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Available Power Transfer Capability Enhancement with UPFC using Power Flow Methods

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ABSTRACT: Determination and enhancement of Available Transfer Capability (ATC) are important issues in deregulated operation of power systems. The use of FACTS device is necessary to maximize power transfer transactions during normal and contingency situations. ATC is computed using Continuation Power Flow (CPF) method considering both the thermal limits and voltage profile. Cat Swarm Optimization (CSO) is used as an optimization tool to determine the location and controlling parameters of UPFC. The methodology is tested on IEEE 14 and 30 bus systems with UPFC controller in terms of TTC improvement.

KEY WORDS: ATC, UPFC, Power Flow methods, MATLAB-SIMULINK, Voltage Profile.

I.INTRODUCTION

Promoting competitive electric markets for electric power trading is the main aim of an electric industry restructuring. Under deregulated environment, the substantial increase in power transfer is the important requirement. Over a wide range of system operating conditions and constraints, it is necessary to maintain economical and secure operation. However the restrictions to provide new facilities can be economic, ecological and social problems that minimize the operational alternatives. The better services and reduced prices can be provided to the customers.

Based upon the NERC's definition of ATC and its determination [1]. transmission network can be restricted by thermal, voltage and stability limits. FACTS concept makes it possible to use circuit reactance, voltage magnitude, and phase angle as controls to redistribute line flow and regulate voltage profile. With suitable location, the effect of a UPFC and SVC on the ATC enhancement is studied and demonstrated through Case studies. It is shown that installing SVC in the proper location will improve voltage profile as well as ATC, and UPFC will recover the ATC. UPFC can offer an effective and promising solution to boost the usable power transfer capability, thereby improving transmission services [2]. H. Sawhney applied UPFC for ATC enhancement [3]. D. Menniti used SSSC for improvement of ATC [4]. G. Madhusudana Rao gave location of UPFC and SVC using RGA at different locations [5]. N.D. Ghawaghane suggested a criterion for location and reactance of UPFC for ATC improvement [6]. Wang used UPFC to optimize TTC in deregulation [7]. Stephen Gerbex did optimal location of multi-type FACTS devices in a power system by means of GA [8].

In the developing and the developed countries, more so in the latter, the available electrical power supply–demand mismatch is continuously increasing, often resulting in forced power cuts to the customers. This situation is brought in by the fact that the rate at which the demand is increasing is much more than that of the supply. The system operator with a view to supply power reliably likes to know about the capacity of power available for transfer at any moment of time and under all system states. In a deregulated system operation, both the operator and the customers must be knowledgeable about this important system variable known as Available Transfer Capacity (ATC).

To maximize utilization of existing transmission grids, accurate evaluation of ATC is essential while maintaining system security. Here the power system dependability meets electricity market competence. ATC may have a huge force on market outcomes and system dependability.

ISSN: 2350-0328
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Vol. 5, Issue 8 , August 2018

The function of ATC is as follows:

- Electric power must be delivered reliably.
- For changing system conditions flexibility should be provided.
- The need for installed generating capacity is reduced.
- Trading of electric power among systems must be allowed.

Mathematically, ATC is defined as the Total Transfer Capability (TTC) less the Transmission Reliability Margin (TRM), less the sum of existing transmission commitments (which includes retail customer service) and the Capacity Benefit Margin (CBM).

II. INTRODUCTION TO UPFC

Static var compensator, composed of thyristor-switched capacitor (TSC) and thyristor-controlled reactor (TCR) with proper co-ordination of the capacitor switching and reactor control, the VAR output can be varied continuously between the capacitive and inductive ratings of the equipment. In UPFC the degree of series and shunt compensation is controlled. To minimize the switching transients and utilize natural commutation, the operation of thyristor valve is coordinated with voltage and current zero crossings. The UPFC can be effective [11] in transient stability improvement, power oscillation damping and balancing power flow in parallel lines.

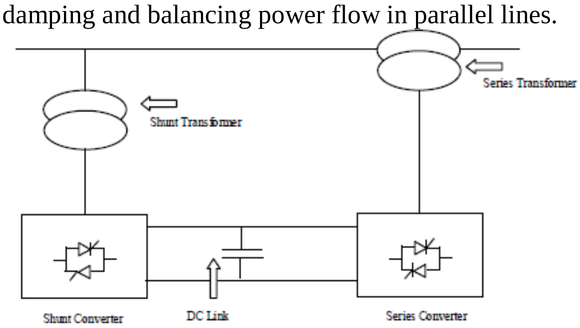

Fig 1: Block Diagram of UPFC

III. OPTIMAL POWER FLOW METHODS

In an OPF, the values of some or all of the control variables need to be found so as to optimize (minimize or maximize) a predefined objective. It is also important that the proper problem definition with clearly stated objectives be given at the onset. The quality of the solution depends on the accuracy of the model studied. Objectives must be modeled and its practicality with possible solutions.

Objective function takes various forms such as fuel cost, transmission losses and reactive source allocation. Usually the objective function of interest is the minimization of total production cost of scheduled generating units. This is most used as it reflects current economic dispatch practice and importantly cost related aspect is always ranked high among operational requirements in Power Systems. OPF aims to optimize a certain objective, subject to the network power flow equations and system and equipment operating limits.

The optimal condition is attained by adjusting the available controls to minimise an objective function subject to specified operating and security requirements. Some well-known objectives can be identified as below: Active power objectives 1. Economic dispatch (minimum cost, losses, MW generation or transmission losses) 2. Environmental dispatch 3. Maximum power transfer Reactive power objectives MW and MVAr loss minimization.

General goals
1. Minimum deviation from a target schedule 2. Minimum control shifts to alleviate Violations 3. Least absolute shift approximation of control shift Among the above the following objectives are most commonly used: (a) Fuel or active power cost optimization (b) Active power loss minimization (c) VAr planning to minimize the cost of reactive power

ISSN: 2350-0328
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Vol. 5, Issue 8 , August 2018

support The mathematical description of the OPF problem is presented below: OPF Objective Function for Fuel Cost Minimization The OPF problem can be formulated as an optimization problem [2, 5, 6, 18] and is as follows:
Total Generation cost function is expressed as:

$$F(PG) = \sum(ai + \beta PGi + \gamma PGi2) \text{ ....(1)}$$

The objective function is expressed as:

$$Min\ F(PGi) = f(x,u) \text{................(2)}$$

Subject to satisfaction of Non-Linear Equality Constraints:

$$G(x,u) = 0 \text{.......................(3)}$$

And Non Linear Inequality Constraints:

$$H(x,u) \leq 0 \text{.........................(4)}$$

$$umin \leq u \leq umax$$

$$xmin \leq x \leq xmax$$

Continuation power flow
The method, Continuation power flow (CPF) is a comprehensive tool for tracing the steady state behavior of the power system due to parametric variation [11]. The area real and/or reactive loads, bus real and/or reactive loads and real power generations at generator or PV buses are the parameters which are varied. Continuation methods are also known as path following or curve tracing which are used to trace solution curves. This is for general non-linear algebraic equations with a parametric variation. The CPF method has the following four basic elements:
Parameterization is a mathematical way of identifying each solution for quantifying previous solution or next solution.
Predictor is to find an approximate point for the next solution. Tangent or secant method is used for this purpose.
Corrector is to correct error in an approximation produced by the predictor before it accumulates.
Step size control is to adapt the step length for shaping the traced solution curve.
Fig. 1 shows the flowchart for Continuation Power Flow (CPF) method, and it starts from a known solution and uses a tangent predictor to estimate a subsequent solution corresponding to a different value of the load parameter.

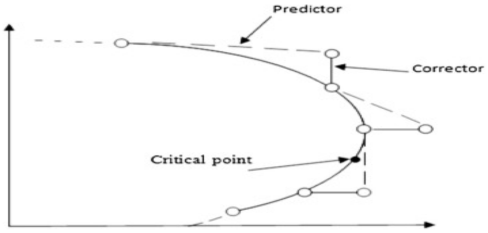

Fig 2: Continuation Power flow method

These applications include steady state voltage control, increase of thermal loading, post contingency voltage control, loop flow and power flow control. SVC and STATCOM are preferred for voltage control where as UPFC is used for loop control and power flow control. The other steady state applications are

Congestion management: Congestion can increase the price and• may become an obstruction for the free electricity trade in the present deregulated environment. FACTS devices like UPFC, TCPAR and UPFC can help to reduce congestion and smoothen location marginal price (LMP) by redirecting the power from congested path to other path which is underutilized.

ATC improvement: ATC is the basis for a power transaction• between the buyer and seller in a deregulated market. A low value of ATC implies the inability of the path for further transaction and may hinder the free competition. UPFC, TCPAR and UPFC can help in ATC enhancement y allowing more power transactions. Reactive power and Voltage control: SVC, STATCOM can be use for this purpose.

ISSN: 2350-0328
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Vol. 5, Issue 8 , August 2018

Loading Margin Improvement: Voltage collapse occurring at the• maximum loadability (nose point) is the main cause of recent world wide block outs. The maximum transfer capability of a power system can be improved by using shunt compensators efficiently.

Power flow and balancing control: UPFC, SSSC, UPFC can be• used to enable the load flow through parallel lines and there by efficient utilization of lines can be made possible.

In recent years, there has been a rapidly growing interest for power engineers to formulate and solve this complex transfer capability problem. As a result, many methods and techniques have been developed; very few methods are practical for large realistic applications [81]. Only three of them are practical for large realistic applications. These are follows: 1) Continuation Power Flow (CPF) method [86] 2) Optimal Power Flow (OPF) method. 3) Repeated Power Flow (RPF) method. CPF is first introduced for determining the maximum loadability, and is also useful for ATC computation.

The advantage of CPF is a successful method even for ill-conditioned power flow equations and at voltage collapse points. However a major disadvantage is that it involves complicated implementation of its parameterization, predictor and corrector and step-size control elements. OPF powerful tools [6]. OPF can be used to maximize the power transfer between two areas assuming that all OPF optimized parameters can be centrally dispatched needs large number of optimal power flows under different conditions and needs more time. The RPF method, power flow equations are repeatedly solved at a succession of points along the specified load/generation increment, for TTC calculation. Compared with SCOPF and CPF, the implementation of RPF is much easier [1].

IV. ALGORITHM FOR REPEATED POWER FLOW METHOD

Repeated power flow (RPF) method [81] involves the solution of a base case, which is the initial system conditions, and then increasing the transfer. After each increase, another load flow is done and the security constraints tested.

The computational procedure of this approach is as follows:

Step 1. Establish and solve for a base case

Step 2. Select a transfer case

Step 3. Solve for the transfer case

Step 4. Increase step size if transfer is successful

Step 5. Decrease step size if transfer is unsuccessful

Step 6. Repeat the procedure until minimum step size reached

Simulation Models and Results:

Optimal Power Flow method:

- Considered 14-bus and 30-bus system for enhancement of power transfer capability.
- By using m-file programming OPF method is adopted (basic optimization method) – identified power losses, transmission losses and cost.
- Identified the weak buses and adopted different FACTS controllers for compensation.

ISSN: 2350-0328
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Vol. 5, Issue 8 , August 2018

- Considered compensation by UPFC
- ATC improvement, loading margin improvement is also considered

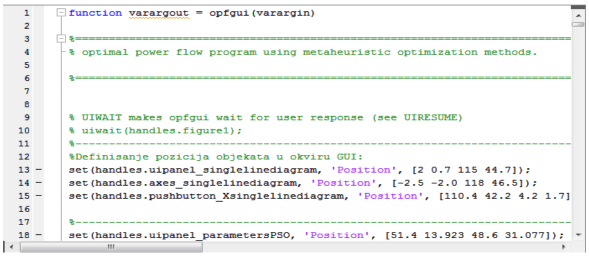

Fig 3: M-file Program for Optimal power flow – GUI

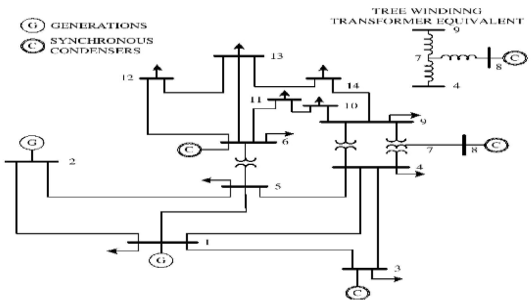

Fig 4: Single Line Diagram adopted

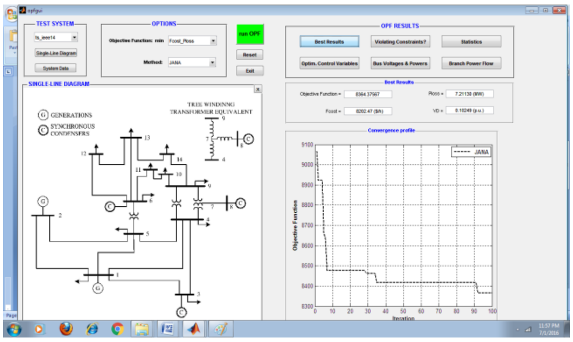

Fig 5: Optimization Results – Convergence profile

Optimum Control Variables

Generator active powers		Generator voltages		Transformer tap settings			Shunt VAR compensations	
Bus No	Pg (MW)	Bus No	Vg (p.u.)	From Bus	To Bus	T (p.u.)	Bus No	Qc (MVAr)
2	36.5646	1	1.0160	4	7	1.0186	14	1.9051e-14
3	36.7880	2	0.9890	4	9	1.0094		
6	11.8620	3	0.9951	5	6	0.9652		
8	25.3790	6	1.0175					
		8	1.0153					

Fig 6: Optimum Control Variables

ISSN: 2350-0328
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Bus Voltages and Powers under Optimum Control Variables

Bus No	V (p.u.)	teta (deg)	Pg (MW)	Qg (MVAr)	Qc (MVAr)	Pload (MW)	Qload (MVAr)
1	1.0160	0	155.6177	13.5867	0	0	0
2	0.9890	-3.3161	36.5646	-33.8543	0	21.7000	12.7000
3	0.9951	-9.1418	36.7880	42.0994	0	94.2000	19
4	0.9869	-7.6917	0	0	0	47.8000	-3.9000
5	0.9869	-6.5804	0	0	0	7.6000	1.6000
6	1.0175	-10.9360	11.8620	26.0046	0	11.2000	7.5000
7	0.9901	-8.8692	0	0	0	0	0
8	1.0153	-6.3204	25.3790	15.1223	0	0	0
9	0.9870	-11.1147	0	0	0	29.5000	16.6000
10	0.9845	-11.3980	0	0	0	9	5.8000
11	0.9971	-11.3006	0	0	0	3.5000	1.8000
12	1.0006	-11.8537	0	0	0	6.1000	1.6000
13	0.9945	-11.8850	0	0	0	13.5000	5.8000
14	0.9711	-12.5833	0	0	1.9051e-14	14.9000	5

Fig 7: Bus voltages and powers under Optimum control variables

Statistics

No. runs	1
Minimum O.F.	8.3644e+03
Maximum O.F.	8.3644e+03
Mean O.F.	8.3644e+03
Std. deviation O.F.	0
Mean TOC (s)	10.0877

Fig 8: Statistics

Table 1: Branch power flow and Loss under optimum control variables

From Bus	To Bus	Active power	Reactive power	Ploss	Qloss
1	**2**	**103.2515**	**12.6176**	**2.0459**	**6.2464**
1	**5**	**52.3661**	**0.9691**	**1.4419**	**5.9522**
2	**1**	**-101.2056**	**-11.6783**	**2.0459**	**6.2464**
2	3	47.6588	-13.9288	1.1580	4.8786
2	4	38.9269	-11.6883	0.9600	2.9128
2	5	29.4846	-9.2589	0.5395	1.6473
3	**2**	**-46.5008**	**14.4969**	**1.1580**	**4.8786**
3	4	-10.9111	8.6025	0.1383	0.3530
4	2	-37.9669	11.2828	0.9600	2.9128
4	3	11.0495	-9.5065	0.1383	0.3530
4	5	-40.6671	13.2140	0.2506	0.7906
4	7	9.4259	-9.7559	0	0.1986
4	9	10.3587	-1.3344	0	0.6190
5	**1**	**-50.9242**	**0.0480**	**1.4419**	**5.9522**
5	2	-28.9450	7.5290	0.5395	1.6473
5	4	40.9178	-12.4234	0.2506	0.7906
5	6	31.3515	3.2464	0	2.7681

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 5, Issue 8 , August 2018

6	5	-31.3515	-0.8518	0	2.7681
6	11	6.6898	7.2118	0.0888	0.1859
6	12	7.8183	3.0061	0.0833	0.1734
6	13	17.5053	9.1385	0.2492	0.4907
7	4	-9.4259	10.1659	0	0.1986
7	8	-25.3790	-13.6310	0	1.4913
7	9	34.8049	3.4651	0	1.3729
8	7	25.3790	15.1223	0	1.4913
9	4	-10.3587	1.9692	0	0.6190
9	7	-34.8049	-2.0921	0	1.3729
9	9	0	-18.5091	0	0
9	10	5.9411	0.6765	0.0117	0.0310
9	14	9.7225	1.3556	0.1257	0.2675
10	9	-5.9294	-0.6455	0.0117	0.0310
10	11	-3.0706	-5.1545	0.0305	0.0713
11	6	-6.6011	-7.0258	0.0888	0.1859
11	10	3.1011	5.2258	0.0305	0.0713
12	6	-7.7350	-2.8327	0.0833	0.1734
12	13	1.6344	1.2327	0.0092	0.0084
13	6	-17.2562	-8.6478	0.2492	0.4907
13	12	-1.6252	-1.2243	0.0092	0.0084
13	14	5.3819	4.0721	0.0787	0.1603
14	9	-9.5968	-1.0882	0.1257	0.2675
14	13	-5.3032	-3.9118	0.0787	0.1603

Table 2: Analysis without FACTS controllers:

From the Optimal power flow the weak buses with power losses are identified for inter and intra buses.

From Bus	To Bus	Active power	Reactive power	Ploss	Qloss
1	**2**	**103.2515**	**12.6176**	**2.0459**	**6.2464**
1	**5**	**52.3661**	**0.9691**	**1.4419**	**5.9522**
2	**1**	**-101.2056**	**-11.6783**	**2.0459**	**6.2464**
3	**2**	**-46.5008**	**14.4969**	**1.1580**	**4.8786**
5	**1**	**-50.9242**	**0.0480**	**1.4419**	**5.9522**

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 5, Issue 8 , August 2018

a) <u>UPFC Result for IEEE 14 Bus sytem</u>

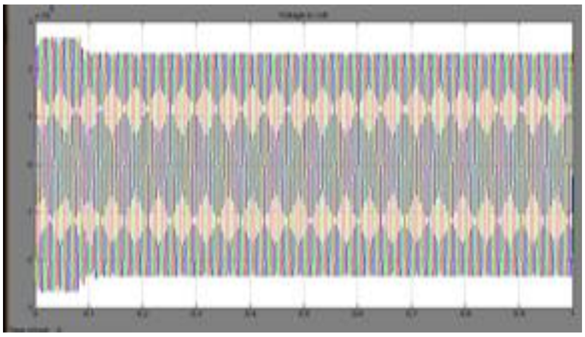


Fig 9: Load Voltage Versus Time (secs)

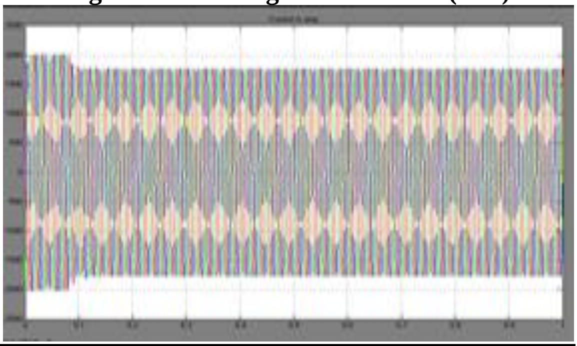


Fig 10 : Load Current Versus Time (secs)

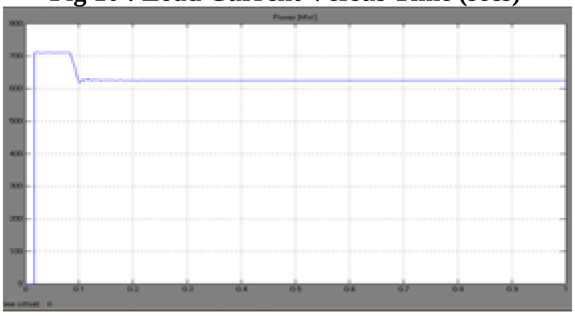


Fig 11: Power versus Time (Secs) Regulated Load Voltage

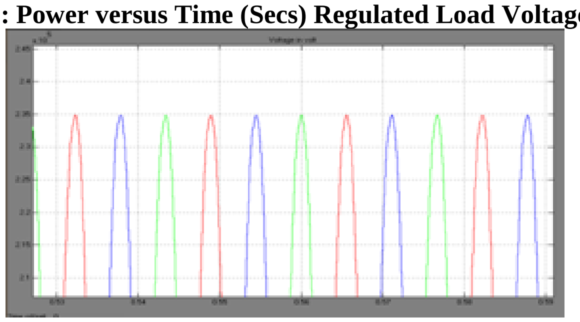


Fig 12: Regulated Voltage Versus Time(Secs) Current

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 5, Issue 8 , August 2018

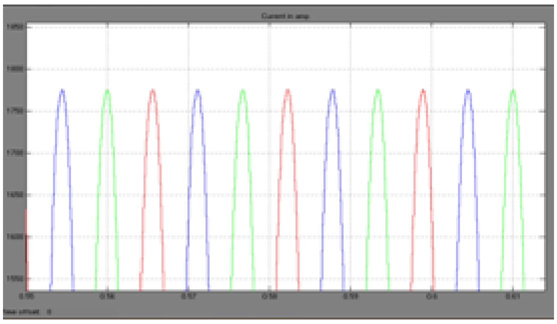


Fig 13: Regulated Load Current Versus Time (secs)

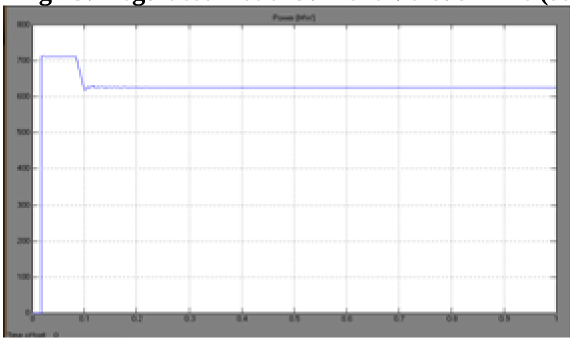


Fig 14: Power Before Compensation Versus Time (Secs)

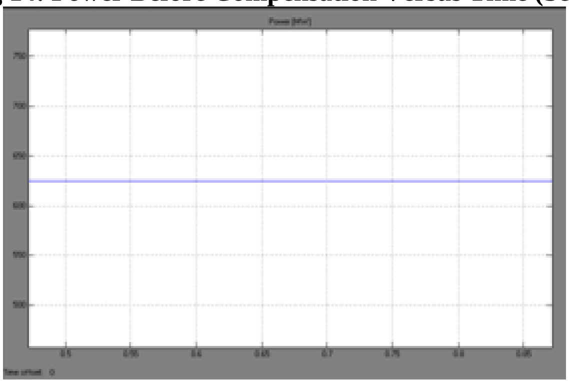
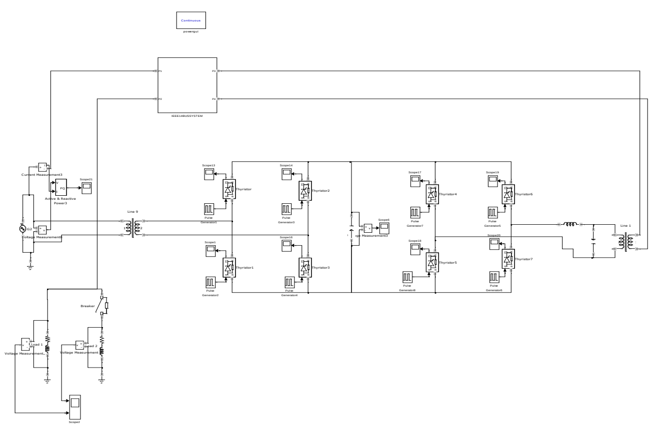


Fig 15: Power after Compensation Versus Time (Secs)

b) UPFC Placement in IEEE 30 Bus system



ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 5, Issue 8 , August 2018

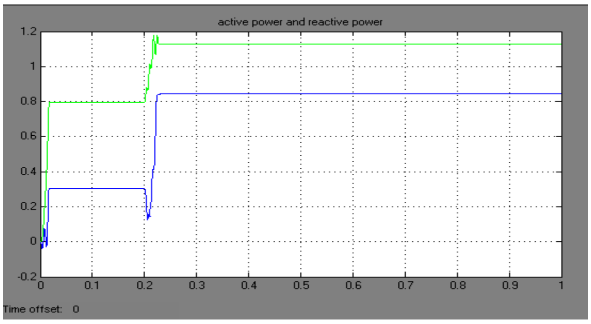


Fig 16: Active and Reactive Power versus time (Secs)

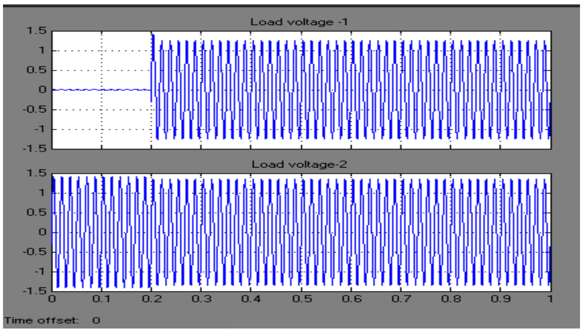


Fig 17: Load Voltages Versus Time (Secs)

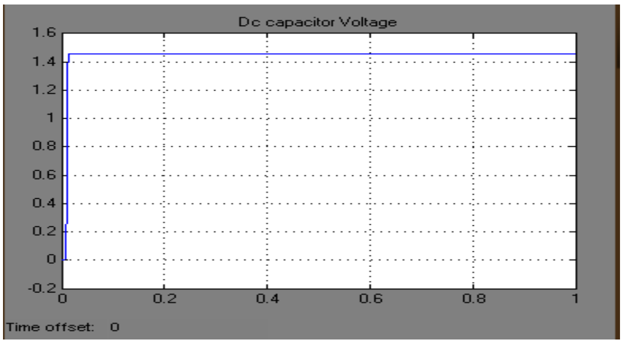
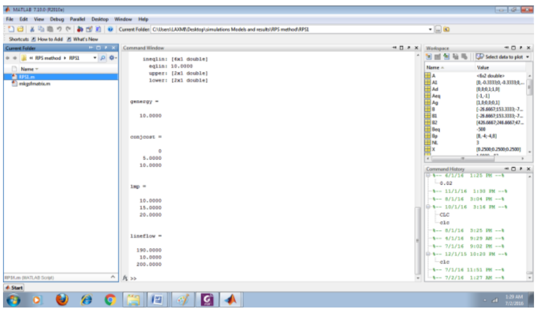


Fig 18: DC Capacitor Voltage Versus Time (Secs)

M-File Program to calculate Locational Marginal Price (IEEE 14 and 30 Bus system)



ISSN: 2350-0328

International Journal of AdvancedResearch in Science, Engineering and Technology

Vol. 5, Issue 8 , August 2018

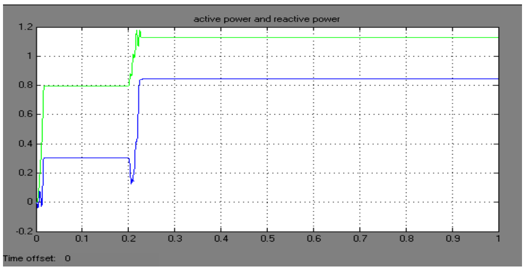


Fig 19: Active and Reactive Power Versus Time (Secs)

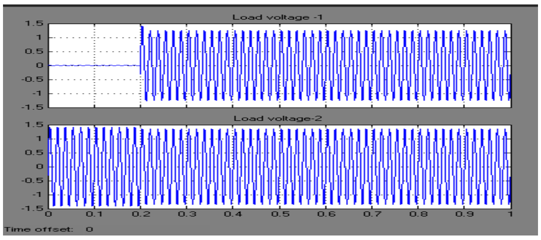


Fig 20: Load Voltage – 1 & 2

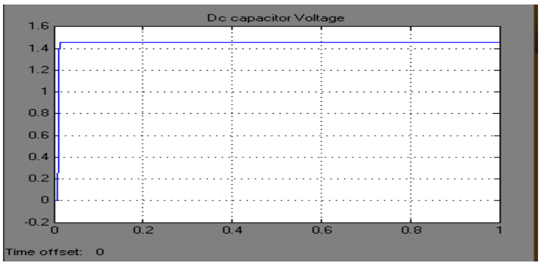


Fig 21: DC capacitor Voltage

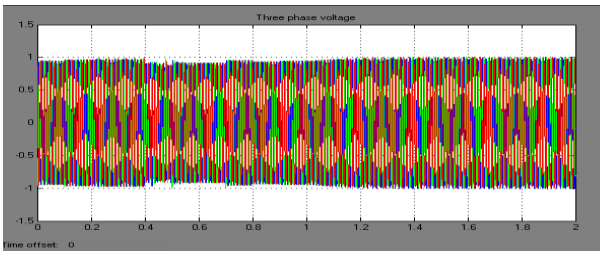


Fig 22: Three Phase Voltages Versus Time (secs)

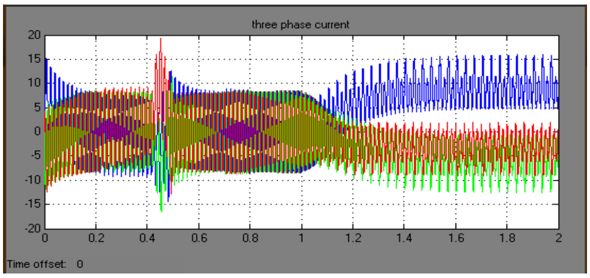


Fig 23: Three Phase Currents Versus Time (secs)

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 5, Issue 8 , August 2018

Table 3: Enhancement of power transfer capability (IEEE 14 Bus System)

Transfer		OPF method	CPF method		RPF method
From Area	To Area	TTC (MW)	TTC (MW)	Constraint	TTC (MW)
1	2	29	36	Violating reactive power limit of generator at bus: 1;	42
3	2	44	48	Voltages at all buses are within permissible limits	53
1	5	43	45	Violating reactive power limit of generator at bus: 1;	50.2

Table 4: Enhancement of power transfer capability (IEEE 30 Bus System)

	Transfer		RPF method	
	From Area	To Area	TTC(MW)	Constraint
Without FACTS devices	29	30	115.9	No Reactive power Limits
FACTS devices(UPFC)			168.1	Violating reactive power limit of generator at bus: 30;

V. CONCLUSION AND FUTURE WORK

The RPF approach is effectively and successfully implemented to determine optimal allocation of multi-type of FACTS devices to maximize TTC between different control areas. Test results from the test system indicate that optimally placed with UPFC compensator by RPF approach could enhance the TTC value far more than OPF and CPF without and with FACTS devices.

REFERENCES

[1].M. Karthikeyan, P. Ajay-D-Vimalraj “Optimal location of shunt FACTS devices for power flow control” IEEE proceeding of ICETECT 2011,pp 154-159.
[2]. M. Kowsalya, K.K. Ray, and D.P. Kothari, ‘Positioning of SVC and STATCOM in a Long Transmission Line’ International Journal of Recent Trends in Engineering, Vol 2, No. 5, November 2009.
[3]. Tan, Y.L., “Analysis of line compensation by shuntconnected FACTS controllers: a comparison between SVC and STATCOM”, IEEE Transactions on Power Engineering Review, Vol.19, pp 57-58, Aug 1999.
[4]. Lin tan and Yowgi Wang “ Design of series and shunt FACTS controller using adaptive nonlinear shunt FACTS controller using adaptive nonlinear coordinated design technique,’ IEEE Tran. On power system Vol. 12, No. 3, Aug. 1997.
[5]. A.A Edris ‘‘Enhancement of first swing stability using a high speed phase shifter” IEEE Tran. on power system, Vo1.6, L991,pp I I1:LI 118.
[6]. Kimbark E W "How to improve system stability without risking sub synchronous resonance " IEEE Tran. 1977, PAS-96(s), pp 1608-1619.
[7]. M H Haque “Optimal location of shunt FACTS devices in long transmission line" IEEE Proceeding. Generation. Transmission & Distribution. Vol. 147, No.4, July 2000.
[8]. Schauder, C, Gernhardt M. Staev E, Lemark, T.Gyugyl, L. Cease T W and Edris, A " Development of a +100MVAR static condenser for voltage control of transmission system" IEEE Tran. 1995, PD-IO (3),pp 1486-1496
[9]. Chandrakar, V.K. Kothari, A.G. “Optimal location for line compensation by shunt connected FACTS controller”, The Fifth International IEEE Conference on Power Electronics and Drive Systems”, Vol 1, pp 151 -156, Nov 2003.
[10]. Nimit Boonpirom, Kitti Paitoonwattanakij, ‘Static Voltage Stability Enhancement using FACTS’ IEEE/PES transmission and distribution Conference and Exhibition Asia Pacific., pp.1 – 5, 2007.
[11]. P. Kundur, J. Paserba, V. Ajjarapu, G. Andersson, A. Bose, C. Canizares, N. Hatziargyriou, D. Hill, A. Stankovic, C. Taylor, T. V. Cutsem and V. Vittal, 'Definition and classification of power system stability', IEEE Trans. Power Systems, 19(2) (2004), 1387-1401 .