Concepts to Maximize the Usage of Distribution Networks - Case study on Jaffna Peninsula Distribution System

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***Abstract*: Usage of distribution networks are always a challenging task as it directly connected to the consumer loads, which are continuously varying. Under or over voltages are one of the major component that limits the expansion of electrical distribution system. This can be eliminated by operating all devices to their optimize positions. This done through applied research study in this paper, which resulted a concept on operational steps while giving a cost effective solution in overall. Here the PSCAD Bergeron model is used for modelling the Jaffna peninsula electrical distribution system. The operation is studied for the full day load pattern thus showed voltage problems in some bus bars especially during peak load conditions. Solutions are proposed and healthy operation is validated with proposed solution. Further the concept on finding the solution is also concluded a general contribution from this study.**

Keywords – Distribution system study, under voltage, concept on distribution system operation, Jaffna peninsula network and distribution system Bergeron model.

I. INTRODUCTION

Increasing load creates challenges in distribution system operation. Expansion of distribution system or modification is always involved with cost. When considering the life cycle analysis of the distribution network, this study proposes the maximum usage of these component the total cost is reduced. Therefore it is required critical study [1] to increase the usage of the distribution system with available devices.

Therw was a rapid increase in load created under voltage challenges, which was reported in the Jaffna peninsula distribution network. Therefore an off-line operational study is done on its components how it can be operated through proactive coordination based set values. This concept of operation with existing devices and pre-set operations will tremendously reduce the cost for rehabilitating or new construction of the distribution network.

This study pushes the distribution network devices' operating capacity up to its full ratings thus the maximum usage this network and devices can be obtained. This reduces frequent new construction and as result the total cost is reduced. This also motivates that any industrial problems, studied through the applied research and development program will be the best solution to operate their system to the full capacity for its operations with good reliability.

This study primarily consider the 33kV system and also the secondary side of the 33/11kV step-down transformers. The losses are mainly considered at the distribution lines and transformers. The system is modelled using the PSCAD simulation package, here appropriate line model (half current locations and the cable lengths) and transformer model are used with the available parameters. At Kilinochchi outgoing feeder, which is 132kV transmission line, towards Chunnakam substation, is modelled with a voltage source with equivalent internal impedance of its fault level.

The RMS voltages are read at the end of each distribution feeders and verified for their compliance with the standard. As per the Sri Lankan electricity Act, No. 20 of 2009 [2][11], the deviation of actual voltage level from its nominal voltage shall not exceed the tolerance values ±6% but on the other hand as per the international standards this can go up to ±10%. But for our studies, voltage tolerance values as ±6% is considered. When the voltage deviate from the standard, various techniques used to manage the voltage to keep within the standard limits. They are:

1. Usage of transformer De-Energised Tap Changers (DETC) {Fixed Tap Method}.
2. Usage of transformer On Load Tap Changers (OLTC).
3. Changing the cable type
4. Increasing the number of circuits.

In this study, initially the yearly load variation was observed and the worst case loading conditions were taken for the detail study.

II. DISTRIBUTION LINES

Distribution lines play a major role to deliver the power to the customer while keeping the voltage magnitude within standard limits. Based on the load requirement and line length, the types and the number of circuits are determined. Accordingly the Jaffna peninsula Medium Voltage (33kV) distribution system was modelled, which also matched with the practically existing model. There were 10 outgoing feeders (Jaffna Express to Parameswara, Jaffna Express to Kompayan, Jaffna, Point Pedro Express, Point Pedro, Chava Express, Chava, KKS1, KKS3, Vaddu Express and Kompayan) from Chunnakam power distribution station. The length of the feeders varies from 5.9km to 42.1km. In these distribution lines, their length and the half current locations were measured at the site and modelled using the PSCAD for this study.

III. TRANSFORMER

There were number of transformers ranging from 2MVA till 31.5MVA capacities modelled in this simulation. They were placed in the respective positions covering losses such as copper and core losses based on the manufacture data [10] and based on the relevant transformer capacity.

IV. LOAD

Loads are mainly depends on the house hold lighting, commercial sectors, government sectors and educational sectors.

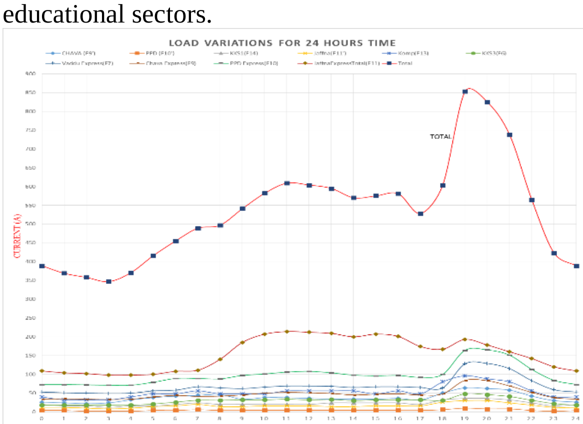

Fig.1: Load variation pattern recorded on 5th of December 2017.

The power variation shown in Fig. 1, which cause two peaks, Night peak is recorded at 7PM (major from the house hold loads) and the Day peak is mostly at 11AM (due to commercial, government and educational sectors). Active power demand for night peak is measured as 47.089 MW and whereas the off-peak demand was 19.134 MW, same time the reactive power demand were 11.724 MVAr and 4.866 MVAr respectively. In all the outgoing feeders from the Chunnakam distribution station, the power factor was measured. At the peak loading condition, the power factor of all the feeders were recorded within the range of 0.943 to 0.998. Further all the electrical power parameters such as voltage, current, power and power factors were measured in this study.

V. SIMULATION

PSCAD Bergeron model were used simulate the distribution lines as it is more suitable for the studies checking the voltages. The simulation network starting from the 132kV bus with the voltage source at Kilinochchi grid substation and the double circuit 67.2km ZEBRA ACSR transmission line, which serves as a tie line that connect the Jaffna peninsula islanding power network to the national grid. Fig 2 shows the detail model of all the components used. The lines and transformers were modeled using the parameters collected based on those line type [8], length, and transformer name plate information.

Initially the load pattern was analyzed, from the data collection, to see the possible worst case situation by collecting throughout the year. Then the worst case peak loading and low loading days were selected. For both days, full day load values at all feeders were listed and prepared for the simulation study. The simulation was done to check the operating conditions of the distribution network by replacing the loads at the busbars from the measured values, which was collected for every 30 minutes interval and throughout the identified days. Then the voltages at the busbars were checked for conforming the healthy operation of the distribution system.

VI. RESULTS

Simulation results were recorded, i.e. the steady state voltages at all busbars were checked for peak and off peak loading conditions. The results were validated with measured voltages at the selected busbars. This validated the model of the distribution network.

When the results were analyzed, it was found that most of the busbars are within the voltage limits, at the peak load of the maximum demand day.

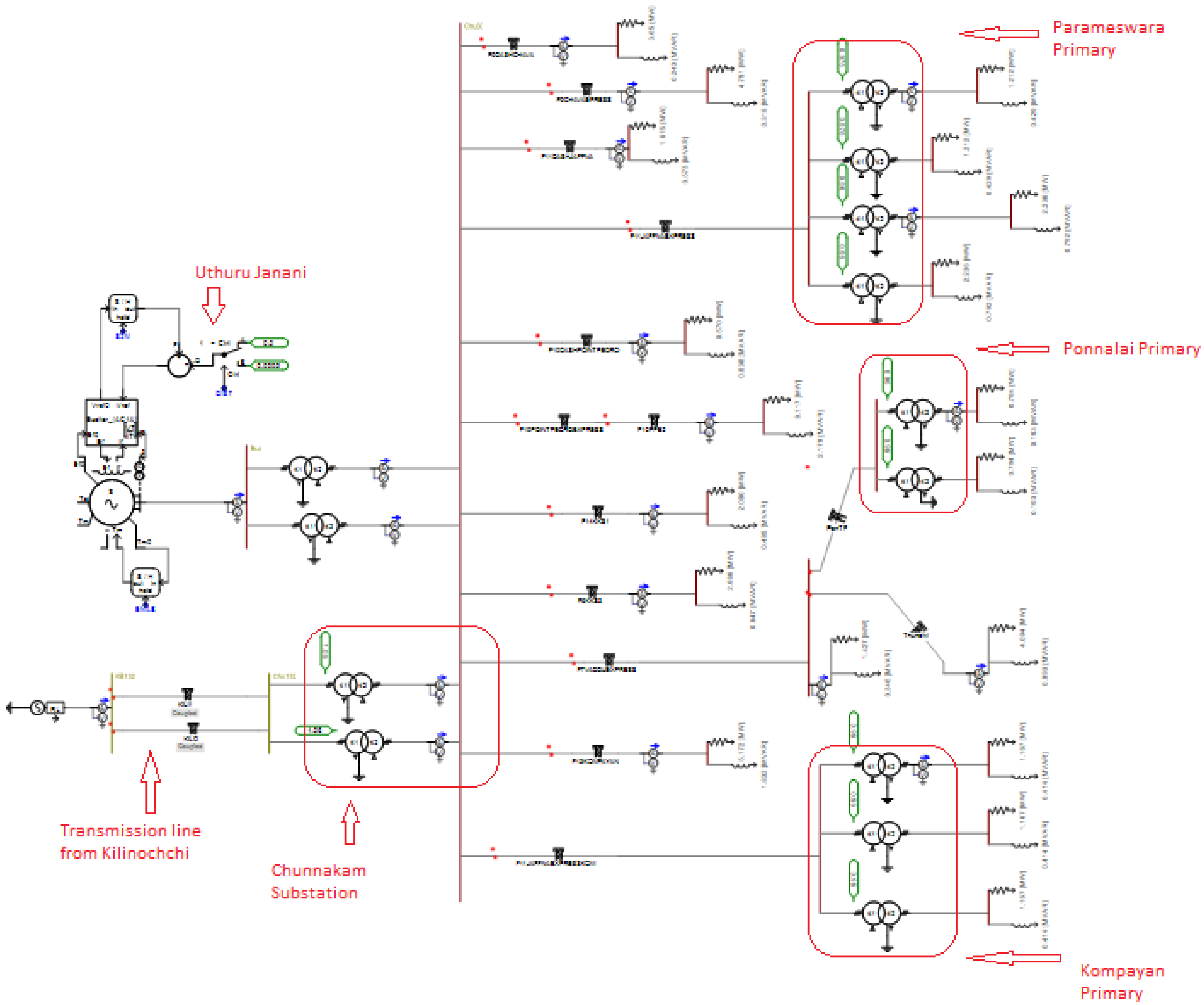

Fig.2: Simulation model of the Jaffna distribution network using PSCAD software

However, at the peak load period all the express lines busbars are having under voltages as shown in Table 1. This was analyzed and proposed a concept, which can be applicable in general for this kind of applied engineering study problem. The cost has been taken at its higher priority level while keeping the quality and reliability of the distribution network operations.

Table1: Worst case results from the simulation

Distribution Line	Steady state Voltage(pu)	
	Simulation Result	
	Peak (7PM)	Off-Peak (3AM)
CHU33Bus (Vt1)	0.9795	0.9927
CHAVA (F9')	0.9645	0.9870
PPD (F10')	0.9782	0.9924
KKS1(F14)	0.9707	0.9897
Jaffna(F11')	0.9744	0.9913
Komp(F13)	0.9632	0.9871
KKS3(F6)	0.9710	0.9894
Vaddu Express(F7)	**0.9272**	0.9718
Chava Express(F9)	**0.9379**	0.9762
PPD Express(F10)	**0.9169**	0.9647
JaffnaExpressPara(F11P)	**0.9373**	0.9704
JaffnaExpressKom(F11K)	**0.9390**	0.9716
Vaddu Express(Thunaivi)	**0.9345**	0.9750

VII. GENERAL CONCEPTS USED TO SOLVE THE VOLTAGE VIOLATIONS

Here the solutions are proposed without any attempt insert any physical layout of the distribution network. Only using the possible tap changers in the transformers were checked to utilized them for eliminating the under voltage problem. Again it was preferred to go for fixed tap changing operation rather on-load tap changer. This is to avoid any transient. Conceptually on-load tap changers are used when fixed tap changers are not possible to overcome the voltage violations. Also the voltage violation is far below from 1pu and far above 1pu within a day of its operation. Let's consider how to use the fixed tap operations in existing transformers.

For this as first step: Here it was always below 1pu. The fixing the tap at upper stream transformers should be considered for this case. Then the tap will be fixed with the value calculated using equation 1. If the voltage violation is not solved then the downstream transformer tap need to be fixed based on the similar concept as in Equation 1. Basically this calculation of the tap and keep it as its fixed tap position, shifts the transformer's operation around the 1pu of its output voltage.

$$Tap_{\max} = \frac{V_{\max\_Off\_Peak}}{1+\left(\frac{V_{\max\_Off\_Peak} - V_{\min\_Peak}}{2}\right)}$$

$$Tap_{\min} = \frac{V_{\min\_Peak}}{1-\left(\frac{V_{\max\_Off\_Peak} - V_{\min\_Peak}}{2}\right)}$$

$$Tap = \frac{Tap_{\max} + Tap_{\min}}{2} \text{ --------------- } Eq\ 1$$

Second step: If the fixed tap method is not worked then on-load tap changer operation can be designed base on similar concept on upstream to downstream transformers.

Third step: If the voltage variation is too fast or fluctuating components is observed, which is expected with increasing penetration on renewable energy generation technologies, then the fast acting varying compensation devices [5,6] such as STATCOM / SVC can be studied for solutions. This cost will be high as it has number of advantages on having fast action, compensating for continuous and fluctuating power requirements and smooth operation without introducing any transient impact due to sudden engaging operation of the device.

VIII. PROPOSED SOLUTION TO THE JAFFNA PENINSULA DISTRIBUTION SYSTEM

From the study result shown in Table 1, it can be seen all voltages are below 1pu. Therefore the upper stream transformer fix taping point is calculated based on the Equation 1. From the Table 1, the maximum voltage during off peak loading condition $V_{max\_Off\_Peak}$ = 0.9927pu and minimum voltage during peak loading condition V_{min_Peak} = 0.9169pu. As a result the fixed tap position to be set is 0.95.

This was set in the simulation to the tap of the upper stream transformer, which is the incoming feeder to the Jaffna Peninsula. The simulation results of voltages at the busbars are shown in Table 2. This shows all the busbars are with very good healthy voltages. The proposed concept and solution is validated through this simulation results.

Table2: Upper stream transformer fixed tap set 0.95 results from the simulation

Distribution Line	Steady state Voltage(pu)	
	Simulation Result	
	Peak (7PM)	Off-Peak (3AM)
CHU33Bus (Vt1)	1.0042	1.0180
CHAVA (F9')	0.9888	1.0122
PPD (F10')	1.0028	1.0178
KKS1(F14)	0.9952	1.0150
Jaffna(F11')	0.9989	1.0166
Komp(F13)	0.9875	1.0123
KKS3(F6)	0.9955	1.0147
Vaddu Express(F7)	0.9506	0.9966
Chava Express(F9)	0.9616	1.0011
PPD Express(F10)	0.9400	0.9894
JaffnaExpressPara(F11P)	0.9609	0.9951
JaffnaExpressKom(F11K)	0.9627	0.9965
Vaddu Express(Thunaivi)	0.9581	0.9999

IX. POSSIBLE SOLUTIONS CAN BE APPLIED FOR FUTURE DEMAND GROWTH

We still haven't utilized the maximum usage in the distribution network. For example the DETC can be set for primary transformers. From Table2: Parameswara primary $V_{max\_Off\_Peak}$ = 0.9951pu, V_{min_Peak} = 0.9609pu, Kompayan primary $V_{max\_Off\_Peak}$ = 0.9965pu and V_{min_Peak} = 0.9627. From these values and using equation 1, it can be calculated to set all Pameswara and Kompayan transformers taps to 0.975.

This can further improve the voltages at Parameswara and Kompayan when the customer demand increases in future.

But the case of PPD Express it have no primary transformers to go for DETC, but one of its line segment which is 12.25km Racoon conductor can be replaced by ELM. Vaddu Express (F7) Ponnalai transformers can go for DETC but that will not improve the voltages at Vaddu Express (Thunaivi). Therefore we can go for ELM conductor from Chunnakam to Vaddu Gantry. To improve Chava express line we can replace Racoon to ELM cable type. After doing all these, the updated voltages are shown at Table3. This shows very healthy operational conditions, which can also handle future demand growth up to some more extend.

Table3: After done all the changes discussed above

Distribution Line	Steady state Voltage(pu)	
	Simulation Result	
	Peak (7PM)	Off-Peak (3AM)
CHU33Bus (Vt1)	1.0037	1.0178
CHAVA (F9')	0.9884	1.0120
PPD (F10')	1.0024	1.0176
KKS1(F14)	0.9947	1.0148
Jaffna(F11')	0.9985	1.0164
Komp(F13)	0.9870	1.0122
KKS3(F6)	0.9950	1.0145
Vaddu Express(F7)	0.9656	1.0027
Chava Express(F9)	0.9829	1.0098
PPD Express(F10)	0.9595	0.9984
JaffnaExpressPara(F11P)	0.9838	1.0198
JaffnaExpressKom(F11K)	0.9861	1.0214
Vaddu Express(Thunaivi)	0.9732	1.0060

X. USAGE OF ON LOAD TAP CHANGER (OLTC) FOR JAFFNA DISTRIBUTION SYSTEM NETWORK

The study also was continued for future increased load. This was done by increasing the present peak load at each and every feeder by a percentage of load addition. That is the addition of 60% to 25% of present peak load. Table 4 below shows the variation of voltages pattern. First of all, the upper stream transformer DETC tap position was set to its minimum value of 0.9 and then the loads were varied as stated above (results are shown in first five columns). Further the simulation was carried out with a light load (shown in the last column).

It can be noticed that up to 125% of the peak load, the DETC method can be used to manage the network without violating the voltage limits. During the light load operation, voltages were within the limits.

However, when the load increases above 125% of the peak load, under voltages were observed in some feeders. It has to be noted that the tap positions are already at their lowest values. Therefore the OLTC will not be an option for the Jaffna peninsula distribution network when the loads are increased above 125% of their existing values.

Table 4: RMS Voltages at the feeders, with 0.9 DETC, when the loads are varied from 160% to 125%.

Distribution Line	Steady state Voltage(pu) Simulation Result					
	VOLTAGE with 160% of PEAK load at 0.90Tap	VOLTAGE with 150% of PEAK load at 0.90Tap	VOLTAGE with 140% of PEAK load at 0.90Tap	VOLTAGE with 130% of PEAK load at 0.90Tap	VOLTAGE with 125% of PEAK load at 0.90Tap	Lightload with 0.9Tap
CHU33Bus (Vt1)	1.0144	1.0171	1.0198	1.0225	1.0238	1.0541
CHAVA (F9')	0.9895	0.9938	0.9980	1.0021	1.0042	1.0540
PPD (F10')	1.0121	1.0150	1.0178	1.0207	1.0221	1.0541
KKS1(F14)	0.9998	1.0034	1.0070	1.0106	1.0123	1.0541
Jaffna(F11')	1.0059	1.0091	1.0123	1.0155	1.0171	1.0540
Komp(F13)	0.9876	0.9919	0.9962	1.0005	1.0026	1.0539
KKS3(F6)	1.0003	1.0039	1.0074	1.0110	1.0127	1.0540
Vaddu Express(F7)	0.9292	0.9369	0.9445	0.9522	0.9560	1.0530
Chava Express(F9)	0.9461	0.9528	0.9595	0.9663	0.9697	1.0541
PPD Express(F10)	0.9130	0.9214	0.9299	0.9384	0.9427	1.0537
JaffnaExpressPara(F11P)	0.9452	0.9520	0.9588	0.9656	0.9690	1.0522
JaffnaExpressKom(F11K)	0.9475	0.9542	0.9609	0.9677	0.9710	1.0529
Vaddu Express(Thunaivi)	0.9412	0.9481	0.9550	0.9620	0.9655	1.0537

Further, OLTC switching operation causes voltage transient/sag. This is due to the arcing at the OLTC switches, which also causes contact erosion and carbonization of the arcing switch oil [3]. As a result the maintenance cost and time will also increase.

XI. USAGE OF ON LOAD TAP CHANGER (OLTC) FOR A DISTRIBUTION NETWORK

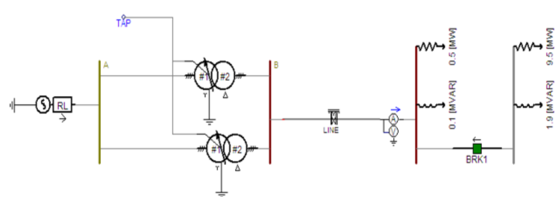

Fig.3: A simple network used to study the concept of the OLTC.

Fig 3 shows a simple network was developed in PSCAD to study the concept of OLTC. Here a 30km Racoon conductor is connected to a light load and then a heavy load is engaged by BRK1 switching operation. The steady stage voltage at the load terminal was measured in this study. BRK1 switch operation was arranged in such a way that initially open, closed at 0.7s and again open at 1.0s. During this period the load terminal voltage varies in from 0.8836 to 0.9939. This shows that the voltage goes out of its lower limit. Hence to mitigate this violation, the transformer DETC position were set to 0.93 and again the load voltage was observed, which varies from 0.9500 to 1.0687. This shows that the voltage exceeds its upper limit. In such situation, the DETC cannot be used to solve this problem. Therefore the next option is to go for OLTC.

In this study during the light load condition the DETC position was set to 0.99 and found that no violation of voltages and it was within the upper limit. Therefore a solution was identified to set the primary side of 2x35.5MVA 132/33 step down transformer TAP at 0.93 or 0.99 when the voltages reached to their lower limit and upper limit respectively. In other words this will help to operate without violating the voltage limits during light and heavy load operating conditions. This is only possible through the OLTC.

Further to the above as the OLTC operation needs an automatic control. The situation was carefully studied and an appropriate control system was developed. Fig 4 shows the schematic diagram of the OLTC automatic and customized control technique.

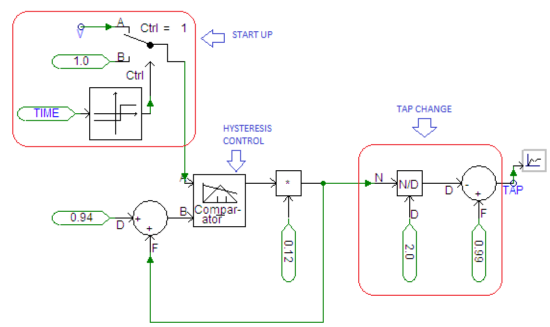

Fig. 4: Schematic diagram of the OLTC automatic and customized controller with two tap positions

The idea of this controller is based on hysteresis control operation, which eliminates the malfunctioning in the switching operation of the OLTC. Hence a quality solution is achieved. The startup block is added to avoid the unnecessary operations in the simulation only. In practice this startup section used to energize the controller after its measurements section gets stabilized.

The operation of hysteresis control block is designed in such a way that when the comparator ‘A’ input greater than ‘B’ input, the output of the comparator will be ‘0’. On the other hand when the comparator ‘A’ input less than ‘B’ input, the output of the comparator will be ‘1’. This helps to shift the value of the comparator input B from 0.94 (lower voltage limit) and 1.06 (upper voltage limit). The shifting of the threshold value, at the comparator input B, helps to avoid malfunction due to variation in the measured voltage due to the change of the OLTC tap positions. This is the excellent operation of adding the hysteresis control block in this control technique. The operation of the Tap change block is to change the TAP position from 0.99 to 0.93 according to the calculated control values.

Fig 5 shows the variation of terminal voltage and the TAP setting against time. It can be noticed that the TAP value changed from 0.99 to 0.93 when the terminal voltage intend to decrease below 0.94 and again increased back to 0.99 when the terminal voltage intend to increase above 1.06pu. The simulation result is conforming that the voltage is kept within its limits by the OLTC operation using the proposed automatic and customized control technique.

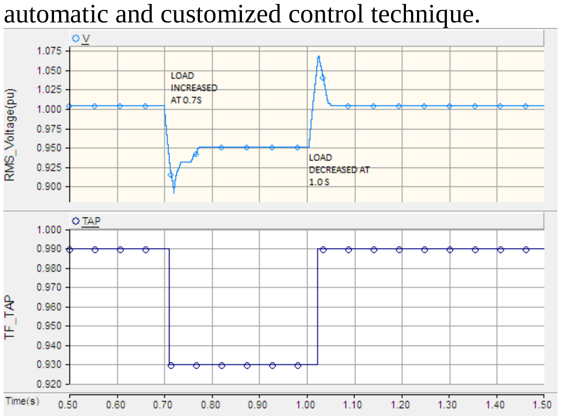

Fig.5: Simulation result of TAP and terminal voltage vs time.

XII. CONCLUSION

The study shows a step by step systematic approach / concept to resolve voltage issues by using available distribution network devices. Here the two major concepts are validated through the simulation study: (i) A concept for calculating the Fixed Tap position (DETC) is developed and elaborated using an equation. Using the PSCAD simulation, it has been validated that the proposed concept is maintaining the voltages within the acceptable limits. (ii) A controller is developed for the OLTC and a concept on calculating the TAP positions for the OLTC is also proposed. The operation of OLTC and its proposed control is validated using the PSCAD simulation study. The results confirmed the network operations are very well kept within the required voltage limits.

XIII. FUTURE WORKS

Future studies will be carried out with STATCOM. This is because Jaffna peninsula and the Northern Province have been very well recognized with renewable energy resources such as wind and solar. As a result it is expected fluctuating generation technology will be integrated to this distribution network.

However the renewable energy technology have been very well developed still the low frequency power fluctuations are exiting due to intermittent nature of the renewable sources which can be eliminated using STATCOM with energy storage [13]. This will be the next task of this research study. This also predicted further improvement with hybrid operation of other existing power plants. In other wards when the power fluctuation occurred, up to some level the STATCOM with energy storage will be used to eliminate, where the upper limit of fluctuating power elimination is depend on energy storage capacity, thus the cost of the energy storage.

It is expected if a hybrid operation is done together with the existing other power plants, that may minimize the cost. As a result the distribution network is expected to be operated within the safe margin while allowing high capacity integration of renewable energy generation technologies.

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