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Active Power Flow Control Using Phase Shifting Transformer and UPFC in AC Transmission Line

Jayshree Patil,

Department of Electrical and Electronics Engineering,

SDM College of Engineering and Technology

Dharwad

Shree.nov19@gmail.com

Prof. Manjula Subrean

Faculty of Department of Electrical and Electronics Engineering

SDM college of engineering and technology

Dharwad

smanjula845@gmail.com

Abstract **-- Electrical power system is huge interconnected power system to meet the consumer demand without interruption and to maintain the stability, to utilize existing system to their maximum limit within stability limit of the system, to solve the congestion problem and improve the power flow in the line. Phase shifting transformer (PST) is used to control the active power flow in transmission line. This active flow control is obtained by adjusting phase angle of voltages at PST terminal. Unified power flow controller (UPFC) is facts device, it can control both the active and reactive power in transmission line by controlling the line parameter like voltage, phase angle and line impedance there by adjusting the line reactance in real time. The power system simulation model for PST and UPFC are developed in MATLAB. By simulating the model without PST and UPFC and then model with PST and UPFC is simulated to obtain the results. Results are compared for different loading condition to analyze the performance of the system with both the model.**

Keyword **– PST, UPFC, Power flow control, active and reactive power, MATLAB/SIMULINK**

I. INTRODUCTION

Now a days there is boost in power demand. As the Electricity play an important role in national growth so there are lots of development in this sector has taken place. Power utility i.e., power Generating company striving to meet the demand by generating the required power. Generated energy needs to be transmitted to the desired area with minimum loses in the transmission line, along with that transmission and distribution company's attempt is to design techniques to maximize the utilization of the existing transmission line. The stability of the system is major concerned by the utility. As and when the power demand has increased, existing generation and transmission system are constrained. The possibility of system to became unstable has magnified. So, it is necessary to design the system closer to their stability limit.

Utility are trying to obtain optimal and profitable operation of the generation, transmission and distribution system. Another major concern of utility is reliability. Reliability is ability of system to provide uninterrupted power to consumer.so to achieve both operational reliability and financial profitability,

It has become clear that more efficient utilization and control of the existing transmission system infrastructure by applying the advance control technology.

For optimally utilizing the transmission line there should be a proper planning. Planning should include length of physical path between generation and load Centre, any alternate paths, loading of the parallel line. There may be uneven loading in parallel path due to difference in their impedances which are caused by conductor sizing number of sub-conductor tower geometry and length of the line. The line with smaller impedance carries more power and vice versa. So, there is threat of overloading of lower impedance transmission line than that of the other lines in the system to provide the required demand by the consumer. Inevitably power flow in the transmission line needs to be controlled so has to maintain stability, security, reliability to the system.

Power flow in system can be controlled by different devices like by using PST, UPFC and other facts devise too. By adjusting the line parameters this can achieved.

PST is a special type of transformer. As known transformers are used to control the power flow between different voltage levels of the grid, they also use phase angle control method between primary and secondary side such transformer is termed as phase shifting transformer or phase shifter. It is a device which control the active flow in the line. The main function of PST is to alter the effective phase displacement between the input voltage and output voltage of a transmission line. Both the magnitude and the direction of the power flow can be controlled by varying phase shift.

Both the active power and reactive power can be controlled by UPFC simultaneously. Power in the line is the function of line impedance, the magnitude of sending end and receiving end voltage and the phase angle between voltages, control is possible controlling one or combinational parameters of the line. It can independently control active and reactive power; therefore, reliability and quality of the supply can increase.

II. OPERATION PRINCIPLES

A. Operating principal of PST

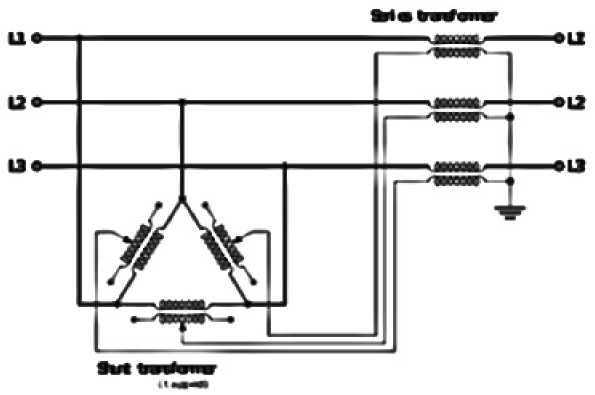
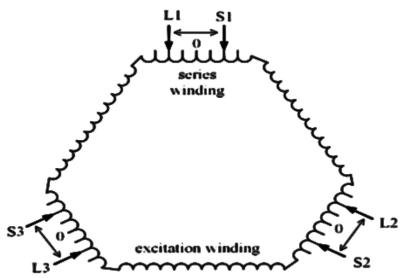


Fig 1. configuration of PST

A PST is a device which control which control the active power flow of lines in a complex power transmission network. The principal function of a phase shifting transformer is to alter the effective phase displacement between the input and output voltage of the transmission line, it controls the amount of active power flow in the line. It is a device which can inject a voltage with controllable phase angle and/or magnitude.

The main circuit of PST consist of the exciting transformer that provides input voltage to the phase shifter; the series transformer, that inject a controllable voltage in the transmission line and the converter or tap changer, which control the magnitude and/or phase angle of the injected voltage.

A converter is used in power electronic based interface, and a tap changer is used in case of mechanical controlled PST.
Different forms of PST are:
a. direct PST



b. indirect PST
c. asymmetrical PST
d. symmetrical PST

Fig .2 Delta -hexagonal type PST

Here by using Delta-Hexagonal type PST. The advantage of this design is that only one tap variable transformer is needed per phase. The phase angle changes almost linearly with tap-changer setting.

B. Operating principal of UPFC

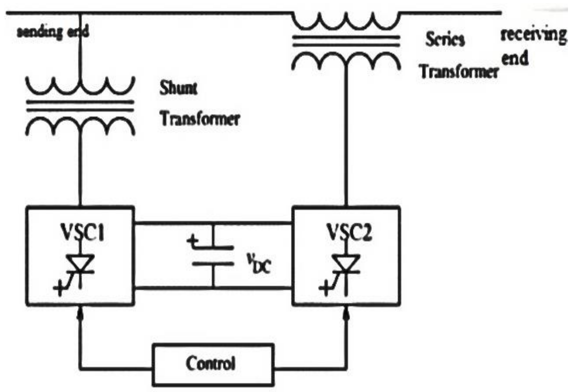


Fig 3. Basics configuration of UPFC

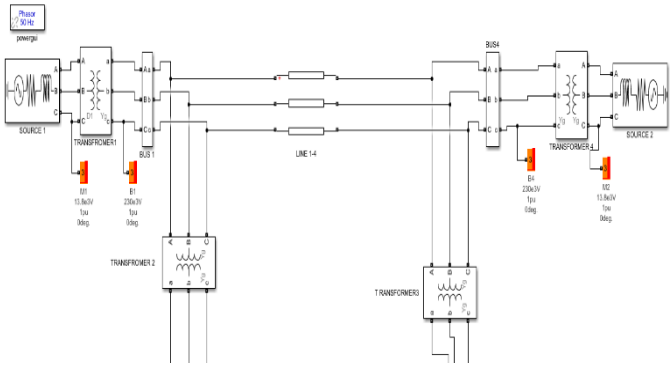
UPFC is the most dynamic FACTS controller in all known controllers' groups. The complexity of the UPFC control also depends on the controlled and the control variables interaction with each other.
UPFC consist of a series and shunt converter connected by a common DC link capacitor. The shunt converter of the UPFC controls the UPFC bus voltage/shun reactive power and the dc link capacitor voltage. The series converter of the UPFC controls the transmission line real/reactive power flows by injecting a series voltage of adjustable magnitude and phase angle.
The interaction between the series injected voltage and the line current leads to real and reactive power exchange between the series converter and the power system. Converter 2 inject an ac voltage with magnitude and angle, via an insertion transformer. The real power at the ac terminal of the insertion transformer is converted by the inverter into dc power that appears at the dc link as positive or negative real power demanded.
The reactive power exchange at the ac terminal is generated internally by the inverter. Converter supplies or absorb the real power demanded by the converter 2 at the common dc link. It is connected back to ac and coupled to the transmission line via a shunt connected transformer.
Converter 1 can also generate or absorb controllable reactive power and can provide independent shunt reactive compensation for the line.
Converter 2 controls the magnitude and the angle, the power flow, voltage regulation, series capacitor compensation, and transmission angle regulation.

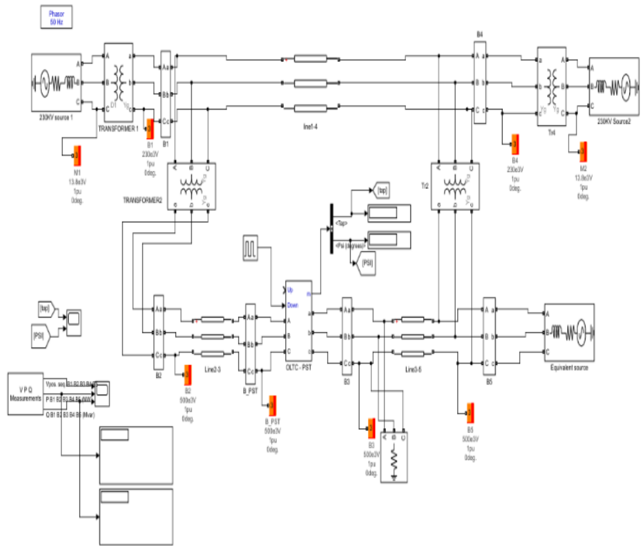
III. SIMULATION MODEL OF PST AND UPFC

The Simulink model of the power system is shown in fig 4. Considered system is a loop configuration. It consists of five buses (B1to B5) and they are connected through a three-transmission line (L1to L3), and system is having two transformers of 500Kv/230Kv transformer. here power plant of 230Kv is situated at bus 1& bus 4 having total generating capacity of 1500MW. Load of 500KV,1500Mva equivalent and a load at bus 3. load flow analysis of the system without any power control device is performed. From the result it can be observed that the transformer 2 is getting overload while supplying the required demand of the system.

Fig 4. Simulink model without any power control device

Case 1: when PST is inculeded in simulink model





PST with onload tap changer is inserted in model in line2 to control the power flow in the line 3 which is overloaded. Here number of taps is set to 20, thus the phase shift resolution is 60/20=3degreeper step is approximated. To control the tap position send signal to either up or down port of PST. To increase the phase shift in positive value need to provide taping to down port of PST. To obtain the requried power flow phase shift of the terminal voltage need to be incresed that is performed by changing/ increaing the taping . power flow result and voltage levels are obtained. Figure 5 shows the model with PST.

Fig 5. Simulink model with PST

Case2: simulink model with UPFC

UPFC is placed in line2 in model to adjust the real and reactive power and voltage of bus 2.

It consist of two 100 MVA ,IGBT type converter i.e.; series and shunt coupled throught a dc capacitor bank. The series converter will gives a maxmium of 10% of the rated line-to-ground voltage. The series conveter is at nominal 100MVA with peak voltage injection of 0.1Pu. the shunt converter is also at nominal 100MVA.the Pref box is programmed with a preliminary active power related to natural power flow. After some time set as set in byass switch Pref is increased by 1 Pu but Qref is held constant as set earlier. Figure 6 shows the model with UPFC.

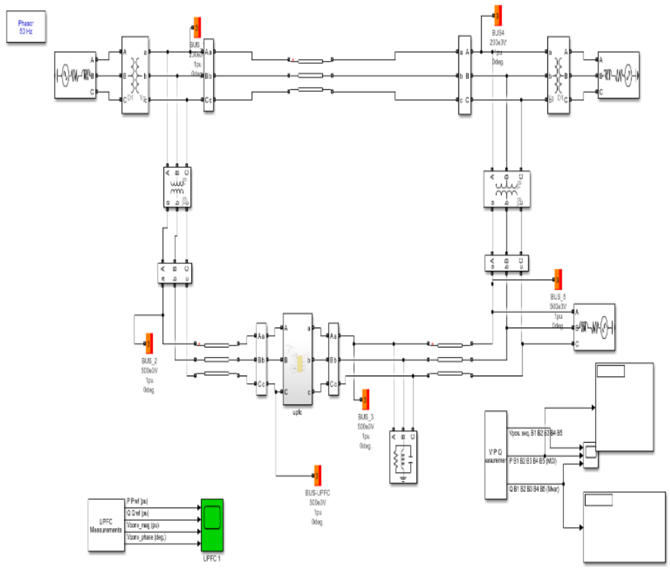


Fig 6. Simulink model with UPFC

The results of optimal power flow like voltage profile , bus power injected , active and reactive power flow are evaluated and tabulated below. In UPFC two outcomes are simulation result of power flow adjustment model and the second outcome is voltage injected module. The performance of system under differnet loaded conditions are analysed and results are tablutaed.

IV. RESULTS

A. Tabluar results

Table of bus injected power at different taping, with and without UPFC at resistive, inductive and capacitive condition results are obtained after simulating the system with the that specified condition.

TABLE I
BUS INJECTED POWER WITH AND WITHOUT PST AT TAPPING MINS FIVE AND MINS TENS

Bus.no	P	Q	P	Q	P	Q
B1	115.3	-20.52	276.5	-26.22	471.8	-30.69
B2	608.8	-68.70	769.1	-64.24	962.8	-14.46
B3	606.9	-40.66	763.1	-95.17	952.6	-208.8
B4	878.7	18.45	715.9	6.21	5168	-1.12
B5	1279	-130.1	1276	-157.2	1270	-250.5
WITHOUT PST			**WITH PST**			

TABLE II
BUS INJECTED POWER WITH AND WITHOUT UPFC AT DIFFERENT RESISTIVE LOADING CONDITION

WITHOUT UPFC					**WITH UPFC**			
R=200MW			**R=600MW**		**R=200MW**		**R=600MW**	
Bus. no	**P**	**Q**	**P**	**Q**	**P**	**Q**	**P**	**Q**
B1	104	-17	147	-21	197	-28	244	-39
B2	597	-61	641	-66	690	-92	737	-121
B3	595	-32	639	-41	687	-27	734	-64
B4	891	25.5	846	16	796	13	748	15
B5	1280	-118	883	-112	1277	-99	883	-108

TABLE III
BUS INJECTED POWER WITH AND WITHOUT UPFC AT DIFFERENT CAPACITIVE LOADED CONDITION

WITHOUT UPFC					**WITH UPFC**			
C=200MVAR			**R=800MW C=500MVAR**		**C=200MVAR**		**R=800MW C=500MVAR**	
Bus .No	**P**	**Q**	**P**	**Q**	**P**	**Q**	**P**	**Q**
B1	88.7	-16	163	-21	197	-29	258	-41
B2	582	-60	657	-64	689	-96	751	-122
B3	581	-30	655	-40	687	-27	748	-64
B4	905	29	830	16	796	16	734	14.5
B5	1478	- 128	686	-107	1476	-110	687	-103

TABLE IV
BUS INJECTED POWER WITH AND WITHOUT UPFC AT DIFFERENT RLC LOADED CONDITION

WITHOUT UPFC					**WITH UPFC**			
R=200MW L=C=200MVAR			**R=800MW L=C=500M VAR**		**R=200MW L=C=200M VAR**		**R=800MW L=C=500M VAR**	
Bus .no	**P**	**Q**	**P**	**Q**	**P**	**Q**	**P**	**Q**
B1	103	-17	164	-21	196	-28	243	-62
B2	597	-61	657	-64	690	-92	736	-198
B3	595	-32	655	-40	687	-27	732	-210
B4	891	25.5	830	16	796	13.1	749	51.3
B5	1280	-119	686	-107	1277	-99	712	-221

TABLE V
MAGNITUDE AND Vangle OF PST &UPFC

WITHOUT PST			**WITH PST (TAP=-5)**		**WITH UPFC**	
Bus .no	**V**	**Vangle**	**V**	**Vangle**	**V**	**Vangle**
B1	0.996	12.661	0.9967	29.38	0.9950	13.96
B2	0.9988	8.39	1.0026	29.37	0.9986	8.97
B3	0.9987	6.32	0.9988	4.26	0.9991	6.55
B4	0.9921	14.5	0.9809	21.4	0.9887	16.62
B5	0.9977	4.95	0.9977	4.95	0.9977	4.95

TABLE VII
POWER FLOW IN LINE

WITHOUT PST			**WITH PST (TAP=0)**		**WITH UPFC**	
Bus .no	**P**	**Q**	**P**	**Q**	**P**	**Q**
L (1-2)	599	-15.36	597	-26.45	610.3	-20.83
L (2-3)	597	-62.63	591	-69.95	608.83	-65.99
L (3-5)	396	-28.0	390.4	-43.86	407.43	-37.96
L (4-1)	104	-26.26	99.92	-32.55	115.65	-27.13
L (4-5)	888	31.47	892.08	26.88	877.01	20.38

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B. Waveforms

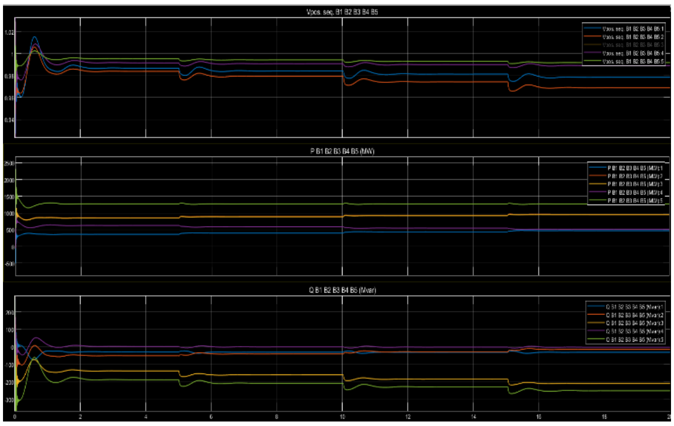


Fig 7. Waveform of Positive Sequence Voltage, Power and Reactive Power of PST

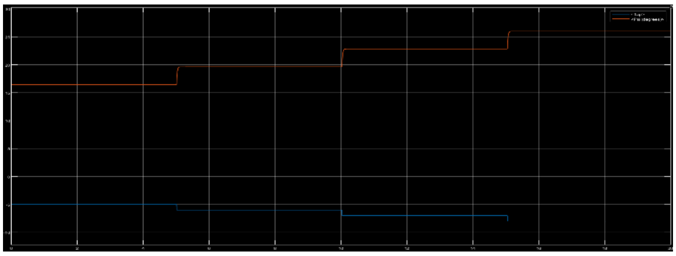


Fig 8. Waveform of Tap and Phase shift of PST

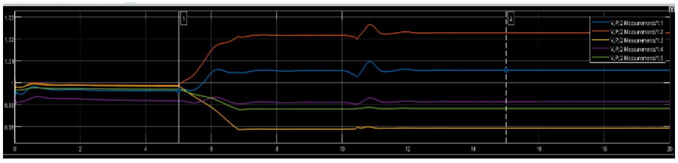
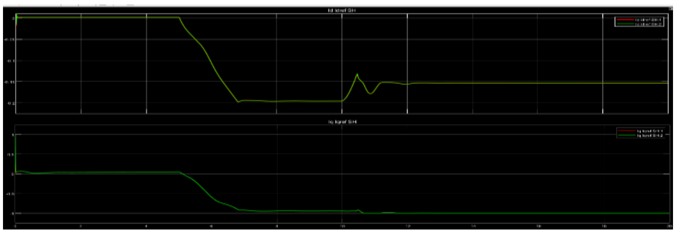
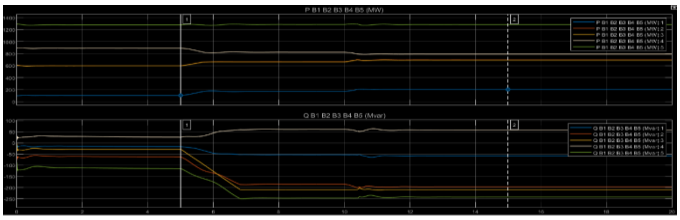
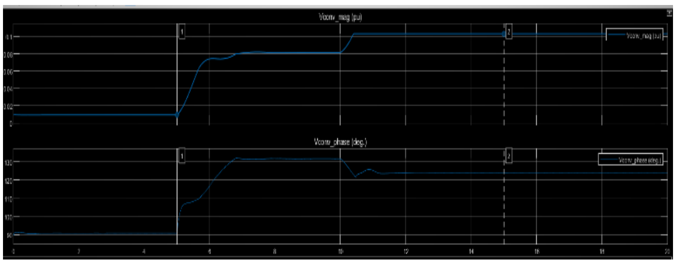


Fig 9. Output waveform Of Voltage, Power & Reactive Power R load of UPFC
Fig 10. Output Waveform of UPFC (R load)

Fig 8. Shunt Direct and Quadrature axis current







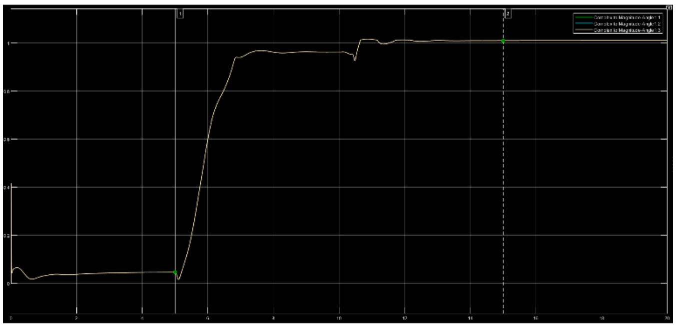


Fig 9: Shunt abc Current

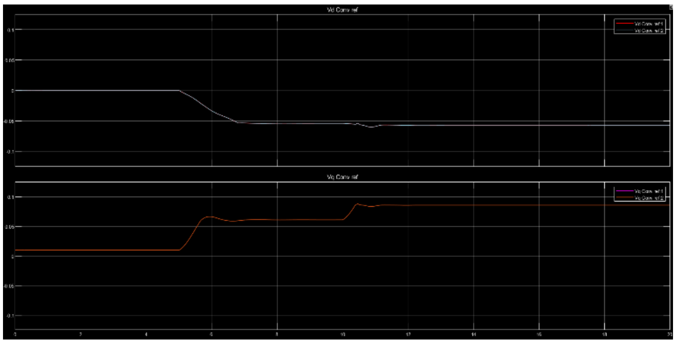


Fig 10: Series Direct and Quadrature Voltage

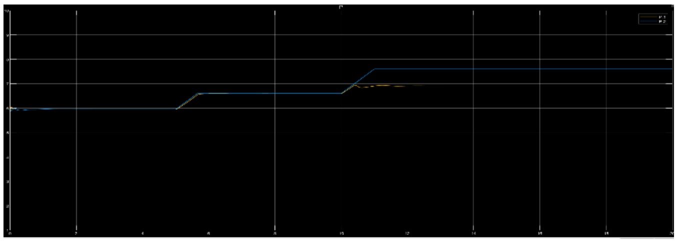
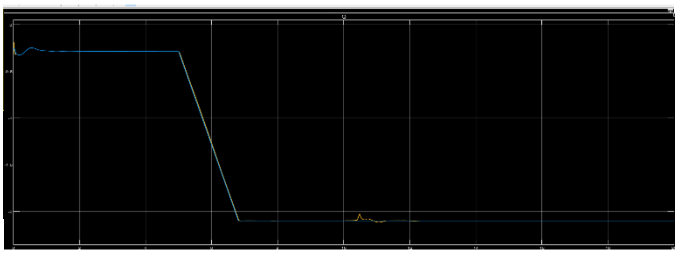


Fig 11: Series Active and Reactive Power



V. CONCLUSION

The PST & UPFC are powerful tools for power flow regulation, by which transfer capability of the transmission line can be increased significantly. When PST & UPFC are incorporated to control the active and reactive power flows in the chosen transmission line, the effectiveness varies with the location of that without the branch power flow constraints. This paper shows the voltage profile with and without PST, real and reactive power flow in transmission lines at different tapping when PST is incorporated. Here, by using power flow adjustment and voltage injection method the power flow is controlled in UPFC. For different loaded condition power injected at different buses is observed and graphically plotted.

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