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Investigation of Proper Facts Technology in Improving the Transmission System Reliability in – North –West Grid Tanzania

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Abstract: ***The northwest grid network of TANESCO (Tanzania state power company) suffers the stressful condition caused by factors such as worst climate condition affecting hydropower source (which is 75% of the total generated units), an over exploitation of the existing transmission system and less or no number of new power system projects, together caused lack of reactive power sources into the system resulting in voltage instability. Research carried in this work observe and record some indication of the severe condition existence, aiming to find methods to relieve this system from voltage instability. The grid section was modeled in MATLAB TM Simulink, by dividing it into smaller sections and then simulated to observe its behavior in MATLAB TM software. FACTS devices Unified Power Flow Controller (UPFC) was applied to each section and results were compared with those from system without FACTS. Implemented models were limited to hydropower sources only (northern and southern). This research work observed the improved voltage condition with the ability of damping oscillations. Then it can be concluded to be successful in the upgrading of this power system grid, and increase the delaying period of its replacement when UPFC is applied. The study recommends carrying out the economic analysis for the application of UPFC into the North - West Grid system. This can be performed to compare the cost with the achievable benefits. And also study of the FACTS device placement for optimization of power flow. The position at which the device is located affects the optimal results.***

Keywords: **UPFC; FACTS; transmission system; MATLAB TM software.**

I. INTRODUCTION

FACTS cover a number of technologies that enhance the security, capacity and flexibility of power transmission systems. Their solutions enable power grid owners to increase existing transmission network capacity while maintaining or improving the operating margins necessary for grid stability. As a result more power can reach consumers with a minimum impact on the environment, after substantially shortening project implementation times, and at lower investment costs – all compared to alternative of building new transmission lines or power generation facilities [1]. FACTS devices are categorized in two main application technologies, series compensation and dynamic shunt compensation. Hence the following connection combinations can be done:

i. Series with the power system (series compensation) [2]
ii. Shunt with the power system (shunt compensation) Both in series and in shunt with the power system [2]

A. The Unified Power Flow Controller (UPFC)

FACTS installation in a power system is usually not intended to perform only one single task, but rather a multiple of tasks which are optimally combined; for example power flow control, voltage control, minimizing the losses, and damping of oscillations. Thus, their proper selection and their location will achieve best the objective for which it was intended and will be less suitable for any other objective [3]. Unified Power Flow Controller (UPFC) is a combination of static synchronous compensator (STATCOM) and a static series compensator (SSSC) which are coupled via a common dc link to allow bi-directional flow of active power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM, and are controlled to provide concurrent active and reactive series line compensation without an external energy source. The UPFC was developed for the real time control and dynamic compensation of AC transmission systems. It is able to control all the parameters affecting power flow in the transmission line. Also it can independently control both the active and reactive power flow in the line. Fig 1 shows the implementation of an example, where the active power can freely flow in either direction between the AC terminal of the converters and each converter can generate and absorb reactive energy independently. It increases power flow, dynamic voltage control and system stabilization.

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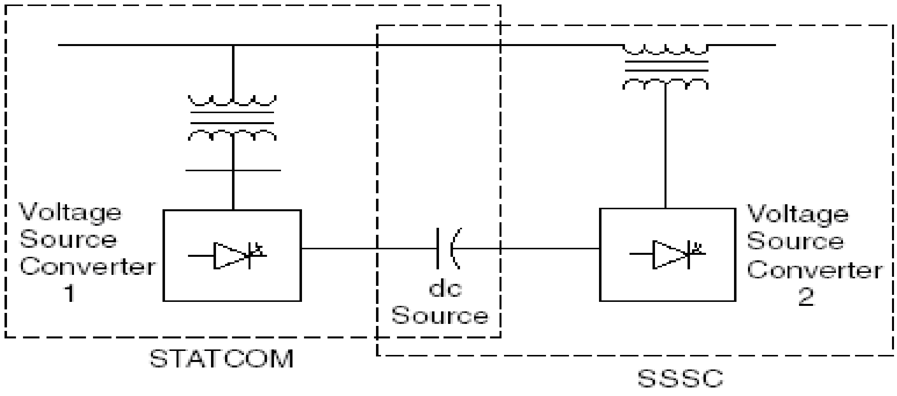
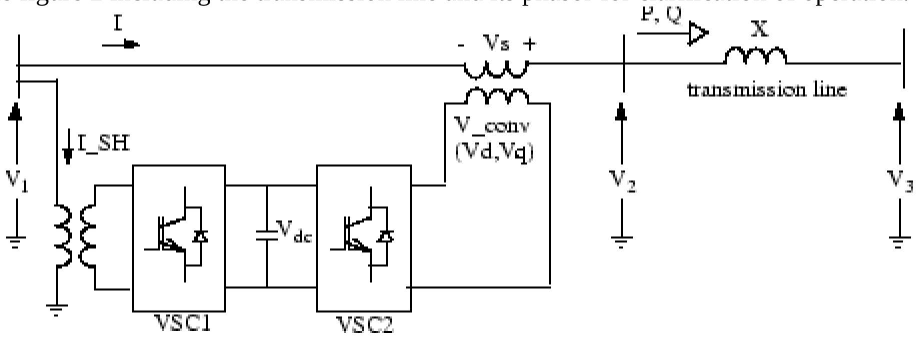
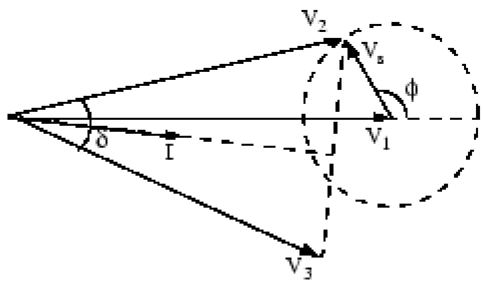


Fig 1: A 1- line diagram of a Unified Power Flow Controller (UPFC) [4]

Figure 1 comprises of a shunt compensator and a series compensator (which is self-commutated inverter). Both connections form the UPFC device contents.

The operation of UPFC can be easily explained through the phasor diagrams, which depict its operation and its impact on power systems. It is the most versatile member of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow on power grids. The UPFC as explained as a combination of a shunt controller (STATCOM) and a series controller (SSSC) interconnected through a common DC bus as shown on the figure 2 including the transmission line and its phasor for clarification of operation.





$$P = \frac{V_2 \times V_3 \times \sin\delta}{X} \quad ......1$$

$$Q = \frac{V_2(V_2 - V_3 \cos\delta)}{X} \quad .....2$$

Fig 2: Line Diagram of UPFC and phasor diagram of Voltages and Currents [4]

The FACTS topology shown in figure 3 provides much more flexibility than the SSSC for controlling the line active and reactive power because active power can now be transferred from the shunt converter to the series converter, through the DC bus. Contrary to the SSSC where the injected voltage Vs is constrained to stay in quadrature with line current I, the injected voltage Vs can now have any angle with respect to line current.

In figure 3 phasor diagram (a), transmission line without the UPFC has very high current resulting to very high power losses where as phasor diagram (b) with UPFC the current is low hence low losses.

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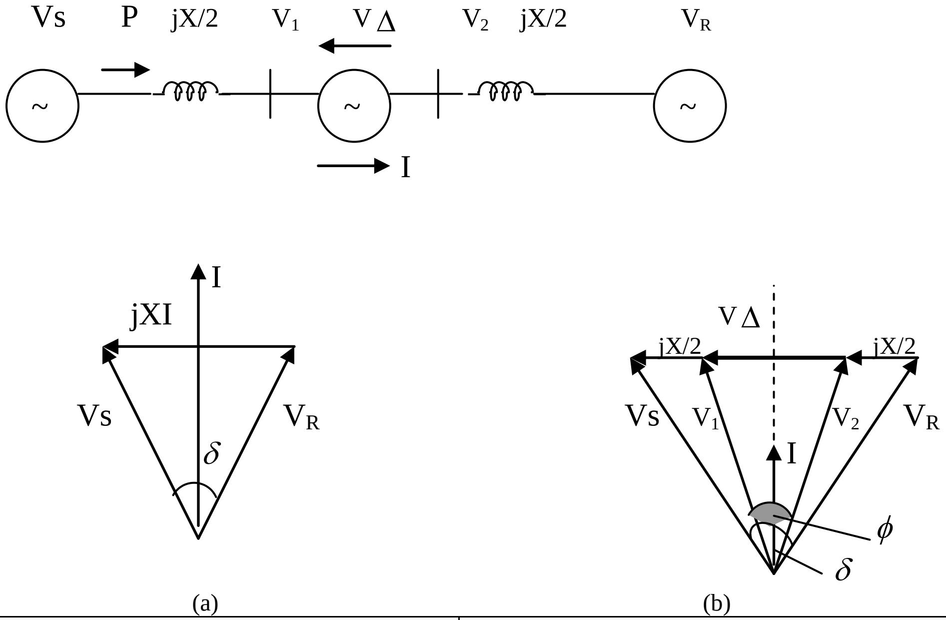

Line values without UPFC	Line values with UPFC
$I = 2\left(\frac{V}{X}\right)\sin\left(\frac{\delta}{2}\right)$, $P = \left(\frac{V^2}{X}\right)\sin(\delta)$	$V\Delta = Vc \bullet j\frac{X}{\lvert I \rvert}$, $I = \left(\frac{2}{X}\right)V\sin\left(\frac{\delta}{2}\right) - \left(\frac{Vc}{2}\right)$

Fig 3: UPFC operation explained through phasor diagram [4]

The phasors of the figure 3 illustrates the operation of UPFC and the control modes as it can work as series compensator (SSSC) and its shunt portion characteristic is similar to that of a STATCOM [3].

Today's challenge of providing quality power has forced TANESCO to have interconnections of its power generating plants. The efficiency of the transmission infrastructure needs to be improved to reduce losses to have maximum power delivery. Such unsatisfactory power delivery and the high demand from consumers have necessitated running the transmission system near or above its operating limits and thus stressing the system and consequently causing frequent grid outages. Such a situation is likely to cause the following problems; Major load rejection (load shedding) causing rise of voltage hence frequent tripping of the grid. Overloaded Transmission system especially during peak load hours. Difficulty in providing expansion that will meet the today's electricity demand, which is rising above the generating capacity at a greater rate yearly.

This situation calls for a study that will investigate Flexible AC Transmission System (FACTS) devices to be used to minimize the problems; analyze the contingencies so as to predict and/or forecast the future situation; and improve the capacity of the transmission systems. Therefore this study investigates proper FACTS technology to provide improved condition in the transmission system reliability, during interconnections of transmission lines from different generating sources.

II. RESEARCH METHODOLOGY

This research work was carried out on the Northwest zone (Mtera to Mwanza via Singida) which is a part in the Tanzanian grid run by Tanzania Electric Supply Company (TANESCO). The research is based on a survey conducted in TANESCO Company substations and departments where relevant data and information was obtained by a combination of measurements, calculations of different transmission line elements, from records and through interviews. The power system in Tanzania has a large number of bus bars with a few connected to generators. A single line diagram represents lines, buses, and generators while loads are indicated by their real power P and reactive power Q.

A. Modeling Power System Section and the Application of UPFC

UPFC is applied to control the power flow in a 220kV transmission system. The contents of the system modeled in figure 5 was rearranged so as to apply UPFC in a loop configuration at the center and power was measured in 5 buses in the loop named (B1, B2, B3, B4, and B5) while the UPFC is bypassed and while it is applied [5]. The device is connected to 230 kV obtained from two transformers 220kV/230kV rated 200MVA and 400MVA respectively. These transformers were connected between the two power plant southern source1 and the northern source2. The resulting power flow in the five buses was displayed in the numeric display meter connected at VPQ Lines scope. The VPQ measurements were obtained as shown in the model figure 5 using the digital display meter placed to tape different variables P(MW), Vpos(pu) and Q(Mvar) in the loop buses. The displayed values of VPQ are tabulated in Table 1.

Table 1: Recorded results of the power flow in the loop UPFC operation

UPFC shunt reading Bypass closed	Bus	B1	B2	B3	B4	B5
	Vpos(pu)	1.022	1.015	1.002	0.9592	0.9951
	P (MW)	*71.52	136.9	135.1	*34.34	*34.65
	Q (MVar)	-4.508	-9.867	2.066	-21	-23.87
UPFC shunt reading Bypass open	V pos(pu)	1.027	1.025	1.013	0.9671	1.006
	P (MW)	*72.68	139.8	138	*34.88	*35.19
	Q (MVar)	-3.84	-14.29	3.789	-23.04	-26.07

* Indicates the reversed direction of power flow

The results shown in table1, reveals the improvement of power flow when the two types of applications was done. Thus with applied UPFC power flow was increased.

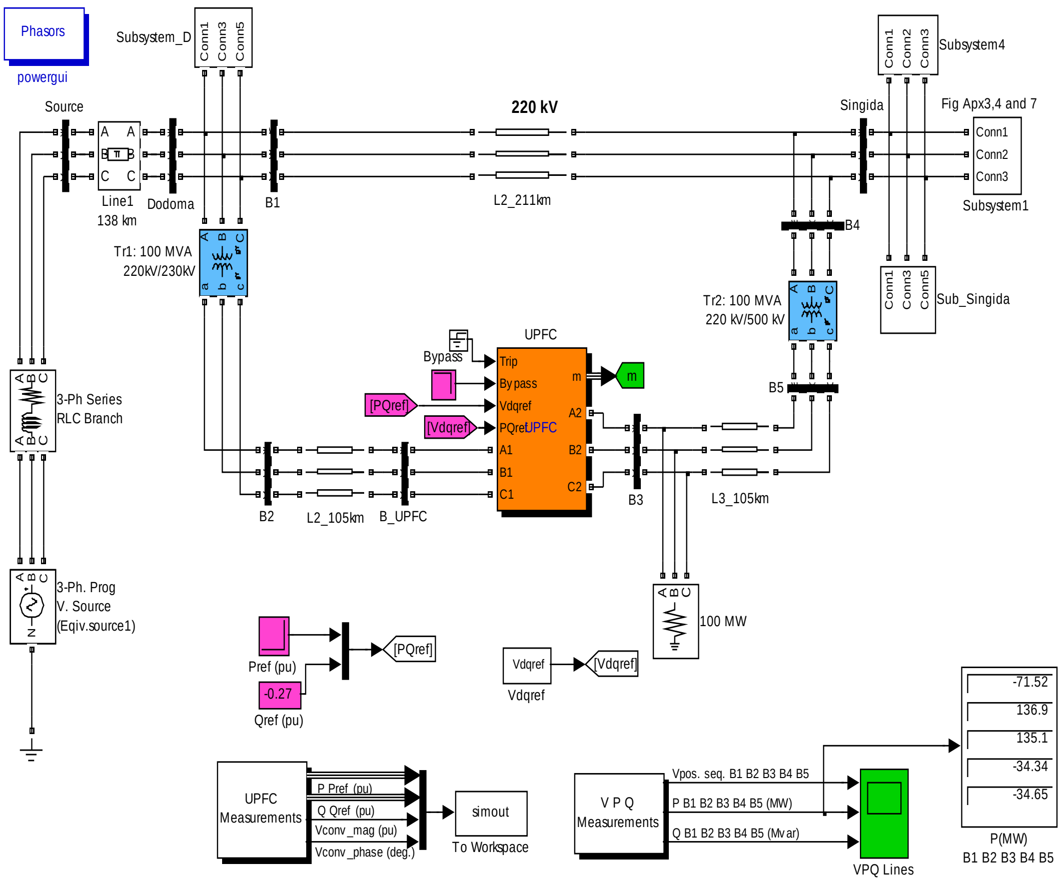

Fig 4: Application of Unified Power flow Controller (UPFC) in control of power

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B. Power System Measurements Results with UPFC applied

Table 2 is the measured amount of voltage and current in the selected bus bars where it reveals the real situation before and the application of UPFC.

Table 2: Measurement Results with UPFC

Name	Phase	Voltage (kV)	Current (A)
Source	A	220 .97∠20.50°	64.58∠-23.99.35°
	B	220.97∠-99.50°	64.58∠-143.99°
	C	220.97∠140.50°	64.58∠96.01°
B1	A	152.65∠-22.24°	113.24∠160.09°
	B	152.65∠-142.24°	113.24∠40.09°
	C	152.65∠-97.76°	113.24∠-79.91°
B2	A	160.67∠-31.33°	99.74∠-22.43°
	B	160.67∠-151.33°	99.74∠-142.43°
	C	160.67∠88.67°	99.71∠97.57°
Dodoma	A	264.37∠7.76°	66.79∠-29.10°
	B	264.37∠-112.24°	66.76∠-149.10°
	C	264.37∠127.76.°	66.76∠88.48°
Singida	A	254.79∠-33.53°	34.28∠-50.75°
	B	254.79∠-153.53°	34.28∠170.75°
	C	254.79∠86.47°	34.28∠69.25°
Arusha	A	256.13∠-4.05°	97.63∠168.90°
	B	256.13∠-124.05°	97.63∠48.90°
	C	256.13∠115.95°	97.63∠71.10°
Bulyankulu	A	254.77∠-11.53°	58.37∠-83.93°
	B	254.77∠-131.53°	58.37∠156.07°
	C	254.77∠108.47°	58.37∠36.07°
Mwanza	A	261 55∠-11.54°	33.19∠13.20°
	B	261 55∠-131.54°	33.19∠133.20°
	C	261 55∠108.46°	33.19∠-72.80°

From Table 2 voltage at bus B1 and B2 was at worst case but when UPFC was applied the voltage was improved to the acceptable value reducing voltage flow outages ie above 220kV. At the point of low voltage the current becomes very high hence power losses.

Figure 5, 6 and 7 shows the point of compensation of the system at 5.2 the reactive power was added to the system. The actual power dropped to its maximum power limit (5.2) where the compensation was done to inject the reactive power into it the process applied in the UPFC and the real power starts to increase. The action of compensation in the UPFC is shown in Figure 8.

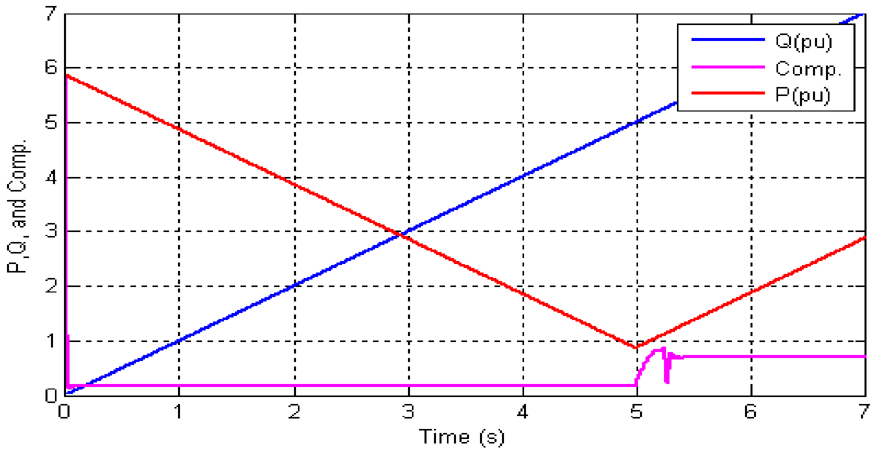

Fig 5: Variation of power (P) vs reactive power (Q)

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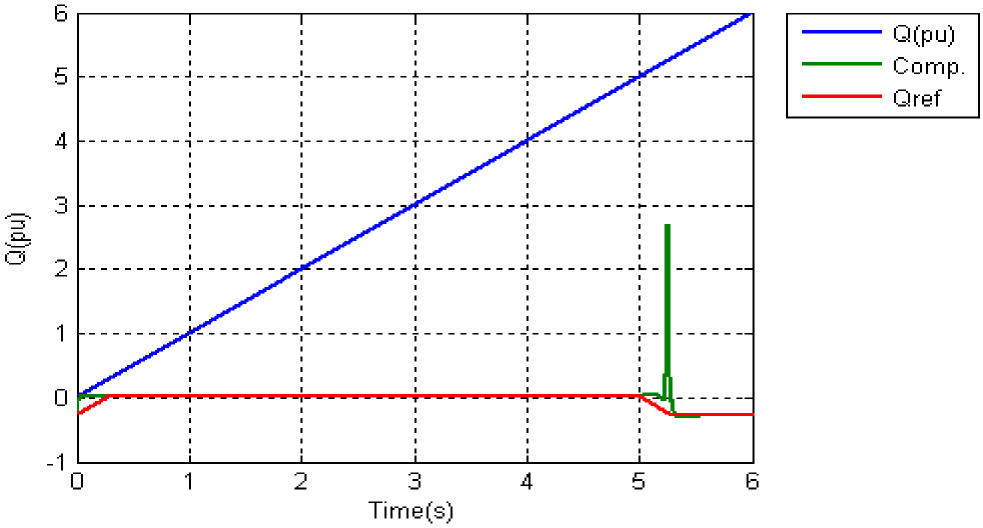

Fig 6: Reactive power compensation in the application of UPFC

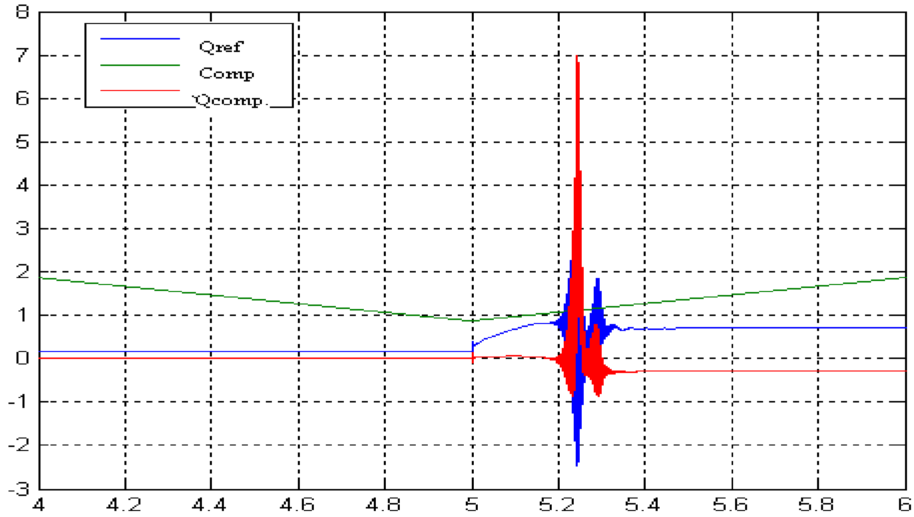

Fig 7: P_SE and Q_SE in the operation of UPFC

The substations listed in table 3 were studied for the period of fifteen days and few cases of the voltage deviation was as in table 3 (Voltage worst case) which was solved in the application of FACTS in this system.

Table 3: Selected substation voltage

Details / Name	Rated kV	Voltage worst case May2007	Simulated Without FACTS (kV)	With FACTS (kV)	
				STATCOM	UPFC
Mwanza	220	202	96.438	182.41	261.55
Singida	220	210	94.424	177.69	254.79
Arusha	220	185	99.438	200.77	256.13
Dodoma	220	206	173.80	102.96	264.39

Source [6]

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III. DISCUSSIONS OF RESULTS

A. Application of UPFC

In this study the application of UPFC into the system, UPFC was inserted and operated at the center. The voltage and current obtained after the simulation are stated as measured results in a powergui. Here also the substations involved in the discussion are Arusha, Singida and Mwanza. The voltage rise shows the capability of UPFC to improve the voltage. If all the control devices are incorporated the working voltage will be normal. Power P (MW) flow, its corresponding reactive power (Q MVar) and the positive sequence voltage (pu) are tabulated in table 1.

Figure 5, 6 and 7 shows the critical point at which the system must be compensated at 5.2 s. real power decreases while reactive power in the system increases and at this point compensation is highly introduced into the system as shown in figure 7.

Application of UPFC made the situation of the voltage much better at Arusha, Singida and Mwanza. This research considers the UPFC as the most corrective type of FACTS in this power system though only some benefits were tested and discussed in this work. Table 1 shows the ability of UPFC to control the direction of power flow in an interconnected system (northern and southern sources).

Table 2 indicates that the device is capable of rising voltage to about 1.5 times for a well designed application, proper placements and sizes of the device required. The appropriate setting of UPFC device, especially the speed of response to changing phase angle and voltage conditions as well as operating modes is easily done at the substation, to optimize FACTS (UPFC) application for power enhancement in the TANESCO power.

IV. CONCLUSIONS AND RECOMMENDATION

Regardless of the economic analysis in the application of FACTS devices, this work has demonstrated FACTS technologies application to power system as a problem solving. And they proved to be capable in the upgrading of voltage level in the power system. They can also stabilize the voltage thus reducing the rise and fall off current and hence power losses. From the applied technology, UPFC had a large effect in Power flow in the power system. If selected to minimize power system problems it will optimize the power transfer capability and therefore quality power to consumers.

Simulated results show that with the application of STATCOM (which works together with SVC in its operation) and UPFC in the TANESCO power system the power constraints e.g. Unnecessary blackout, voltage fluctuations, power losses, and human error in the switching process of the power compensation devices, as FACTS devices are automatically operated and can be located in unmanned substations, will be minimized. Changing of the set points and operation mode can be done remotely (for example, from a substation control room, a regional control center, or a National control center).

The summary in table 4 is the remarks given showing UPFC to be of much benefit to the Tanzania power system. It scores higher in problem solving than other two tested FACTS devices.

Table 4: A summary of FACTS performance in power system

		SVC	STATCOM	UPFC
Voltage and Reactive power Control issues	Low voltage at heavy load			x
	High voltage at light load			x
	Voltage following outage			x
Power flow issues	Parallel line load sharing			x
	Post-fault sharing			x
	Power flow control			x
Dynamic and Stability issues	Lack synchronizing torque			x
	Dynamic flow control and transient stability			x
	Power oscillations			x
Remarks	Discussed in this work			x

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Key:

UPFC	Unified Power Flow Controller

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