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Application of Cat Swarm Optimization in testing Static Load Models for Voltage Stability

G. Naveen Kumar [a] *

[a] Department of EEE, VNR VJIET, Hyderabad, India

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ABSTRACT

Power System Load Modeling is a method which is used to model the power system and essential for voltage stability studies. Voltage stability defines the ability of a power network to maintain steady state voltages at all the buses under normal operating conditions, and when subjected to a disturbance. The research presented as part of this paper, deals with analysis of different static load models for voltage stability studies. The precision of the results are directly related to the load models used in this analysis. The method is analyzed using continuation power flow routine. Flexible AC Transmission System technology with a combination of Cat Swarm Optimization Meta Heuristic Search approach is applied to give a solution for the problem of instability. The effectiveness of the proposed method is demonstrated through quantitative simulation on standard IEEE 14 bus system for contingency condition.

1. Introduction

During the system disturbances and their impacts on other power system elements, system stability is imperilled. The probability of moving to the global instability increases. This will usually make a power system to break up in the isolated sub-systems known as islands and then a complete blackout results unless some precautions are considered. Voltage Stability or Load Stability is one of the concerns in power systems which are heavily loaded, faulted or having a shortage of reactive power [14, 15]. The problem of voltage stability concerns the whole power system, although it usually has a large involvement in one critical area of the power system. Example case of recent massive black out in India's power grid happens to the worst in the decade. Three out of the five regional power grids collapsed leaving about six hundred and seventy million people powerless making July 2012 as the largest blackout month in history. According to [2, 13] Power System Load Modeling is a technique used to model the power system and essential for stability assessments. In this paper, we are trying to analyze different static

*Email : gutha26@gmail.com

load models for voltage stability studies. The accuracy and correctness of the results for voltage stability are directly related to the load models used in this analysis. Different load models would greatly affect voltage stability aspect of an interconnected power system. We are using continuation power flow to analyze the effects of different load models and compare the results.

Flexible AC Transmission Systems in short FACTS controllers are used to control the variables such as phase angle and voltage magnitude at a given bus and line impedance where a voltage collapse is observed [16, 4]. Introducing FACTS controllers is the most effective way for utilities to improve the voltage profile and voltage stability margin of the system. As the size and the cost of the FACTS devices are high, an optimal location and size has to be identified before they are actually installed [8, 9].

Introducing FACTS in stability issues is not a new topic and is being studied over many long years. But the introducing them while analyzing different static load models when the system is under a contingent condition, a generator outage that directly has its effect felt on load centers is a new topic discussed in this paper.

2. Problem formulation

Accurate modeling of loads continues to be a difficult task due to several reasons. Lack of precise information on the composition of the load, changing of load composition with time like day and week, seasons, weather, through time and more influence the load models. Electric utility analysts and their management need evidence of the benefits in improved load representation to justify the effort and expense of collecting and processing load data. Also to modify computer program load models. The interest in load modeling has increased in the last few years, and power system load modeling has become a new research area in power systems stability. Several studies have reported the critical effect of load representation in voltage stability studies. This leads to identify accurate load models than the traditionally used ones.

Though ours is not the first paper to test various static load models for determining the voltage stability limits of a power network, it happens to be the first one to analyze four different static load models under one roof and also to apply cat swarm optimization technique for the power networks under contingent conditions. The static load models we are testing include ZIP model or Polynomial model, Exponential Load Model, Frequency Dependent load model and Voltage Dependent load model. FACTS technology is employed to give a solution for instability margins.

To analyze the maximum loading parameter and bus voltage magnitude profile aspects, we are simulating the PV curves for the system with different types of loads. We are trying to analyze these loads under contingency condition which was not addressed earlier. We are considering the problem case of generator outage contingency while performing the load testing. We are trying to improve the voltage magnitude profile, maximum loading parameter using FACTS controllers. A solution is given to mitigate the harmful effects of voltage instability criterion on the power system using FACTS controllers via Cat Swarm Optimization. The objective function for achieving the above is defined as follows

$$F = \{F_1, F_2, F_3\} \tag{1}$$

The functions F_1, F_2 and F_3 are defined and used in optimization process.

$$F = \Phi_1 F_1 + \Phi_2 F_2 + \Phi_3 F_3 \tag{2}$$

In our study, the fitness function is defined as a sum of three terms with individual criteria. The first part of the objective function concerns the voltage level. It is favorable that buses voltages be as close as possible to 1 p.u. Equation (3) shows the voltage deviation in all buses.

$$F_1 = F_V = \sum_{i=1}^{nb} (V_i)^2 \tag{3}$$

Where nb is the number of buses and V_i is the voltage of bus i.

F_2-This function represents the optimal location and size of UPFC which has its dependence on F_1.This is related to having the minimum possible UPFC sizes regarding to the control of UPFC that is given by (4).

$$F_2 = F_s = \alpha \sum_{j=1}^{m} Q_j \tag{4}$$

Where 'm' is the number of UPFC and 'Q_j' is the value of UPFC's Kvar and 'α' is a weight in order that the terms in the fitness function are comparable in magnitude. Value of UPFC's Kvar considering the control strategy and UPFC's model is achieved. The maximum loadability of power system is extremely important and hence it is considered as the third part of the objective function. So, finally, the third issue in our problem is determining inverse of maximum loadability, given as follows :

$$F_3 = F_{SM} = 1/\lambda_{Critical} \tag{5}$$

Therefore, the objective function is given by the following equation.

$$F = \Phi_1 F_V + \Phi_2 F_S + \Phi_3 F_{SM} \tag{6}$$

The objective function for the load model testing is defined as follows.

$$E = \{E_1, E_2\} \tag{7}$$

The functions E_1 and E_2 are defined as

The first part of the objective function concerns the voltage level. It is favorable that buses voltages be as close as possible to 1 per unit according to equation (8).

$$E_1 = E_V = \sum_{i=1}^{nb} (V_i)^2 \tag{8}$$

The second issue in our problem is determining inverse of maximum loadability, given as follows.

$$E_3 = E_{SM} = 1/\lambda_{Critical} \tag{9}$$

The functions E_1 and E_2 are defined and used in optimization process.

$$E = \mu_1 E_1 + \mu_2 E_2 \tag{10}$$

Therefore, the objective function is given by (11).

$$E = \mu_1 E_V + \mu_2 E_{SM} \tag{11}$$

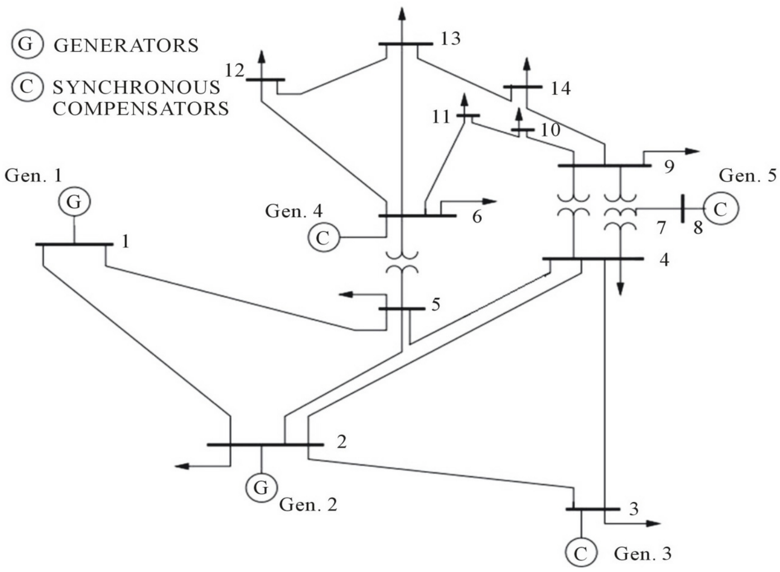

Fig. 1 – IEEE 14 Bus Network.

3. Cat swarm optimization, facts and static load models

3.1. Introduction to Cat Swarm Optimization

Optimization techniques find a variety of use in many fields. The use of these techniques in power systems is playing an important role for the optimal location of FACTS devices. In the field of optimization, many algorithms were being proposed in the recent past.

To name a few, Genetic Algorithm (GA), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), Simulated Annealing (SA) etc. Some of these optimization algorithms were developed based on swarm intelligence. Cat Swarm Optimization in short CSO, the algorithm, is motivated from PSO and ACO. According to the literatures, PSO with weighting factor usually finds the better solution faster than the pure PSO, but according to the experimental results, Cat Swarm Optimization (CSO) presents even much better performance [10, 11]. CSO is a Meta Heuristic search approach. This search technique is considered to be a very simple one as compared to other optimization and heuristic approaches existing such as GA, SA, CCEA, PSO etc. to name a few. We can though use a simple local search algorithm like a gradient based optimization for optimal location of FACTS controllers but when applied to large interconnected power networks, it fails in identifying accurate solution and is not a suggested approach. Also the procedures like GA, PSO, ACO, SA etc. become very tedious to implement and are already tested by many researchers and have reached a saturation level. One can appreciate the importance of Cat Swarm optimization which was presented in articles [1] and [3]. Authors have stressed the point in using this algorithm, an advanced one which combines speed and ease in finding solution, an optimum one for various problems of engineering.

In Cat Swarm Optimization, we first model the behavior of cats into two sub-models, namely, seeking mode and tracing mode. Seeking mode is used to model the situation of the cat, which is resting, looking around and seeking the next position to move to. Tracing mode is the sub-model for modeling the case of the cat in tracing some targets. Once a cat goes into tracing mode, it moves according to its own velocities for every dimension [12]. The algorithmic flow routine for the CSO can be explained through the flow chart in Fig. 2 taken from [11].

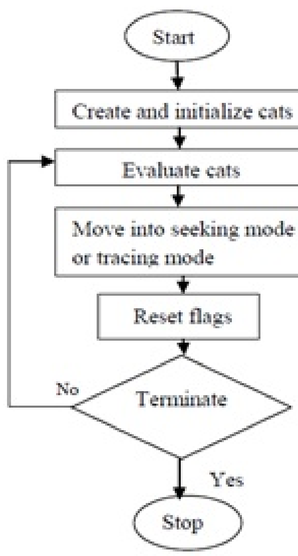

Fig. 2 – Flow chart for Cat Swarm Optimization.

3.2. FACTS Controllers

Flexible AC Transmission Systems (FACTS) are being used in power systems since 1970s with an objective of improving system dynamic performance [5]. Due to the environmental, right of way, and cost problems in power systems, many transmission lines have been forced to operate at almost their full capacities worldwide. FACTS controllers enhance the static performance which includes increased loading, congestion management, reduced system loss, economic operation, etc., and dynamic performance that is damping of power system oscillation, increased stability limits, etc. The concept of FACTS involves family of semiconductor and electronic devices, with advanced and reliable controls. We are using Unified Power Flow Controller in our application.

3.2.1. Unified Power Flow Controller

The Unified Power Flow Controller, in short, UPFC comes with a combination of a static synchronous compensator (STATCOM) and static synchronous series compensator (SSSC) coupled with a common DC voltage link. The main advantage of the UPFC is in controlling active and reactive power flows in a transmission line. The connection structure is shown in figure 3.

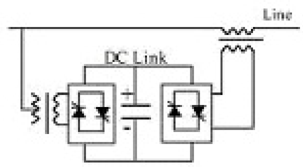

Fig. 3 – Structure of UPFC.

3.3. Static Load Models Used

3.3.1. ZIP model or polynomial model

The static characteristics of the load can be classified into constant impedance, constant current and constant power load, depending on the power relation to the voltage. Constant impedance loads examples : Residential loads and lighting loads such as bulbs e.t.c. Constant current load examples : Transistors, transducers and incandescent lamps. Constant power loads are switching regulators and industrial loads.

3.3.2. Frequency Dependent model

A static load model which includes frequency dependence is called a frequency dependent load. Examples for frequency dependent loads are refrigerators, freezers, air conditioners, water heaters, pumps and ovens.

3.3.3. Voltage Dependent model

A voltage dependent load is an electrical device whose power consumption changes with the voltage being supplied to it. Examples for these loads are the most common types of incandescent lamps, standard tungsten filament lamps, tungsten halogen and reflector lamps and motor load.

3.3.4. Exponential recovery model

In exponential load model the active and reactive power injections of load bus are related to bus voltage through exponential function. Examples for these loads are residential loads, lighting loads and motor loads.

4. Implementation, results and discussion

We are installing and simulating the IEEE 14 bus system independently with each type of the load models described in section 4.3 at the load buses. The system modeled and loaded with these different static loads will become instable. The values of the voltage magnitude profiles at different buses are depicted in table 1. The maximum loading parameter details with and without loads are given in Table 2. From the results in tables 1 and 2, we can observe that frequency dependent loads and exponential recovery loads have a considerable increase in loading parameter when compared to ZIP and voltage dependent loads. Even though the maximum loading parameter is appreciable, the voltages magnitude profiles at different buses were observed to be less. This is not around 1P.U. Apart from the above, we have also performed generator outage contingency. There are four working generators in the case study and contingency is performed for all the four generators. The results for n-1 generator outage contingency are given in Table 3. Generator6 contingency was observed to be the worst case. For the different types of load models tested, generator6 contingency is performed and the results of voltage profile are taken.

Table 1 – Voltages Magnitude Profiles for different loads.

BUS. No.	ZIP load	Voltage Dependant Load	Frequency Dependant Load	Exponential Recovery Load
Bus1	1.0566	1.0566	1.0566	1.0566
Bus2	0.89264	0.88923	0.91956	0.91165
Bus3	0.75932	0.74094	0.76727	0.75224
Bus4	0.73748	0.74086	0.81655	0.80345
Bus5	0.76214	0.76757	0.84161	0.82977
Bus6	0.81924	0.83625	0.94378	0.93282
Bus7	0.78969	0.80221	0.91208	0.89938
Bus8	0.93511	0.94304	1.0099	1.0024
Bus9	0.72905	0.74587	0.89255	0.87733
Bus10	0.72392	0.74231	0.89501	0.87959
Bus11	0.76108	0.77959	0.91591	0.90226
Bus12	0.77332	0.79402	0.92785	0.91496
Bus13	0.75599	0.77805	0.92092	0.90724
Bus14	0.68821	0.71354	0.88901	0.87218

After identifying the cases for which there is maximum deviation in the voltages, using the Cat Swarm Optimization technique, we find the optimal location and size of UPFC to improvise the maximum loading limit of the system and also to bring the system voltages back to the pre disturbance values (or) near pre-disturbance values. We are incorporating three UPFC's based on the results obtained by observing the voltage magnitude profile at different buses. The reason for taking only three devices is purely based on voltage magnitude profiles of the system buses and the economic viability. The UPFC locations are based upon the contingent conditions observed as part the generator outage contingency analysis considered to be preview analysis. The voltages of buses 2 and 3 are observed to be low, even after erecting UPFC and during contingency for the reason due to the initial conditions considered as part of the system data.

Table 2 – Selected architecture of the neural network.

	Without any Load Model	With ZIP Load	With VD Load	With FD Load	With ER Load
Maximum Loading Parameter (λ_{max})	2.375	2.653	2.7571	3.1718	3.14

VD : Voltage Dependant
FD : Frequency Dependant
ER : Exponential Recovery

Table 3 – Voltage Magnitude Profiles for n-1 Generator Outage Contingencies.

Bus. No.	Generator2 contingency	Generator3 contingency	Generator6 contingency	Generator8 contingency
Bus1	1.0567	1.0573	1.0578	1.0577
Bus2	0.8654	0.90921	0.94851	0.9468
Bus3	0.83462	0.63846	0.88584	0.88123
Bus4	0.76674	0.74524	0.7753	0.7781
Bus5	0.78377	0.78206	0.78519	0.80179
Bus6	0.84667	0.84777	0.6188	0.80123
Bus7	0.80842	0.79897	0.75073	0.68728
Bus8	0.94893	0.94258	0.91456	0.68728
Bus9	0.74593	0.74036	0.64519	0.64628
Bus10	0.74119	0.73773	0.61473	0.64798
Bus11	0.78286	0.7821	0.60458	0.71204
Bus12	0.79818	0.80089	0.56428	0.74493
Bus13	0.77869	0.78153	0.55067	0.71966
Bus14	0.70172	0.70264	0.52881	0.61031

For installing the UPFC, its size in terms of VAR rating is determined using Cat Swarm Optimization technique. The optimum size of the UPFC's used here in terms of its converter ratings vary from one load type to another with 50% gain and a Time constant of 0.1. The UPFC is used in constant voltage mode. Maximum values of V_p, V_q and I_q are 1.15, 1.15 and 1.1 in P.U. and Minimum values of V_p, V_q and I_q are 0.85, 0.85 and 0.9 respectively.

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The Parameters that constitute the dimensions of the position of CAT in this case are :

No. of Iterations carried for CSO : 50

No. of Cats used : 03

No. of Cats in seeking mode : 02

No. of Cats in tracing mode : 01

Amongst the three UPFC's used, two UPFC's are taken in seeking mode and one is taken in tracing mode respectively. The location is decided based on contingency analysis given in table 3. 50 numbers of iterations are run for this technique, of which the global best solution is taken in to consideration. Table 4 shows the improvement in voltage profile and maximum loading parameter for ZIP load with generator6 contingency when three UPFC's are used in the bus locations 14-13, 5-4, and 14-9 with size 1kvar, 1kvar, and 0.15kvar respectively. Table 5 shows the improvement in voltage profile and maximum loading parameter for Voltage Dependant load with generator6 contingency when three UPFC's are used in the bus locations 14-13, 5-4, and 14-9 with size 0.7kvar, 1kvar, and 1kvar respectively. Table 6 shows the improvement in voltage magnitude profile and maximum loading parameter for Frequency Dependant load with generator6 contingency when three UPFC's are used in the bus locations 14-13, 5-4, and 14-9 with size 1kvar, 1kvar, and 1kvar respectively. Table 7 shows the improvement in voltage magnitude profile and maximum load-ability limit for Exponential Recovery load with generator6 contingency when three UPFC's are used in the bus locations 14-13, 5-4, and 14-9 with size 1kvar, 1kvar, and 0.15kvar respectively. Finally, it is observed near bus4, bus5, bus9, bus13 and bus 14 for which a deterioration of voltages happened for various load models under generator6 outage contingency. This was overcome by incorporating UPFC. The objective function for load modeling is achieved by improving the voltage magnitude profile to near 1 P.U. and maximum loading parameter also improved. The bar graphs in Fig. 4, Fig. 6, Fig. 8 and Fig. 10 and PV curves in Fig. 5, Fig. 7, Fig. 9 and Fig. 11 also depict the same.

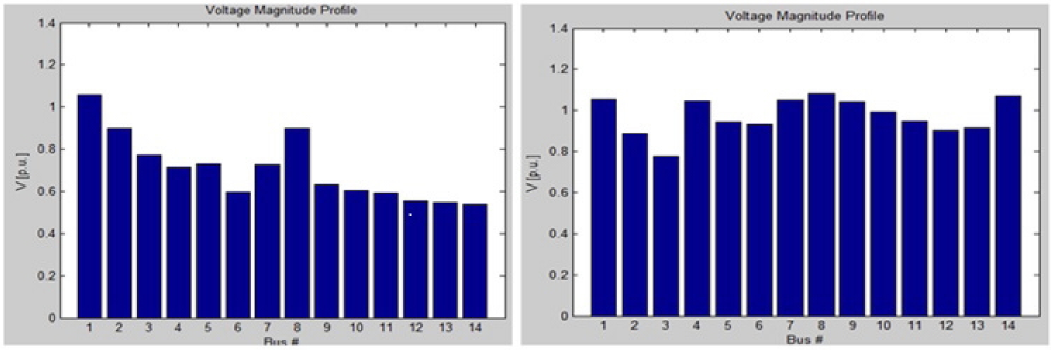

Fig. 4 – Voltage magnitude profile before and after placement of UPFC's (ZIP Load).

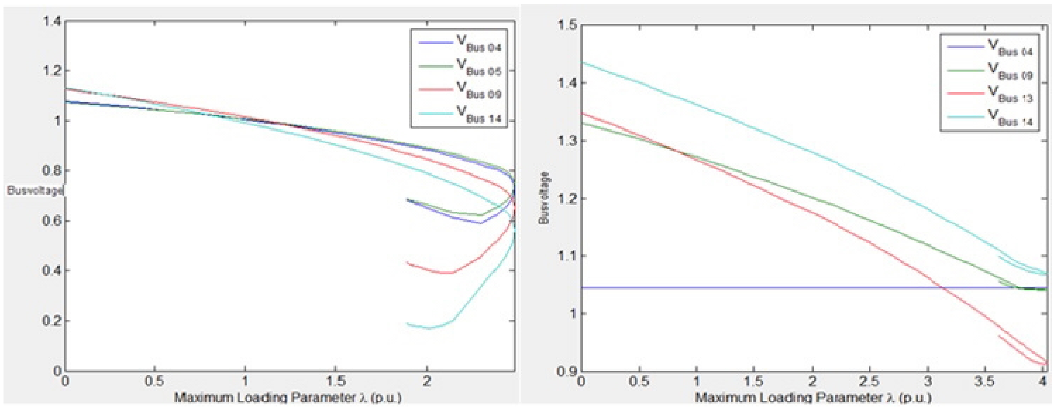

Fig. 5 – PV curves before and after placement of UPFC's (ZIP Load).

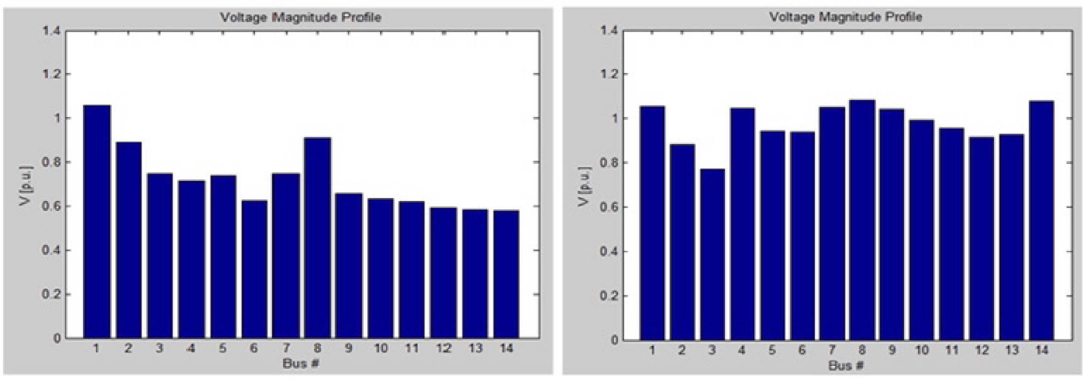

Fig. 6 – Voltage magnitude profile before and after placement of UPFC's (Voltage Dependant Load).

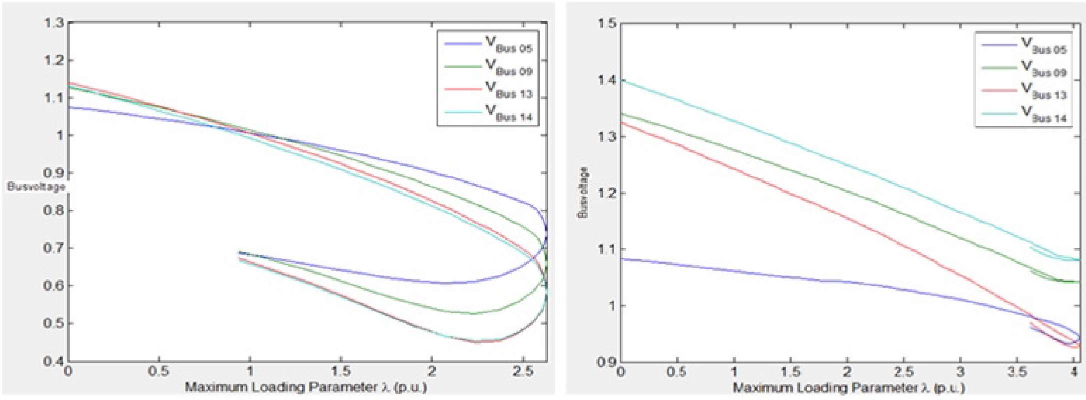

Fig. 7 – PV curves before and after placement of UPFC's (Voltage Dependant Load).

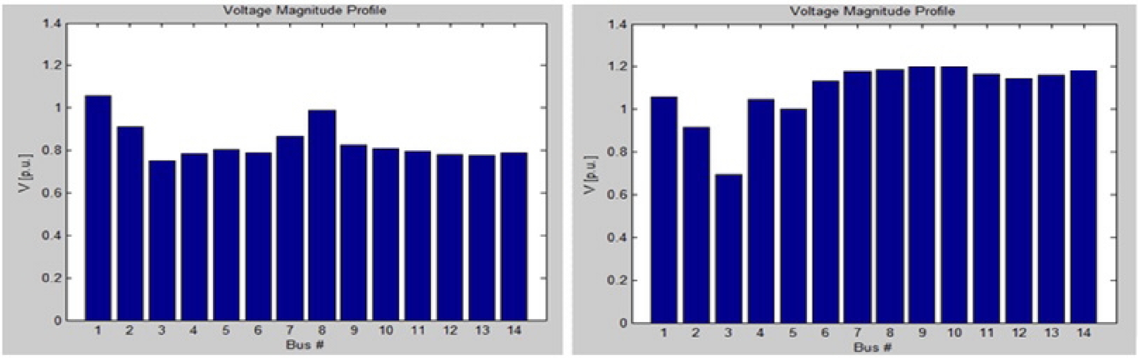

Fig. 8 – Voltage magnitude profile before and after placement of UPFC's (Frequency Dependant Load).

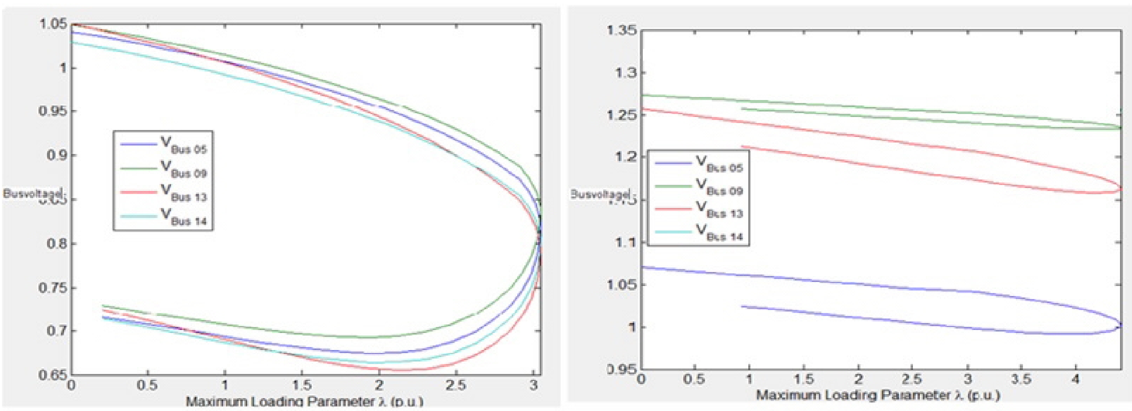

Fig. 9 – PV curves before and after placement of UPFC's (Frequency Dependant Load).

The reason for choosing three UPFC devices lies in the fact that the economy in installing the devices and operating them also plays a prominent role. In present day scenario, it costs approximately 80 USD per one KVAR to operate. This approximates to 5000 INR for operation in India. UPFC has both real and reactive power components but in this paper only reactive power is considered for the reason that the load centers have a direct impact on reactive power consumption. Various load models considered here show a deficit in reactive power for which reactive power compensation is provided. Though STATCOM and SVC devices are present, we are interested in showing a solution using advanced heuristic and FACTS technologies rather than resorting to primitive solutions.

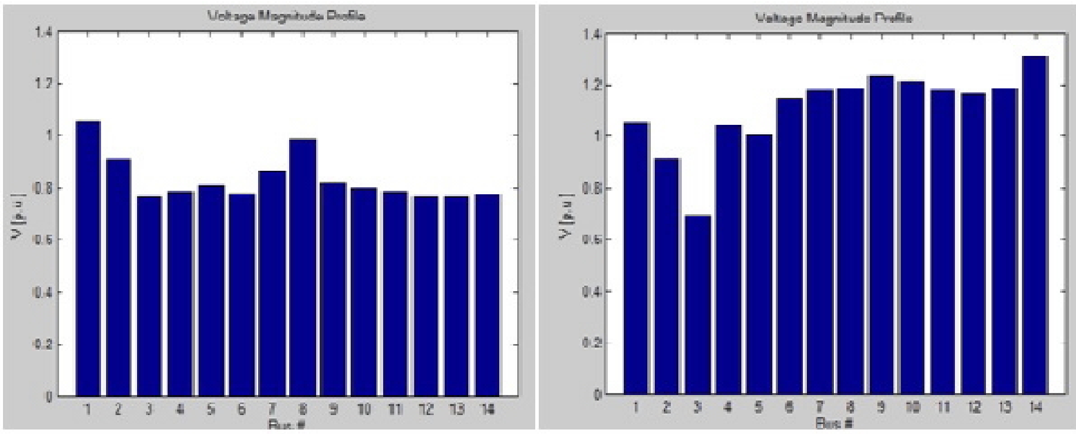

Fig. 10 – Voltage magnitude profile before and after placement of UPFC's (Exponential Recovery Load).

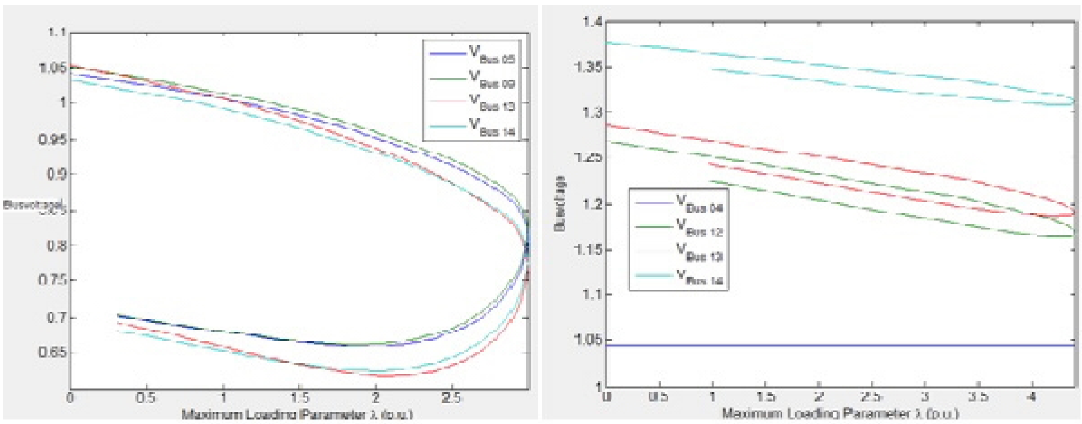

Fig. 11 – PV curves before and after placement of UPFC's (Exponential Recovery Load).

Table 4 – Voltage Magnitude Profile before and after generator6 outage contingency for ZIP load.

BUS. NO.	V(P.U) before Contingency with ZIP Load (Without UPFC's)	V(P.U) after Contingency with ZIP Load (Generator6)	V(P.U) after Contingency with ZIP Load (With 3 UPFC's)
01	1.0566	1.0566	1.0566
02	0.89264	0.89682	0.88534
03	0.75932	0.77122	0.77642
04	0.73748	0.71229	1.045
05	0.76214	0.7312	0.94191
06	0.81924	0.5936	0.93158
07	0.78969	0.72699	1.048
08	0.93511	0.89847	1.0809
09	0.72905	0.63318	1.041
10	0.72392	0.60518	0.99179
11	0.76108	0.58968	0.94877
12	0.77332	0.55395	0.90409
13	0.75599	0.54552	0.91522
14	0.68821	0.5402	1.069
MLP (λ_{max})	2.653	2.4808	4.0395

Table 5 – Voltage Magnitude Profile before and after generator6 outage contingency for Voltage Dependant Load.

BUS. NO.	V(P.U) before Contingency with VD Load (Without UPFC's)	V(P.U) after Contingency with VD Load (Generator6)	V(P.U) after Contingency with VD Load (With 3 UPFC's)
01	1.05660	1.0566	1.0566
02	0.88923	0.89083	0.88406
03	0.74094	0.74525	0.77031
04	0.74086	0.71576	1.045
05	0.76757	0.73732	0.94359
06	0.83625	0.62234	0.94094
07	0.80221	0.74553	1.0482
08	0.94304	0.91107	1.081
09	0.74587	0.65817	1.0419
10	0.74231	0.63285	0.9942
11	0.77959	0.61913	0.95433
12	0.79402	0.58976	0.9161
13	0.77805	0.58288	0.92837
14	0.71354	0.58004	1.0807
MLP (λ_{max})	2.7571	2.6285	4.0534

Table 6 – Voltage Magnitude Profile before and after generator6 outage contingency with Frequency Dependant Load.

BUS. NO.	V(P.U) before Contingency with FD Load (Without UPFC's)	V(P.U) after Contingency with FD Load (Generator6)	V(P.U) after Contingency with FD Load (With 3 UPFC's)
01	1.0572	1.0572	1.0572
02	0.91956	0.90944	0.91451
03	0.76727	0.74971	0.69206
04	0.81655	0.78305	1.045
05	0.84161	0.80494	1.0001
06	0.94378	0.78668	1.131
07	0.91208	0.86449	1.1782
08	1.0099	0.98705	1.1855
09	0.89255	0.82281	1.2339
10	0.89501	0.81029	1.2073
11	0.91591	0.79597	1.1663
12	0.92785	0.77815	1.1426
13	0.92092	0.77753	1.1614
14	0.88901	0.78815	1.0837
MLP (λ_{max})	3.1718	3.0441	4.4052

Table 7 – Voltage Magnitude Profile before and after generator6 outage contingency with Exponential Recovery Load.

BUS. NO.	V(P.U) before Contingency with ER Load (Without UPFC's)	V(P.U) after Contingency with ER Load (Generator6)	V(P.U) after Contingency with ER Load (With 3 UPFC's)
01	1.057	1.057	1.057
02	0.91165	0.91466	0.91794
03	0.75224	0.76788	0.69561
04	0.80345	0.78675	1.045
05	0.82977	0.80683	1.0046
06	0.93282	0.78063	1.1498
07	0.89938	0.86135	1.1813
08	1.0024	0.98513	1.1884
09	0.87733	0.81587	1.2379
10	0.87959	0.80206	1.2152
11	0.90226	0.7881	1.18
12	0.91496	0.76894	1.1663
13	0.90724	0.76751	1.1884
14	0.87218	0.77622	1.3099
MLP (λ_{max})	3.14	2.9936	4.422

5. Conclusion

The work presented here details a load model study for voltage stability using Cat Swarm Optimization. The case study considered was modeled using different static loads in generator outage contingency condition and analyzed for their performance in terms of voltage magnitude profile and maximum loading parameter. The different load models show an impact of instability in the system for which a solution is given using UPFC. A method is also presented to determine the optimal location and size of UPFC to enhance the stability. This method is based on Cat Swarm Optimization (CSO). This algorithm is in implementing compared to earlier AI techniques. It is capable of finding multiple optimal solutions, giving more flexibility to make the final decision about the location of the FACTS controller. On conclusion, we present application of an advanced technique to address stability issues arising in large power systems when connected and operated with different load models. The future scope of this work deals with the testing of above techniques for higher order IEEE case studies and practical networks.

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Authors

Dr G Naveen Kumar obtained his B.Tech, M.Tech and PhD from Jawaharlal Nehru Technological University, Hyderabad. He is currently working as Assistant Professor in Electrical and Electronics Engineering department at VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, India. His research interests include embedded system applications to power systems problems.