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MODULATION OF TRANSFORMER LESS UPFC BASED FUZZY CONTROL SYSTEM

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Abstract-In this paper control strategy for the new transformer less brought together power stream controller (UPFC) is proposed. the traditional UPFC that comprises of two consecutive inverters needs extensive and frequently convoluted crisscross transformers for seclusion and achieving high power rating with wanted voltage waveforms. To overcome the issues, a totally transformer less UPFC which is rely on an imaginative design of two course multilevel inverters have been proposed. When contrasting and customary innovation the new UPFC has a few advantages, similar to light weight, transformer less, low value, quick powerful reaction and high proficiency. Hence in this paper we can see that it is chiefly actualized on the adjustment and control of the transformer less UPFC idea which including the upgraded basic recurrence regulation for high effectiveness and low aggregate consonant bending, free responsive and dynamic power control over the transmission line, dc-connect voltage adjust control, soon .by utilizing the recreation comes about we can check the new idea UPFC alongside proposed control technique. In this paper both the dynamic and enduring state - reaction results will be appeared.

Keywords: Unified power flow controller, Fuzzy logic controller, multilevel inverter.

I. Introduction

The UPFC which can control, in the meantime or specifically, every one of the parameters influencing power stream inside the conductor (i.e., voltage size, impedance, and stage point) [1]– [3]. The conventional UPFC comprises of two consecutive associated voltage source inverters that offer a run of the mill dc interface, as appeared in Fig. 1. The infused arrangement voltage from inverter-2 are regularly at any point as for the line current, that gives finish adaptability and controllability to oversee both dynamic and receptive power streams over the transmission line. The resultant genuine power at the terminals of inverter-2 is given or consumed by inverter-1 through the normal dc interface. Along these lines according to the outcome, UPFC is that the premier adaptable and effective flexible air conditioning transmission frameworks gadget. It'll viably downsize clogs and increment the bent of existing transmission lines. This enables the last framework to oversee at its hypothetical generally capacity. The fundamental administration procedures, transient examination, and brilliant operation worries for UPFC territory unit explored. the ordinary UPFC has been put into many savvy applications, that has the ensuing highlights: 1) each electrical converters share steady dc connect; 2) every inverter need to trade genuine power with each other} and furthermore the link; 3) a transformer must be utilized as an interface between the line and each inverter. To boot, any utility-scale UPFC wants 2 high-voltage, powerful (from a few MVA to a few MVA) inverters.

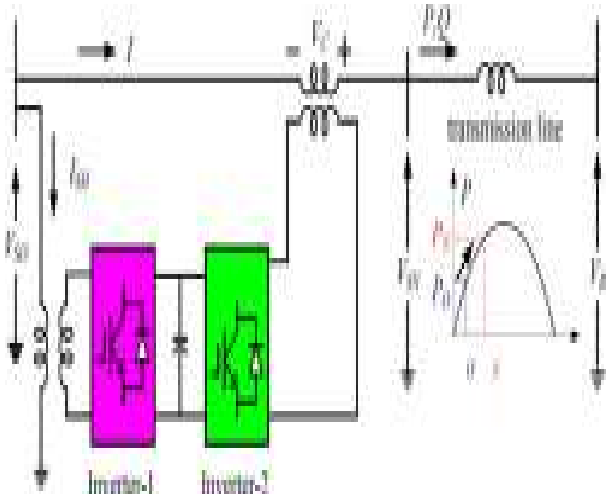

Fig. 1. Traditional UPFC.

To achieve their required VA evaluations and wanted voltage waveforms this high-voltage, powerful inverters need to utilize substantial and complex crisscross transformers. The crisscross transformers are: 1) awfully expensive (30– 40% of aggregate framework cost); 2) loss (half of the full power misfortunes); 3) massive (40% of framework land range and ninetieth of the framework weight); and 4) defenseless to disappointment.

The crisscross electrical gadget which are generally rely upon the UPFCs which are still too moderate in the dynamic reaction inferable from monstrous time consistent of charging inductance over protection and make administration challenges attributable to electrical gadget immersion, polarizing current, and voltage surge. As of

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late, there square measure 2 new UPFC structures beneath examination: 1) the grid converter-based UPFC and 2) disseminated control stream controller (DPFC) got from the standard UPFC. The first uses the grid convertor substitution the consecutive inverter to dispose of the dc capacitor with air conditioning capacitor on one side of the network converter. The DPFC utilizes a few disseminated arrangement inverters coupled to the transmission line through single-turn transformers, and the basic dc connect between the shunt and arrangement inverters is wiped out. The single-turn transformers lose one outline flexibility, along these lines making them much bulkier than a customary electrical gadget given a same VA rating. In synopsis, both UPFCs still need to utilize the transformers, which unavoidably because a proportionate previously mentioned issues related with transformers, (for example, substantial, loss, high cost, and moderate accordingly). The course multilevel inverter (CMI) is that the main sensible inverter innovation to accomplish high-voltage levels without the utilization of transformers, countless gadgets (diodes), or a substantial number of capacitors. The CMI-based STATCOMs (up to ±200 M_{var}) are placed in Europe and Asia Be that as it may, the CMI couldn't be specifically utilized as a part of the customary UPFC, because of the conventional UPFC needs two inverters associated consecutive to adjust dynamic power trade.

To manage this issue, an UPFC with two eye to eye associated CMIs was produced in [27] to wipe out the crisscross transformers that are required inside the standard multipulse inverter-based UPFC. Be that as it may, despite everything it required a detachment transformer. To kill the transformer totally, another transformer less UPFC in light of an imaginative setup of two CMIs has been proposed in [28]. The framework setup is appeared in Fig. 2(a) and principle framework parameters for a 13.8-kV/2-MVAprototype (target framework) are appeared in Table I. As appeared in Fig. 2(a), the transformer less UPFC comprises of 2 CMIs, one is arrangement CMI, that is straightforwardly associated offbeat with the transmission line; while the other is shunt CMI, that is associated in parallel to the sending end after arrangement CMI. Each CMI is made out of a progression of fell H-connect modules as appeared in Fig. 2(b). The transformer less UPFC has imperative advantages over the typical UPFC, for example, to a great degree standard structure, light weight, high power, high reliability, ease, and a quick unique reaction.

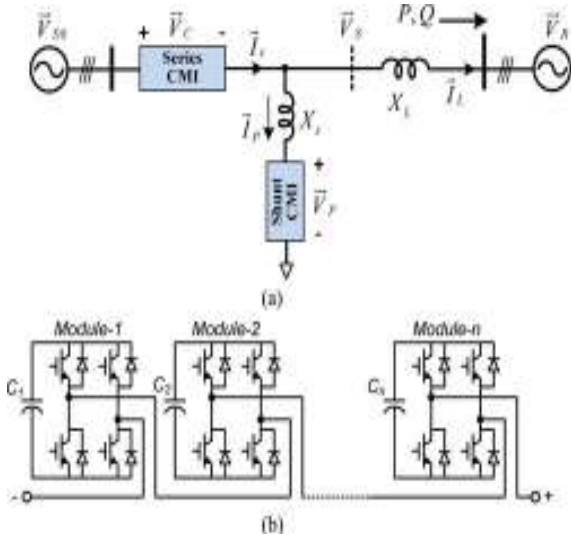

Fig. 2. New transformerless UFPC. (a) System setup of transformerless UPFC. (b) One period of the fell multilevel inverter.

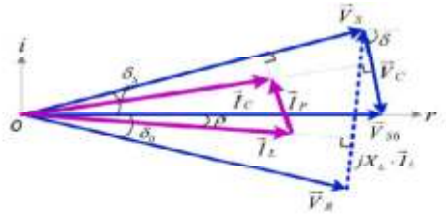

Fig. 3. Phasor chart of the transformerless UPFC

TABLE I

Main System Parameters

S.No	Parameters	Value
1	System Power Rating	2 MVA
2	V_{so} rms	13.8 KV
3	Max series CMI current, I_c rms	84 A
4	Max shunt CMI current, I_p rms	42 A
5	Vdc series	600 V
6	Vdc shunt	600 V
7	H-bridge Dc capacitance	2350 µF
8	No of H-bridges per phase in series	20
9	No of H-bridges per phase in shunt	10

The essential operation standard, operation extend, and required VA rating for arrangement and shunt CMIs are dissected amid this paper. For the balance and control of this new UPFC additionally have a few adjustments: 1) UPFC control stream control, similar to voltage direction, line impedance pay, stage moving or concurrent control of voltage, impedance, and stage point, along these lines accomplishing freely control both the dynamic and receptive power stream in the line; 2) for H-scaffolds of both arrangement and shunt CMIs dc capacitor voltage adjust control; 3) balance of the CMI for low aggregate consonant mutilation (THD) of yield voltage and low exchanging misfortune; 4) quick framework dynamic reaction.

The balance and control for the new transformer less UPFC has been introduced in this paper to address previously mentioned challenges. At low voltage level (4160 V) the UPFC usefulness with proposed control strategy is checked. By utilizing the reenactment comes about both the enduring state and dynamic reactions results will be dissected in this paper.

II. Power Flow and Dc-Link Voltage Control of Transformer less UPFC

2.1 Dynamic Models of UPFC System

The conditions got from the phasor graph in Section II are restricted to unfaltering state operation examination. So as to plan the vector-arranged control for the proposed transformer less UPFC with considering both unfaltering state and dynamic execution, the dynamic modules are vital. The models depend on synchronous (dq) reference outline. The stage edge of unique sending-end voltage Vs0 is gotten from an advanced stage bolted circle, which is utilized for abc to dq change. The dynamic models for the entire framework appeared in Fig. 2(a) will be partitioned into a few sections. To begin with, we can get the dynamic model from the new sending-end transport to accepting end transport

$$\begin{cases} V_{sd} = R_L i_{Ld} + L_L \dfrac{di_{Ld}}{dt} - \omega L_L i_{Lq} + V_{Rd} \\ V_{sq} = R_L i_{Lq} + L_L \dfrac{di_{Lq}}{dt} - \omega L_L i_{Ld} + V_{Rq} \end{cases}$$

Since the new sending-end voltage versus is equivalent to unique sending-end voltage vs0 less arrangement CMI infused voltage vc , along these lines we have

$$\begin{cases} V_{cd} = V_{S0d} - V_{Sd} \\ V_{cq} = V_{S0q} - V_{Sq} \end{cases}$$

Moreover, the model from the new sending-end to shunt CMI is

$$\begin{cases} V_{sd} = R_s i_{pd} + L_s \dfrac{di_{pd}}{dt} - \omega L_s i_{pq} + V_{pd} \\ V_{sq} = R_s i_{pq} + L_s \dfrac{di_{pq}}{dt} - \omega L_s i_{Pd} + V_{pq} \end{cases}$$

Power Flow and Overall DC Voltage Control

To outline an impression framework, at steady time, keep up the condenser voltages of each CMIs which may severally direct the dynamic power P and receptive Q inside the line, at the given worth. Fig. 8(a) demonstrates the general framework, that is part into 3 phases, i.e., organize I to arrange III

Stage I: the count from P∗/Q∗ t and I ∗ p0. The V ∗ C0 is that the voltage reference for arrangement CMI, per the link control order that is created as given in (5), though I * PO current reference for shunt CMI, that is utilized to remain zero dynamic power for each CMIs as given. Note that instead of plotting V * C0 specifically from (5), a substitute approach is appeared in Fig. 8(b). Here, the street current reference I∗ Ld/I∗ Lq is figured out of the P∗/Q∗ reference, at that point the d-and q-hub parts of arrangement voltage V_{cod} , V ∗ C0q ar computed per (23), wherever the dynamic model of (20) is encased. the street current is management in an exceptionally approach of decoupling feed forward control, so higher line current dynamic reaction may well be accomplished

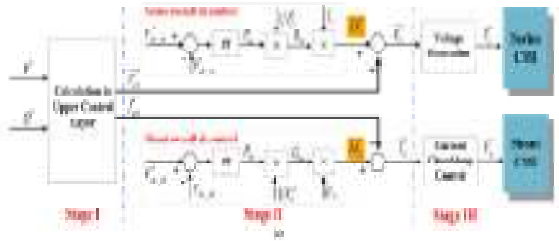

Fig. 8. Control framework for transformerless UPFC. (an) Overall control chart for both power stream and dc capacitor voltage control

Stage II: thusly the general dc-connect voltage regulation. With the V ∗ C0 and I ∗ p0 which is given in arrange I the dc-interface voltage can't be kept up owing to the resulting 3 primary reasons: 1) the CMIs always have an impact misfortune, 2) the computation mistake caused by the parameter deviations, 3) the blunder amongst reference and genuine yield. in order to oversee dc-connect voltage with higher quality, 2 factors ΔVC and ΔIP were presented for the independent dc-interface voltage control of arrangement CMI and shunt CMI, severally, as appeared in Fig. 8(a). amid this figure, V ∗ dc sh and V ∗ dc se square measure dc voltage references for shunt and arrangement CMIs, severally; Vdc sh and Vdc se square measure the arrived at the midpoint of dc criticism of shunt and arrangement CMIs, individually. For the arrangement CMI, Pse is that the yield of general dc-connect voltage

control loop, Rse is then ascertained by isolating Pse by I2C (square of rms cost of arrangement CMI current), at last ΔVC is that the result of Rse and arrangement CMI current IC . Clearly, the presented ΔVC is typically to some degree with arrangement CMI IC , which may be viewed as dynamic voltage part. Basically,Rse is that the proportional protection of arrangement CMI, and furthermore the dc-connection will be adjusted once Pse is satisfactory Ploss (add up to control loss of arrangement CMI). For the shunt CMI, ΔIP is presented for the dc-interface voltage administration in an exceedingly comparative approach. The numerical model and watchful parameters style for the dc voltage administration will be found in [31]. As a rule, the CMI should be contemplated as 3 single-stage inverters, subsequently; the dc electrical condenser voltage can contain the 2ω (two times of the essential recurrence) part. to remain the normal dc track the summon while not being experiencing the 2ω swell, the data measure of current control circle and dc voltage control circle is intended to be differential. For example, the present control circle has been intended to claim speedy dynamic reaction (e.g., half cycle, 8 ms), though dc voltage administration circle has been intended to have a ton of slower powerful reaction (e.g., 10 cycles). amid this approach, the 2ω swell will be smothered inside the voltage control circle.

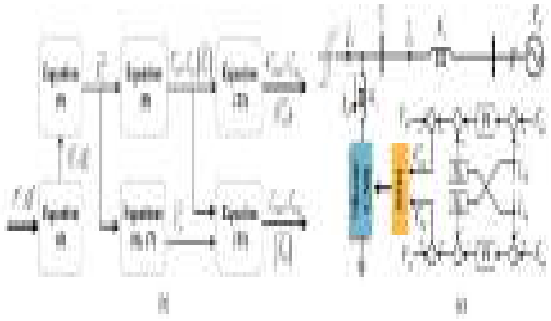

Fig. 8. Control framework for transformer less UPFC (b) point by point count from P ∗/Q∗ to V ∗ C 0 and I ∗ p 0 , and (c) current shut circle control for shunt CMI.

Stage III: voltage and current age for arrangement and shunt CMI, severally. For arrangement CMI, yield voltage may be straightforwardly produced from the reference V ∗ C by FFM. Though for shunt CMI, decoupling criticism current control is utilized to oversee yield current to take after the reference current I ∗ P , as appeared.

III. FUZZY LOGIC CONTROLLER

In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. Since the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required in FC.

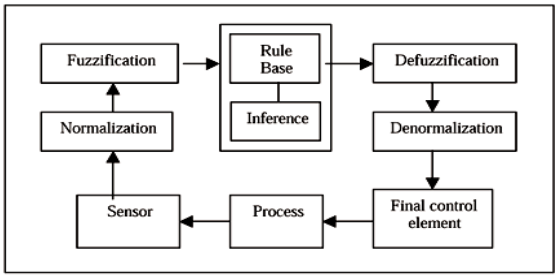

Fig.10.Fuzzy logic controller

The FLC comprises of three parts: fuzzification, interference engine and defuzzification. The FC is characterized as i. seven fuzzy sets for each input and output. ii. Triangular membership functions for simplicity. iii. Fuzzification using continuous universe of discourse. iv. Implication using Mamdani's, 'min' operator. v. Defuzzification using the height method.

TABLE III: Fuzzy Controller Rules

CE \ E	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NS	ZE
NS	NB	NB	NS	ZE	PS
ZE	NB	NS	ZE	PS	PB
PS	NS	ZE	PB	PB	PB
PB	ZE	PS	PB	PB	PB

Simulation Results

To approve the common sense of the transformer less UPFC framework with arranged adjustment and administration equation, a 4160-V investigate setup has been created as appeared in Fig. 12(a), and furthermore the fundamental framework parameters for this investigate setup are given in Table III. Fig. 12(b) demonstrates the relating identical circuit of this investigates setup that is in venture with the circuit arrangement appeared in Fig. 2(a). In Fig. 12(b), the proportionate accepting end voltage V R has same abundance as unique sending-end voltage V S0 , however 30° section protection. This 30° section protection is presented by electrical gadget two with Y/Δ arrangement (Y/Δ, 480 V/4160 V). the basic elements of the UPFC (i.e., voltage control, line electric protection remuneration, part moving and correspondent administration of voltage, electric protection and point) are tried bolstered this setup. Some recreation comes about are given amid this segment.

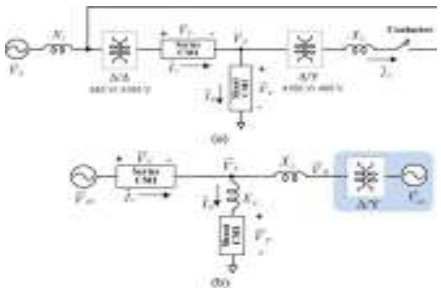

Fig. 12. 4160-V transformer less UPFC test setup. (a) Circuit setup and (b) relating equal circuit

IV. UPFC Operation - Phase Shifting

The UPFC will execute as a perfect point controller, that accomplishes the predetermined part move (driving or slacking) of the main sending-end voltage with none alteration in greatness. three in operation focuses with very surprising moved stages are considered as appeared in Fig. 13(a) case A1: 30°, (b) case A2: 15°, and (c) case A3: 0°. Every one of the 3 section moving cases (case A1 to case A3) are investigated and comparing test comes about are appeared in Figs. 14– 17.

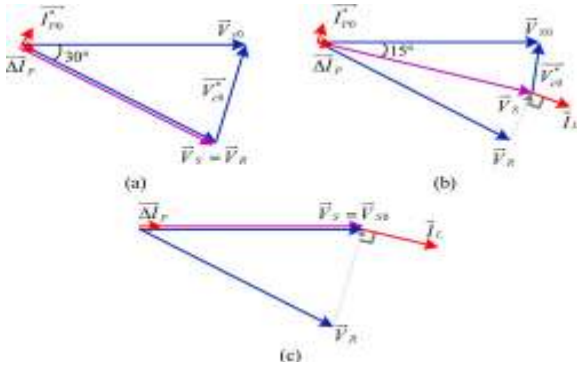

Fig. 13. UPFC working focuses with various stages moving: (a) case A1: 30°, (b) case A2: 15°, and (c) case A3: 0°.

A few discourses about the test outcomes are given as takes after:

From the fig. 14 which demonstrates the recreation waveforms of UPFC in operation from case A1 to case A2 (Phase moving 30° to 15°). As specified some time recently, inside the investigate setup, there's as of now 30° section refinement between the principal sending-end voltage −→V S0 and furthermore the less than desirable end voltage V R. For case A1, arrangement CMI voltage VC is infused to move V S0 by 30° protecting material, thus, V S = V R. amid this case, UPFC is utilized to remunerate voltage refinement caused by electrical gadget 30° section move. Hence, the following line current amid this case is kind of zero. Though for case A2, new sending-end voltage V S is moved from V S0 by 15°, consequently, there's 15° section qualification between V S and V R. this can end in with respect to 7-A (top esteem) line current. Fig. 14(a) and (b) demonstrates the exploratory waveforms of shunt current data preparing a, line current I_{La}, and shunt CMI yield line voltage V_{pab} . Once the part voltage of shunt CMI were created by FFM with improved move plots for low specialist's degree, the street voltage would have even lower specialist's degree in view of nonappearance of the triplen music amid an adjusted three phase framework. From Fig. 14, it demonstrates the street voltage is to a great degree close bended with none extra channels. Moreover, Fig. fourteen conjointly demonstrates this swimmingly and immediately raised from zero to 7 An, once the in operation intention is changed from case A1 to A2.

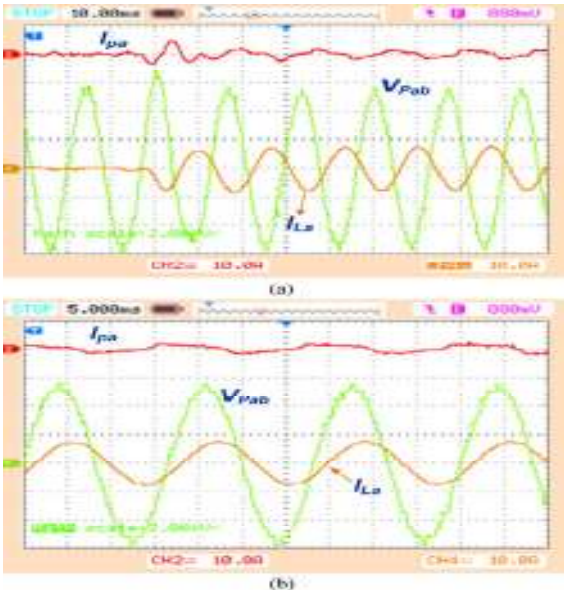

Fig. 14. waveforms of UPFC working from case A1 to case A2 (stage moving 30° to 15°): (a) shunt CMI line voltage VP stomach muscle , shunt CMI stage current IP a, and line current ILa , and (b) the zoomed in waveforms

According to the recreation waveforms of UPFC in operation from case A2 to case A3 (Phase moving 15° to 0°) are appeared in Fig. 15. Fig. 15(a) demonstrates the shunt CMI part voltage VP a, VP b and line current I_{La}, I_{Lb}, I_{Lc}. The Vpa and Vpb are stair-case waveforms that are created by the FFM with improved switch edges. At that point the fig. 15(b) demonstrates the street current I_{La} and shunt CMI line voltage VP abdominal muscle. For case A3, part moving is zero degree, showing a framework while not remuneration. In this manner, V S is equivalent to V_{S0} , and hence the stage between V S and V R is 30°. The following current adequacy amid this case is 14 A.

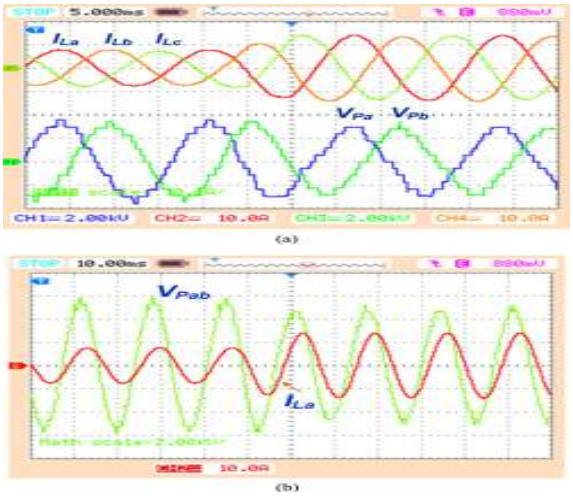

Fig. 15. waveforms of UPFC working from case A2 to case A3 (stage moving 15° to 0°): (a) shunt CMI stage voltage VP a , VP b and line current ILa , ILb , ILc , and (b) line current ILa and shunt CMI line voltage VP abdominal muscle .

From the fig. 16 which demonstrates the deliberate dynamic reaction with in operation reason dynamical from case A2 to case A3, wherever the present abundancy would correction from 7 to 14 A. Since the framework dynamic model has been encased inside the administration equation as appeared in Fig. 8, the UPFC framework has accomplished snappy dynamic reaction, with dormant period < 10 ms. This dynamic execution is sufficiently sweet for transmission-level power stream administration.

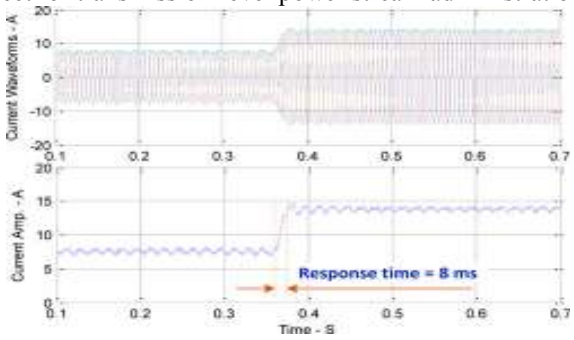

Fig. 16. Measured dynamic reaction with working point changing from case A2 to case A3 (stage moving 15° to 0°).

From the fig. 17 which demonstrates the reproduction aftereffects of dc electrical condenser voltage of every arrangement and shunt CMIs once in operation from case A2 to case A3, wherever high 3 waveforms relate to normal dc voltage of each part, and base one compares to normal dc voltage of every one of the 3 stages. all through the progress, the dc interface voltage for all intents and purposes unbroken steady, which infers the dc connect voltage will be controlled to take after the reference reliably notwithstanding in operation focuses. B.

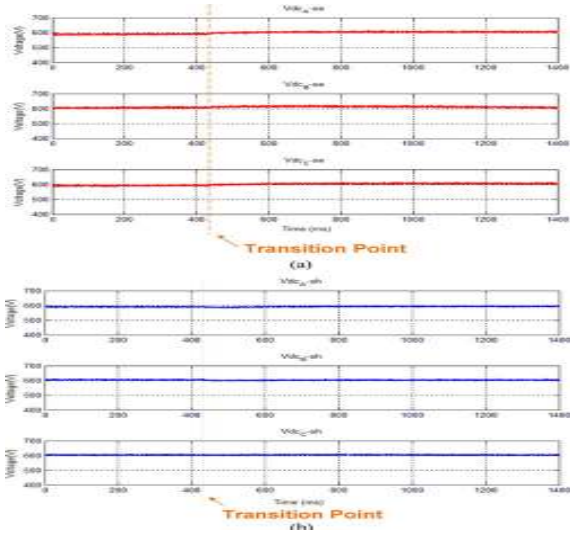

Fig. 17. consequences of dc capacitor voltage of arrangement and shunt CMIs, from case A2 to case A3 (stage moving 15° to 0°): (a) dc capacitor voltage of arrangement CMI and (b) dc capacitor voltage of shunt CMI.

V. UPFC Operation - Line Impedance Compensation

UPFC work of line electrical wonder pay is totally not quite the same as stage moving, wherever the arrangement CMI voltage V C is infused in development with the street current. Practically it's sort of like arrangement capacitive or inductive line remuneration earned by static synchronous arrangement compensator. Fig. 18 demonstrates 3 operation focuses with line impedance pay, (a) caseB1: unique line electric protection while not pay is up to 0.5 p.u., (b) case B2: proportional line electric protection once remuneration is up to 1 p.u., and (c) case B3: proportionate line impedance once pay is up to time. For case B1 (same as case A3), framework while not pay has 0.5 p.u. voltage betweenV S and V R (comparing to 30° voltage contrast). With the line electric protection up to 0.31 H (0.5 p.u.) given in Table III, the came about line current is one p.u. (sufficiency 14 A), that will be that the ostensible current for electrical gadget one and electrical gadget a couple of inside the 4160-V check setup. on account of this constraint of transformers, for case B2 and case B3, UPFC is by configuration controlled to broaden the street electric protection.

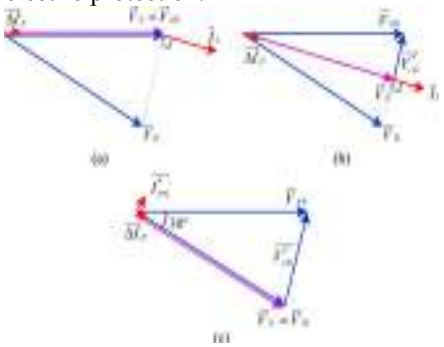

Fig. 18. UPFC working focuses with line impedance remuneration: (a) case B1: unique line impedance without pay = 0.5 p.u., (b) case B2: proportionate line impedance after pay = 1 p.u., and (c) case B3: equal line impedance after pay = α

In this manner at whatever point the transformerless UPFC is furthermore prepared to downsize the line impedance for higher line current (or higher P/Q). Fig. 19 demonstrates the trial aftereffects of UPFC operation from case B1 to case B2, wherever the street electrical wonder altered from unique 0.5 p.u. while not pay to one p.u. when pay. Fig. 19(a) demonstrates the waveforms of shunt CMI part voltage VP a, VP b and line current ILa, ILb, ILc, wherever the street current swimmingly changed from fourteen to seven A (crest esteem) because of the multiplied line electric protection. Fig. 19(b) demonstrates the waveforms of the arrangement CMI infused voltage VCa and line current ILa. From this figure, we will see the street current ILa is protection VCa by 90°, which recommends the arrangement CMIs go about as inductors. this can be the clarification that, once pay, the line impedance is duplicated from 0.5 to 1 p.u. Fig. 20 demonstrates the dynamic reaction with operational reason dynamic from case B1 to case B2. The deliberate response time is with respect to 8 ms.

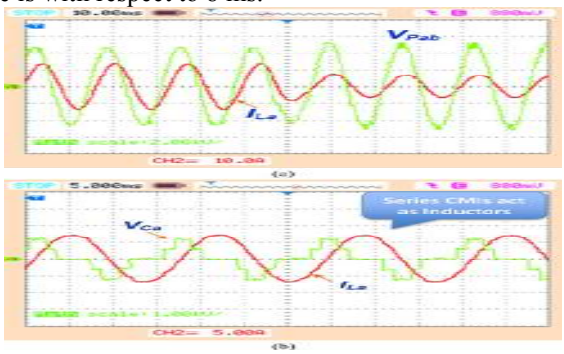

Fig. 19. waveforms of UPFC working from case B1 to case B2 (line impedance from unique 0.5 p.u. without remuneration to 1 p.u. after remuneration): (a) line current ILa and shunt CMI line voltage VP abdominal muscle , (b) line current ILa and arrangement CMI stage voltage VC a .

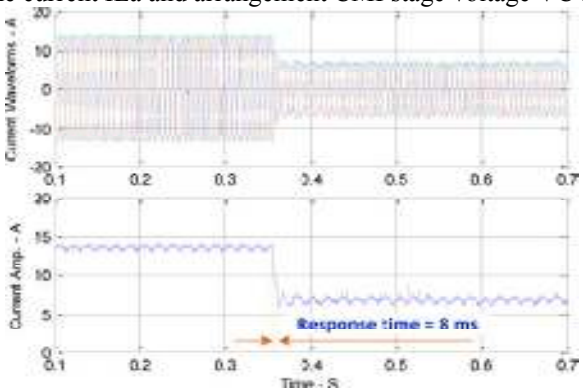

Fig. 20. Measured dynamic reaction with working point changing from case B1 to case B2 (line impedance from unique 0.5 p.u. without remuneration to 1 p.u. after pay).

VI. UPFC Operation - Independent P/Q Control

The elements of voltage control, area moving and line resistivity remuneration square measure from the position of old power transmission administration. As a matter of fact, the UPFC will only administration the size and point in time of the infused voltage continuously along these lines on keep up or differ the dynamic and responsive power stream inside the line to fulfill stack request and framework in operation conditions, i.e., independent P/Q administration. The blue bend in Fig. 21(a) demonstrates the transmittable dynamic power P and getting end receptive power letter of the letters in order versus receivingend voltage point in time δ0 inside the unsalaried framework, wherever unique sending-end voltage is orientated to 0°.

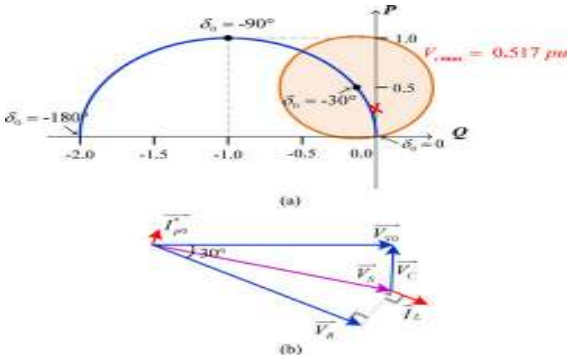

Fig. 21. Free P/Q control: (a) control area of the feasible dynamic power P and getting end receptive power Q with arrangement CMI voltage = 0.517 p.u. what's more, δ0= − 30◦, (b) case C1: P = 0.25, Q = 0.

The hover in Fig. 21(a) demonstrates the administration district of the conceivable dynamic power and accepting end receptive power with arrangement CMI voltage sufficient to zero.517 p.u. also, point in time δ0 break even with to−30◦. By and large, at any given δ0 , the transmitted dynamic power P still as receivingend receptive power letter of the letters in order inside the circle will be controlled by the UPFC, obviously, with the rating constraint of arrangement and shunt CMIs [28]. numerous in operation purposes of independent P/Q administration are tried. Fig. 21(b) demonstrates the phasor outline for one in all the check cases, case C1: P = zero.25, Q = 0, amid this case, line current IL is in segment with getting end voltage VR due to zero accepting end receptive power letter of the letter set. amid this case, the computed line current adequacy is seven.5 A. Fig. 22 demonstrates the comparing reenactment waveforms, (a) line current ILa and shunt CMI line voltage VP abdominal muscle, and (b) line current ILa and arrangement CMI area voltage VCa.

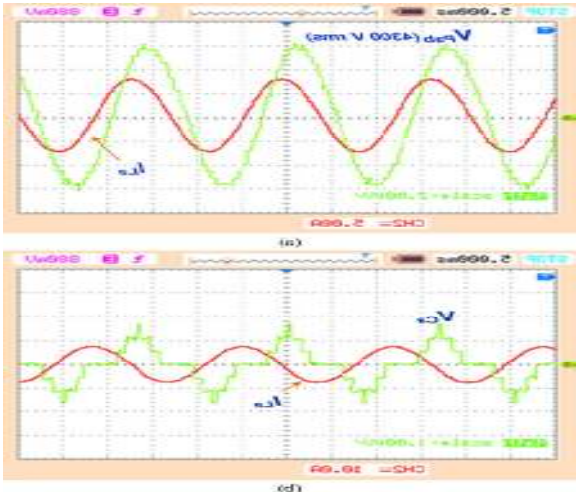

Fig. 22. waveforms of UPFC operation case C1: P = 0.25, Q = 0: (a) line current ILa and shunt CMI line voltage VP abdominal muscle , and (b) line current ILa and arrangement CMI stage voltage VC a .

Conclusion

This paper is executed with a most recent adjustment and control strategy for the transformer less UPFC, along these lines it is trailed by a few highlights: 1) All UPFC capacities, for example, line impedance pay, voltage direction, impedance and stage point, consequently accomplishing autonomous receptive and dynamic power stream control over the transmission line; 2) FFM of the CMI for to a great degree diminishes THD of yield voltage, high productivity and low exchanging misfortune; 3) quick unique reaction (<10 ms); 4) Dc capacitor voltage adjusting control for both arrangement and shunt CMIs. In addition the transformer less UPFC alongside the proposed regulation and control have be introduced anyplace in the network to augment/advance vitality transmission over the current lattices, empower high infiltration of sustainable power sources and abatements the transmission blockage.

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