Interconnection of Kiriketi Pumped Storage Power Plant in Sri Lanka

MTAP Wickramarathna, *Associate Member, SLEMA,*
BSc Eng. (Hons) (Moratuwa), MSc (Moratuwa), C.Eng., MIE (SL)
Electrical Engineer, Ceylon Electricity Board, P O Box 540, Colombo, Sri Lanka

Key word: pumped storage power plant

Abstract

The site referred to as the Kiriketi oya has three options to develop a 500MW Pumped Storage Power Plant (PSPP). Since all the optional sites are located in the same area, the interconnection study can be considered common for all the three options. This interconnection study is done to connect only one 500MW PSPP which will consist of four 125MW machines. The planning criteria of Ceylon Electricity Board (CEB) have been followed. The study shows that the 500MW Kiriketi PSPP should be directly connected to the 220kV Kotmale power station (PS) bus bar using a 30km long 220kV double circuit of 2xZebra transmission line.

Introduction

The location of the prospective Kiriketi Pump Storage Power Plants (PSPP) is on the Kiriketi Oya, north of the Samanalawewa Reservoir in Haputale, in the Central Province of Sri Lanka. Haputale is about 190 km from the capital, Colombo.

There are a few 132/33kV Grid Substations (GSs) situated in close proximity to the power plant site, such as the Nuwara Eliya GS and the Balangoda GS. Since the proposed capacity of Kiriketi PSPP is 500MW (125MWx4) it should be connected to a 220kV network or higher voltage. The nearest 220kV point is Upper Kotmale PS, but the capacity of Upper Kotmale PS-Kotmale PS 220kV transmission line (2cct. 18.5km, Zebra) is not adequate to serve an additional 500 MW from Keriketi. So the Kiriketi PSPP should be directly connected to the Kotmale power station bus bar using 220kV transmission line (2cct, 30km, and 2xZebra).

This paper has focused not only the Kiriketi PSPP interconnection but also the scheduling of generation which can optimize hydropower generation, while reducing thermal generation. In that scenario, thermal power plants located in Colombo area are basically used for reactive power supply which does not consume much fuel. System studies were conducted under four scenarios of HMDP-Hydro Maximum Day Peak, TMDP-Thermal Maximum Day Peak, HMNP-Hydro Maximum Night Peak, TMDP-Thermal Maximum Night Peak.

The studies were conducted according to the transmission planning criteria of the Ceylon Electricity Board (CEB). The planning criteria are to ensure quality and reliability of supply under normal operating conditions as well as under contingencies.

Planning criteria'

1. **Voltage Criteria**

The voltage criterion defines the permitted voltage deviation at any live bus bar of the network under normal and contingency operating conditions, as given in Table 1.

Table 1 - Allowable Voltage Variations

Bus Bar Voltage	Allowable Voltage Variation (%)	
	Normal operating condition	Single contingency condition
220 kV	±5%	-10% to +5%
132kV	±10%	±10%

2. **Thermal Criteria**

The design thermal criterion limits the loading of any transmission network element, to avoid overheating owing to excessive current flow.

The loading of elements should not exceed their rated thermal loading values for steady state conditions.

3. Security Criteria

The performance of the transmission system under a contingency situation is taken into consideration in the security criteria. The adopted contingency level for the planning purposes is N-1, i.e. outage of any one element of the transmission system at a time.

After the outage of any one element (i.e. any one circuit of a transmission line or a transformer and without any adjustment or corrective measure), the system should be able to meet the distribution demand while maintaining the bus bar voltage levels. Loading of all the remaining elements should not exceed their emergency ratings specified.
After system readjustment following a disturbance described above, the voltage and loading of elements should return to their corresponding normal limits.

4. Stability Criteria

Stability criteria should ensure system stability during and after a system disturbance.
With all the equipment in service, the system should remain stable in case of:

- A three phase fault
- Loss of any one generation unit
- Load rejection by loss of any transformer
- A three-phase fault at any one overhead line terminal will be cleared by the primary protection with successful and unsuccessful auto reclosing.

5. Short Circuit Criteria

The short circuit criteria limits the maximum three phase circuit currents at the 132kV, 33kV and 11kV busbars of any grid substation (see Table 2), to protect the transmission and distribution network elements downstream.

Table 2 - Allowable Maximum 3 Phase Short Circuit Levels

Bus bar Voltage	System	Maximum 3-Phase Fault Level (kA)
132kV and above	Overhead	40.0
	UG cable	40.0
33kV	Overhead	13.1
	UG cable	16.0
11kV	UG cable	20.0

6. Generation Dispatch

The transmission network should allow generation scheduling in merit order and should not require regular operation of out-of-merit generation to prevent an unacceptable voltage profile or loading condition in the event of an outage of any transmission circuit.

Transmission System Studies for Kiriketi PSPP-4 x 125 MW in Year 2015

HMDP Case
In normal operating conditions, no voltage violations were observed. However, Polpitiya-Sithawaka and Sithawaka-Athurugiriya 132kV transmission lines were loaded by 186% and 149% respectively. In present network Kosgama Grid Substation (GS) and Sithawaka GS are fed by both Polpitiya and Kolonnawa GSs. The above loading can be solved by changing the present line arrangement of Kolonnawa-Kosgama, Kolonnawa-Sithawaka, Sithawaka-Polpitiya and Polpitiya-Kosgama 132kV transmission lines, in such a way that Kosgama GS connect only to Kolonnawa GS by double circuit and Sithawaka GS connect only to Polpitiya GS by a double circuit.

Under single contingency operating conditions, no voltage violations were observed but there were a few thermal violations. In the outage of one three-winding transformer at Kotugada, the 33kV winding of the remaining three-winding transformer is loaded by 132%. This problem can be mitigated by constructing a new Kotugoda GS. In the outage of one three winding transformer at Biyagama, the 33kV winding of the remaining three winding transformer is loaded by 135%. This problem can be mitigated by installing a 60MVAr Breaker Switch Capacitor (BCS) define at Biyagama 33kV bas bar. In the outage of one New Chilaw-Madampe circuit (cct), the remaining cct is loaded by 123%. This overloading occurs owing to design limitation of the transmission line, i.e. the tower lines have been designed for 54 °C maximum operating temperature and it reaches the maximum sag level under lower transmission levels. So it is proposed to upgrade the New Chilaw- Madampe transmission line to operate at 75°C. In the outage of one Pannipitiya-Kolonnawa circuit (cct), the remaining cct will be overloaded by 137%. An outage of Colombo A-Dehiwala 132kV cable results 132% loading in the Pannipitiya.-Jayawardanapura ccts. Both the above overloading situations can be mitigated by method no 1.

*Mitigation method no 1: Pannipitiya – Kolonnawa 132 kV lynx line has been constructed in 1971. Tower lines have been designed for 54 °C maximum operating temperature. It is almost 40 years old.

Overloading occurs owing to the lack of generation in Colombo. Therefore, the mitigation method is to construct a 132kV cable between Pannipitiya and Kolonnawa. The other option is to implement operational solutions in contingencies, such as switching off the J'pura connection from Pannipitiya-Kollonnawa line and supply J'pura GS from the cable only. However, in some contingencies, making operational interventions will be difficult.

TMDP Case
In normal operating conditions no voltage violations are observed. However, Polpitiya-Sithawaka 132kV transmission line is loaded by 152%. The mitigation method to this overloading is to change the present line arrangement of Kolonnawa-Kosgama, Kolonnawa-Sithawaka, Sithawaka-Polpitiya and Polpitiya-Kosgama 132kV transmission lines to double circuit of Kolonnawa-Kosgama and double circuit of Polpitiya-Sithawaka, by year 2016.

Under single contingency operating conditions, no voltage violations were observed but there will be a few thermal violations. In the outage of one three winding transformer at Kotugada, the 33kV winding of the remaining three winding transformer will be loaded by 140%. This problem can be mitigated by constructing the New Kotugoda GS. In the outage of one three winding transformer at Biyagama, the 33kV winding of the remaining three winding transformer will be loaded by 125%. This problem can be mitigated by installing 60MVAr BCS at the Biyagama 33kV bas bar. In the outage of one New Chilaw- Madampe cct, the remaining cct is loaded by 123%. This overloading occurs owing to design limitations of the transmission line, i.e. the tower lines have designed for 54°C maximum operating temperature and it reaches the maximum sag level under lower transmitting levels. Therefore, it is proposed to upgrade the New Chilaw- Madampe transmission line to operate at 75°C. In the outage of one Pannipitiya-Kolonnawa cct, the remaining cct is loaded by 122%. In the outage of Colombo A-Dehiwala 132kV cable results 117% loading in the Pannipitiya.-Jayawardanapura ccts. Both the above overloading situations can be mitigated by method no 1 above. In the outage of one Kolonnawa-Arangala cct, the remaining cct is loaded by 123%. This can be mitigated by constructing the Kolonnawa-Arangala 2nd cct.

HMNP Case
In normal operating conditions, no voltage or thermal violations were observed.

In the outage of one three winding transformer at Kotugada, the 33kV winding of the remaining three winding transformer is loaded by 128%. This problem can be mitigated by constructing the New Kotugoda GS by 2010. In the outage of one three winding transformer at Biyagama, the 33kV winding of the remaining three winding transformer is loaded by 153%. This problem can be mitigated by installing 60MVAr BCS at the Biyagama 33kV bas bar by 2010. In the outage of one three winding transformer at New Anuradhapura, the 220kV & 33kV winding of remaining three winding transformer are loaded by 132% & 164% respectively. This can be mitigated by installing a 3rd 220/132/33kV inter-bus transformer. In the outage of Polpitiya-Kosgama cct, Polpitiya-Sithawaka cct is loaded by 130%. It can be mitigated by changing the present line arrangement of Kolonnawa-Kosgama, Kolonnawa-Sithawaka, Sithawaka-Polpitiya and Polpitiya-Kosgama 132kV transmission lines to double circuit of Kolonnawa-Kosgama and double circuit of Polpitiya-Sithawaka by year 2016.

TMNP Case
In normal operating conditions no voltage or thermal violations are observed.

In the outage of one three winding transformer at Kotugada, the 33kV winding of remaining three winding transformer is loaded by 128%. This problem can be mitigated by constructing the New Kotugoda GS. In the outage of one three winding transformer at Biyagama, the 33kV winding of remaining three winding transformer is loaded by 152%. This problem can be mitigated by installing a 60MVAr BCS at Biyagama 33kV bas bar. In the outage of one three winding transformer at New Anuradhapura, the 220kV & 33kV winding of remaining three winding transformer are loaded by 138% & 164% respectively. This can be mitigated by installing a 3rd 220/132/33kV inter-bus transformer. In the outage of Embilipitiya 220/132/33 kV inter-bus transformer, the New Laxapana-

Balangoda 132kV line is loaded by 123%. Installation of 2nd 220/132/33kV inter-bus transformer will solve this problem.

Transmission Losses

The transmission losses corresponding to the year 2015 for the two scenarios with and without Kiriketi PSPP are listed in the Table 3.

Table 3 - Transmission Losses

Year	Condition	Transmission Loss (MW) without Kiriketi PSPP	Transmission Loss (MW) with Kiriketi PSPP
2015	HMNP	98.4	87.2
2015	TMNP	122.8	108.8
2015	HMDP	103.5	48.6
2015	TMDP	100.3	52.8

Short Circuit Analysis

Maximum three phase short circuit levels at each grid substation in Sri Lanka in year 2015 were calculated and compared with the existing breaker capacities and no violations were observed.

Transient Stability Analysis

Transient system stability analysis was carried out for year 2015. During the study, the transmission system was subjected to specific pre-identified transient system disturbances which are expected to be critical.
Studies were carried out under two switching sequences as given below.

I. Successful Re-closing :
t=0 Fault occurs
t=120ms, fault cleared & circuit tripped
t=620ms, circuit re-closed

II. Unsuccessful Re-closing :
t=0 Fault occurs
t=120ms, circuit tripped
t=620ms, circuit re-closed with fault
t=740ms circuit tripped

In the study, the embedded generators are not taken into account. Following assumptions were made when carrying out stability studies.

1. A 5% spinning reserve was maintained
2. An automatic load shedding scheme was incorporated in the study in order to sustain the stability of the system.
3. Typical exciter and governor models were included for all generators.
4. Load damping effect was considered

Dynamic simulation Results

The dynamic studies were conducted for the year 2015 with Kiriketi PSPP, for the system conditions of TMNP and HMNP. Some results of the transient stability diagrams are shown below.

Conclusion

The study showed 500MW Kiriketi PSPP should be directly connect to the 220kV Kotmale power station bus bar using the 30km long 220kV double circuit of 2xZebra transmission line.

References

[1] Planning of Pumped Storage Power Plants in Sri Lanka, M.T.A.P. Wickramarathna, SLEMA Journal, Volume 14-No.2, September 2011.

[2] Study on Pumped Storage Power Plants and Optimization for Peaking Power generation in Sri Lanka Volume II- Site Selection and Basic Design Configurations Report by M.T.A.P. Wickramarathna.

[3] Study on Pumped Storage Power Plants and Optimization for Peaking Power generation in Sri Lanka Volume IV- Interconnection of Kiriketi Pumped Storage Power Plant Report by M.T.A.P. Wickramarathna.

[4] Long Term Transmission Development Plan 2008-2016, Ceylon Electricity Board.

Figure 1 - TMNP- Frequency Variation when Puttalam 285MW Unit Drop

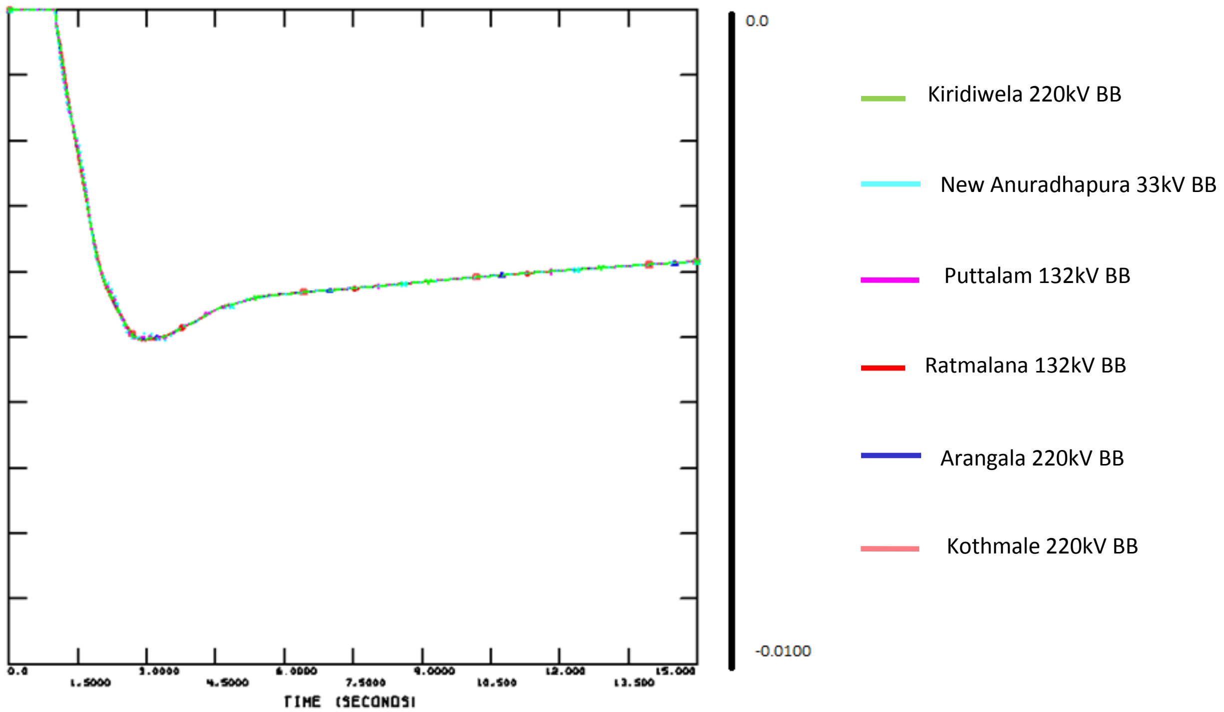

Figure 2 - TMNP- Voltage Variation when Puttalam 285MW Unit Drop

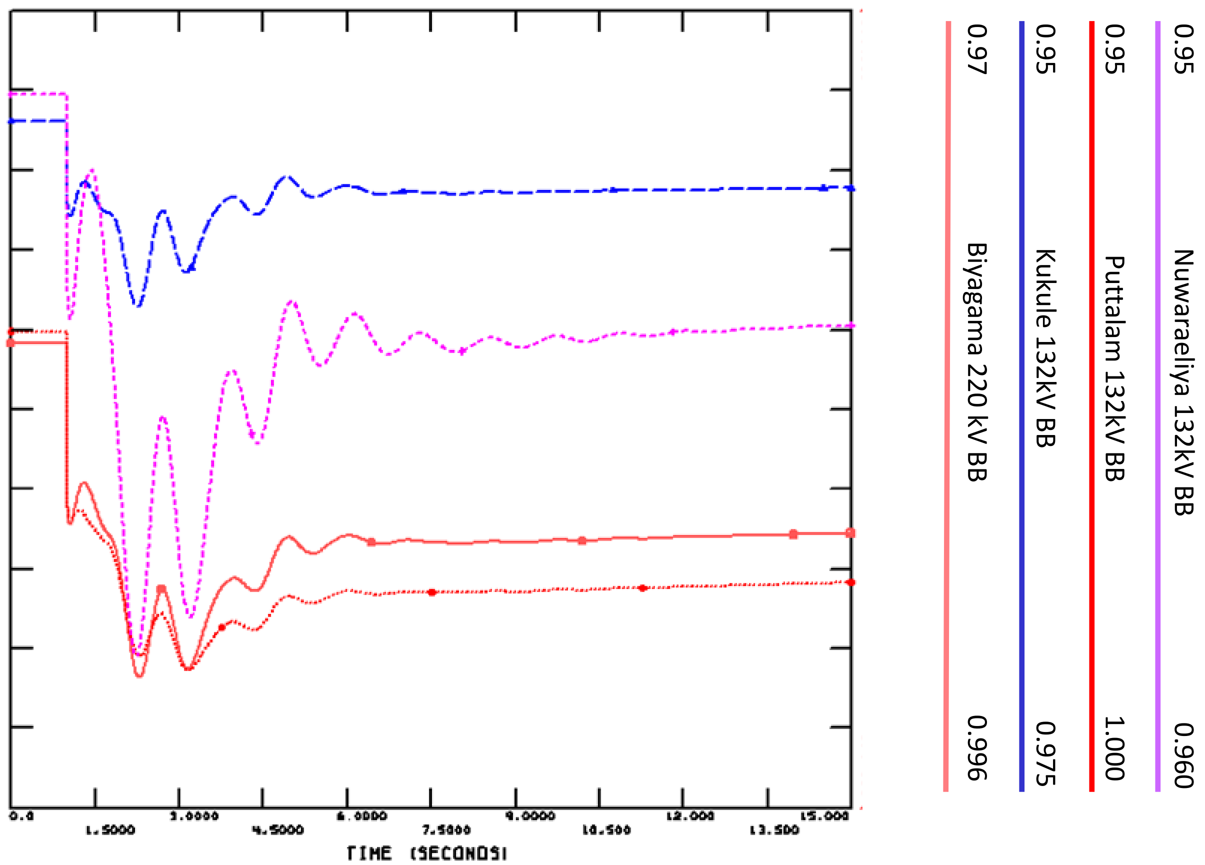

Figure 3 - TMNP- Frequency Variation when there is a Three Phase Short Circuit Fault on One of the 220kV Overhead Line between Kiriketi PS and Kotmale PS at Kotmale End. Successful re-closing is assumed.

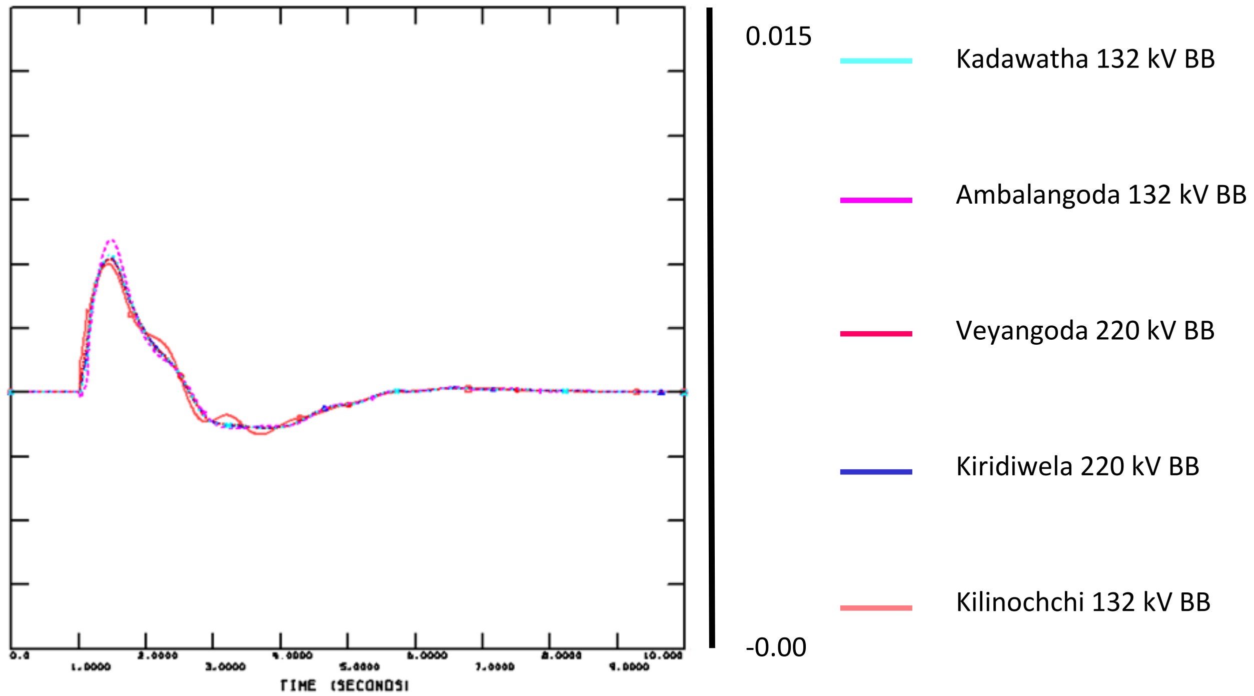

Figure 4 - TMNP- Voltage Variation when there is a Three Phase Short Circuit Fault on One of the 220kV Overhead Line between Kiriketi PS and Kotmale PS at Kotmale End. Successful re-closing is assumed.

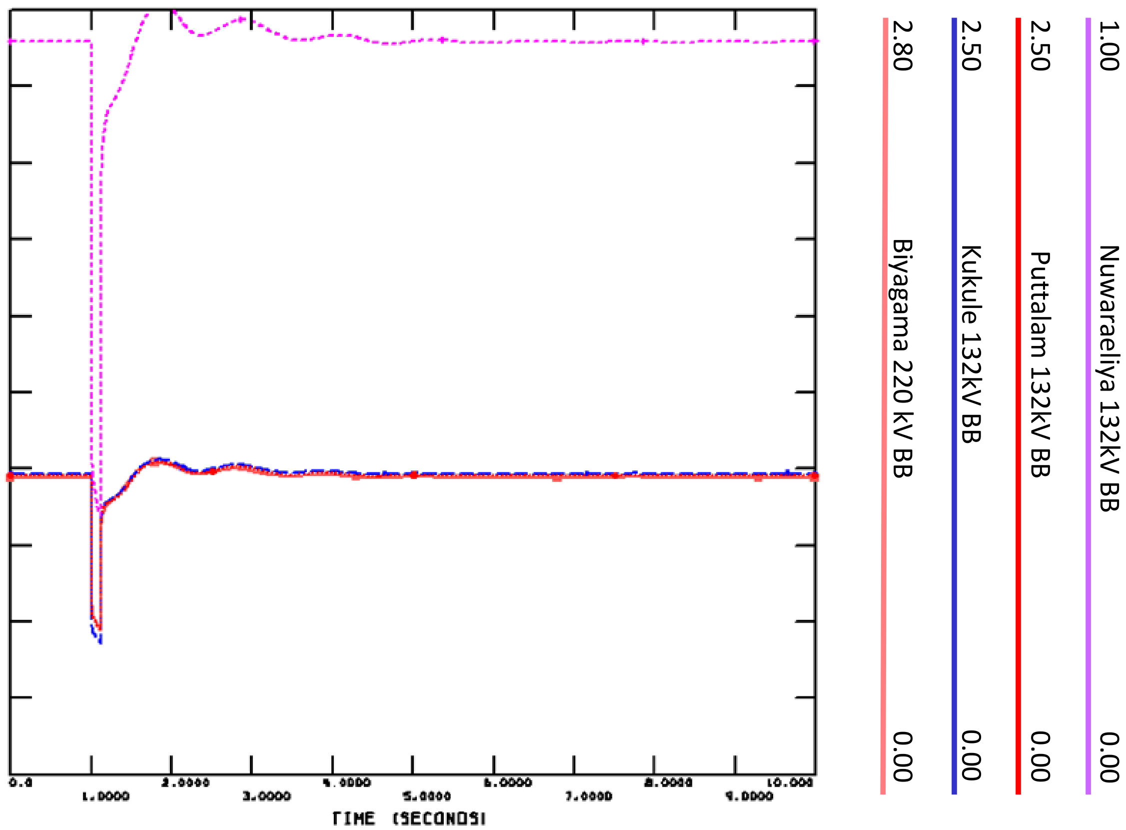

Figure 5 - TMNP- Relative Rotor Angle Variation when there is a Three Phase Short Circuit Fault on One of the 220kV Overhead line between Kiriketi PS and Kotmale PS at Kotmale End. Successful re-closing is assumed.

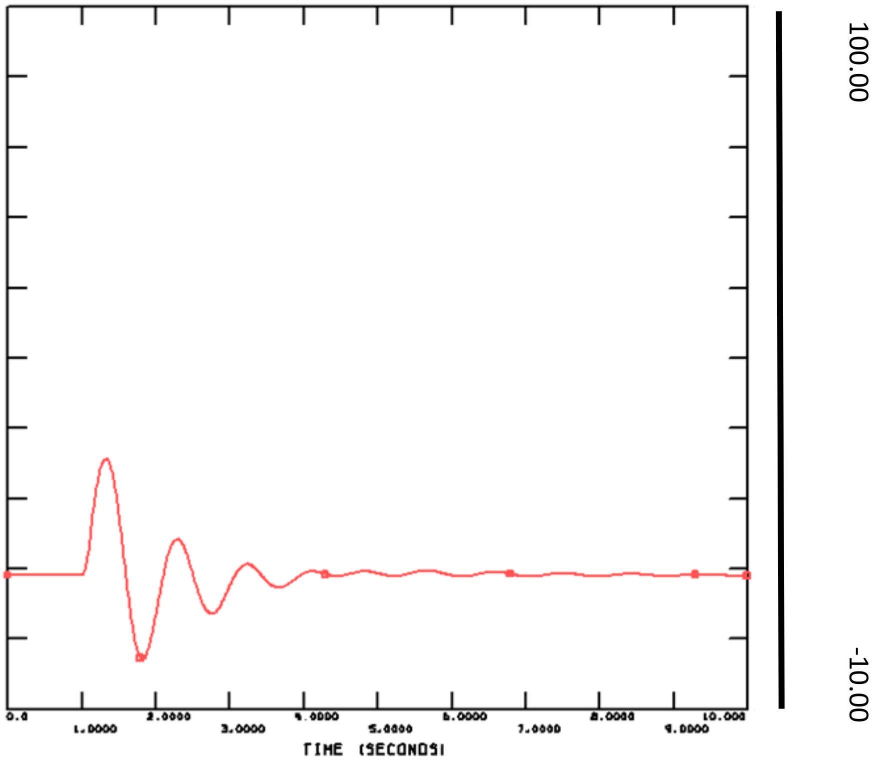

Figure 6 - TMNP- Frequency Variation when there is a Three Phase Short Circuit Fault on One of the 220kV Overhead Line between Kiriketi PS and Kotmale PS at Kotmale End. Unsuccessful re-closing is assumed.

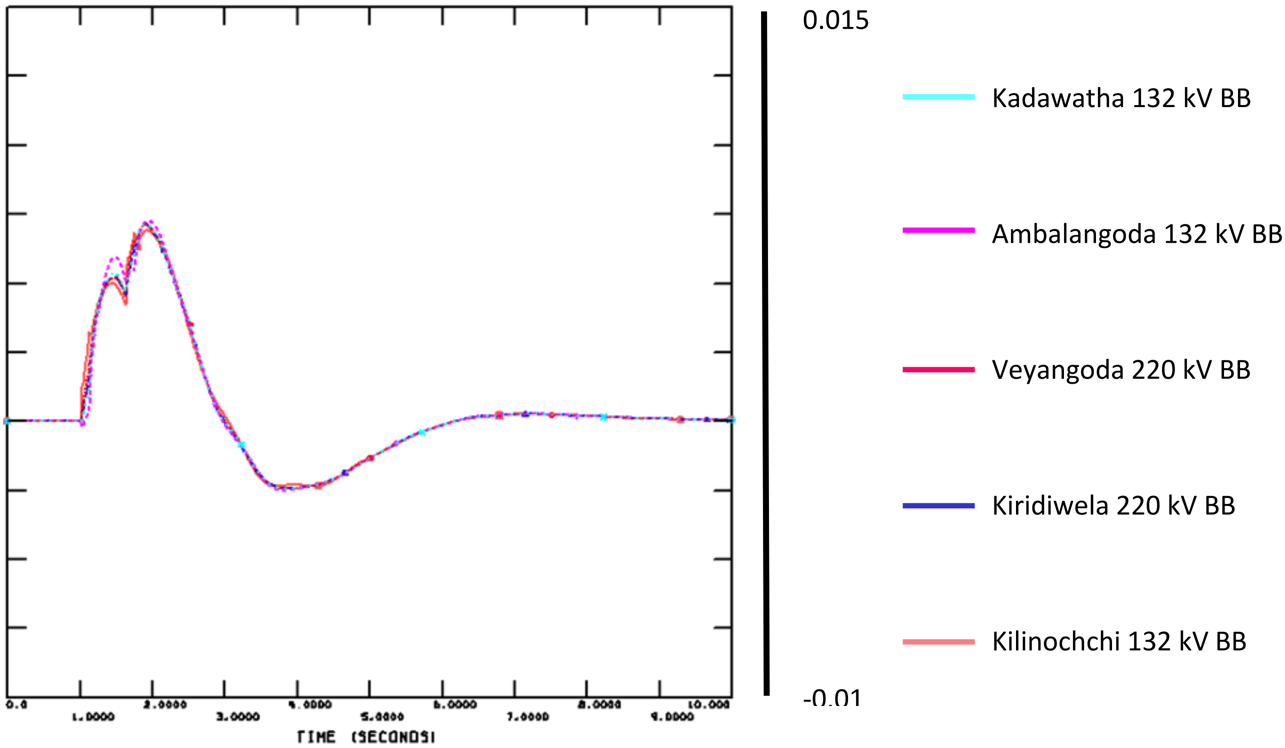

Figure 7 - TMNP- Voltage Variation when there is a Three Phase Short Circuit Fault on One of the 220kV Overhead Line between Kiriketi PS and Kotmale PS at Kotmale End. Unsuccessful re-closing is assumed.

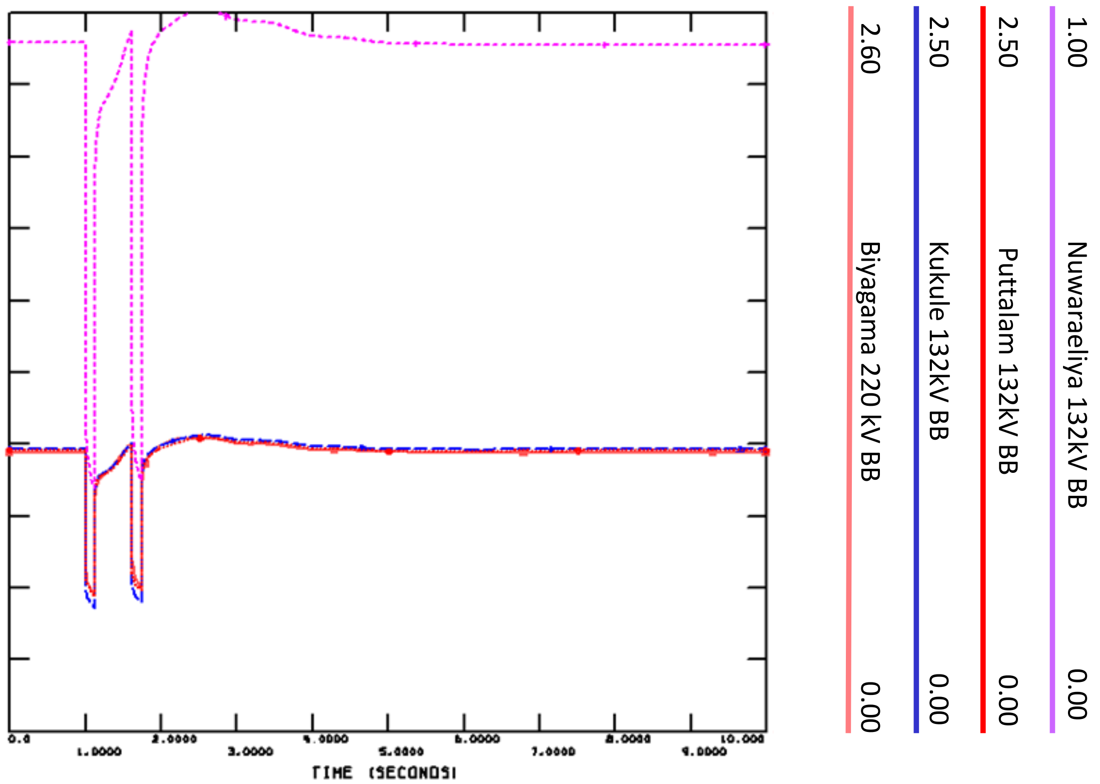

Figure 8 - TMNP- Relative Rotor Angle Variation when there is a Three Phase Short Circuit Fault on one of the 220kV Overhead Line between Kiriketi PS and Kotmale PS at Kotmale End. Unsuccessful re-closing is assumed.