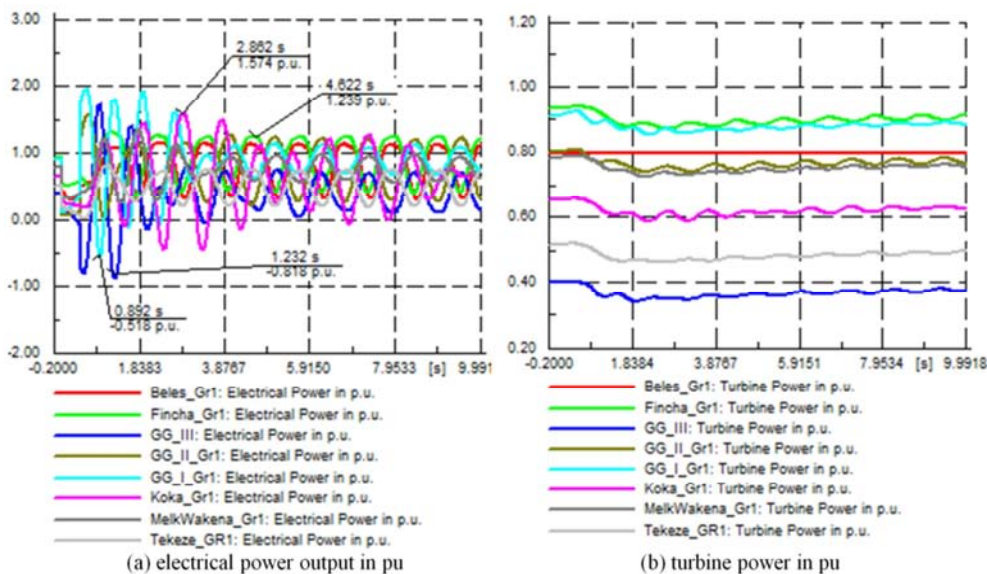*Figure 7. Voltage profiles of critical buses.*

2.3. Cascading Events

(a) electrical power output in pu

(b) turbine power in pu

Figure 8. Turbine power input and electrical power output of HPP generators for a fault clearing time of 450 ms.

As we have discussed above, the line fault on Gilgel Gibe II_Sekoru 400 kV line would not result in the blackout of January 6, 2016 if the fault were cleared within 150 ms. A similar transient simulation is done for the given short circuit fault with a fault clearing time of 200 ms, 250 ms, 300 ms, 350 ms, 400 ms and 450 ms. From the simulation results, it is observed that the system survivability is up to a fault clearing time of 400 ms. However, when the fault clearance time exceeds 450 ms, the system could no longer survive from cascaded tripping of components. The sequence of cascading events observed on the SCADA (as it was obtained from NLDC archive) and the simulation result obtained here are synonymous for a fault clearance time of 450 ms. The RMS simulation results for a fault clearing time of 450 ms are shown in Figures 8, 9 and 10.
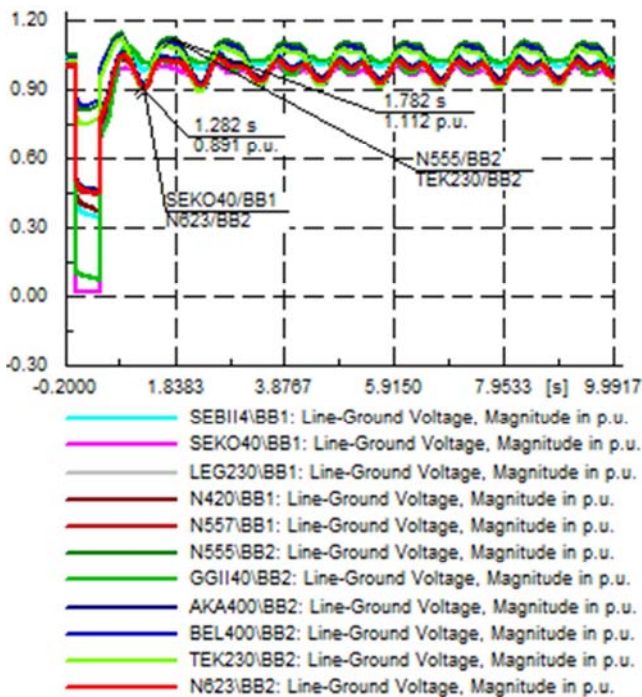

Figure 9. *Voltage profiles at critical buses for a fault clearing time of 450 ms.*

The turbine power input to the HPP generators were showing a decrease from the steady state value by their corresponding governor actions to compensate for the increase in the speed of generators. The electrical power output of these generators was unable to damp and recover to the steady state values as is indicated in Figure 8.

The bus voltages and their corresponding frequency deviations at critical buses of EEP are shown in Figure 9. Accordingly, the voltage at Kality_I 230 kV bus was oscillating around the lower limit of the bus voltage and the voltages at the rest of the critical buses were recovered well above 0.95 pu with damped oscillations after the fault has been cleared at 450 ms.
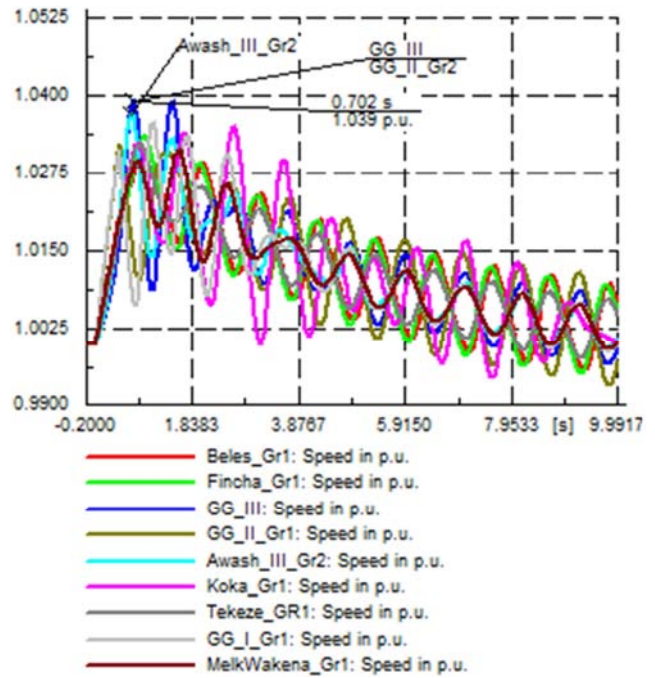

Figure 10. *Speed profiles of HPP generators for a fault clearing time of 450 ms.*

As it is observed from Figure 10, the speed (frequency) of Gilgel Gibe II HPP generators was reached to 1.039 pu around 70.2 ms. In addition, the speed of Awash III and GG III HPP generators were increased to 1.037 pu and 1.039 pu respectively at around 71.8 ms. In this case, the frequency of GG II HPP generators has been drastically increased and they lost synchronism and became monotonically unstable. Their rotor angle is swinging back and forth. Therefore, the corresponding over frequency protection tripped all the four units of GG II HPP. Let the tripping of GG II HPP generators at 70.2 ms, Awash III and GG III HPP generators at 71.8 ms be called as switching event 1 (SE-1), just to describe it shortly. Therefore, applying these switching events (SE-1) with a time domain simulation of 10 seconds, the results are indicated in Figures 11, 12, 13, 14 and 15.

After SE-1, the terminal voltages of HPP generators, though there was a decrease in their magnitude, it was well above 0.90 pu with damped oscillations. There was a high reactive power deficit in the system and as a result Beles HPP generators were forced to generate high reactive power near to their lower limits. These conditions are indicated in Figure 11.

As GG II and GG III HPP generators tripped, the remaining generation was unable to supply the load. As a result, the electrical power output of the remaining generators was rising beyond 1.0 pu to satisfy the load-generation balance. This situation is indicated in Figure 12. In addition, there was a reverse power flow (-0.616 pu) to the generators of GG I HPP at around 1.106 seconds.
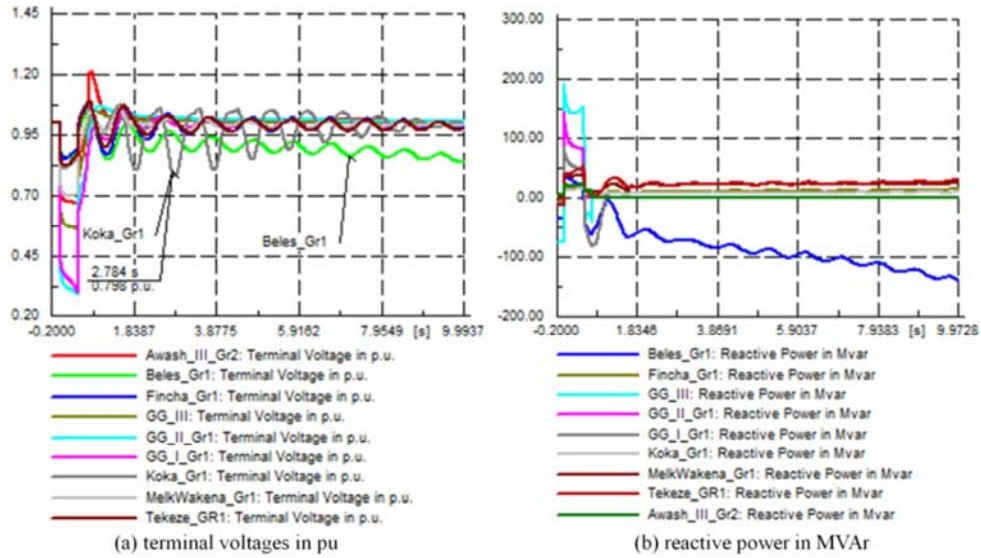
Figure 11. *Terminal voltage and reactive power supplied by HPP generators after SE-1.*
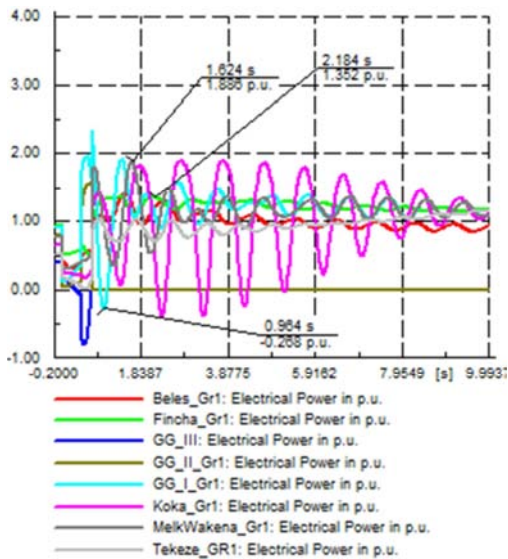

Figure 12. *Electrical power output of HPP generator after SE-1.*
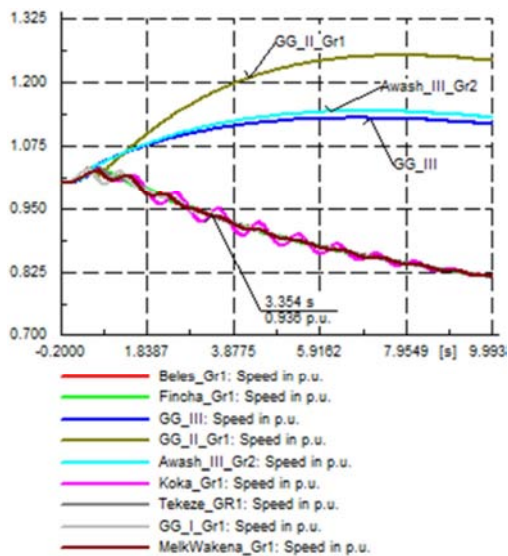

Figure 13. *Speed profiles of HPP generators after SE-1.*

As GG II HPP generators had tripped, the system lost 27% of the total system generation and therefore, the balance between the load plus the losses and the generated power had been violated. As a result, the system frequency had been deteriorated and the speed of generators was continually depressed went below 0.98 pu after SE-1. Further observation can be made on Figure 13.

On the other hand, the voltages at the load buses were demolished and the system lost its consistency, as it is shown in Figure 14.
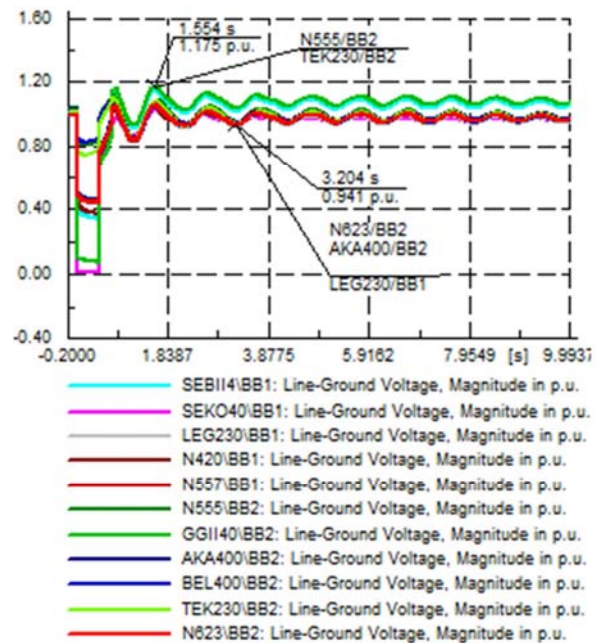

Figure 14. *Voltages at critical buses after SE-1.*

The voltage across GG II_Sebeta II 400 kV line was reached to 1.172 pu (overvoltage) at around 1.651 seconds, as shown in Figure 15.
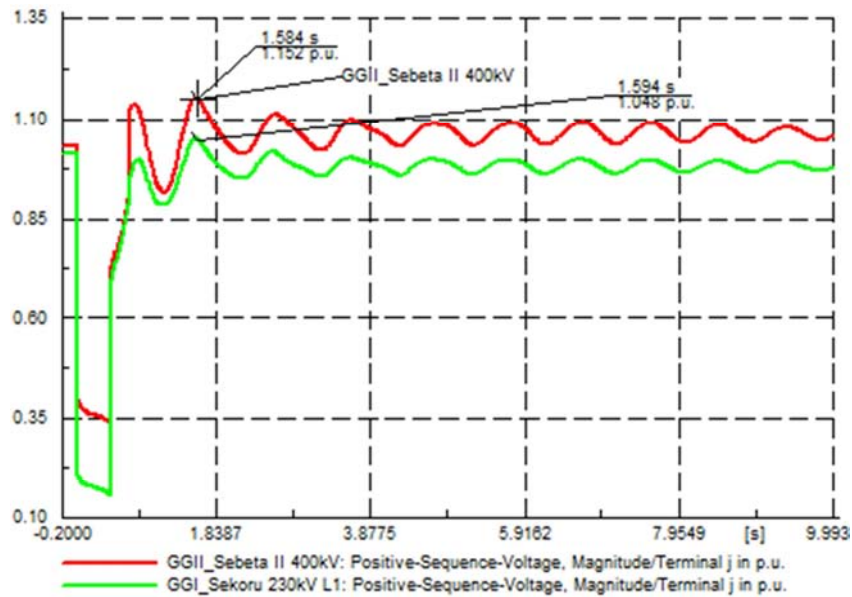
Figure 15. Voltage across lines after SE-1.

Therefore, components having out of limit parameters continued to trip by their corresponding protection systems and created cascading events. SE-1 aggravated the situation and was followed by switching event 2 (SE-2) and includes:

1. Tripping of GG I HPP generators with reverse power protections.
2. Tripping of GG II_Sebeta II 400 kV line by overvoltage protection.

After SE-2, again a 10-second time domain transient simulation was performed and it is observed that the system was unable to recover from its weaknesses. The simulation results are depicted in Figures 16, 17 and 18. Accordingly,

Melkawakena and Koka HPP generators were further overloaded and finally tripped by overcurrent and under-frequency protections, respectively. The speed of Tekeze HPP generator has been declined below 0.925 pu at around 3.314 seconds. On the other hand, the speed of Fincha, Beles, and Awash II HPP generators were also decreased drastically, and they finally became overloaded. Most of these HPP generators were tripped by under frequency protection relays. This frequency collapse was not easily recovered by governor actions and therefore, the cascaded tripping of HPP generators by overcurrent and under-frequency protections were continued.

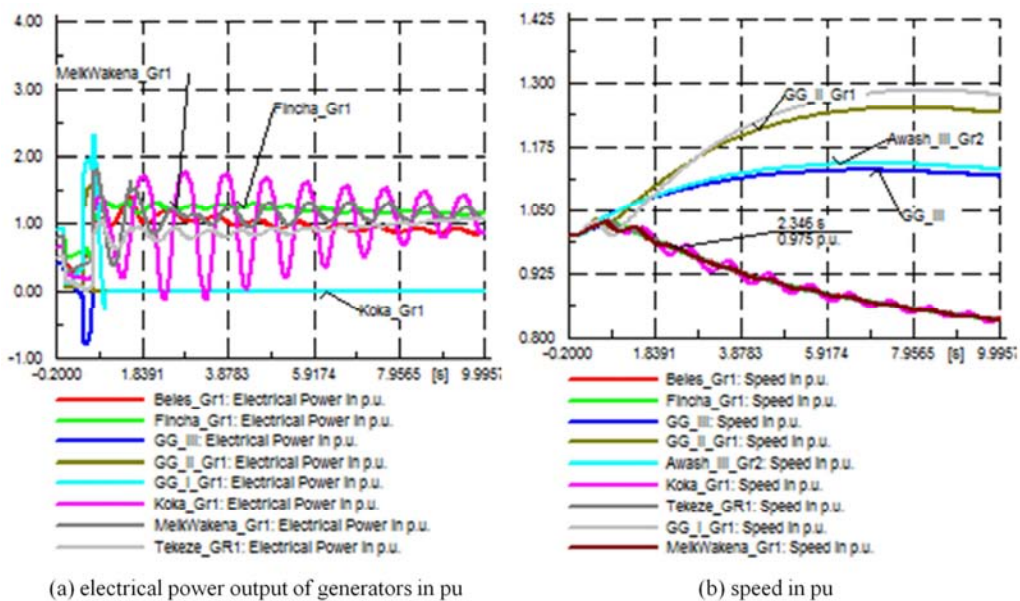(a) electrical power output of generators in pu

(b) speed in pu

Figure 16. Electrical power output and speed profiles of HPP generators after SE-2.

Moreover, the terminal voltages of Beles HPP was lowered below 0.85 pu and the reactive power supplied by each

generator was increased to -100 MVAr to support the reactive power deficit in the system, as it is shown in Figure 17.
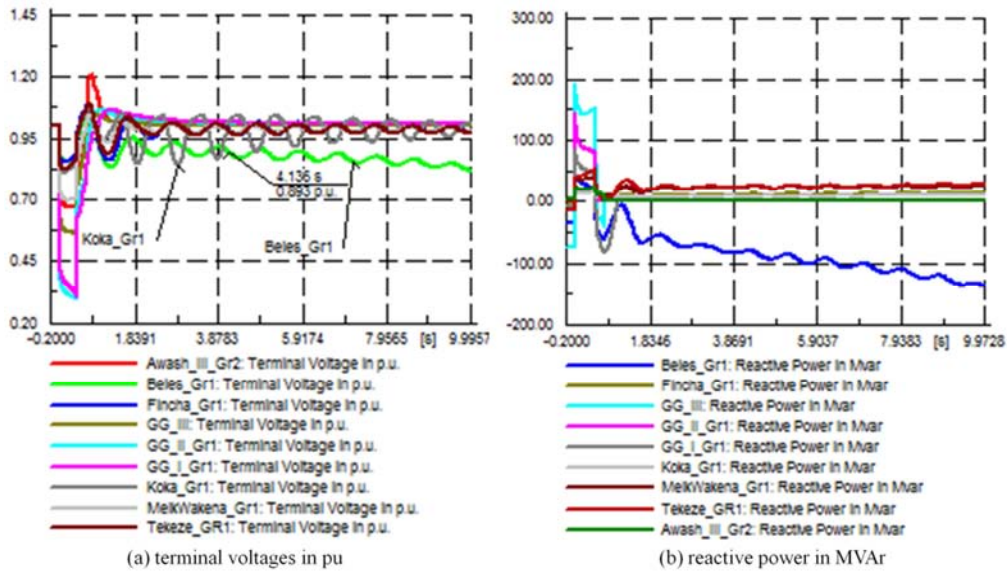
(a) terminal voltages in pu   (b) reactive power in MVAr

Figure 17. Terminal voltage and reactive power supplied by HPP generators after SE-2.

The tripping of GG II _Sebeta II 400 kV line and GG I HPP generators also forced the path of the load flow to change to the remaining generating plants and nearby transmission lines. This further aggravated the situation and GG I_Sekoru 230 kV line became overloaded and finally tripped by overcurrent protection. The voltages at critical buses (like Kality I 230 kV, Legetafo 230 kV, Sekoru 400 kV,

etc..) declined below 0.90 pu and their corresponding frequencies were collapsing to 41 Hz (frequency collapse has occurred) as shown in Figure 18. As a result, there was no way to recover the system to its normal state and the system cascaded tripping was continued till the system was totally collapsed within 60 seconds.
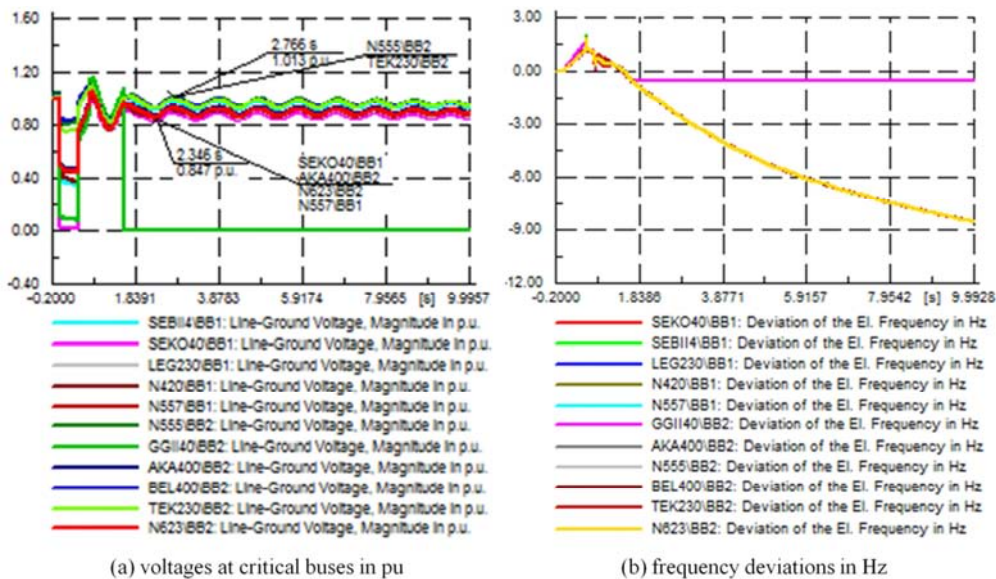

(a) voltages at critical buses in pu   (b) frequency deviations in Hz

Figure 18. Voltage and their corresponding frequency deviation at critical buses after SE-2.

2.4. Final State of the System

Finally, the Ethiopian electric power system collapsed and left all the customers in dark. All the power plants and equipment were out of service and all network areas of the country were affected.

2.5. System Restoration

The restoration time for the important loads of the capital,

Addis Ababa, was made with 40 minutes and most of the substations were restored within 2.5 hours. Customers sustained power cuts lasting between 40 min to 2.5 hours.

2.6. Process of the January 6, 2016 Blackout

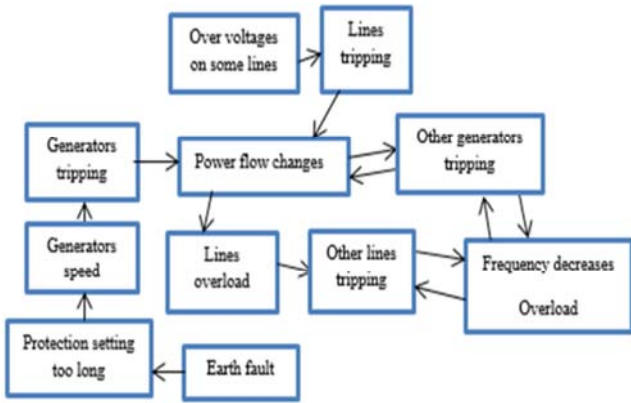The process of the January 6, 2016 blackout can be summarized as shown below.

Figure 19. Process of the January 6, 2016 blackout.

3. Recommendations to Prevent the Blackouts

As can be seen from Section 2, the root cause of the blackout was due to the slow fault clearing time. This is so because the amount of kinetic energy gained by the generators during a fault is directly related to the fault duration. The quicker the fault is cleared the less the disturbance it causes [10]. Two-cycle breakers, together with high-speed relays and communication, are now widely used in locations where rapid fault clearing is important [11].

Moreover, the blackout of 6th January 2016 happened due to the slow fault clearing time settings of the protective relays of the faulted line. In this section, the system with the given short circuit fault is simulated with a fault clearing time of 150 ms. The simulation results depicted that the speed of GG I and GG II HPP generators were increased to only 1.012 pu during the fault and returned to 1.001 pu with damped oscillations after the fault has been cleared. This is depicted in Figure 20. The terminal voltages of all the HPP generators were returned to 1.0 pu after the fault has been cleared. The reactive power generated from these generators was also within limits with this fault clearing time. Figures 20 (c) and 20 (d) show the terminal voltages and reactive power generated by HPP generators with a fault clearing time of 150 ms.
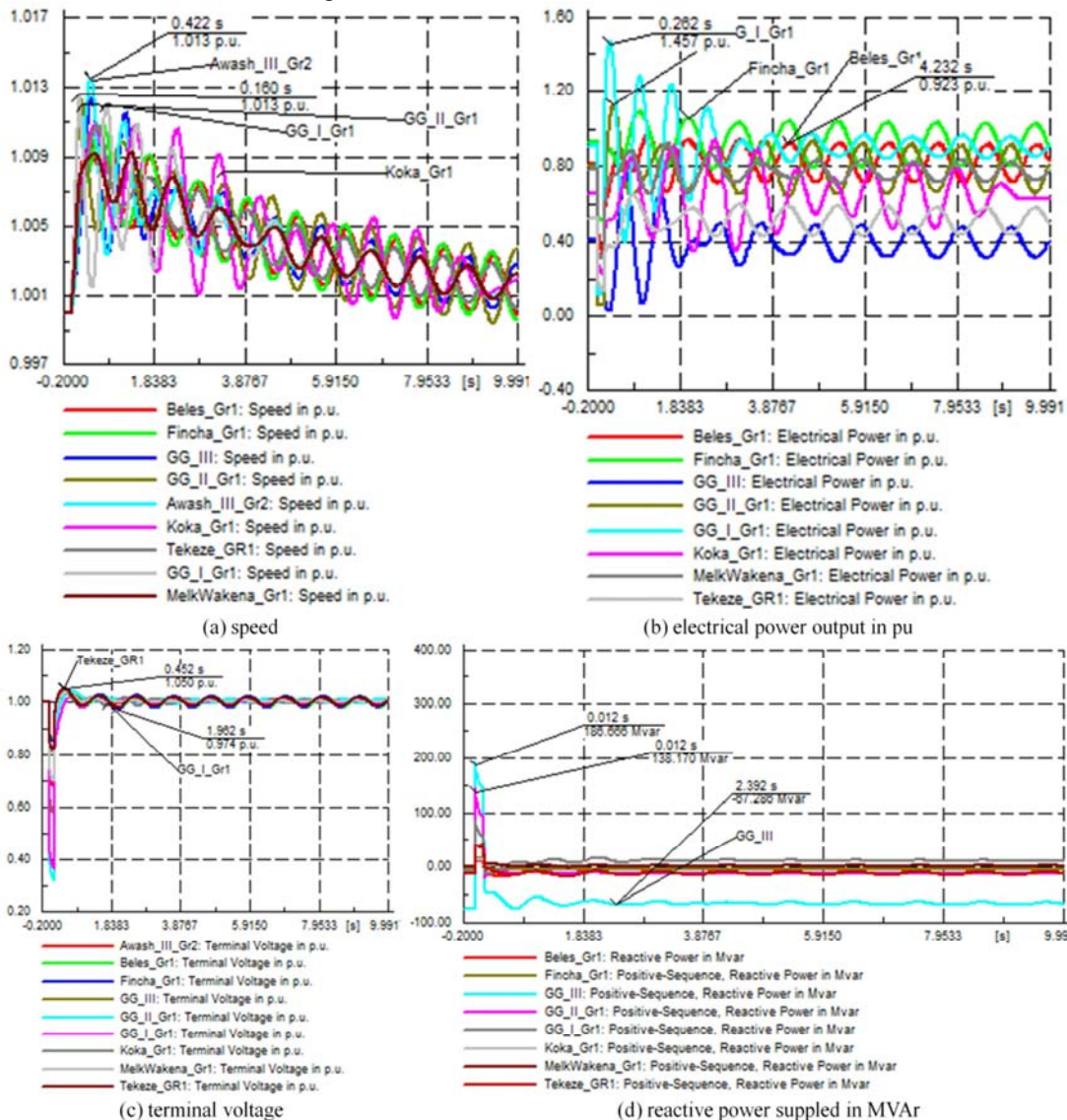

(a) speed

(b) electrical power output in pu

(c) terminal voltage

(d) reactive power suppled in MVAr

Figure 20. Profiles of HPP generators for a fault clearing time of 150 ms.

The voltages at critical buses were also returned to above 0.97 pu after the fault has been cleared. The frequency deviations were not exceeding 0.45 Hz during the fault and returned to below 0.20 Hz after the fault has been cleared. Figure 21 shows these conditions.
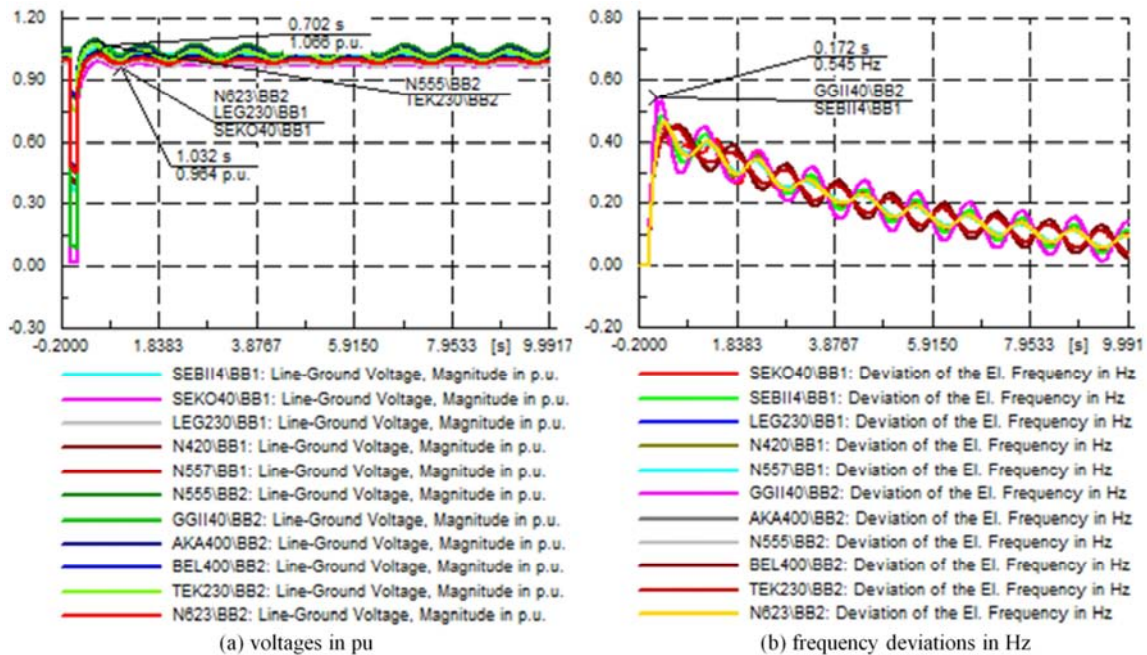

Figure 21. *Voltages and their corresponding frequency deviations at critical buses for a fault clearing time of 150 ms.*

Therefore, from the above analysis, we can conclude that the blackout of January 6, 2016 could be preventable if the three-phase short circuit fault that happened on GG II _Sekoru 400 kV line was cleared within 150 ms.

4. Lessons Learned from the Blackout

From December 2015 to January 2016 alone, four blackouts were happened on EEP's network. These blackouts were created a great impact on residential customers, businesses, and public organizations. In order to mitigate the problem, EEP has taken various measures including installation of under frequency load shedding (UFLS) relays at various selected network sites to prevent the frequency collapse during the disturbance. A shunt reactor having 45 MVAr capacity was installed at Wolaita Sodo 400 kV substation to protect the network from the overvoltage during light load conditions.

5. Conclusions

The society is becoming more dependent on electricity and needs reliable, uninterrupted, secure and affordable supply. Electric utility companies have worked to meet these desires. However, due to natural and human made problems reliable electricity supply of the society has got bottlenecks. In the third world countries like Ethiopia, electricity blackout becomes a headache and is more frequent. Hence, this paper presented an analysis of the Ethiopian Electric power system and one typical blackout of the 6th January 2016. The sequence of events in the blackout

and its analysis showed that the cause of the blackout was linked to the slow breaker actions (not clearing the short circuit fault as fast as possible). This is due to the slow fault clearing time settings of the protective relays. As it is observed in the analysis above, the 6th January 2016 blackout that happened on the EEP grid was preventable if the fault was cleared within 150 ms. Based on the identified blackout cause, a method that can help mitigate likelihood of similar blackouts is proposed. Thus, EEP has to explore this method to combat the frequent occurrences of other similar blackouts.

References

[1] M. Shahidehpour, Handbook of Electrical Power System Dynamics: Modeling, Stability and Control, Piscataway: IEEE Press, 2013.

[2] D. Novosel, "System Blackouts: Description and Prevention," in 2004 IEEE International Conferenceon Electric Utility Deregulation, Restructuring and Power Technologies (DRPT2004), Hong Kong, April 2004.

[3] J. A. S. T. Paul Hines, "Trends in the History of Large Blackouts in the United States," IEEE, 2008.

[4] S. K. S. S. R. N. R. K. P. Subrata Mukhopadhyay, "An Indian Experience of Defense Against Blackouts and Restoration Mechanism Followed," IEEE, New Delhi, 2008.

[5] J. L. Chen-Chin Liu, "Patterns of Cascaded Events in Blackouts," in 2008 IEEE PES General Meeting, Iowa, USA, 2008.

[6] W. B. I. D. Association, "International Development Association Project Paper on a Proposed Additional Credit to the Federal Democratic Republic of Ethiopia for the Electricity Network Reinforcement and Expansion Project," World Bank, Ethiopia, May 6, 2016.

[7] E. E. Power, "Grid Disturbance report," 2016.

[8] SINOHYDRO CORPORATIONS Ltd, "Nifas Silk 132/15kV Substation Protection Relay Setting Manual - Calculation Note," Transmission & Substation Rehabilitation and Upgrading Project, Addis Ababa, 2015.

[9] Ramasamy Natarajan, Computer -Aided power System Analysis, New York: Marcel Dekker, 2002.

[10] P. Kundur, Power System Stability and Control, New York: McGraw-Hill, 1994.

[11] Dr. M. El-Shimy, Dynamic Security of Interconeected Power Systems, vol. 1 & 2, Cairo: LAMBERT, 2015.