

Energy Efficiency through Unified Power Flow Controller

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Abstract-This paper describes the theory of voltage regulation and power loss minimization using unified power flow controller along with their different modes of control. One of the major causes of voltage instability is reactive power so it is forcefully infused into the power network system to keep up higher node voltage. Unified power flow controller (UPFC) is an electrical device for providing fast-acting reactive power compensation on high-voltage electricity transmission networks. Various operating modes and their comparison is presented. The result of one UPFC installed is given and their obtained results are discussed. Real power control and dynamic compensation is achieved. A case study presented demonstrates the intensified voltage to transfer the well-organized power reducing losses.

Keyword- Voltage regulation, FACTS, power loss minimization, reactive power, UPFC, control modes.

I. INTRODUCTION

Now days, option to proceed, and cost concerns have deferred the development of both power stations and new transmission lines. The interest for electronic vitality has kept on developing in numerous countries. This circumstance has impelled enthusiasm for furnishing officially existing network with more prominent working adaptability and better use. A unified power flow controller (UPFC) which is a standout among the most encouraging system in the FACT's, has the capability of intensity flow control. It also does voltage regulation in power transmission network. (Iqbal, 2018) (Gholipour,2005)

The voltage regulation is the level of voltage difference between no load and full load voltages of a transformer concerning its full load voltage. It keeps voltages inside the recommended range that can be endured by the electrical gear utilizing that voltage. As a rule, they work as factor protections i.e., opposition diminishes when the electrical load is substantial and increments when the load is lighter. The voltage regulation is normally used in case of alternators and power system calculations. (Schauder,1998). The ideal voltage regulation is 0%. It should be as low as possible for proper operation of the electrical devices. Typically control factor is a deciding element in the optional voltage, control factor impacts voltage regulation. This implies the voltage regulation of a transformer is a dynamic, load- dependent number. A properly designed and rated transformer is expected to provide a certain amount of constancy, maintaining a specific level of voltage at its rated

capacity. The voltage regulation is described as its ability to maintain the same level of voltage with a very minimum variation throughout a given range of load capacity. (Gholipour,2005) (Noroozian,1997)

Power loss minimization is an essential viewpoint in circulation system where the load variety is more looked at different networks. There are distinctive techniques to limit the power loss like DG series capacitor situation, load adjusting and so forth. Among those strategies DG arrangement was much gainful on the grounds that it is straightforwardly identified with real power loss. (Fujita, Control and analysis of a unified power flow controller, 1999) (Farooq,2018)

Among all FACTS controllers, UPFC is the most comprehensive multifunctional FACTS device. UPFC is one of the typical FACTS devices which can simultaneously control all parameters of power system (transmission voltage, line impedance and phase angle) and provide dynamic compensation to the power system. A UPFC is an electrical device for providing fast-acting reactive power compensation on high-voltage electricity transmission networks. It acts as a compensating and phase shifting device simultaneously. UPFC is the device which can control simultaneously all these parameters in power flow and it combines the features of two FACTS devices such as STATCOM and SSSC. (Kannan, 2004) (Gholipour,2005)

The main function of UPFC is voltage control and power flow control. It comes under series and shunt devices configuration of FACTS devices. It acts as a shunt compensating and phase shifting device simultaneously. These two devices are two Voltage Source (VSI) connected respectively in shunt with transmission line through a shunt transformer and in series with the transmission line through series transformer, connected to each other by a common dc link including a storing capacity. (Fujita, Control and analysis of a unified power flow controller, 1999) The shunt inverter is used for voltage regulation at the point of connection injecting a reactive power flow into the line and to balance the real power flow exchanged between the series inverter and the transmission line. The series inverter can be used to control the real and reactive line power flow inserting an opportune voltage with controllable magnitude and phase in series with transmission line. (Noroozian,1997) (Iqbal,2018)

II. ROLE OF UPFC

The UPFC is one of the worthy controller within FACTS devices as it serves to control all the parameter's (voltage, current and phase angel) simultaneously at same time UPFC

has more control factors, Compared with alternate FACTS devices, it can change an assortment of system parameters during operation. It is essential in controlling the power flow in the transmission line effectively also reduces the total harmonic distortion. It thus provides greater ability to transfer power between controlled areas.

This device helps to damp the power oscillations that could damage the system. It has amazing ability to improve voltage to exchange control proficiently and to lessen receptive power losses. The UPFC system can improve control network transient strength properly and adequately. Voltage is improved in the real and reactive powers through the transmission line when UPFC is present. It contains numerous control targets which can be utilized for power flow control, loop flow control, load sharing among parallel passages, improvement of transient soundness, moderation of system oscillations and voltage (reactive power) regulation. The UPFC system has the points of interest like reduced maintenance and capacity to control real and reactive power. (Choudhary,2018)

III. CONFIGURATION OF UPFC

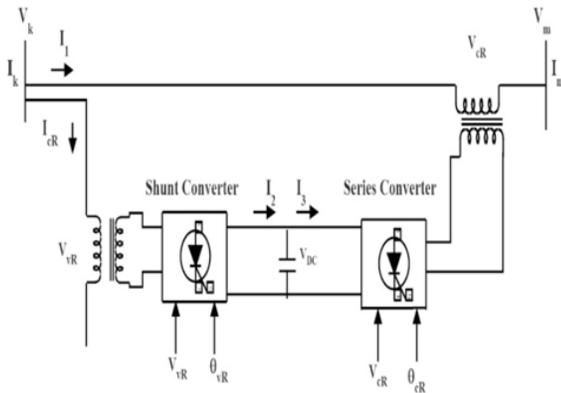


Fig.1: Diagram of UPFC

It contains two voltage source converters (VSC) that are coupled through shared DC interface capacitor. The UPFC comprises of a mix of a series system. The series system goes about as a controllable voltage-source, while the shunt system goes about as a controllable current source. The principle motivation behind the shunt system is to manage the dc connect voltage by altering the measure of dynamic power drawn from the transmission line. Furthermore, the shunt system has the ability of controlling reactive power. (Gandhar,2013) (Mihali,1996)

VSC-1 is combined with transmission line by means of shunt transformer and arrangement converter VSC-2 is related with transmission line by means of series transformer. The parallel branch transformer is associated parallel with connection to the transmission line, while the series branch transformer is practically a boosting transformer. The parallel branch is in

actuality a static compensator (Mihali,1996) ((SM), 1999).

IV. UPFC TECHNIQUE FOR POWER FLOW

A. Decoupled UPFC model-

This model of UPFC is fit for directing the power flow from node m to node k and to control the nodal voltage magnitude at node k. The sending end of UPFC is transformed into a PQ bus, while the receiving end into PV bus. This technique is basic yet it isn't obvious from it how the model can be utilized in circumstances when the UPFC isn't controlling the voltage magnitude, line dynamic power and line reactive power[15][17].

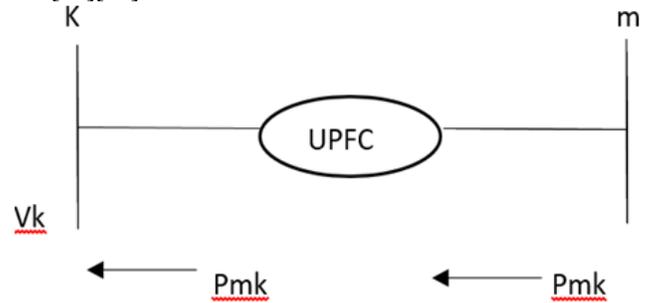


Fig.2: Decoupled UPFC model

B. Injection model of UPFC-

This model of UPFC has a series fixed reactance X_s together with a lot of active and reactive nodal power injection. The fascination of this detailing is that it may be actualized effectively in existing power flow program and UPFC can be changed in accordance with work as a voltage controller, arrangement compensator or stage shifter. The significant disadvantage of this model is that immensely essential part of the programmed UPFC parameter change has not been tended.[15][17].

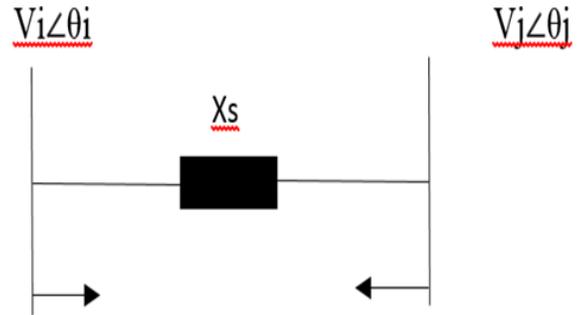


Fig.3: Injection model of UPFC

C. Comprehensive NR UPFC Model-

Attempting to go around the constraints in the decoupled and infusion UPFC model a newly developed and complete UPFC is presented. This model is clear expansion of the power flow. The benefit of this is that UPFC demonstrate has over the Decoupled and infusion display is that UPFC state factors are joined prompting extremely robust iterative solution. This

additionally enables to control the dynamic and reactive power at the same time just as the voltage magnitude. The disadvantage of this model is that the UPFC can't be acclimated to work in voltage regulation, impedance compensation, and phase shift mode (Pandita,2013) (Mr.S.Natarajan,2017)

V. OPERATION PRINCIPLE

Fundamentally, the UPFC structure is like that of the stage moving transformer. Basic DC connect empowers to stream real power toward any path among AC terminal of two converters. It comprises of a parallel and series branch, each comprising of the transformer, the power electronic converter with turn- off proficient semiconductor system and the DC circuit. At this stage the most critical actuality is that the parallel branch can as a receptive current source, in light of the fact that the maximal yield reactive current is free of terminal voltage. The series branch speaks to the supposed progressed controllable arrangement compensation. (Liu, 2005) (S.Muthukrishna,2010).

The infused voltage of the boosting transformer is opposite to the line current. The series converter, every one of the two simply portrayed UPFC branches can create or assimilate the reactive power free of one another. The depicted properties don't change if the DC circuits of the two systems are associated and if the regular DC circuit comprises of capacitor. The series converter is controlled to infuse a voltage in series with the line. Moreover, the stage heavenly attendant of voltage can be autonomously fluctuated from 0 to 360° . In this procedure the series converter exchanges both real and reactive power with the transmission line. In spite of the fact that the reactive power is inside generated/absorbed by series converter, the real power generated/consumed is made possible by the dc- energy storage system that is, the capacitor. (Makkar, 2006)

The shunt-connected converter 1 is used generally to supply the real power demand of converter 2, which it gets from the transmission line itself. The shunt converter keeps up steady voltage of the dc transport. Along these lines net real power drawn from the AC network is proportionate to the losses of two converters and their coupling transformers. (Sen, 1998) (A.Jayalaxmi, 2004)

VI. CONTROL MODES

A. Shunt VSC Operating Modes:-

1. *VAR control mode*- In VAR control mode the reference input is an inductive or capacitive VAR ask. The shunt inverter control makes an interpretation of the VAR reference into a comparing shunt current demand and changes the gating of the inverter to build up the ideal current. The control utilizes current criticism signals acquired from current transformers (CTs) normally

situated on the bushings of the shunt coupling transformer. A feedback signals represent to the dc bus voltage is additionally required.

2. *Automatic Voltage Control Mode*- In voltage control mode, the shunt inverter reactive current is consequently directed to keep up the transmission line voltage at the purpose of association with a reference estimate, with a characterized droop. The droop characterizes the per unit voltage error per unit of inverter reactive current inside the present scope of the inverter. The automatic voltage control utilizes voltage input signals acquired from precise potential transformers estimating the voltage, at the substation bus sustaining the shunt coupling transformer. ((SM), 1999), (Patil, 2017) (SapnaKanchi, 2013)¹ (A.Jayalaxmi G. T.,2004)

TABLE 1:- COMPARISON WITHIN SHUNT MODES.

Modes	Benefits	Drawbacks
VAR Controls	Translate reference VAR into corresponding shunt current.	Understate frequency and magnitude of extreme loss
	Establish the desired current.	
AVCM	Transmission line voltage is maintained.	Sometimes voltage imbalance may occur between different levels
	Reactive current is automatically regulated.	

B. Series VSC Operating Modes:-

The arrangement inverter controls the greatness and edge of the voltage infused in series with the line. This voltage infusion is constantly proposed to impact the stream of intensity hanging in the balance, yet the genuine estimation other infused voltage can be resolved in a few distinctive ways. These include:

1. *Direct Voltage Injection Mode* – The arrangement inverter essentially creates a voltage vector with extent and stage point asked for by reference input. A unique instance of direct voltage infusion is the point at which the infused voltage is kept in quadrature with the line current to give purely reactive series compensation.
2. *Phase Angle Control Mode* – The phase displacement is determined between the sending and receiving end voltage which further results in the reference input in this mode.
3. *Line Impedance Control Mode* – The series infused voltage is controlled in extent to the line current with the goal that the series addition transformer shows up

impedance when seen from the line. The ideal impedance is indicated by reference input and as a rule it might be mind boggling impedance with resistive and receptive segments of either extremity. Normally care must be taken in this mode to keep away from estimations of negative opposition or capacitive reactance that would cause reverberation or in security.

- Automatic Power Flow Control Mode – The UPFC has the extraordinary ability of autonomously controlling both the real power stream. This ability can be valued by translating the arrangement infused voltage, as a controllable two dimensional vector amount. This infused voltage vector can be picked suitably to constrain any ideal current vector (inside points of confinement) to stream on hold, subsequently building up a comparing power stream. In automatic control stream control mode, the arrangement infused voltage is resolved consequently and ceaselessly by a vector control system to guarantee that the ideal P and Q are kept up regardless of system changes. The transmission line containing the UPFC along these lines appears to whatever is left of the power system as a high impedance control source. This is a very amazing method of activity that has not recently been feasible with traditional line remunerating hardware.

arrangement inverter as a SSSC. Under this condition, neither one of the inverters is equipped for retaining nor is producing real power with the goal that just the work in the respective conceivable. On account of the series inverter this implies any infused voltage must be in quadrature with the line current. Line power can at present be controlled. In the impedance imitating mode, just receptive impedance can be copied. Elective courses of action are conceivable relying upon the establishment. (A.Jayalaxmi,2004)

VII. CASE STUDY

IEEE-3 Bus system

In this system, the UPFC is introduced on line 2– 3 as shown in fig.4, buss 4 is the extra imaginary buss. Fig.5 demonstrates the outcomes for the PQ control of the three transport system with the UPFC introduced on line 2 – 3.

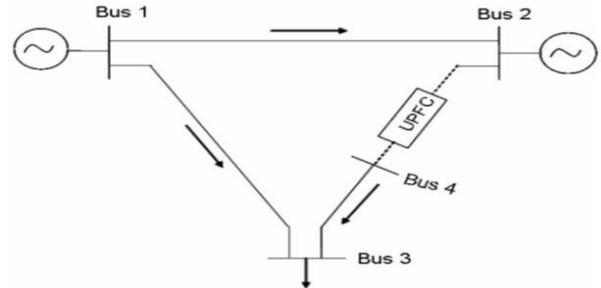


FIG.4: THREE BUS SYSTEM

TABLE 2:- COMPARISON WITHIN SERIES MODES

Modes	Benefits	Drawbacks
DVIM	Generates voltage vector with magnitude	High recovery voltage sometimes
	Helps to provide Compensation	
PASEM	Phase shifts voltage from V2 to V1.	Mal operations of distance relay
LIEM	Voltage is controlled in proportion to line current	Negative resistance may
	Series transmission appears as a impedance.	
APECM	Independently controls real and reactive power	Increases in fault current
	Establish corresponding power flow.	

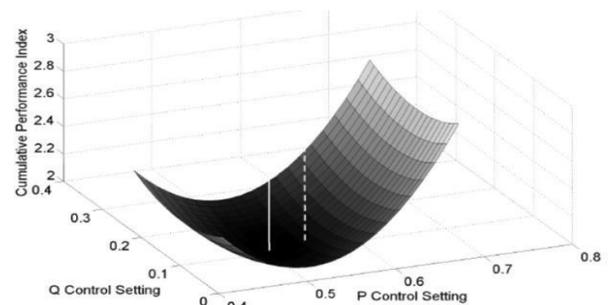


Fig.5: Control Settings

This figure demonstrates the PQ infusions of the UPFC at steady state (dashed line) and at the ideal settings (strong line) given by the SQP calculation. Tables I through IV demonstrate the bus solution and line flow when UPFC establishment. It tends to be seen from these outcomes that the voltages and point contrasts between buses are within the limitations.

C. Stand Alone and Alternative Modes:-

Contingent upon the necessities of a specific establishment, switchgear can be given, to permit both of the two inverters to work autonomously of the other by separating their normal dc terminals and part the capacitor bank. For this situation, the shunt inverter works as an independent STATCOM, and the

TABLE 3:- BUS SOLUTION AND LINE FLOW BEFORE INSTALLATION OF UPFC

Bus	Voltage	Angle	Pgen	Qgen	Pload	QLoad
1	1.02	0	0.708	0.28	0	0

2	1	0.578	0.5	- 0.045	0	0
3	0.981	- 3.639	0	0	1.2	0.5

From (i)	To (j)	P_{ij}	Q_{ij}	S_{ij}	S_{Max}
1	2	0.039	-0.012	0.144	0.187
1	3	0.67	0.293	0.746	0.857
2	3	0.539	0.094	0.56	0.671

TABLE 4:- BUS SOLUTION AND LINE FLOW AFTER INSTALLATION OF UPFC

Bus	Voltage	Angle	Pgen	Qgen	Pload	QLoad
1	1.02	0	0.708	0.27	0	0
2	1	0.015	0.5	- 0.035	0	0
3	0.982	- 3.843	0	0	1.2	0.5

From (i)	To (j)	P_{ij}	Q_{ij}	S_{ij}	S_{Max}
1	2	0.003	-0.0141	0.141	0.187
1	3	0.705	0.28	0.77	0.857
4	3	0.503	0.106	0.531	0.671

A. Result discussions:

With the consolidation of spectral density based choice, the sags are all the more successfully been evaluated and sifted. During the time spent filtration, wherein filtration depended on band request and the determination standard is made on the mutilation variety. In this work the density of the bending variety is estimated and choice is made dependent on the density of such distortion and with this SAG Level is restricted to about 8% than coding technique.

VIII. CONCLUSION

By comparing different papers, it has been concluded that voltage regulation and power loss minimization can be improved by using UPFC along with it when UPFC's

operation is studied in different modes, it is also observed that among all the combination the best result were found in series connection of UPFC in respective of shunt. With the fuse of spectral based determination, the droops are all the more successfully been assessed and separated. In this paper the determination criteria is made on the mutilation variety. With such choice the observed SAG Level is limited to about 8% than the conventional coding strategy.

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