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A COMPREHENSIVE NEWTON RAPHSON FACTS MODEL FOR THE POWER FLOW SOLUTION OF PRACTICAL POWER NETWORKS

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ABSTRACT

This paper aimed to give modern (or) new version for STATCOM. And this paper aimed to give power flow solution by using Newton Rapshon method. Old STATCOM model consist of VSC and shunt connected transformer. New STATCOM model consist of VSC and LTC (Load Tap Changer). New VSC consist of tap changing transformer. Transformer primary connected to ac system bus, secondary connected to DC bus. The DC bus draws no current. The magnitude and phase angle to tap changing transformer indicates amplitude modulation and phase shift of PWM inverter.

This paper also contains load flow model of UPFC. UPFC controls active power, reactive power and also controls voltage magnitude of bus. The sending and receiving end of the UPFC are decoupled. They are separated by a capacitor in parallel. The sending end acts as PV bus, the receiving end of UPFC acts as PQ bus. The active and reactive power in PQ bus, and voltage magnitude at PV bus are controlled by UPFC. Active power supplied by PV bus is same as PQ bus of UPFC. The UPFC parameter are calculated by Newton – Raphson Method. The original dimensions of the mismatch vector and Jacobion matrix are not attered at all. UPFC will regulates power flow and minimize power losses.

KEYWORDS: FACTS, Newton- Raphson, STATCOM, UPFC,VSC).

INTRODUCTION

The STATCOM is the key element of FACTS controllers. It is alternate of static var compernsator (SVC). It is building block of FACTS equipment. Such as UPFC, IPFC. It is also a part of VSC-HVDC links. So FACTS controllers are used in HVDC transmission-STATCOM consist of Voltage source vonverter (VSC) and a transformer. The transformer is load tap changing (LTC) transformer[11].The available present model at fundamental frequency is represented by controllable voltage source behind a coupling impedance. It is static part of synchronous condenser. In this model STATCOM output voltage may be adjusted with ac system voltage.

The reactive power is controlled by change of magnitude voltage of converter with ac system voltage. The present model explains STATCOM's operations from ac side. It fails to explain it operation from dc side. In this model ac voltage is expressed as a function of the dc voltage and amplitude modulation ratio. DC switching losses in dc bus are not represented in this model. In most of STATCOM model at fundamental frequency, there is no way to tell about the converter operation is within the linear region of operation. In this model switching losses are neglected. Ohmic losses are neglected.

To over come these defects a new STATCOM is presented. In this model VSC is consist of tap-changing transformer and a variable shunt susceptance [11]. The primary of this transformer is VSC's ac side. The secondary of this transformer is VSC's dc side. In this new VSC model takes into consideration of phase shifting and scaling factor of PWM control. VSC is operated at constant dc voltage. A small capacitor is used to support voltage at dc bus. This small capacitor does not give reactive power to power grid. The new model takes account of the VSC switching and ohmic losses separately in this new VSC model no separate load flow solution algorithm is required to present dc circuit. In this model tap changing transformer of the VSC yields the ac and dc circuit. VSC is series connected with LTC transformer[11]. This model consist of control capability both ac and dc sides of converter. This models very useful when applied to VSC-HVDC or UPFC.

NEW VOLTAGE SOURCE CONVERTER MODEL

A. Voltage Source Converter (VSC) Main Characteristics.

The STATCOM consist of series connected voltage source converter (VSC) and an LTC transformer[11]. Primary connected to ac power network. VSC is designed to give two level or multilevel output made up of switches by PWM control. It consist of small capacitor on its dc side to support dc voltage for converter operation.

Converter decides capacitor voltage level by changing its output voltage lag ac system voltage by small phase angle. The capacitor bank value C_{dc} is shown in fig - 1 the VAR generation and absorption carried out by control of PWM. PWM controls and shifts current and voltage waveforms within the VSC to give leading or lagging VAR.

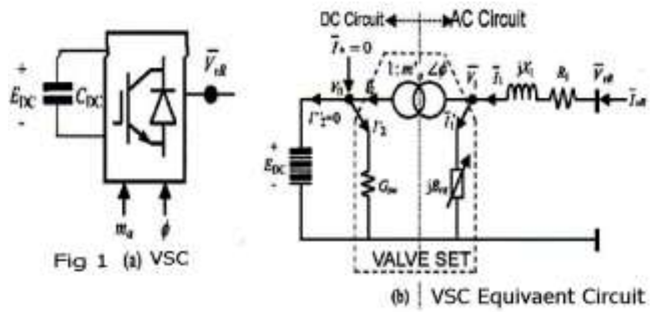

Fig 1 (a) VSC

(b) VSC Equivaent Circuit

VSC has no inertia, its input and output are instantaneous VSC does not change system impedance. It generate reactive power VSC consist of variable succeptance of Beq. Beq will gives reactive power of VSC[11].

B. VSC Admittance Matrix:

The fundamental frequency model of VSC is shown fig. VSC consist of tap changing transformer do not have switching losses. It is a nullator (appendix) it contains source current zero. Source capacitor is 'C_{dc}' it contains norator has variable succeptance (Beq). DC capacitor is represented by battery having voltage E_{dc} primary is connected to ac power system. Secondary is connected to dc node. DC bus consist of current dependent residents G_{sw}[11]. Reactive power supplied by it is zero, real power through it is dc power. Node 1 voltage.

$V_1 = m_a^1 e^{J\phi} E_{dc}$

m_a^1 = tap magnitude of tap changing transformer.

The $m_a^1 = \frac{\sqrt{3}}{2} m_a$ for level 3-ϕ VSC. $(0 < m_a < 1)$

ϕ = Phase angle V_1 w.r.to system phase reference.

V_{dc} = dc bus voltage

X_1 = series reactance of VSC

R_1 = Series resistance of VSC

i_2 = secondary winding current

$$i_2 = i_2^1 + i_2^{11} \qquad i_2^{11} = 0$$

under steady state In tap changing transformer reactive power flow through it is zero. It is due to Xeq supplied all reactive power.

Power supplied= $(V_o I_2)_{secondary} = (V_1(i_1^* - i_1^*))_{primary}$ –(1)

The switching loss model consist of conductance G_0 depend, on dc current and voltage.

In general 'G_0' depends on load current

$$G_{sw} = G_0 \left(\frac{I_2^{act}}{i_2^{nom}} \right)^2, Y_1 = 1/(R_1 + jx_1)$$

$$\frac{v_1}{v_0} = m_a^1 \angle^{\phi}$$

$$\begin{pmatrix} I_{vr} \\ I_0 \end{pmatrix} = \begin{pmatrix} Y_1 & -m_a^1(\cos\theta + J\sin\theta)Y_1 \\ -m_a^1(\cos\theta - J\sin\theta)Y_1 & g_{sw} + m_a^{12}(Y_1 + JB_{eq}) \end{pmatrix} \begin{pmatrix} v_{vr} \\ v_0 \end{pmatrix} \quad (2)$$

C. Voltage Sourced Converter Power Equations. Nodal power equations

$$p_{vr} = g_1 V_{vr}^2 - m_a^1 V_{vR} V_0 \left[g_1 \cos(\theta_{VR} - \theta_0 - \phi) + B_1 \mathrm{Sin}(\theta_{VR} - \theta_0 - \phi) \right]$$
$$Q_{vr} = -B_1 V_{vR}^2 - m_a^1 V_{vR} V_0 \left[G_1 \mathrm{Sm}(\theta_{vR} - \theta_0 - \phi) - B_1 \cos(\theta_{vR} - \theta_0 - \phi) \right]$$
$$P_0 = \left(m_0^{1^2} G_1 + G_{sw} \right) v_0^2 - m_a^1 V_{vR} V_0 \left[G_1 \mathrm{Cas}(\theta_0 - \theta_{vR} + \phi) + B_1 \mathrm{son}(\theta_0 - \theta_{vQ}^{td}) \right] \quad (3)$$
$$Q_0 = -m_a^{1^2} (B_1 + B_{e4}) v_0^2 - m_a^1 V_{vR} V_t \left[G_1 \mathrm{Sw}(\theta_0 - \theta_{vR} + \phi) - B_1 \mathrm{cas}(\theta_0 - \theta_{vR} + \phi) \right]$$

D. VSC Linearized Equations:

These equations are non linear equations. Load flow solution carried out by using Newton-Raphson method. This solution involves linearization of nodal power equations[11].

$$\begin{bmatrix} \Delta P_{uR} \\ \Delta Q_{uR} \\ \Delta P_0 \\ \Delta Q_0 \\ \Delta P_{0-uR} \\ \Delta Q_{0-uR} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_{vR}}{\partial \theta_{vR}} & \left(\frac{\partial P_{vR}}{\partial m_\alpha'}\right) m_\alpha' & \frac{\partial P_{vR}}{\partial \theta_0} & 0 & \frac{\partial P_{vR}}{\partial \phi} & \frac{\partial P_{vR}}{\partial B_{eq}} \\ \frac{\partial Q_{vR}}{\partial \theta_{vR}} & \left(\frac{\partial Q_{vR}}{\partial m_\alpha'}\right) m_\alpha' \frac{\partial Q_{vR}}{\partial \theta_0} & 0 & \frac{\partial Q_{vR}}{\partial_\phi} & & \frac{\partial Q_{vR}}{\partial B_{eq}} \\ \frac{\partial P_0}{\partial \theta_{vR}} & \left(\frac{\partial P_0}{\partial m_\alpha'}\right)_{00} m_\alpha' \frac{\partial P_0}{\partial \theta_0} & 0 & \frac{\partial P_0}{\partial \phi} & & \frac{\partial P_0}{\partial B_{eq}} \\ \frac{\partial P_{0-VR}}{\partial \theta_{vR}} & \left(\frac{\partial P_{0-vR}}{\partial m_\alpha'}\right) m_\alpha' \frac{\partial P_{0-vR}}{\partial \phi} & 0 & \frac{\partial P_{0-vR}}{\partial \phi} & & \frac{\partial P_{0-vR}}{\partial B_{eq}} \\ \frac{\partial Q_{0-VR}}{\partial \theta_{vR}} & \left(\frac{\partial Q_{0-vR}}{\partial m_\alpha'}\right) m_\alpha' \frac{\partial P_{0-vR}}{\partial \phi_0} & 0 & \frac{\partial P_{0-vR}}{\partial \phi} & & \frac{\partial P_{0-vR}}{\partial B_{eq}} \end{bmatrix} \begin{bmatrix} \Delta\theta_{uR} \\ \frac{\Delta m_0'}{m_\alpha'} \\ \Delta\theta_0 \\ \frac{\Delta v_0}{v_0} \\ \Delta\phi \\ \Delta B_{eq} \end{bmatrix} \quad (4)$$

Power Mismatches are

Δp_{vR}, ΔQ_{vR}, Δ_{Po}, Δ_{Qo}, Δp_{o-vR}, ΔQ_{0-vR}

State variables and increments

$\Delta\theta_{vR}$, $\Delta m^1{}_a$, $\Delta_{\theta o}$, Δ_d, Δp_{o-vR}, ΔB_{-eq}

Assumptions:

- If voltage regulations is not applied at node $_{vR}$, $m_a{}^1$ is a state variable
- If Newtan-Raphson power flow solution dc bus is treated as a PV bus, with zero real power injection. It has constant voltage E_{dc},
- Phase angle at node 'O' is independent of circuit parameters.
- Initial parameters $m_a^1 = \frac{\sqrt{3}}{2}$, $\phi = 0$
- VSC is operated in linear region
- ϕ has no limits

E. Voltage Source Converter Test Cases

VSC is used to supply reactive power:

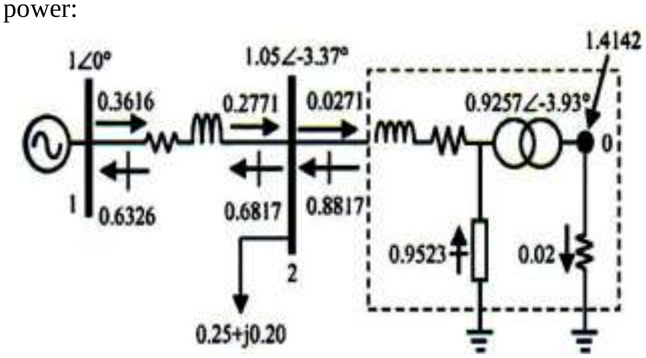

Fig 2 : VSC providing Voltage Support at bus 2

It is 3-bus system
Bus 1 – Slack bus V = 120
Bus 2 – Load bus P = 0.25, Q = J 0.20
Bus 3 – dc bus V = 1.414220

It is three bus systems. It consists of one generator, one transmission line and one ac/dc converter (VSC). The generator node is taken to be the slack bus where voltage magnitude is kept at 1p.u and phase angle as reference. But'0' represented as dc bus of VSC circuit. Phase angle of voltage at bus 0 is zero. Newton Raphson power flow algorithm converges in seven iterations. VSC consumer 0.0271 p.u of active power from the system and supplies 0.8817 p.u of reactive power to the system. The susceptance produces 0.9523 p.u of reactive power and its capacitive susceptance stands at Beq = 0.7408 p.u.

POWER FLOW STATCOM MODEL

For fundamental frequency STATCOM consist of VSC and interfacing transformer (or) load Tap changer (LTC). The bus at which STATCOM connected is PV bus[11].

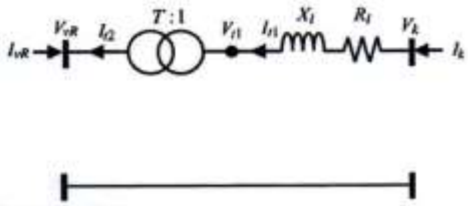

Fig 3. LTC transformer equivalent.

STATCOM equivalent circuit is shown in fig-4. This circuit is used to derive mathematical model of the controller for power flow solution [2]

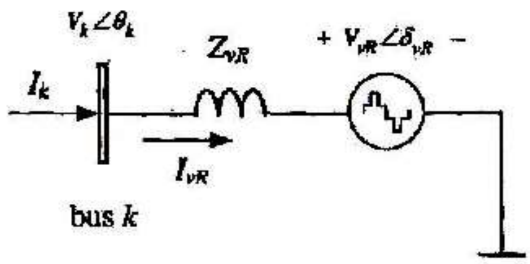

Fig 4. Static Compensator (STATCOM) equivalent circuit.

STATIC SHUNT COMPENSATOR

Purpose of Shunt Compensator:-

The steady state transmittable power increases and voltage profile can be improved by reactive shunt compensation shunt connected reactors are applied to minimize line over voltage under light load conditions. Shunt connected capacitors are applied to maintain voltage levels at heavy load condition.

Var compensation is used for voltage regulation at the midpoint and at end to prevent voltage instability voltage control to increase tragient stability and damp power oscillation. [1]

Static var generators:-

Controllable reactive power generated by dc to ac and ac to dc switching converters. The reactive power generated by a voltage sourced converter is like to conventional rotating synchronous machine. The reactive convert I drawn by synchronous compensation is depend on E, V, X

$$I = \frac{V - E}{X}$$

The reactive power exchanges

$$Q = \frac{1 - E/V}{X} V^2$$

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If E>V converter supplies reactive power.
If E<V converter receives reactive power.

VSC consist of capacitor. This converter produces 3-Φ voltage of system frequency. It consist of tie reactance of relatively small one. All converters composed of H Bridges.[1]

Since VSC supplies reactive power, real power supplied by dc source is zero. Reactive power at dc side is zero. So dc capacitor has no role, converter only supplies reactive power. In VSC sinusoidal out put pure voltages, and draws sinusoidal reactive currents from ac system and zero current from dc capacitor. In common VSC semi conductor devices one not lossless. So they take energy form dc capacitor. The ability of supplying real and reactive power exchange is good feature requiring power oscillation damping. [1]

After doing some complex operations are following active and reactive power equations are obtained for STATCOM at bus k [2]

$$
\begin{aligned}
P_{VR} &= V_{VR}^2\, G_{VR} + V_{VR}\, V_k \left[G_{vR}\cos(\theta_{VR}-\theta_k) + B_{VR}\,\mathrm{Sin}(\delta_{VR}-\theta_k)\right]\\
Q_{VR} &= -V_{VR}^2\, B_{VR} + V_{VR}\, V_k \left[G_{vR}\sin(\delta_{VR}-\theta_k) - B_{VR}\cos(\delta_{VR}-\theta_k)\right]\\
P_k &= V_{Vk}^2\, G_{VR} + V_k\, V_{VR} \left[G_{VR}\cos(\theta_k-\delta_{vR}) - B_{VR}\sin(\theta_{VR}-\delta_k)\right] \qquad (5)\\
Q_k &= -V_k^2\, B_{VR} + V_k\, V_{VR} \left[G_{VR}\sin(\theta_k-\delta_{vR}) - B_{VR}\cos(\theta_k-\delta_{VR})\right]
\end{aligned}
$$

Using these equations (5)the linearised STATCOM model is given below

$$
\begin{bmatrix} \Delta P_k \\ \Delta Q_k \\ \Delta P_{vR} \\ \Delta Q_{vR} \end{bmatrix}
=
\begin{bmatrix}
\frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial V_k} V_k & \frac{\partial P_k}{\partial \delta_{vR}} & \frac{\partial P_k}{\partial V_{vR}} V_{uR} \\
\frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial V_k} V_k & \frac{\partial Q_k}{\partial \delta_{vR}} & \frac{\partial Q_k}{\partial V_{uR}} V_{uR} \\
\frac{\partial P_{uR}}{\partial \theta_k} & \frac{\partial P_{uR}}{\partial V_k} V_k & \frac{\partial P_{uR}}{\partial \delta_{uR}} & \frac{\partial P_{uR}}{\partial V_{uR}} V_{uR} \\
\frac{\partial Q_{uR}}{\partial \theta_k} & \frac{\partial Q_{uR}}{\partial V_k} V_k & \frac{\partial Q_{uR}}{\partial \delta_{uR}} & \frac{\partial Q_{uR}}{\partial V_{uR}} V_{uR}
\end{bmatrix}
\begin{bmatrix} \Delta\theta_k \\ \frac{\Delta V_k}{V_k} \\ \Delta\delta_{uR} \\ \frac{\Delta V_{uR}}{V_{uR}} \end{bmatrix} \qquad (6)
$$

A. STATCOM Test Cases

Five Bus System

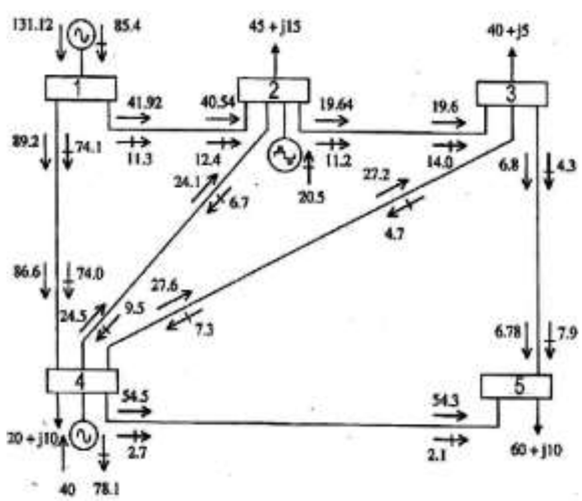

Fig 5 : STATCOM Power Flow Results

XVR ≤ 0.1 p.u.

The power flow result indicates that STATCOM generates 20.5 VAR to maintain voltage magnitude at 1p.u. at bus 2. STATCOM parameters associated with this amount of reactive power generation are V_{VR}=1.0205 p.u. and δ_{VR} = -4.83^0. Slack bus (1) reduces its reactive power generation by 6%. Reactive power from bus 1 – 2 reduces by 30%. The generator connected at bus – 4 increases its share of reactive power absorption.

30-bus system:
IEEE – 30 bus system is selected for test results fixed capacitor banks at nodel 10 and 24 are replaced by STATCOM

These STATCOMs are used to set voltage magnitudes at their points of connection with the power grid. The dc voltage is kept at 1.4142 p.u. The STATCOM losses are quite low because currents drawn by the two STATCOMS are low.

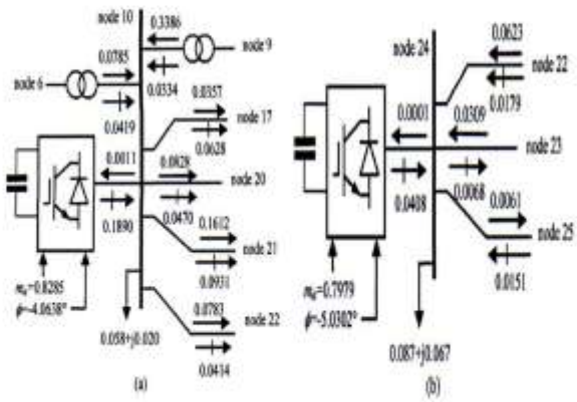

Fig -6 STATCOMS supplying reactive power

POWER FLOW MODEL FOR UPFC

The equivalent circuit consists of two coordinated synthronous voltage sources at fundamental frequency the equivalent CKT is shown in fig -7 [2]

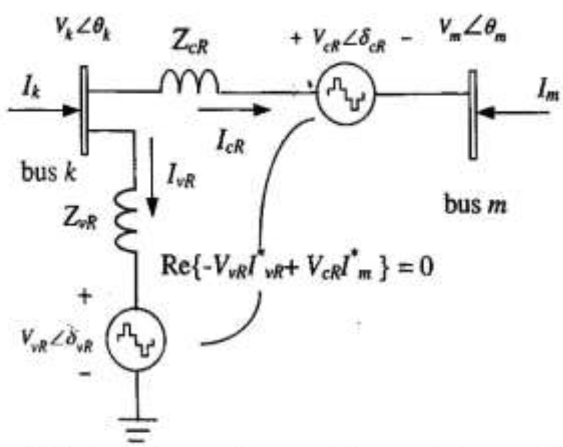

Fig 7. **Unified power flow controller equivalent circuit**

The main advantages of UPFC are

- In UPFC model state variables are adjusted simultaneously with nodal network state variables.
- UPFC controls active and reactive power simultaneously as well as voltage magnitude.
- Some analytical equations are derived to provide good UPFC initial conditions.
- The losses of UPFC coupling transformer an taken into account.

Based on the equivalent circuit active and reactive power equations at bus K [4]

$$\begin{aligned} P_k = {} & V_k^2 G_{kk} + V_k V_m [G_{km} \cos(\theta_k - \theta_m) + B_{km} \sin(\theta_k - \theta_m)] \\ & + V_k V_{cR} [G_{km} \cos(\theta_k - \delta_{cR}) + B_{km} \sin(\theta_k - \delta_{cR})] \\ & + V_k V_{uR} [G_{uR} \cos(\theta_k - \delta_{uR}) + B_{uR} \sin(\theta_k - \delta_{uR})] \end{aligned} \quad (7)$$

$$\begin{aligned} Q_k = {} & V_k^2 B_{kk} + V_k V_m [G_{km} \sin(\theta_k - \theta_m) - B_{km} \cos(\theta_k - \theta_m)] \\ & + V_k V_{cR} [G_{km} \sin(\theta_k - \delta_{cR}) + B_{km} \sin(\theta_k - \delta_{cR})] \\ & + V_k V_{uR} [G_{uR} \sin(\theta_k - \delta_{uR}) + B_{uR} \cos(\theta_k - \delta_{uR})] \end{aligned}$$

At bus m:

$$\begin{aligned} P_k = {} & V_m^2 B_{mm} + V_m V_k [G_{mk} \cos(\theta_k - \theta_m) + B_{km} \sin(\theta_m - \theta_k)] \\ & + V_m V_{cR} [G_{mm} \cos(\theta_m - \delta_{cR}) + B_{km} \sin(\theta_m - \delta_{cR})] \end{aligned}$$

$$\begin{aligned} Q_m = {} & V_m^2 B_{mm} + V_m V_k [G_{mk} \sin(\theta_m - \theta_k) - B_{mk} \cos(\theta_m - \theta_k)] \\ & = + V_m V_{cR} [G_{mn} \sin(\theta_m - \delta_{cR}) - B_{mm} \cos(\theta_m - \delta_{cR})] \end{aligned} \quad (8)$$

Series converter

$$\begin{aligned} P_{cR} = {} & V_{cR}^2 G_{mm} + V_{cR} V_k [G_{km} \cos(\delta_{cR} - \theta_k) + B_{km} \sin(\delta_{cR} - \theta_k)] \\ & = V_{cR} V_m [G_{mm} \cos(\delta_{cR} - \theta_m) + B_{mm} \sin(\delta_{cR} - \theta_m)], \\ Q_{cR} = {} & V_{cR}^2 B_{mm} + V_{cR} V_k [G_{km} \sin(\delta_{cR} - \theta_k) + B_{km} \cos(\delta_{cR} - \theta_k)] \\ & + V_{cR} V_m [G_{mm} \sin(\delta_{cR} - \theta_m) + B_{mm} \cos(\delta_{cR} - \theta_m)]; \end{aligned} \quad (9)$$

Shunt converter:

$$\begin{aligned} P_{uR} &= -V_{uR}^2 G_{uR} + V_{uR} V_k [(G_{uR} \cos(\delta_{uR} - \theta_k) + B_{uR} \sin(\delta_{uR} - \theta)] \\ Q_{uR} &= V_{uR}^2 B_{uR} + V_{uR} V_k [(G_{uR} \sin(\delta_{uR} - \theta_k) + B_{uR} \cos(\delta_{uR} - \theta)] \end{aligned} \quad (10)$$

Assuming loss-less converter valves, the active power supplied to the shunt converter, P_{uR}, equals the active power demanded by the series converter, P_{cR}; that is,

$$P_{vR} + P_{cR} = 0$$

Further, if the coupling transformers are assumed to contain no resistance then the active power at bus k matches the active power at bus m. Accordingly,

$$P_{vR} + P_{cR} = P_k + P_m = 0$$

A. Test Results:-

a) Five Bus System:

$V_{CR} = 0.04$ P.U $\delta_{CR} = 87.130$

$V_{VR} = 1$PU $\delta_{VR} = 0^0$

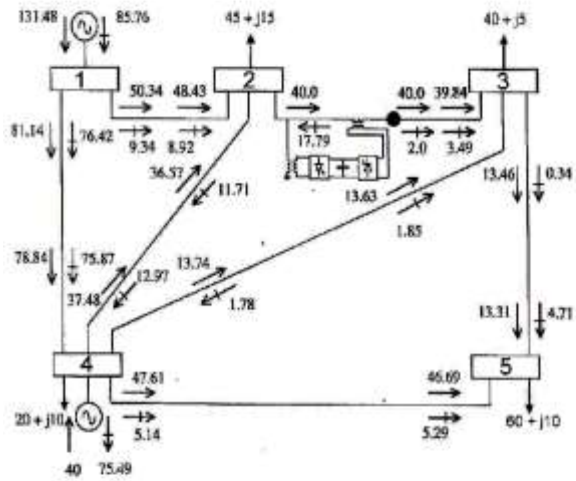

Fig.8 Five-bus test network with one unified power flow controller, and power flow results

There is 32% increase in active power flows toward bus 2 active, reactive powers exchanged by UPFC [2]. This increase in active power is needed due to large amount of active power demanded by UPFC series converter UPFC generates reactive power generator at bus 1 decreases its reactive power generation by 5.6%

b) IEEE-2171 – Bus System:
Two UPFC placed at 32-bus in parallel

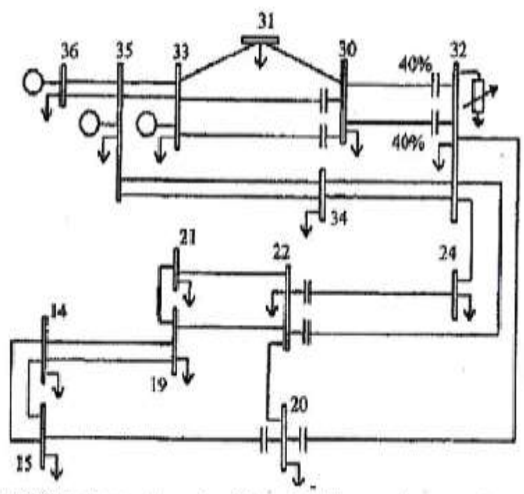

FIG.9 Relevant part of the 2172 - nodes system

Table – I
UPFC Power Flow Model Comparison

UPFC	UPFC-1		UPFC-2	
Parameters	Proposed	Rcf.	Proposed	Ref
V_{cR} (p.u.)	0.4882	0.4882	0.4937	0.4937
θ_{cR} (deg.)	52.76	52.76	52.88	52.88
V_{cR} (p.u.)	0.9403	0.9403	0.9403	0.9403
θ_{vR} (deg)	-19.54	-19.54	-19.56	-19.56

Table – II
Effect of UPFC Losses on its Final Parameters

UPFC	UPFC-1		UPFC-2	
Parameters	Lossless	Losses	Lossless	Losses
V_{cR} (p.u.)	0.4882	0.4882	0.4937	0.4937
θ_{cR} (deg.)	52.76	52.76	52.88	52.88
V_{cR} (p.u.)	0.9403	0.9403	0.9403	0.9403
θ_{vR} (deg)	-19.54	-19.54	-19.56	-19.56

Table – III
Effect of UPFC Losses its Final Parameters

UPFC	Power UPFC-1 (MW)		Power UPFC-2 (MW)	
Parameters	Proposed	Ref.	Proposed	Ref
Lossless	610	-610	620	-620
Losses	610	-562.6	620	-571.1

Table – IV
Effect of Initial Conditions

UPFC-1				UPFC-2				Itera tions
V_{cR}	θ_{cR}	V_{vR}	θ_{vR}	V_{cR}	θ_{cR}	V_{vR}	θ_{vR}	
0.25	0.0	1.0	0.0	0.25	0.0	1.0	0.0	7
0.25	1.80	1.0	0.0	0.25	180	1.0	0.0	8
0.15	83.1	1.0	0.0	0.16	82.8	1.0	0.0	6

Existing SVC and two SCCs have been replaced by two UPFCs operation parallel at 32 bus. The function of SCC is performed by the UPFC series converters. Active power transmission capability increased by 15% And reactive power in maintained at same level. The function of SVC is done by UPFC shunt converters, which maintains voltage magnitude at p.u.UPFC parameters are shown in Table-I:The effect of the UPFC coupling transformer losses are included. The effect of losses on UPFC parameter are shown in table II The effect of losses on active power flow is shown table III. In order to show the impact of good UPFC initial conditions on convergence, deferent series voltage source initial conditions were used . Table –IV shows three different initial condition.

CONCLUSION

A STATCOM model for power flow solutions using the Newton-Raphson method has been introduced. A New VSC model is presented. Switching losses clinic losses and connecting LTC transformer are included. Test results included for five-bus and 30-bus system. The complex tap changer in VSC model and real tap change on LTC model enable an effective voltage regulation at the point of connection with the grid and at the VSC's ac node. A General UPFC power flow model has been presented on this paper. This model has been included in a Newton rophson load flow algorithm. Improper selection of initial condition degrades Newton's quadratic convergence.

APPENDIX

The equivalent circuit of VSC is shown in fig.10

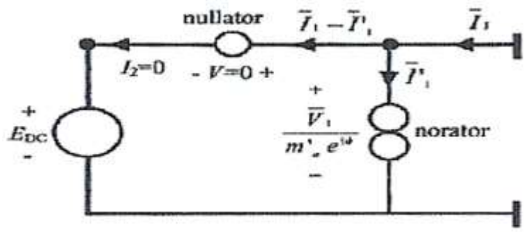

Fig-10 Equivalent circuit of VSC interms of electronic circuit elements

In steady state a charged dc capacitor takes no current. Hence in steady this circuit behaves as nullor operates on a dc source. The nullor is consist of nullator and a norator. The nullator and norator are said to be linear. Norator always paired with nullator [11]. Nullator and norator are said to be linear, time invariant oneport elements. Nullator has zero current through it and zero voltage across it. Norator have an orbitary current through it and an arbitrary voltage across its terminals . Nullator has zero voltage, zero-current connections. Nullator, norator are current and voltage sources at same time. Norator is a voltage or current source with infinite gain.

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