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SECURITY ASSESMENT AND ENHANCEMENT OF AN INTERCONNECTED POWER SYSTEM USING DIFFERENT FACTS DEVICES CONSIDERING VOLTAGE DEPENDENT LOADS AND ZIP LOADS

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ABSTRACT
This paper has demonstrated the need for the proper remedial measures for security enhancement depending on system conditions, the dynamic behaviour of the reactive part of loads can be more significant than the real part. This paper had indicated that the dynamic load models will not only affect the damping of electromechanical modes, but can also have an influence on which generators participated in the mode. As load parameters vary, this participation can also vary. In this approach, with Voltage Depended Load (VDL) models and ZIP loads are considered for the quick restoration few FACTS devices are incorporated with boundary values. The security enhancement results are provided to highlight the overall security and suitability of the approach. The significant of the corrective measures to be adopted for the load uncertainty was also considered with load parameters variation. The proposed scheme is adopted in IEEE 14 bus test system. The optimized result can be utilized for the improvement of the system performance.

Keywords: Flexible AC Transmission System (FACTS), Interline Power Flow Controller (IPFC), Mixed Load and Thermostatically Controlled Loads

1. INTRODUCTION

This paper proposes the control strategy for power system security assessment of an interconnected power system with Voltage Dependent Load (VDL) and ZIP Loads which is governed by the Flexible AC Transmission system (FACTS) controllers when the arrangement is impending an severe crisis state. First the islanding of the power system is avoided with the adoption the few FACTS devices. The scheme is adopted in test system of IEEE 14 bus using bacterial foraging optimization algorithm. The basic restoration assessment for the interconnected power system with Voltage Dependent Load (VDL)/ ZIP Loads has been conceded out and the various remedial control actions using few FACTS devices are considered for the power system security enhancement [1]. The maximum allowable limits are fixed if the system survives for all realistic contingencies or with reduced allowable limits by some small amount to provide a margin that would account for changes in conditions when the actual limit is in force.

II. MATHEMATICAL MODELLING OF VOLTAGE DEPENDENT LOAD (VDL)

Voltage Dependent Loads (VDL) represents the power relationship to voltage as an exponential equation of nonlinear load model. The load powers PH and QH are represented as negative powers as they are engrossed from the bus and are as follows [2]

$$-P_H = P_0 (v/v_0)^{\gamma p} \tag{2.1}$$

$$-Q_H = Q_0 (v/v_0)^{\gamma q} \tag{2.2}$$

Where v_0 is the initial value of the load bus voltage obtained from power flow solution. Generally the exponent values of the model for different load components γ_p and γ_q are considered as (0, 1or 2). Equations can be directly included in the formulation of power flow analysis. However, VDLs are generally initialized after the power flow analysis, P_0 and Q_0 are computed based on constant PQ load powers (P_{L0} and $Q_{L0});$ In this case, the initial voltage is not knownV_0, the subsequent equation can be used,

$$P = P_0 V^{\gamma p} \tag{2.3}$$

$$Q = Q_0 V^{\gamma q} \tag{2.4}$$

Where γ_p , γ_q are the active and reactive power exponents respectively. P_0 and Q_0 initial values of depend on the status parameter k. If k=1, after the power flow analysis the VDL is initialized and P_0, Q_0 are denoted in percentage of the PQ load power allied at the VDL bus.

$$P_0 = \frac{k_p}{100} P_L \tag{2.5}$$

$$Q_0 = \frac{k_q}{100} P_L \quad (2.6)$$

2.1 MATHEMATICAL MODELLING OF ZIP LOAD

Polynomial or ZIP loads are the nonlinear load model whose powers are represented by the quadratic expression of the bus voltage. The ZIP model, equations (2.7) and (2.8), is a polynomial model that represents the sum of these three categories [3]

$$-p_H = g\left(\frac{v}{v_0}\right)^2 + I_p \frac{v}{v_0} + p_m \quad (2.7)$$

$$-q_H = b\left(\frac{v}{v_0}\right)^2 + I_q \frac{v}{v_0} + q_m \quad (2.8)$$

Where v_0 is the initial voltage of the load bus and is obtained from the power flow solution. Other parameters of ZIP load is initialized after the power flow analysis [4] the parameters can be defined based on the PQ load powers P_{L0} and Q_{L0}.

$$g = \frac{g}{100}\frac{P_{L0}}{v_0^2}, \qquad I_p = \frac{I_p}{100}\frac{P_{L0}}{v_0}, \qquad P_m = \frac{p_m}{100} P_{L0}$$

$$b = \frac{b}{100}\frac{Q_{L0}}{v_0^2}, \qquad I_q = \frac{I_q}{100}\frac{Q_{L0}}{v_0}, \qquad q_m = \frac{q_m}{100} Q_{L0}$$

If the first voltage V_0 not known, then the subsequent equations can be used

$$-p_H = gv^2 + I_p v + p_m \quad (2.9)$$

$$-q_H = bv^2 + I_q v + q_m \quad (2.10)$$

As the parameters are constants and indicate the nominal power they can be separated into constant impedance, constant current and constant power [5].

III. IDENTIFICATION OF MODEL PARAMETERS.

The real and reactive power representations of the model are

$$P_H = [1 + K_p(V-1)].(1 - P_{drop}) + P_{dyn}.(G.V^2 - 1) \quad (2.11)$$

$$Q_H = [1 + K_q(V-1)].(1 - Q_{drop}) + Q_{dyn}.(B..V^2 - 1) \quad (2.12)$$

Considering the equation (2.11), using re-parameterization the nonlinear relationship between P (active power), V (voltage at the load bus), G (conductance) and the parameters P_{dyn}, P_{drop} and K_P, and the model can be written as (2.13).

$$P_H = [x(1) + x(2).(V - 1)] + P_{dyn} .(G..V^2 - 1) \quad (2.13)$$

$$x(1) = (1 - P_{drop}) \quad (2.14)$$

$$x(2) = x(1).K_p \quad (2.15)$$

$$z(t) = \gamma^t(t)\theta_p \quad (2.16)$$

$$\theta_p = (x(1).\ x(2).\ P_{dyn}) \quad (2.17)$$

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The least squares method is used [6] to diminish the function (2.17) and to get the most excellent estimate for the parameter vector θ_p.

$$L(\theta_p) = \sum_{k=1}^{N} \left(P_{simulated}\left(t_K,\ \theta_p\right) - P_{measured}\left(t_K,\ \theta_p\right)\right)^2 \quad (2.18)$$

The same procedure is applied for the reactive power also. The nonlinear model parameters can also be estimated accurately by an iterative approach as mentioned below, Initial estimate x_o for the parameters is selected. Best estimates are compared with the initial estimates to decide for further improvement [7].

IV.COMPUTATION OF VOLTAGE COLLAPSE PERFORMANCE INDICES (VCPI)

With the power flow model, Jacobian Matrix J represents the first derivatives of active and reactive power mismatch equations, ΔP = ΔP(θ, E) and ΔQ = ΔQ(θ, E), with respect to the voltage magnitude E and angles θ, i.e., the linearization of these equations yields

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = J \begin{bmatrix} \Delta \theta \\ \Delta E \end{bmatrix} \quad (4.42)$$

Where [ΔP], [ΔQ], [Δθ] and [ΔE] are the increments change in nodal bus powers, reactive power, angles and voltage magnitudes.

$$[J] = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \quad (2.19)$$

$$J_1 = \frac{\partial P}{\partial \theta},\quad J_2 = \frac{\partial P}{\partial E},\quad J_3 = \frac{\partial Q}{\partial \theta},\quad J_4 = \frac{\partial Q}{\partial E} \quad (2.20)$$

The voltage stability of the system is affected by both P and Q. However, at each operation point we keep P constant and evaluate voltage stability by considering the incremental relationship between Q and (E or V). This is analogous to the Q-V curve approach. In [8], the authors proposed to reduce the load-flow Jacobian to the first derivative of reactive power equations in relation to voltage magnitude, by assuming that the generator and load buses present no active power variation, i.e., ΔP = 0. Thus,

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \theta \\ \Delta E \end{bmatrix} \quad (4.45)$$

$$[\Delta\theta] = -[J_{P\theta}]^{-1}.\ [J_{PE}].\ [\Delta E] \quad (2.21)$$

$$[\Delta Q] = [J_{Q\theta}]\ \ [\Delta E] + .\ [J_{QE}].\ [\Delta E] \quad (2.22)$$

After substituting $[\Delta\,\vartheta\,]$, $[\Delta\,Q\,]$

$$[\Delta Q] = \left([J_{QE}] - [J_{Q\theta}].[J_{P\theta}]^{-1}.\ [J_{PE}].\ [\Delta E]\right) \quad (2.23)$$

or

$$\left[\Delta Q_{l_{oad}}\right] = [J].[R].\left[\Delta E_{l_{oad}}\right] \quad (2.24)$$

$$\Delta Q = \left(J_4 - J_3 J_1^{-1} J_2\right) \Delta E = JR\ \Delta E \quad (2.25)$$

Where

$$[J].[R] = \left([J_{QE}] - [J_{Q\theta}].[J_{P\theta}]^{-1}.\ [J_{PE}]\right) \quad (2.26)$$

$$\left[\Delta V_{l_{oad}}\right] = [J].[R]^{-1}.\left[\Delta Q_{l_{oad}}\right] \quad (2.27)$$

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$$\Delta E = \left(J_4 - J_3 J_1^{-1} J_2\right)^{-1} \Delta Q \quad = JR^{-1} \ \Delta Q \tag{2.28}$$

Where $[J][R]^{-1}$ is called inverse reduced V-Q Jacobian matrix. Its i[th] diagonal element is the V-Q sensitivity at the bus i.

Few parameters can be directly measured and can be used in real time application to compute proximity to collapse index quickly. An example of such indicator is sensitivity of the generated reactive powers with respect to load parameters and voltage magnitude. Voltage Collapse Performance Index (VCPI) is obtained using sensitivity analysis computation using the relation between voltage change and reactive power change and the elements of the inverse of the reduced Jacobian matrix *JR* are Q-V sensitivities [9]. The diagonal components $\partial Vi/\partial Qi$ are the self sensitivities and the nondiagonal elements $\partial Ek/\partial Qi$ are the mutual sensitivities. The sensitivities of voltage controlled buses are equal to zero. For a quite stable system when Q decreases at specified bus or buses [10], its effect on the voltage magnitude of the system buses should be minor. The sensitivity indices are interpreted as follows:

Positive sensitivities: Stable operation; the smaller the sensitivity, the more stable the system. As stability decreases, the magnitude of the sensitivity increases, becoming infinite at the stability limit (maximum loadability).

Negative sensitivities: Unstable operation. The system is not controllable, because all reactive power control devices are designed to operate satisfactorily when an increase in Q is accomplished by an increase in V.

V. SIMULATION RESULTS AND OBSERVATIONS

IEEE 14 bus system is considered for the Security Assessment studies. The performance analysis of IEEE 14-bus, 5-generator system coordinated with different types of Dynamic load models without and with FACTS devices were studied [11-17]. And the optimum utilization requirement with the FACTS devices for each load was determined using BFO technique [18-22]. In this case of study the buses 4, 5 and 14 are connected with VDL and ZIP Loads. The FACTS devise are connected as follows

1. SVC at Buses 4, 5 and 14.
2. UPFC between Buses 4 and 5, i.e. in Line 7.
3. UPFC between Buses 14 and 13, i.e. in Line 20.
4. IPFC between Buses 4 and 5, i.e. between Lines 7 and 9.
5. IPFC at Bus 14 i.e. in between Lines 17 and 20
6. IPFC at Bus 14 i.e. in between Lines 17 and 20

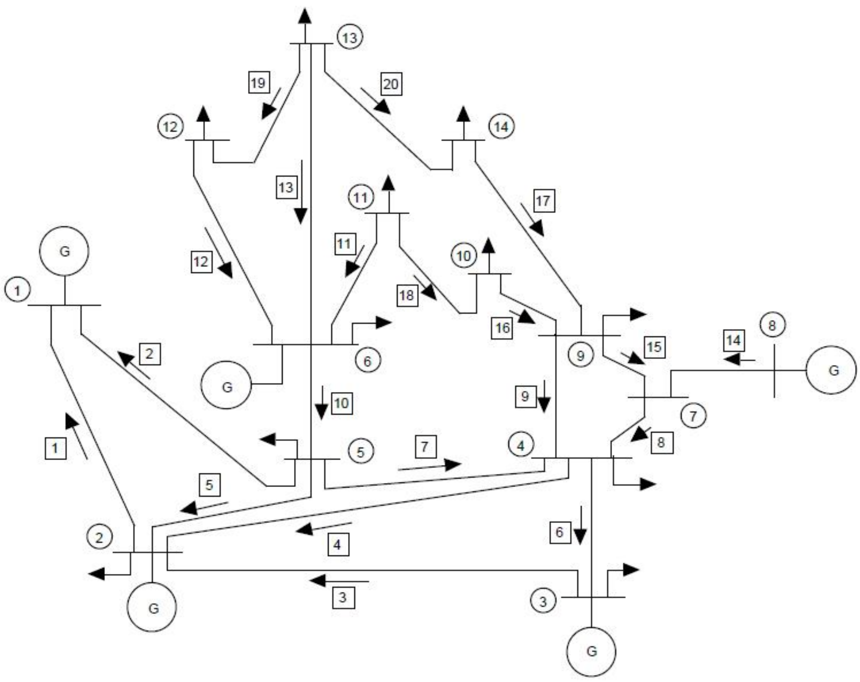

Fig-1: IEEE 14 Bus Systems

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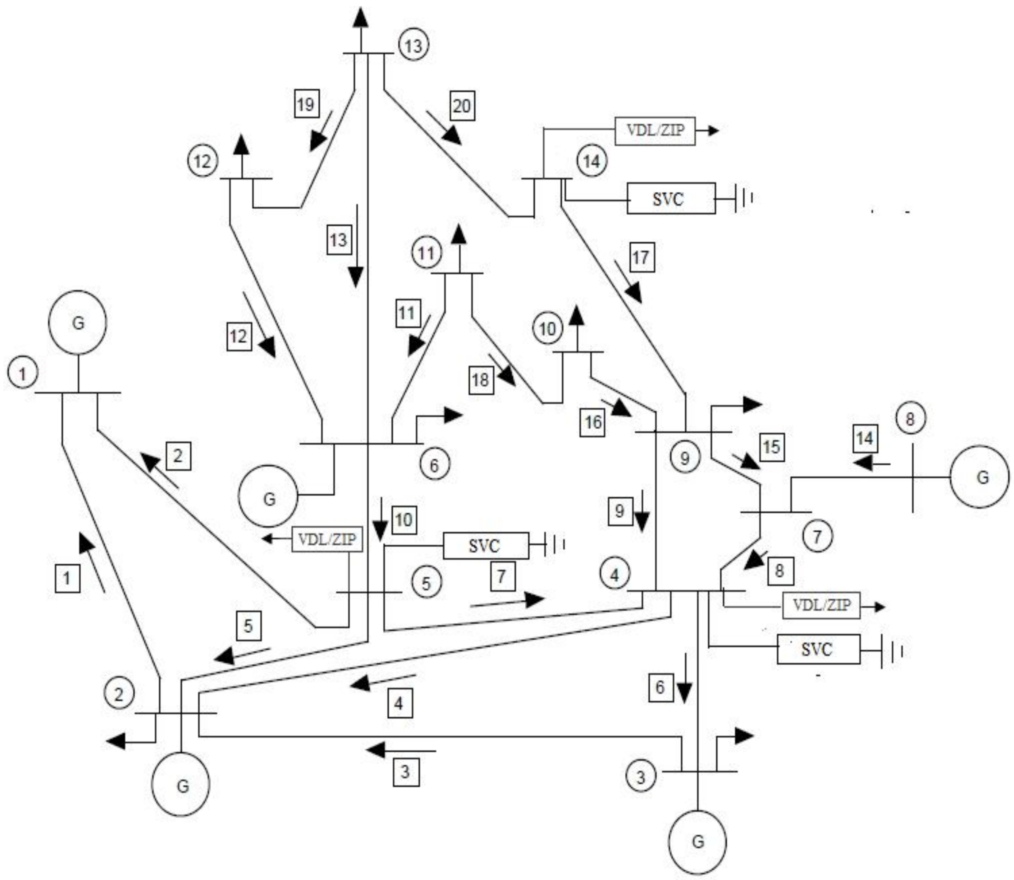

Fig-2: Single line diagram representation of IEEE 14 bus system with various SVC controllers

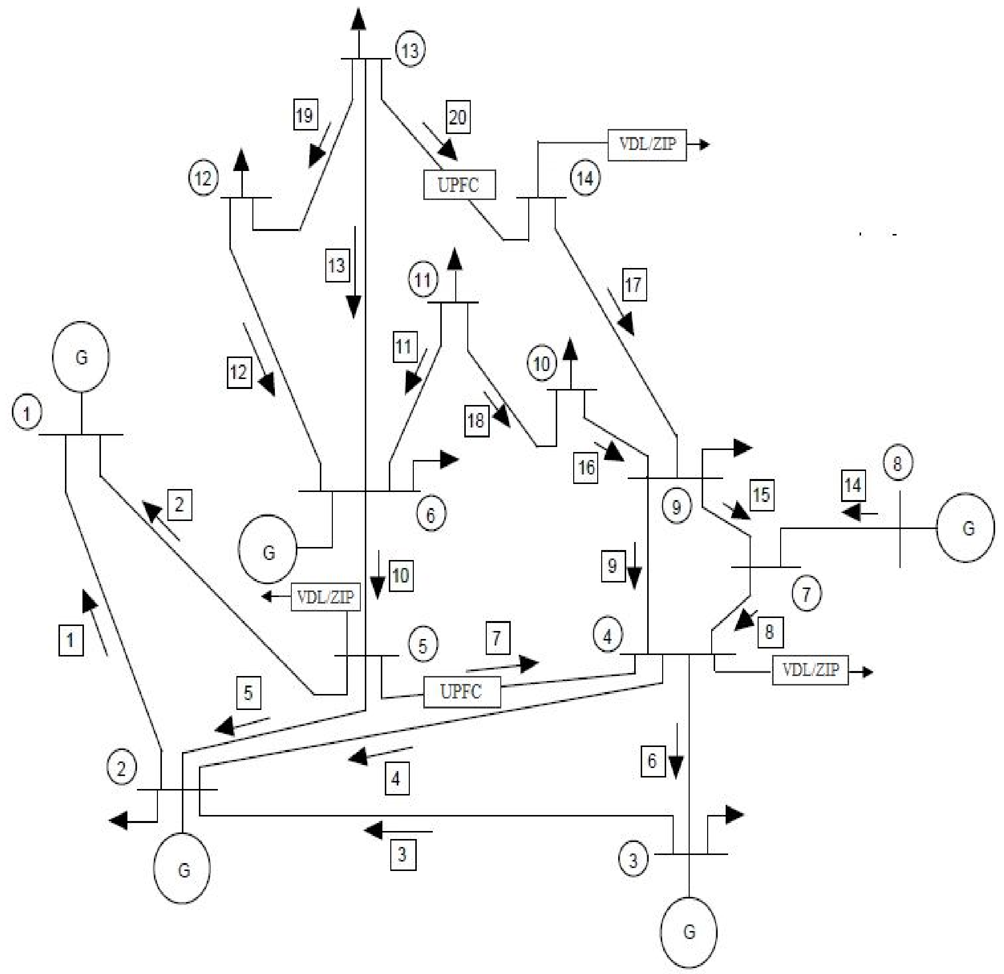

Fig-3: Single line diagram representation of IEEE 14 bus system with various UPFC controllers

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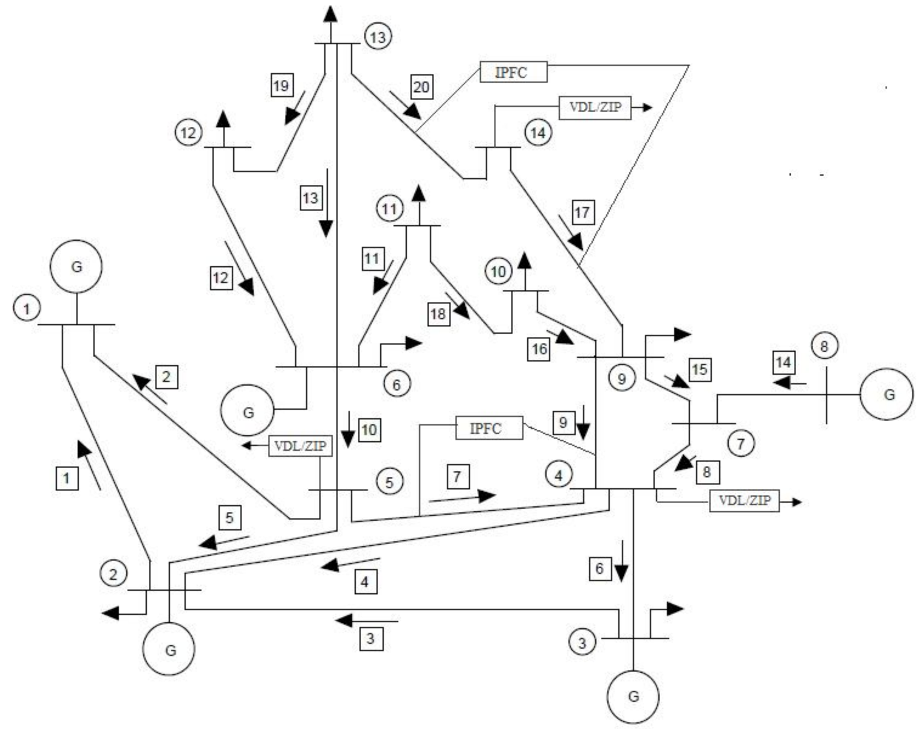

Fig-4: Single line diagram representation of IEEE 14 bus system with various IPFC controllers

Table-1: Power flow solution for IEEE 14 Bus systems with VDL Load in bus 4, 5 and bus 14

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0000	0.0000	2.3485	-0.4328
2	1.0000	-5.899	0.1830	0.6521
3	0.9800	-14.668	-0.9420	0.3070
4	0.9608	-11.565	-0.4780	0.0390
5	0.9622	-9.888	-0.0760	-0.0160
6	1.000	-16.291	-0.1120	0.1050
7	0.9774	-14.960	0.0000	0.0000
8	1.0000	-14.959	0.0000	0.1283
9	0.9620	-16.784	-0.2950	-0.1660
10	0.9606	-17.023	-0.0900	-0.0580
11	0.9762	-16.793	-0.0350	-0.0180
12	0.9823	-17.269	-0.0610	-0.0160
13	0.9755	-17.317	-0.1350	-0.0580
14	0.9482	-18.202	-0.1490	-0.0500

Table-2: Weak bus identification using VCP indices with VDL Load

BUS	VCP INDICES
4	37.1684
5	34.1629
14	23.1737
7	19.0999
10	14.1190
13	10.3430
11	8.2745
12	5.3145
9	4.9980

Table-3: Power flow solution for IEEE 14 Bus systems with VDL Load and SVC in bus 4

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	0.00	2.2681	-0.0643
2	1.0000	-5.402	0.2472	-0.0306
3	0.9900	-14.185	-0.9420	0.3035
4	0.9800	-11.352	-0.4780	0.0430
5	0.9764	-9.610	-0.0592	0.0232
6	1.0000	-15.935	-0.1120	-0.0151
7	0.9658	-14.733	0.0000	0.0000
8	1.0000	-14.732	0.0000	-0.0806
9	0.9698	-16.571	-0.2950	-0.1660
10	0.9671	-16.785	-0.0900	-0.0580
11	0.9795	-16.500	-0.0350	-0.0180
12	0.9827	-16.929	-0.0610	-0.0160
13	0.9762	-17.005	-0.1350	-0.0580
14	0.9513	-18.035	-0.1614	-0.0541

Table-4: Power flow solution for IEEE 14 Bus systems with VDL Load and SVC in bus 5

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	- 0.000	2.2677	-0.0745
2	1.0000	-5.392	0.2472	-0.0557
3	0.9900	-14.200	-0.9420	0.3444
4	0.9731	-11.206	-0.4780	0.0390
5	0.9800	-9.650	-0.0591	0.0196
6	1.0000	-15.943	-0.1120	0.0153
7	0.9827	-14.631	0.00	0.0000
8	1.0000	-14.630	0.00	-0.0981
9	0.9669	-16.484	-0.2950	-0.1660
10	0.9647	-16.714	-0.0900	-0.0580
11	0.9783	-16.467	-0.0350	-0.0180
12	0.9825	-16.934	-0.0610	-0.0160
13	0.9758	-16.999	-0.1350	-0.0580
14	0.9495	-17.988	-0.1614	-0.0541

Table-5: Power flow solution for IEEE 14 Bus systems with VDL Load and SVC in bus 14

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	0.000	2.2687	-0.0330
2	1.0000	-5.422	0.2473	-0.1385
3	0.9900	-14.290	-0.9420	0.3732
4	0.9670	-11.189	-0.4780	0.0390
5	0.9685	-9.508	-0.0594	0.0229
6	1.0000	-15.802	-0.1120	0.0251
7	0.9845	-14.656	0.0000	0.0000
8	1.0000	-14.656	0.0000	-0.0851
9	0.9741	-16.506	0.2950	-0.1660
10	0.9706	-16.712	-0.0900	-0.0580
11	0.9814	-16.409	-0.0350	-0.0180
12	0.9862	-16.864	-0.0610	-0.0160
13	0.9827	-17.070	-0.1350	-0.0580
14	0.9482	-18.202	-0.1490	-0.0500

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Table-6: Weak bus identification indices after incorporating SVC unit in bus 4, 5 and 14 in a IEEE 14 bus system with VDL Load

BUS	VCP INDICES
4	36.7603
5	28.1737
14	20.4378
7	18.1071
10	13.4062
13	9.6290
11	7.8766
12	5.1158
9	4.8146

Table-7: Power flow solution for IEEE 14 Bus systems with VDL Load and UPFC connected to the Bus 4 in line 7

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	0.000	2.2709	-0.0922
2	1.0000	-5.401	0.2472	-0.1086
3	1.0000	-14.249	-0.9420	0.3546
4	0.9900	-11.482	-0.4780	0.0437
5	0.9826	-9.678	-0.0590	0.0234
6	1.0000	-15.870	-0.1120	-0.0244
7	0.9900	-14.579	0.0000	0.0023
8	1.0000	-14.579	0.0000	-0.0568
9	0.9741	-16.488	-0.2950	-0.1660
10	0.9706	-16.7005	-0.0900	-0.0580
11	0.9814	-16.431	-0.0350	-0.0180
12	0.9831	-16.860	-0.0610	-0.0160
13	0.9768	-16.937	-0.1350	-0.0580
14	0.9541	-17.952	-0.1614	-0.0541

Table-8: Power flow solution for IEEE 14 Bus systems with VDL Load and UPFC connected to the Bus 5 in line7

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	- 0.000	2.2689	-0.1180
2	1.0000	-5.366	0.2471	-0.1455
3	1.0000	-14.158	-0.9420	0.3548
4	0.9900	-11.341	-0.4780	0.0434
5	0.9900	-9.803	-0.0588	0.0201
6	1.0100	-15.960	-0.1120	0.0083
7	0.9920	-14.675	0.0000	0.0000
8	1.0000	-14.675	0.0000	-0.0455
9	0.9777	-16.490	-0.2950	-0.1660
10	0.9754	-16.716	-0.0900	-0.0580
11	0.9887	-16.474	-0.0350	-0.0180
12	0.9927	-16.931	-0.0610	-0.0160
13	0.9861	-16.995	-0.1350	-0.0580
14	0.9603	-17.962	-0.1614	-0.0541

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Table-9: Power flow solution for IEEE 14 Bus systems with VDL Load and UPFC connected to the Bus 14 in line 20

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	0.000	2.2689	-0.0426
2	1.0000	-5.416	0.2472	-0.1151
3	0.9900	-14.267	-0.9420	0.3621
4	0.9688	-11.201	-0.4780	0.0390
5	0.9707	-9.541	-0.0593	0.0230
6	0.0100	-15.845	-0.1120	0.0402
7	0.9847	-14.618	0.0000	0.0000
8	1.0000	-14.618	0.0000	-0.0685
9	0.9793	-16.435	0.2950	-0.1660
10	0.9768	-16.650	-0.0900	-0.0580
11	0.9894	-16.385	-0.0350	-0.0180
12	0.9949	-16.855	-0.0610	-0.0160
13	0.9900	-17.009	-0.1350	-0.0575
14	0.9900	-18.604	-0.1614	-0.0526

Table-10: Weak bus identification indices after incorporating UPFC unit in Line 7and 20 in a IEEE 14 Bus system with VDL Load

BUS	VCP INDICES
4	32.9007
5	24.2566
14	16.7444
7	14.7694
10	9.4875
13	5.6394
11	3.8012
12	1.0973
9	0.9985

Table-11: Power flow solution for IEEE 14 Bus systems with VDL Load and IPFC Between lines 9 and 7 at bus 4

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	0.000	2.2707	-0.1619
2	1.0000	-5.351	0.2471	-0.2584
3	1.0000	-14.082	-0.9420	0.2953
4	1.0000	-11.466	-0.4780	0.0438
5	1.0000	-9.925	-0.0586	0.0209
6	1.0100	-15.891	-0.1120	-0.0559
7	1.0000	-14.547	0.0000	0.0023
8	1.0000	-14.546	0.0000	-0.0000
9	0.9845	-16.416	-0.2950	-0.1660
10	0.9810	-16.643	-0.0900	-0.0580
11	0.9916	-16.407	-0.0350	-0.0180
12	0.9932	-16.855	-0.0610	-0.0160
13	0.9871	-16.926	-0.1350	-0.0580
14	0.9647	-17.879	-0.1614	-0.0541

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Table-12: Power flow solution for IEEE 14 Bus systems with VDL Load and IPFC Between lines 9 and 7 at bus 5

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	- 0.000	2.2696	-0.1618
2	1.0000	-5.349	0.2471	-0.2586
3	1.0000	-14.080	-0.9420	0.2953
4	1.0000	-11.464	-0.4780	0.0438
5	1.0000	-9.918	-0.0586	0.0209
6	1.0200	-15.787	-0.1120	0.0365
7	1.0049	-14.671	0.0000	0.0000
8	1.0000	-14.671	0.0000	-0.0278
9	1.0000	-16.395	-0.2950	-0.1611
10	0.9957	-16.602	-0.0900	-0.0580
11	1.0041	-16.335	-0.0350	-0.0180
12	1.0038	-16.734	-0.0610	-0.0160
13	0.9981	-16.841	-0.1350	-0.0580
14	0.9785	-17.785	-0.1614	-0.0541

Table-13: Power flow solution for IEEE 14 Bus systems with VDL Load and IPFC Between lines 17 and 20 at bus 14

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	0.000	2.2669	-0.0589
2	1.0000	-5.404	0.2472	-0.0696
3	0.9900	-14.228	-0.9420	0.3373
4	0.9731	-11.250	-0.4780	0.0390
5	0.9745	-9.573	-0.0592	0.0231
6	1.0200	-15.686	-0.1120	0.0459
7	0.9981	-14.661	0.0000	0.0000
8	1.0000	-14.661	0.0000	-0.0090
9	1.0000	-16.445	0.2950	-0.1604
10	0.9957	-16.625	-0.0900	-0.0580
11	1.0040	-16.297	-0.0350	-0.0180
12	1.0048	-16.656	-0.0610	-0.0164
13	1.0000	-16.783	-0.1350	-0.0578
14	1.0000	-18.231	-0.1614	-0.0530

Table 14: Weak bus identification indices after incorporating IPFC unit in Lines 7, 9, 17 and 20 in an IEEE 14 Bus system with VDL Load

BUS	VCP INDICES
4	30.8309
5	22.2802
14	11.1702
7	9.1742
10	8.8010
13	5.6075
11	3.7335
12	0.8957
9	0.8166

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Table-15: Power flow solution for IEEE 14 Bus systems with ZIP Load in bus 4, 5 and bus 14

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	0.0000	2.3630	-0.4339
2	1.0000	-5.385	0.1830	0.6576
3	0.9800	-14.727	-0.9420	0.3087
4	0.9605	-11.637	-0.4780	0.0390
5	0.9619	-9.956	-0.0790	0.0168
6	1.0000	-16.446	-0.1120	0.1105
7	0.9770	-15.090	0.0000	0.0000
8	1.0000	-15.890	0.0000	0.1304
9	0.9614	-16.945	-0.2950	-0.1660
10	0.9601	-17.182	-0.0900	-0.0580
11	0.9760	-16.950	-0.0350	-0.0180
12	0.9821	-17.438	-0.0610	-0.0152
13	0.9750	-17.496	-0.1350	-0.0580
14	0.9393	-30.181	-0.3521	0.0129

Table-16: Weak bus identification index with its percentage before and after incorporating FACTS in IEEE 14 Bus system with VDL Load

Bus No.	VCP Index							
	Without FACTS		SVC		UPFC		IPFC	
	Actual	%	Actual	%	Actual	%	Actual	%
4	37.16	**100**	36.76	**98.87**	32.90	**88.48**	30.83	**82.92**
5	34.16	**100**	28.17	**82.46**	24.25	**70.98**	22.28	**65.22**
14	23.17	**100**	20.43	**88.14**	11.74	**72.196**	11.17	**48.174**

Table-17: Weak bus identification using VCP indices with ZIP Load

BUS	VCP INDICES
4	37.1803
5	34.1731
14	23.1878
7	19.1071
10	14.1262
13	10.3490
11	8.2766
12	5.3158
9	5.0146

Table-18: Power flow solution for IEEE 14 Bus systems with ZIP Load and SVC in bus 4

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	0.00	2.4962	0.1418
2	1.0000	-8.71	0.2289	-0.1436
3	1.9900	-21.73	-1.0362	0.3428
4	1.9800	-18.16	-0.5258	0.0486
5	0.9736	-15.48	-0.0652	0.0208
6	1.0000	-26.27	-0.1232	0.0390
7	0.9841	-24.24	0.0000	0.0000
8	1.0000	-24.23	0.0000	-0.0930
9	0.9675	-27.55	-0.3245	-0.1826
10	0.9642	-27.79	-0.0990	-0.0638
11	0.9777	-27.23	-0.0385	-0.0198
12	0.9806	-28.08	-0.0671	-0.0176
13	0.9711	-28.58	0.1485	0.0638
14	0.9392	-32.89	-0.3873	0.0142

Table-19: Power flow solution for IEEE 14 Bus systems with ZIP Load and SVC in bus 5.

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	0.00	2.4992	-0.1632
2	1.0000	-8.68	0.2288	-0.2244
3	0.9800	-21.60	-1.0362	0.3005
4	0.9687	-17.87	-0.5258	0.0429
5	0.9800	-15.58	-0.0651	0.0173
6	1.0000	-26.30	-0.1232	0.0339
7	0.9790	-24.06	0.0000	0.0000
8	1.0000	-24.06	0.0000	0.1193
9	0.9626	-27.40	-0.3245	-0.1826
10	0.9603	-27.68	0.0990	-0.0638
11	0.9756	-27.19	-0.0385	-0.0198
12	0.9803	-28.11	-0.0671	-0.0176
13	0.9704	-28.60	-0.1485	-0.0638
14	0.9361	-32.84	-0.3873	0.0142

Table-20: Power flow solution for IEEE 14 Bus systems with ZIP Load and SVC in bus 14

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	0.00	2.4993	-0.0941
2	1.0000	-8.75	0.2290	0.3640
3	0.9988	-21.80	-0.0362	0.3488
4	0.9592	-17.86	-0.5258	0.0429
5	0.9619	-15.33	-0.0655	0.0204
6	1.0100	-26.19	-0.1232	0.0651
7	0.9820	-24.09	0.0000	0.0000
8	1.0000	-24.09	0.0000	-0.0995
9	0.9741	-27.38	0.3245	-0.1826
10	0.9716	-27.63	-0.0990	-0.0638
11	0.9863	-27.10	-0.0385	-0.0198
12	0.9945	-28.05	-0.0671	-0.0176
13	0.9881	-28.73	-0.1485	-0.0638
14	0.9800	-33.67	-0.3873	0.0181

Table-21: Weak bus identification indices after incorporating SVC unit in bus 4, 5 and 14 in a IEEE 14 bus system with ZIP Load

BUS	VCP INDICES
4	35.6802
5	31.8207
14	29.7509
7	15.7071
10	13.5262
13	9.7490
11	7.8766
12	5.0158
9	4.7146

Table 22: Power flow solution for IEEE 14 Bus systems with ZIP Load and UPFC connected to the Bus 4 in line 7

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	0.00	2.4962	0.1699
2	1.0000	-8.72	0.2289	-0.0047
3	1.0000	-21.89	-0.0362	0.3941
4	0.9900	-18.32	-0.5258	0.0495
5	0.9799	-15.55	-0.0651	0.0210
6	1.0000	-26.09	-0.1232	0.0047

7	0.9900	-23.92	0.0000	0.0035
8	1.0000	-23.92	0.0000	-0.0568
9	0.9729	-27.32	-0.3245	-0.1826
10	0.9668	-27.57	-0.0990	-0.0638
11	0.9800	-27.04	-0.0385	-0.0198
12	0.9811	-27.90	-0.0671	-0.0176
13	0.9720	-28.40	0.1485	0.0638
14	0.9428	-32.64	-0.3873	0.0142

Table-23: Power flow solution for IEEE 14 Bus systems with ZIP Load and UPFC connected to the Bus 5 in line7

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	0.00	2.4992	-0.1935
2	1.0000	-7.98	0.0939	-0.3405
3	1.0000	-20.97	-1.0362	0.3942
4	0.9900	-17.40	-0.5258	0.0488
5	0.9900	-15.07	-0.0651	0.0604
6	1.0100	-25.54	-0.1232	0.0195
7	0.9903	-23.39	0.0000	0.0000
8	1.0000	-23.39	0.0000	-0.0549
9	0.9754	-26.65	-0.3245	-0.1826
10	0.9727	-26.91	0.0990	-0.0638
11	0.9869	-26.42	-0.0385	-0.0198
12	0.9907	-27.31	-0.0671	-0.0176
13	0.9811	-27.79	-0.1485	-0.0638
14	0.9484	-31.94	-0.3873	0.0142

Table-24: Power flow solution for IEEE 14 Bus systems with ZIP Load and UPFC connected to the Bus 14 in line 20

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	0.00	2.4993	-0.0956
2	1.0000	-8.75	0.2290	0.3601
3	0.9800	-21.89	-0.0362	0.3460
4	0.9596	-17.89	-0.5258	0.0429
5	0.9622	-15.35	-0.0655	0.0204
6	1.0100	-26.21	-0.1232	0.0387
7	0.9835	-24.11	0.0000	0.0000
8	1.0000	-24.11	0.0000	-0.0905
9	0.9733	-27.39	0.3245	-0.1826
10	0.9742	-27.64	-0.0990	-0.0638
11	0.9877	-27.12	-0.0385	-0.0198
12	0.9955	-28.11	-0.0671	-0.0176
13	0.9900	-28.85	-0.1485	-0.0628
14	0.9900	-33.80	-0.3873	0.0184

Table-25: Weak bus identification indices after incorporating UPFC unit in Line 7and 20 in a IEEE 14 Bus system with ZIP Load

BUS	VCP INDICES
4	27.6731
5	23.7566
14	21.7802
7	12.3694
10	9.6075
13	5.7594
11	3.8012
12	0.9973
9	0.8985

Table-26: Power flow solution for IEEE 14 Bus systems with ZIP Load and IPFC Between lines 9 and 7 at bus 4

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	0.00	2.4962	0.1645
2	1.0000	-7.64	0.2485	-0.1779
3	1.0000	-19.42	-0.9420	0.2944
4	1.0000	-16.49	-0.4780	0.0452
5	0.9906	-14.04	-0.058	0.0234
6	1.0300	-23.43	-0.1120	0.0051
7	1.0042	-21.74	0.0000	0.0000
8	1.0000	-21.74	0.0000	-0.0239
9	0.9993	-24.56	-0.2950	-0.1660
10	0.9968	-24.76	-0.0900	-0.0580
11	1.0095	-24.27	-0.0350	-0.0180
12	1.0159	-25.05	-0.0610	-0.0160
13	1.0099	-25.62	0.1350	0.0580
14	1.0000	-29.83	-0.3521	0.0160

Table-27: Power flow solution for IEEE 14 Bus systems with ZIP Load and IPFC Between lines 9 and 7 at bus 5

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	0.00	2.4992	-0.1703
2	1.0000	-7.68	0.2486	-0.2084
3	1.0000	-19.31	0.9420	0.2946
4	1.0000	-16.22	-0.4780	0.0450
5	1.0000	-13.94	-0.0581	0.0234
6	1.0400	-23.65	-0.1120	0.0150
7	1.0049	-21.26	0.0000	0.0055
8	1.0000	-21.26	0.0000	-0.0276
9	1.0005	-21.26	-0.2950	-0.1660
10	0.9997	-24.29	0.0900	-0.0580
11	1.0160	-24.13	-0.0350	-0.0180
12	1.0283	-25.43	-0.0610	-0.0160
13	1.0236	-26.26	-0.1350	-0.0580
14	1.0000	-28.34	-0.3521	0.0154

Table-28: Power flow solution for IEEE 14 Bus systems with ZIP Load and IPFC Between lines 17 and 20 at bus 14

Bus No.	Voltage Magnitude	Voltage Angle	Real Power	Reactive Power
1	1.0300	0.00	2.4993	0.1739
2	1.0000	-7.67	0.2486	0.2138
3	1.0000	19.28	-0.9420	0.2947
4	1.0000	-16.18	-0.4780	0.0449
5	0.9924	-13.97	-0.0581	0.0235
6	1.0500	-23.94	-0.1120	0.02162
7	1.0055	-21.02	0.0000	0.0000
8	1.0000	-21.02	0.0000	-0.0313
9	1.0018	-23.61	0.2950	-0.1660
10	1.0026	-24.05	-0.0900	-0.0580
11	1.0224	-24.14	-0.0350	-0.0180
12	1.0412	-25.86	-0.0610	-0.0160
13	1.0384	-26.92	-0.1350	-0.0580
14	1.0000	-27.26	-0.3521	0.0137

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Table-29: Weak bus identification indices after incorporating IPFC unit in Lines 7, 9, 17 and 20 in an IEEE 14 Bus system with ZIP Load

BUS	VCP INDICES
4	20.5878
5	16.8944
14	11.3220
7	9.7742
10	8.9210
13	5.7275
11	3.7335
12	0.7957
9	0.7166

Table-30: Weak bus identification indices with its percentage before and after incorporating FACTS in IEEE 14 Bus system with ZIP Load

Bus No.	Without FACTS		SVC		UPFC		IPFC	
	Actual	%	Actual	%	Actual	%	Actual	%
4	37.02	**100**	33.88	**91.51**	30.02	**81.09**	27.95	**75.49**
5	34.03	**100**	27.67	**81.31**	23.75	**69.79**	21.78	**64.02**
14	23.17	**100**	20.58	**88.82**	16.89	**72.89**	11.32	**48.85**

V. CONCLUSION

This paper deals with the coordinated emergency control with the usage of various FACTS devices especially SVC, UPFC, IPFC units. A method is needed to rapidly re-balance the power by either shedding some loads to maintain power flow to the remaining loads or directing the power flow across transmission corridors with greater capacity In this study, Bacterial Foraging optimization (BFO) technique was adopted to ensure the stability of the system with various types of loads. Using the BFO algorithm the FACTS devices are turned to ensure sufficient power flow capacity so as to meet out the load effectively if the network is reconfigured to bypass the loss in the transmission capability. By adjusting the magnitude and phase angle of the series voltage source, the apparent impedance of the transmission line may be varied. This change in impedance may be translated into a similar change in maximum power flow capacity across the line. If the load cannot be served under the current operating scenario, then the BFO algorithm is used to solve by determining the minimum number of line capacity changes (implemented by the FACTS devices) that are required to continue to satisfy the load. It can be concluded that BFO technique is can be easily be adopted in ensuring an effective optimization technique in searching the optimum value of real and reactive power loading. It has been found that with the UPFC, IPFC controller, the risk of load shedding is considerably reduced and can easily be adopted for emergency control. From the results it has been found that the FACTS devices especially UPFC and IPFC successfully prevent the system from blackout and restore the system faster. The result point out that the FACTS devices parameter influence on the power system stability limits even though is negligible, it should be verified when other type of optimized technique are employed to the power system network

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