Study of Northern Province Medium Voltage Network Interconnection with the Sri Lankan Power Grid

A. Ananthasingam, R. Shailajah, N. Yoganathan, S. Arunprasanth, A. Atputharajah and M.A.R.M. Fernando

Abstract: Interconnection of power systems will strengthen the power grid due to its inertia addition. However, interconnection of long distanced large loads and generating plants causes problems like voltage drops, line overloading, power fluctuation and difficulties in black start up. The literature survey resulted that the Flexible AC Transmission System is a proven technology as solution.

In Sri Lanka, the Jaffna Peninsula MV network is planned to be re-connected to the main grid network in 2013. This paper discusses about reliable and efficient operation of the Sri Lankan power grid as whole after this interconnection. In this study the present, 2016 predicted Sri Lankan transmission network and Northern MV networks were modelled. Growth rate of the Jaffna Peninsula was calculated using the 2007 to 2011 recorded historical data. Simulated results on load flow and fault analysis were similar to the operational data, thus validated the modelled network.

In Sri Lankan power system, the longest transmission line will interconnect the loads and generators at Northern Province with main grid. Solutions to the problems related to this interconnection were studied with an optimally placed Static VAr Compensator. This study has proven better performance in reducing overloading, improving voltage profile and easy black start up.

Keywords: Sri Lankan Transmission network, Jaffna Peninsula, Growth rate calculation, Reactive power compensation, Static VAr Compensator

1. Introduction

In Sri Lankan existing power system, Jaffna peninsula is operated as islanded mode generation since 1990. Until 1990 Jaffna Peninsula was operated with the national grid by a 132 kV double circuit transmission line from Anuradhapura to Chunnakam. In that period there was a diesel power plant of 15 MW at Chunnakam grid. During the civil war the Killinochchi grid and the transmission line to Chunnakam were damaged and Jaffna MV network was isolated. But in a developing small country like Sri Lanka, further islanded operation makes power networks smaller in size and causes problems. Problems related to thermal generation are high generation costs, environmentally harmful gas emission and high replacement cost of the machines [1 and 2]. Therefore Ceylon Electricity Board (CEB) has already planned to re-connect the Jaffna peninsula with the Sri Lankan transmission network by 2013.

This Interconnection is targeted to strengthen the existing system while transmitting the power to the northern part. To make sure the efficient interconnection, several factors have to be considered at the planning stage; such as power quality and reliability issues. In the view point of this interconnection the load centre (Northern part of Sri Lanka) is located far from the generation (Central part of Sri Lanka). Therefore after the connection using long AC transmission lines (about 224 km long) may bring numerous technical challenges, which are on the system reliability, stability and power quality.

Therefore a study on these issues is timely effort. Reactive power compensation is chosen as a suitable option to satisfy these challenges

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[2-7]. There are different types of reactive power compensators such as Static VAr Compensator (SVC), Static Compensator (STATCOM), Unified Power Flow Controller (UPFC), and Dynamic Voltage Restorer (DVR) [4].

There was an SVC in Galle which is already connected to the transmission network. However, it is not in operation at the moment. According to the CEB plan the SVC Galle will be in operation by 2013. Therefore this paper propose one of the solution which is another SVC in Northern province by considering the reactive power compensation, improvement of the voltage profile, damping power fluctuation, easy black start up and mainly long term usage.

This study was focused to (i) find 2016 load in northern province, (ii) check any overloading or under voltage problem in the interconnection at 2016 and (iii) propose an optimum placement of SVC in the Sri Lankan transmission network to make the Northern power system reliable and stable after the interconnection with the consideration of cost and advantages of SVC. As a result, the effort mainly involves with demand and generation forecast, modelling of Sri Lankan transmission network as in 2016 and several case studies on Sri Lankan transmission network as in 2016. The reason for selecting year 2016 model of transmission network is according to CEB plan the major plants such as Puttalam coal power last two steps (600 MW) and Trinco coal power plant (500 MW) will be connected to the network by this year.

2. Literature review

2.1 Network modelling

Modelling of power system network is the foundation of a power system analysis. Modelling consume the most attention as it is the backbone for all the power system analyses. Ongoing system operational directions, future plans on expansion of the power system such as new additions of generations/transmissions are done through the power system modelling [8].

2.2 Sri Lankan Transmission network-2011 and Jaffna power system-2011

Sri Lankan transmission system consists of 2 different transmission voltages 220 kV and 132 kV. Hydro and thermal generations are the main generation technologies followed in Sri Lanka and the generation voltages are around 12.5 kV, 13.8 kV. Total installed capacity is 3141 MW and the number of power stations 139. Peak demand is about 2163 MW. Total energy generation is about 29.35 GWh/day and 60% is thermal power generation and the rest 40% is hydro power generation [9 and 10]. Hydro power plants are divided into 5 Groups. Mahaweli complex-plants operated by the water from Mahaweli River, Laxapana Complex-plants operated by the water from Kelani River, Samanala Wewa, Kukule Ganga and other small hydro. The thermal plants classified into two, those are CEB thermal and IPP thermal.

Existing Jaffna power system consist an islanded diesel operated generations and MV network [10]. But with this generation, system is not cost effective [1 and 2]. According to the CEB plan interconnection of the Jaffna Peninsula with the national grid is the best solution [9 and 10]. However, as the interconnection is made through long transmission line which is about 224 km there will be some issues on power quality, system reliability and stability.

2.3 Improving power system reliability and stability

Power electronics based FACTS device technology allows to increase loading possibility, improve the system reliability and stability, provides voltage control with the great advantage of having high speed response to disturbances. It can also control line impedance, line voltage, active and reactive power flows in the line [5].

In long transmission lines, voltage stability is the main issue. The load variations, switching of system elements such as transmission lines, reactors, capacitor banks and transformers affect the voltage significantly. Increase of load may cause voltage collapse or light load may cause voltage rise. For these problems, the SVC is proven as the best power system voltage control device. Reactive power compensation is normally used in the transmission systems to improve network voltages and power transfer capability. It is also used in the distribution networks to compensate large amount of reactive power [4-7 and 11].

SVC is a shunt-connected device, which absorbs or injects reactive power to maintain or control specific parameters of the electrical power system. Its operations can be made for voltage control, power factor control, damping of power fluctuation, etc. [13]. SVCs are based on Thyristor Switched Capacitors (TSCs) or Breaker Switched Capacitors (BSCs), and

Thyristor Controlled Reactors (TCRs) with the dynamic on-off capability [4 and 5].

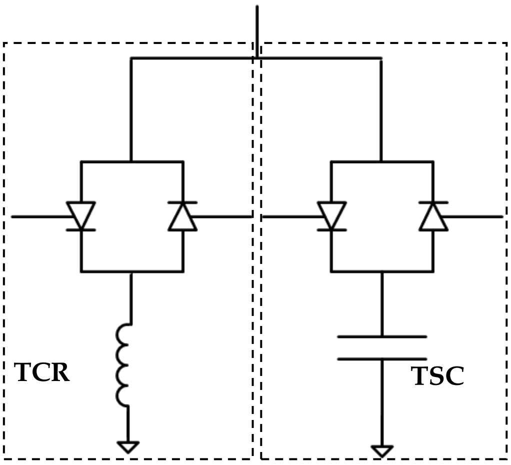

Figure 1 - Single line diagram of SVC

Advantages of using an SVC are fast response to change in system voltage, dynamic reactive power supply and absorption capability damping capability and more reliable. SVC is considered as the lower cost alternative device to the STATCOM and UPFC [4 and 5]. Further it has long life time. Therefore it is selected as better solution in this study.

3. Methodology

This study was carried out through the following steps shown in Figure 2.

Initially, the present Sri Lankan transmission network-2011 and Jaffna MV network-2011 were modelled using Integrated Power System Analysis (IPSA) simulation tool. Load flow analysis was done on each model for different scenarios and the results were observed.

In the second step, the modelled Sri Lankan Transmission network was upgraded to 2016 with the consideration of future load demands and generation according to the CEB plan. Future demand and generation of the Jaffna peninsula were calculated separately, because the growth rate in Jaffna peninsula is different from other part of the island as a result of the civil war. A method was also developed to find the growth rate of Jaffna peninsula [Section 3.3-A]. From that two growth rates were calculated and the highest one was selected. Then the complete Sri Lankan 2016 transmission network was modelled with the newly predicted Jaffna demand.

As the next step, several case studies were done using the modelled Sri Lankan power system network as in 2016, with night and day peak scenarios.

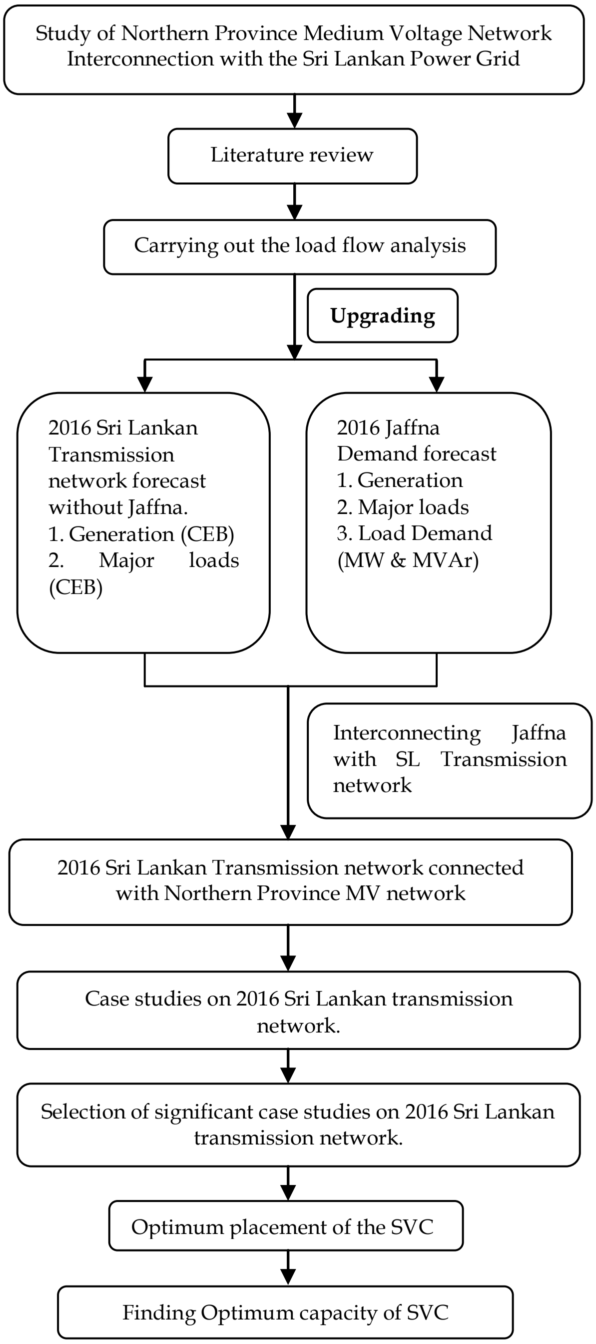

Figure 2 – Methodology followed

The highest power generation observed in night peak around 8 p.m. All the industrial and domestic electricity usages are high at this time. But in the day peak which is the second highest generation, most of the industries are involved and it is around 11 a.m. Those case studies were analysed mainly into two different sets: (i) with all the CEB predicted reactive power compensators and (ii) By removing some of the reactive power compensators at Jaffna peninsula and instead placing the SVC at different locations. In this analysis, the following cases were considered, (i) with and without the Trincomalle coal power plant (500 MW), (ii) with and without Nuracholai coal power plant (600 MW) and (iii) with and without Chunnakam (30 MW) power plant. The Trincomalle coal power plant and Nuracholai coal power plant were considered because, both the Trincomalee -500 MW (completion date July 2016) and Nuracholai-600 MW (completion date April 2014) plants will be in operation by the year of 2016 [12]. These two plants will have major role in Sri Lankan power generation by the year of 2016 because of the higher capacity and the main target of this study is the interconnection of the Jaffna MV network with the national grid. Therefore the Chunnakam plant was also considered in the above case studies. Then the worst cases were considered based on the result on violations of operating conditions. For those worst cases placement of SVC was studied in different locations. Then optimum placement of the SVC was found to solve those violations.

3.1 Modelling of 2011 Transmission Network

The 2011 power transmission network was modelled by IPSA. Here the Jaffna peninsula is isolated from the transmission network. To study about the Sri Lankan power network three cases such as (i) Day peak, (ii) Night peak and (iii) Off peak, as shown in Figure 3, were considered with thermal maximum scenario.

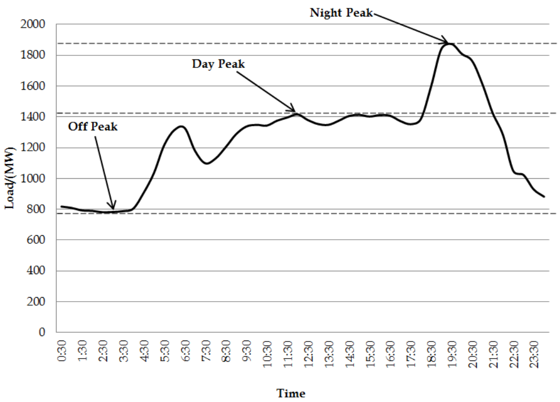

Figure 3 - Daily Electricity Load Curve in Sri Lanka (Source CEB)

3.2 Jaffna MV network modelling

The Jaffna MV network modelling was done from few officially collected raw data. Jaffna MV network refers the 33 kV and 11 kV. In the existing Jaffna MV network available power generation is thermal. Power station is located at Chunnakam. Table 1 shows the details about the all three power distributers.

According to the available data, there were 436 distribution transformers. This Jaffna MV network was modelled using IPSA software tool. The main difficulty was to find the load demand of each transformer for the night & day peak scenarios.

Table 1 - Power distributor details of Jaffna

Power distributors	IPP1	IPP2	CEB
Contract power/MW	18	15	13
No of generator	7	18	14
No of transformers	2x(11/33 kV)	6x(0.4/11 kV) 2x(11/33 kV)	14x(0.4/33 kV)

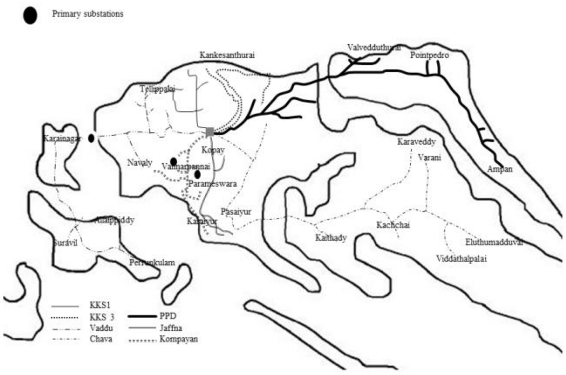

Figure 4 - Physical arrangement of the Jaffna MV network

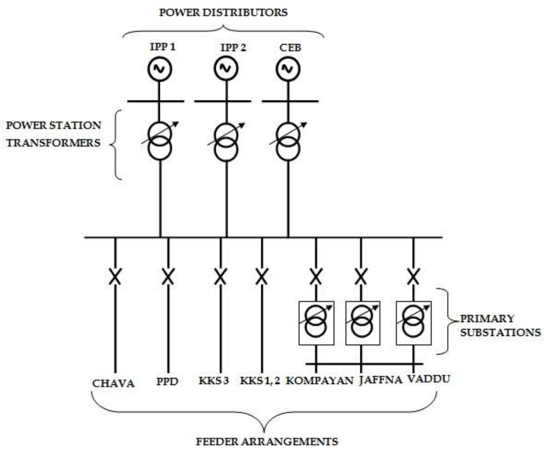

Figure 5 – Chunnakam power station arrangement

Different approaches were used to give the load demand for each transformer. In usual practice, using measured active and reactive power generation data of each generator units and load demand data of each distribution transformer at a particular day and time is used. However, the measured load demand for all the distribution transformers was not received. Therefore the load demand of the each feeder was taken and it was divided by the number of distribution transformers, connected to that particular feeder. Load flow study on the modelled Jaffna MV network was carried out successfully for both the day and night peak scenarios.

3.3 Modelling of 2016 transmission network

Already available model of the Sri Lankan Transmission network was upgraded to 2016 using the data given in the CEB guidelines [9]. The Jaffna peninsula demand was predicted with the calculated growth rate.

A Prediction of Jaffna load demand

Typical growth rate of Sri Lanka is about 6% per year [9]. When it comes to Jaffna it varies because of different reasons such as war, displacement of people during and after the war and also last two year changes are due to several developments carried out. This irregular variation directed to do a separate study on this topic. Here total demand was calculated by the addition of the predicted domestic demand and major loads demand.

A.1 Prediction of domestic load demand

The possible methods to predict the domestic MW, MVAr demands are (i) from the consumer records and monthly electricity usage, (ii) calculation from the load curve, (iii) calculation using measured data of the generation and (iv) calculation using measured demand in each transformer. Last five years data were collected from CEB to carry out this task. Since in recent past no any major loads were recorded, this domestic demand was calculated without considering the major loads. This paper explains demand prediction according to the (ii) and (iii) ways.

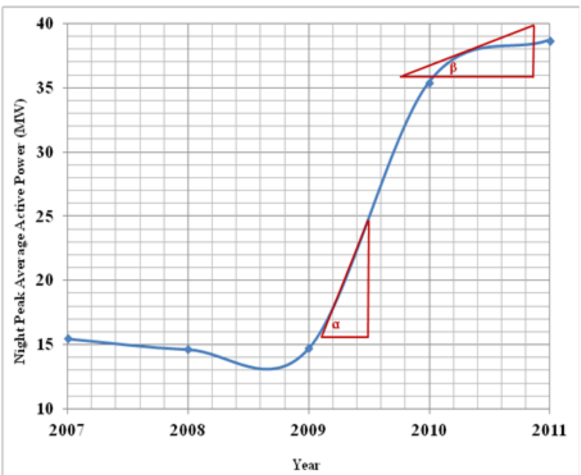

Figure 6 – Load increase with years to calculate the growth rate in Jaffna peninsula

Figure 6 shows the plot of generation data with years by taking an assumption that there were no power cuts during this five year period. Since there is no linearity found in the plot, 2016 demand was predicted by using selected two gradients in a graph as shown in Figure 6.

A.2 Prediction of major load demand

From the collected data (required MVA for the sectors) of the major loads, the demand for the major loads was calculated separately with the assumption of the power factor is 0.8.

3.4 Important cases considered in this study

Different cases were studied on the 2016 modelled transmission network to check the reliability. Initially, studies were conducted with Mechanically Switched Capacitors (MSC) at Chunnakam according to the CEB load prediction. Table-2 shows 8 cases considered with different combinations of generation units and all of them were studied for two scenarios such as day and night peaks.

Table 2 - different combinations of generation units

Cases	Jaffna	Puttalam	Trinco
1	On	On	On
2	On	On	Off
3	On	Off	On
4	On	Off	Off
5	Off	On	On
6	Off	On	Off
7	Off	Off	On
8	Off	Off	Off

As the next level of the study above mentioned different generation combinations were studied with the placement of SVC in the Killinochchi and Vavuniya grid separately. Two different predicted demand of Jaffna were calculated as mentioned in Figure 6. Study cases were analysed using the maximum predicted demand. Total of 48 cases were studied for finding the optimum placement of SVC.

4. Results

The following results are obtained by the load flow study by using IPSA simulation tool

4.1 Study on Jaffna MV network-2011

Table 3 - Violated buses in Load flow study

Scenario	Over loaded transformer
Day peak	Punkankulam (G014) and Kanagaratnam sub no-2 (G003)
Night peak	Punkankulam (G014)

4.2 Study on Sri Lankan transmission network-2011

Voltage violation criteria (132 kV: -10% to +5% and 33 kV: ± 2%) practiced in Sri Lanka [9] was used to identify the voltage violated buses.

Table 4 - Results of Load flow study

Day	Loading Condition	Voltage Violated Grid Sub Station	Transmission line Over Loading
19/08/2011 (Week day)	Off Peak	-	-
	Day Peak	Galle and New Anuradhapura	Polpitiya-Kiribath kumbura 132 kV line
	Night Peak	Galle, New Anuradhapura and Ampara	Colombo(E)-Colombo(F) 132 kV Cable
21/08/2011 (Sun day)	Off Peak	-	-
	Day Peak	-	Polpitiya-Kiribath kumbura 132 kV line and Kollonnawa-Pannipitiya 132 kV line
	Night Peak	Galle, New Anuradhapura, Ampara and Valachchennai	Colombo(E)-Colombo(F) 132 kV line

4.3 Demand prediction of Jaffna (2016)

Table 5 - Results from the load curve

Year	2016	
Predicted MW value	Night Peak	Day Peak
	49	24.5

Table 6 - Results from the collected data

Year	2016 (using gradients 1 and 2)			
Loading Condition	Day peak		Night peak	
Growth Rate	1	2	1	2
Predicted Active power demand/MW	32.5	43.2	43	53.867
Predicted reactive power demand (A)/MVAr	12.2	13.539	8.88	23.859

Table 7 - Predicted future major loads

Demand	Apparent power/MVA	Active power/MW	Reactive power/MVAr
Total	28.23	22.584	16.929

Table 8 - Total predicted demand at Jaffna at 0.4 kV

Year		2016			
Loading condition		Day peak		Night peak	
Growth rate		1	2	1	2
Total predicted power	Active/ MW	55.084	65.784	65.584	76.451
	Reactive /MVAr	29.120	30.468	25.800	40.788

4.4 Case studies

A Result of base case studies - with all MSCs according to the CEB Plan

Table 9 - Base case studies - with all MSC

Busbar	Day Peak	Night Peak	
Case No	5	1	2
Chunnaham- 132 kV	0.854	0.829	0.669
Chunnaham- 33 kV	1.000	0.993	0.792
Killinochchi- 132 kV	0.872	0.827	0.684
Killinochchi- 33 kV	1.005	0.919	0.728
Vavunia- 132 kV	0.902	0.864	0.764

In the simulation carried out with the day peak scenario for cases 1, 2, 3, 4, 6, 7 and 8, no voltage violations (except case 5 as shown in table 9, where under voltage conditions are highlighted) were observed, but all the simulation cases were converged in IPSA load flow analysis, which used the fast decoupled Newton-Raphson method. Similarly a study was carried out for the night peak scenario and it was observed only case 3 succeed without any voltage violations. It is important to notify that the cases 4, 5, 6, 7 and 8 were diverged even with less number of iterations. This is mainly because of the disconnection of two large power plants together (n-2 contingency criteria), therefore they did not converge. This confirmed that one of these two power plant project should complete before providing the predicted load demand. In cases 1 and 2 had some violation as shown in table 9, but those cases converged.

B Result of SVC placement in Killinochchi

Table 10 - Results with a 25 MVAr SVC placed in Killinochchi (33 kV)

Busbar	Day Peak	Night Peak	
Case No	5	1	2
Chunnaham- 132 kV	0.904	0.886	0.720
Chunnaham- 33 kV	1.015	1.02	0.819
Killinochchi- 132 kV	0.924	0.887	0.757
Killinochchi- 33 kV	1.006	0.980	0.910
Vavunia- 132 kV	0.929	0.896	0.810

C Result of SVC placement in Vavuniya

Table 11 - Results with a 25 MVAr SVC placed in Vavuniya 33 kV

Busbar	Day Peak	Night Peak	
Case No	5	1	2
Chunnaham- 132 kV	0.900	0.859	0.698
Chunnaham- 33 kV	1.007	1.018	0.807
Killinochchi- 132 kV	0.915	0.862	0.726
Killinochchi- 33 kV	0.996	0.964	0.786
Vavunia- 132 kV	0.941	0.900	0.808

D Selection of worst case

Out of the possible 3 cases (cases 1, 2 and 5) the worst case was case 2 at night peak. This has shown that it is possible to succeed the simulation if it has some variable reactive power compensation to boost the voltage. Therefore this case 2 night peak was selected to analysis with the SVC and to find the optimum solution of it.

E Optimum solution

The case 2 night peak was simulated with many possible solutions by changing the size of Kilinochchi SVC (25 MVAr) and the results show that it is not enough to improve the voltage profile. Then according to the CEB plan the MSC value is increased from 0 MVAr to 60 MVAr. Finally the optimum solution was found when placed a 25 MVAr SVC at Kilinochchi-33kV and a 60 MVAr MSC at Chunnakam. Table 12 shows the results.

Table 12 – Results with optimum solution

Busbar	Without SVC	With SVC in		Optimum Solution
		Killinochchi	Vavuniya	
Chunnaham-132 kV	0.669	0.720	0.698	0.906
Chunnaham-33 kV	0.792	0.819	0.807	0.984
Killinochchi-132 kV	0.684	0.757	0.726	0.901
Killinochchi-33 kV	0.728	0.910	0.786	0.980
Vavunia-132 kV	0.764	0.810	0.808	0.900

4.5 Further Studies-Transient Analysis

In IPSA, the equivalent circuit for the whole network at the New-anuradhapura grid was modelled without considering Chunnakam, Kilinochchi, Vavuniya and Mannar grids. Then the above 4 grids were connected. Then the below studies were carried out with and without SVC.

Figure 7 shows the observed waveform of voltage variation on IPSA at Kilinochchi 132 kV busbar with & without SVC, when a three-phase-ground fault was applied at Kilinochchi 132 kV busbar and the fault was removed after 200ms. SVC model in IPSA simulation package (Ver. 1.6) does not have control for damping power fluctuations. Therefore the waveform in figure 7 doesn't show oscillation damping. But it has been proven in [13] that the SVC works perfectly for power oscillation damping if the relevant control is incorporated. Small oscillations in the voltage may result larger voltage in power. Placement of SVC brings damping control as an added advantage, which will be helpful in the future, when the long transmission line is loaded much with the developments in northern part of Sri Lanka.

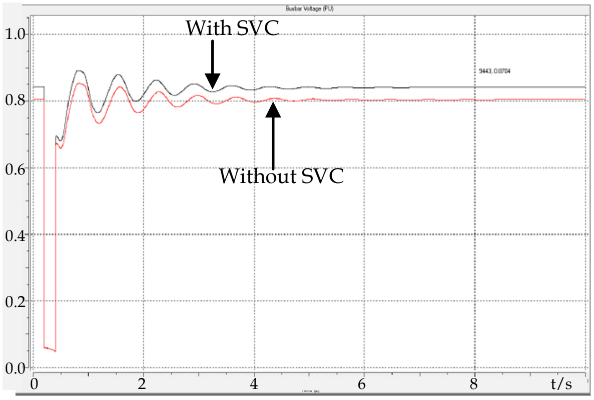

Figure 7: Voltage variation at Kilinochchi 132 kV busbar with & without SVC

4.6 Easy black start

Figure 8 shows the contribution from the SVC on the voltage control during the black start-up.

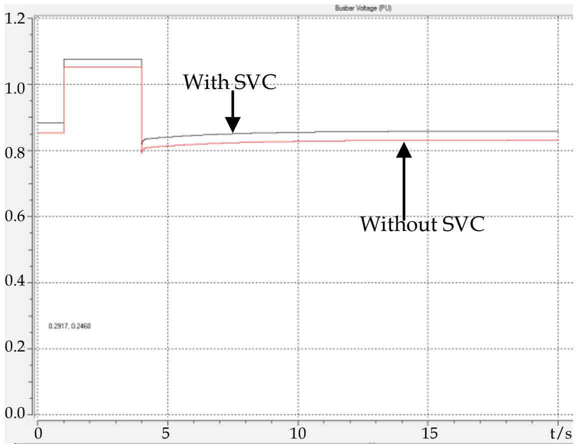

Figure 8: Black start voltage profile of Kilinochchi 132 kV busbar during transient.

Simulation at 1 second of run, the line connecting Kilinochchi-132kV and Chunnakam-132kV grids was disconnected and then reconnected at 4 second. During this period, only the generation and load at Chunnakam, were disconnected. It was notified that the over voltage (greater that 1.05pu) when load is disconnected and under voltage (lower that 0.9pu) when loads were connected without MSC. Therefore this proves during black start-up process the busbars will have chances to get over voltage and under voltage. This may keep on tripping and black start-up will be difficult. Therefore a dynamic voltage compensator such as SVC will help to the black start up process also.

Another option is using Chunnakam power station and do the restoration with few loads in islanded mode and finally connected to the main grid. However, synchronisation should be done between two systems carefully. Dynamics of this operation need to be studied further. This paper discussed the SVC application with many functions including black start up.

5. Discussion

According to the Long Term Transmission Plan (2011-2020) released by the CEB, the predicted night peak active and reactive power demands of the Jaffna Peninsula are 64.4 MW and 13.1 MVAr respectively. But this study results predicted the Jaffna Peninsula demands as 76.45 MW and 40.78 MVAr. The reason for this variation is the consideration of the actual system and the ongoing growth rate prediction. CEB has proposed the predicted reactive power compensation for the Jaffna peninsula as 30 MVAr. The study explained in this paper proposed an additional reactive power compensation of 25 MVAr at Kilinochchi or Vavuniya to supply the predicted demand. But from the case studies, it was proved that Kilinochchi is the best place for the system reliable and efficient if the reactive power compensator includes SVC also. From the results it was observed that 25 MVAr reactive power compensation is not enough to keep the system with the best solution. Therefore further analyses were conducted. As the result of them addition of 30 MVAr MSC to the CEB predicted MSC at Jaffna Peninsula together with the 25 MVAr SVC at Killinochchi is the best solution for the efficient and reliable Sri Lankan power system. With this compensation Northern power system grid will be efficient and reliable.

6. Conclusions

This research yields an accurate model of the predicted Sri Lankan transmission network, which includes Northern part of Sri Lanka. Addition to that this study explains the growth rate calculation using historical data and consideration of the future Jaffna developments (explained in section 3.3-A). Further this paper proposes integration of FACTS devices to improve the power system performance in terms of voltage boosting, damping power fluctuations and easy black start-up. SVC has been proposed to achieve static and dynamic control for steady state and transient operations such as continuous reactive power compensation for smooth voltage control and fast reactive power control for black startup. Optimum placement of SVC has been suggested to avoid violations to bring the power system efficient and reliable.

All the observed problems were solved by the placement of the 25MVAr SVC at killinochchi and 60MVAr as the total MSC placement at Jaffna

Authors of this paper strongly believe that this paper will be a supportive document to CEB planning engineers as an independent study, which suggests using SVC as a solution to the reactive power compensation. Further studies can be made to minimum possible capacity of the SVC with some cost analysis.

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