The Unified Power Flow Controller for Power System Stability

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Abstract— With the developing interest of power, on occasion, it isn't conceivable to erect new lines to confront the circumstance. Adaptable AC Transmission System (FACTS) utilizes the thyristor controlled gadgets and ideally uses the current power organize. Certainties gadgets assume an imperative part in controlling the receptive what's more, dynamic power stream to the power arrange and consequently both the framework voltage vacillations and transient strength. This paper proposes the Unified Power Flow Controller (UPFC) as a power electronic based gadget that has capacity of controlling the control course through the line by controlling its arrangement and shunt converters, additionally joined with Distributed Generation (DG) associated in the DC connect to moderate power quality unsettling influences. The proposed control will empower expanded associations of sustainable power sources in the savvy matrix. The capacity of the conspire has been researched the change of transient steadiness and voltage vacillations of between region control framework.

Key words: UPFC, DG, FACTS

I. Introduction

The solutions to improve the quality of supply in the electrical networks with distributed generation go through the applications of the developments in semiconductor power devices, that is to say, the utilization of static power converters in electrical energy networks [1]. The technological advances in power semiconductors are permitting the development of devices that react more like an ideal switch, totally controllable, admitting high frequencies of commutation to major levels of tension and power [2].The concept of distributed generation (DG) is generally associated to the development of the renewable energy sources such as fuel cells, wind energy and solar cells, another factor to keep in mind in the development and configuration of the electrical system. The DG will need an important electronic equipment based on power converters that facilitate the integration of these sources of energy, without damaging over the reception quality of the users connected to the electricity network [3].The FACTS controllers offer great opportunities to regulate the transmission of alternating current (AC), increasing or diminishing the power flow in specific lines and responding almost instantaneously to the stability problems. The potential of this technology is based on the possibility of controlling the route of the power flow and the ability of connecting networks that are not adequately interconnected, giving the possibility of trading energy between distant agents [4].One particular concept, called the Unified Power Flow Controller (UPFC), has been presented by Gyugi in 1992 [5],that combines the functions of some FACTS devices and is capable to control a wide range of typical transmission parameters, such as voltage, line impedance and phase angle. The UPFC is perhaps the most versatile of the FACTS controllers, offering a unique combination of shunt and series compensation and guaranteeing flexible power system control[6-7]. The flexible power flow control and high dynamics can be achieved by applying electronic power converters. It is particularly beneficial to use power converters based on full controlled switches, such as Gate Turn Off thyristors (GTO)and the more recently available high power Insulated Gate Bipolar Transistor (IGBT), which are suitable to handle higher switching frequencies [5].The objective of this paper is to present the model and performance of a UPFC connected to a transmission line, when the active and the reactive power reference values are changed, respectively the behavior of the DC voltage must be reviewed because it will affect on the connected DG (section IV). Finally, investigates the stability improvement of inter area system using the UPFC (section V). The simulation results are carried out using Power System Analysis Matlab Toolbox (PSAT) to validate the performance of the UPFC.A Unified Power Flow Controller (UPFC) is an individual from Realities gadgets. It comprises of two strong state synchronous voltage source converters coupled through a typical DC connect as appeared in "Fig. 1,".

II. System configuration

The DC interface gives a way to trade dynamic power between the converters. The arrangement converter infuses a voltage in arrangement with the framework voltage through an arrangement transformer. The power move through the line can be directed by controlling voltage greatness and edge of arrangement infused voltage [8]. The infused voltage and line current decide the dynamic and responsive power infused by the arrangement converter. The converter has a capacity of electrically producing or engrossing the receptive power. The shunt converter additionally has a capacity of autonomously providing or engrossing responsive energy to manage the voltage of the AC framework [9]. The UPFC is a gadget put between two transports alluded to the UPFC sending transport (B1) and the UPFC accepting transport (B2), It comprises of two voltage-sourced converters (VSCs) with a regular DC-connect. For the major recurrence display, the VSCs are replaced by two controlled voltage sources as shown in “Fig. 1,”.

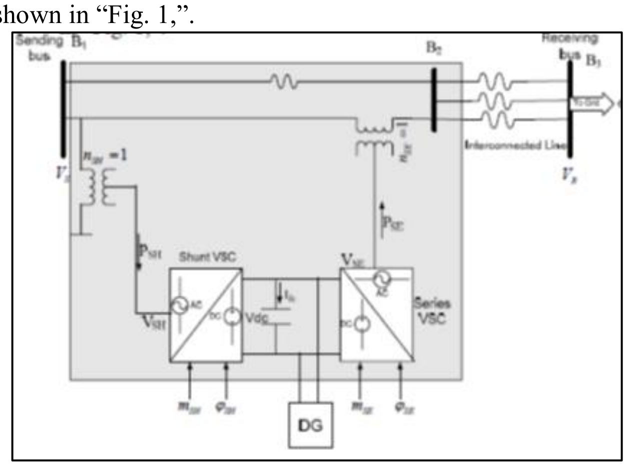

Fig. 1: Configuration of UPFC.

By applying the Pulse width regulation (PWM) method to the two VSCs, the accompanying conditions for extents of shunt and arrangement infused voltages can be gotten.

$$V_{sh} = m_{SH} \frac{V_{DC}}{2\sqrt{2}\eta_{SH} V_B} \quad 1$$

$$V_{SE} = m_{SE} \frac{V_{DC}}{2\sqrt{2}\eta_{SE} V_B} \quad 2$$

Where,
m_{SH} = amplitude modulation index of the shunt VSC control signal.
m_{SE} = amplitude modulation index of the series VSC control signal.
n_{SH} = shunt transformer turn ratio.
n_{SE} = series transformer turn ratio.
V_g = the system side base voltage in kV.
V_{DC} = DC-link voltage in kV.
And the phase angles are:

$$\delta_{SH} = \delta_S - \varphi_{SH} \quad 3$$

$$\delta_{SH} = \delta_S - \varphi_{SH} \quad 4$$

$$\delta_{SE} = \delta_S - \varphi_{SE} \quad 5$$

Where,
φ_{SH} =firing angle of the shunt VSC with respect to the phase angle of the sending bus voltage.
φ_{SE} =firing angle of the series VSC with respect to the phase angle of the sending bus voltage.

Both voltage sources are demonstrated to infuse voltages of crucial power framework recurrence as it were. The UPFC is set on high-voltage transmission organize; this game plan requires venture down transformers to permit the utilization of energy electronic gadgets for the UPFC. The arrangement converter infuses an AC voltage ( ) SE S SE V = V ∠ δ −ϕ in arrangement with the transmission line. The arrangement voltage extent SE V and its stage point SE ϕ as for the sending transport are controllable in the scope of 0 ≤ SE V ≤ SE max V and 0 ≤ SE ϕ ≤ 360°. The shunt converter infuses controllable shunt voltage with the end goal that the genuine segment of the current in the shunt branch balances the genuine power requested by the arrangement converter. The receptive power can't course through the DC-interface. It is consumed or on the other hand produced (traded) locally by every converter. The shunt converter worked to trade the receptive power with the Air conditioning framework gives the likelihood of free shunt pay for the line. On the off chance that the shunt infused voltage is directed to deliver a shunt responsive current segment that will keep the sending transport voltage at its prespecified esteem. Keeping in mind the end goal to demonstrate how the line control stream can be influenced by the UPFC, it is put toward the start of the transmission as appeared in "Fig. 1," When the line conductance is disregarded; the intricate power got at the less than desirable end of the line is given by

$$S = \overline{V_R}\, \bar{I}^*{}_{Line} = \bar{V}_R \left(\frac{\bar{V}_S + \bar{V}_{SE} + \bar{V}_R}{JX}\right)^* \quad 6$$

The complex conjugate of this complex power can be expressed as:

$$S^* = P - JQ = \bar{V}^*{}_R \left(\frac{\bar{V}_S + \bar{V}_{SE} + \bar{V}_R}{JX}\right) \quad 7$$

By performing simple mathematical manipulations and separating real and imaginary parts of Eq. (7), the following expressions for real and reactive powers received at the receiving end of the line are

$$Q = \frac{-V_R{}^2}{X} + \frac{V_S V_R}{X}\cos(\delta) + \frac{V_R V_{SE}}{X}\cos(\delta - \varphi_{SE}) \quad 8$$

$$P_{min}(\delta) \le P \le P_{max}(\delta) \quad 9$$

It was stated previously that the UPFC series voltage magnitude can be controlled between 0 and SE max V and its phase angle can be controlled between 0 and 360° at any power angle δ. It can be seen from "(8),", "(9)," and "Fig. 2," that the real and reactive power received at bus R can be controlled when a UPFC is installed as:

$$Q_{min}(\delta) \le Q \le Q_{max}(\delta) \quad 10$$

$$P_{SH} = P_{SE} \quad 11$$

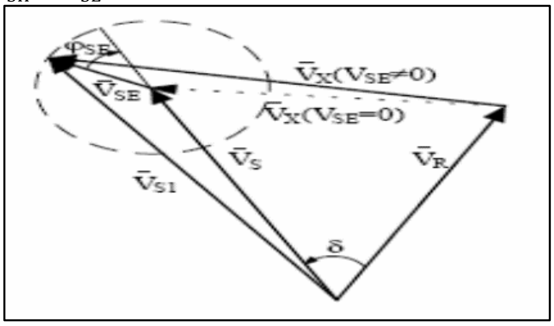

Fig. 2: Controlled series voltage

III. SYSTEM MODELLING

To reproduce a power framework that contains an UPFC, the UPFC should be demonstrated for relentless state and dynamic activities. Additionally, the UPFC show should be interfaced with the power framework show. Subsequently, the displaying and interfacing of the UPFC with the power organize are portrayed

A. UPFC Steady-State Model

For unfaltering state task of the DC interface voltage stays consistent at its pre-indicated esteem. If there should arise an occurrence of a lossless DC connect the dynamic power provided to the shunt converter fulfills the dynamic power requested by the arrangement converter

$$\bar{V}_S = \bar{V}_{SH} + \bar{I}_{SH} Z_{SH} \quad 12$$

The Load stream (LF) show talked about here expect that UPFC is worked to keep dynamic and receptive power stream on the transmission line at the getting transport, and the sending transport voltage greatness at their pre-indicated values [11]. In this case the UPFC can be supplanted by a proportionate generator at the sending transport (PV-type transport) and a heap at the getting transport (PQ-type transport) as appeared in "Fig. 3,".

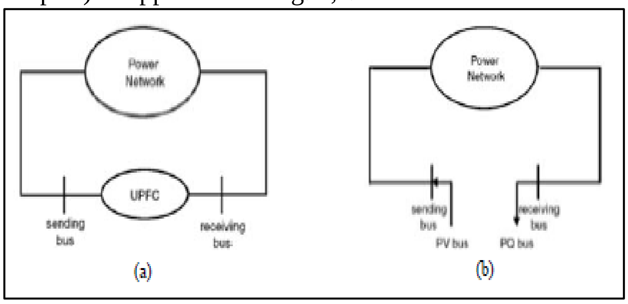

Fig. 3: UPFC with the power system: (a) Schematic (b) Load flow Mode.

Power demanded at the receiving bus is set to the desired real and reactive power at that bus. The real power injected into a PV bus for a conventional LF algorithm is kept constantan the reactive power is adjusted to achieve the prespecified voltage magnitude. With the UPFC, the real power injected into the sending bus is not known exactly. This real power injection is initialized to the value that equals the prespecified real power flow at the receiving bus. During the iterative procedure, the real power adjusted to cover the losses of the shunt and series impedances and to force the sum of converter interaction to become zero. The algorithm, in its graphical form, is given in "Fig. 4,".

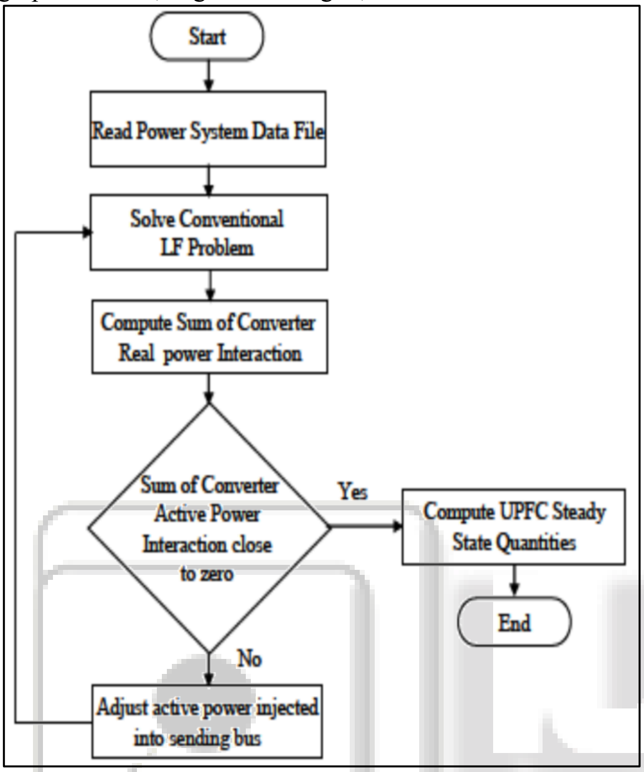

Fig. 4: Load flow algorithm.

To obtain the LF solution of a power network that contains the UPFC an iterative procedure is needed. The active power injected at the sending bus is

$$\bar{V}_S = \bar{V}_{SH} + \bar{I}_{SH} Z_{SH} \quad 13$$

It ought to be noticed that there is no requirement for the iterative methodology to process the UPFC control parameters. They can be figured straightforwardly after a traditional LF arrangement. Dismissing transformer misfortunes and instating the dynamic influence infused into sending transport to the dynamic power stream controlled hanging in the balance, the joining of the proposed LF calculation is acquired inside one stage.

B. *UPFC Dynamic Model*

For transient stability studies, the DC link dynamics have to be taken into account and can no longer be applied. The DC link capacitor will exchange energy with the system and its voltage will vary. The power frequency dynamic model has been implemented in the Power System Analysis Toolbox software (PSAT). The following equation describes this model

$$CV_{DC}\frac{dv_{DC}}{dt} = (P_{SH} - P_{SE})S_B \quad 14$$

The system side base values: SB and VB are selected as base power and base voltage, respectively, and all AC variables are normalized using these base quantities.

C. *Interfacing the UPFC with the Power Network*

To get the system arrangement (transport voltages and streams) an iterative approach is utilized. The UPFC sending and accepting transport voltages can be communicated as an element of the generator interior voltages EG, While, the UPFC Control yield decide the UPFC infusion voltage sizes (VSH what's more, VSE). Be that as it may, the stage edges of the infused voltages θSE and θSH are obscure since they rely upon the stage edge of the sending transport voltage θS which is the aftereffect of the organize arrangement. The calculation for interfacing the UPFC with the power organize is appeared, as a stream talk in "Fig. 5,".

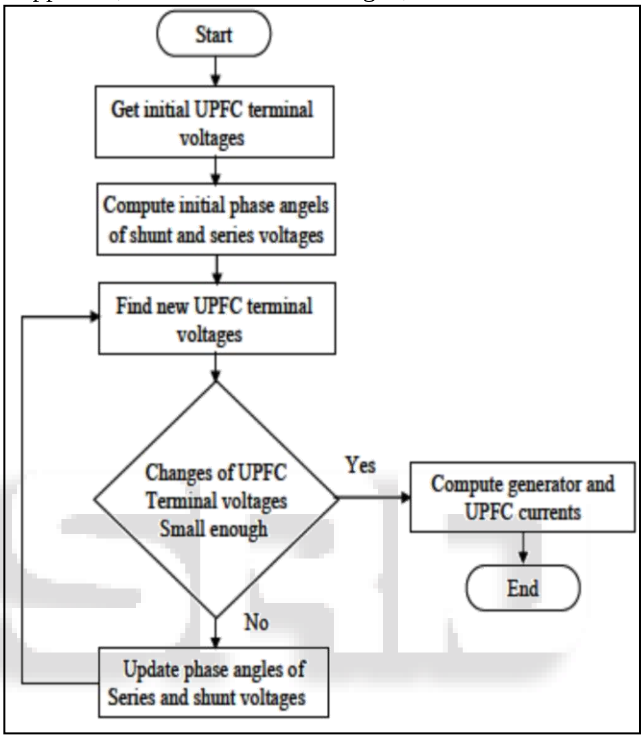

Fig. 5: interfacing of UPFC with the power network algorithm

$$\bar{V}_U = L_G\bar{E}_G + L_C\bar{V}_C \quad 15$$

IV. Numerical Simulations

The Unified Power Flow Controller (UPFC) is utilized to control the power stream in a 500 kV transmission framework. The UPFC situated at the left end of the 75-km line L2, between the 500 kV transports B1 and B2 is utilized to control the dynamic and responsive power coursing through transport B2 while the controlling voltage at transport B1 as appeared in "Fig. 1," It comprises of two 100-MVA, three-level, 48-beat GTO-based converters, one associated in shunt at transport B1 and another associated in arrangement between transports B1 and B2. The shunt and arrangement converters can trade control through a DC transport. The arrangement converter can infuse a greatest of 10% of ostensible line-to ground voltage (28.87 kV) in arrangement with line L2."Fig. 6," demonstrates that the dynamic power relentless state is come to (P=+8.7 pu) after a transient period enduring around 0.15 sec. Likewise it can be seen that P is inclined to the new settings (P=+10 pu) subsequent to changing the reference an incentive at t=0.25 sec. It can be seen from "Fig. 7," at t=0.5 sec, the reference an incentive for receptive power has been changed to 0.7 pu and the estimation of Q has inclined to the new incentive after 0.15 sec. Thus, the dynamic control has a little changes around its relentless state an incentive due to the adjustments in the responsive power and bad habit verse due to the changes of the dynamic power at t = 0.25 sec and there is a little change in the responsive power.

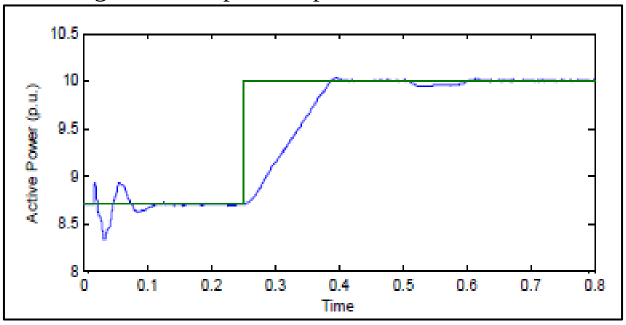

Fig. 6: UPFC responses for changing active power

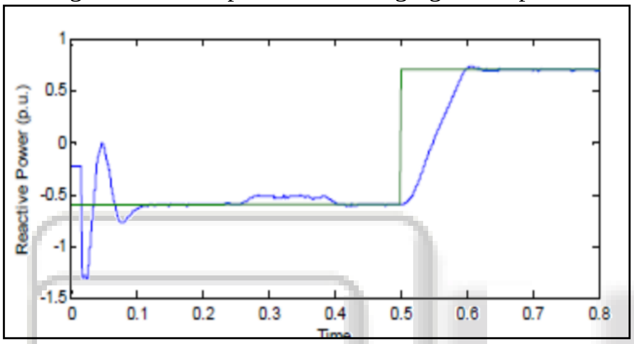

Fig. 7: UPFC responses for changing reactive power

This control of the receptive power is gotten by shifting the greatness of the auxiliary voltage Vs created by the shunt converter while keeping it in stage with the transport B1 voltage Vp as appeared in "Fig. 8," that Vs began to show up at t = 0.5 sec because of changing the estimation of the receptive power. Additionally it can be seen from "Fig. 9," that the Vdc increments from 17.5 kV to 21 kV because of the expanding of the receptive power which will affect the associated DG through the DC connect, Along these lines, it is prescribed later on research to decide the kind and size of the associated DG and concentrate the impact on its execution and solidness because of the voltage deviation.

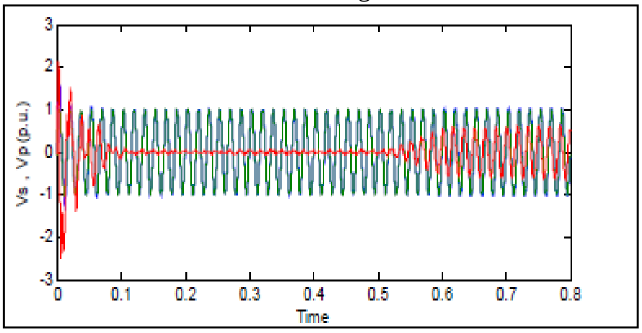

Fig. 8: Series and Parallel injected voltages

V. CASE STUDY

The execution of the UPFC is tried on a two-area– four generator framework (test framework) as appeared in "Fig. 10,". Information for this framework can be found in index 1.The two territories are indistinguishable to each other and interconnected with two parallel 230-km tie lines that convey around 400 MW from territory 1 (generators 1 and 2) to territory 2 (generators 3 and 4) amid ordinary working conditions [14]. The UPFC is set at the start of the lower parallel line between transports 101 and 13 to control the power move through that line and to control voltage level. A three stage blame is connected at transport number 3, zone 1 at t = 1s. The blame is cleared at t = 1.05s by opening breaker at transport 101 on upper line from transport 03 to transport 101. An examination of the reenactment comes about for the test framework without the UPFC furthermore, with the UPFC.

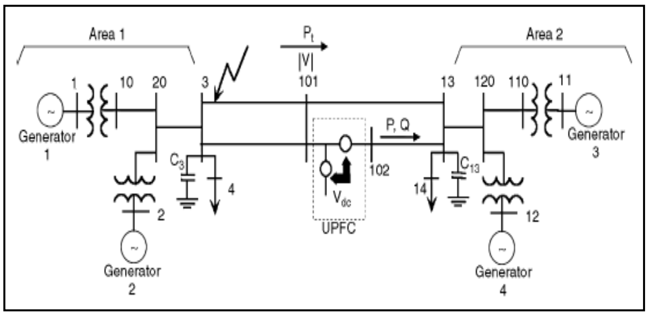

Fig. 10: Two-area–four-generator test system.

"Fig. 11," demonstrates that the rotor speed swings are better damped on account of the framework with UPFC and it can be seen that, the framework recoups rapidly after the blame is cleared and achieves the coveted power stream in around 14 sec. in spite of the fact that the power stream control has beneficial outcome on the principal swing transient in the framework.

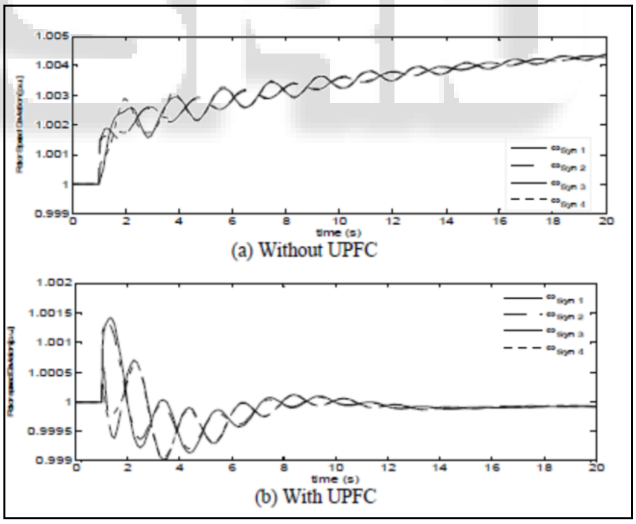

Fig. 11: Rotor speed deviation

On account of the framework without the UPFC, there is no damping for the rotor edge swings which imply that the framework won't recoup a satisfactory state and "Fig. 11," demonstrates the disparity of the rotor speed. So the framework will free the soundness. On the other, on account of the framework without the UPFC the voltage vacillations has leaving as far as possible as appeared in "Fig. 12," Likewise, it can be seen that, the UPFC is worked to keep the transport voltage at as far as possible.

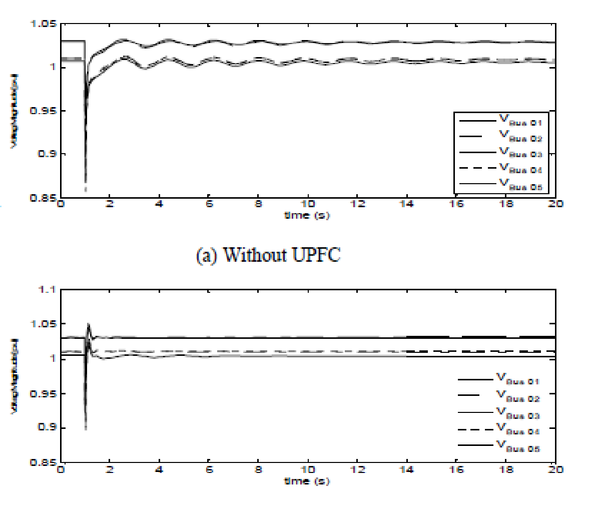

Fig. 12: Bus Voltage Magnitudes

VI. CONCLUSION AND OUTLOOK

The framework proposed in this paper has the elements of enhancing power quality and guaranteeing the coherence of power supply, the UPFC has been proposed to control all the while genuine and responsive power streams in the transmission line and to manage the voltage transport utilizing the FACTS. This gadget makes a gigantic effect on control framework dependability improvement and stacking of transmission lines near their warm cutoff points. Subsequently, the gadget gives control framework administrators much required adaptability to fulfill the requests that the deregulated control framework forces. Reenactment comes about have demonstrated that the UPFC is able to do controlling the line control stream and supporting the voltage level in extraordinary working conditions and following the progression changes in dynamic and receptive power stream reference esteems. The proposed control and adjustment strategy constitute more suggested technique for interconnection of scattered capacity and sustainable power sources (e.g. sun based vitality, power module and wind vitality e.t.c.) to the utility to define the savvy framework. Along these lines, it is prescribed later on work to outline a half breed sunlight based/energy components/twist cultivate as a Static Synchronous compensator (STATCOM) to manage the voltage profile and the power stream in the circulation organize, additionally contemplate the best area of the utility to associate the overabundance sustainable power sources concerning power quality, voltage profile improvement and dynamic security.

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