IMPROVING TRANSMISSION LINE LOADABILITY LIMITS USING IPFC

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ABSTRACT

An electric power system is a network consists of electrical apparatus deployed to supply, transfer, store, and use electric power. An example of an electric power system is the grid that provides power to an extended area. An electrical grid power system can be broadly divided into the generators that supply the power, the transmission system that carries the power from the generating centers to the load centers, and the distribution system that feeds the power to nearby homes and industries. Smaller power systems are also found in industry, hospitals, commercial buildings and homes. The majority of these systems rely upon three-phase AC power—the standard for large-scale power transmission and distribution across the modern world. Specialized power systems that do not always rely upon three-phase AC power are found in aircraft, electric rail systems, ocean liners and automobiles. There are two ways are usually followed for reducing the power demand such as by installing the power stations, or by extending the range of transmission line loadability. As a result, of overloaded the existing transmission lines and to falling power system stability. So decreasing voltage stability is a big issue and its leads to voltage collapse. In earlier, Power system stabilizer (PSS) control provides a positive contribution by damping generator rotor angle swings, which are in a broad range of frequencies in the power system. These modes are present in all interconnected systems and the damping is a function of tie line strength and unit loading factors. In this paper IPFC is involved for increasing the real power flow. The IEEE 14 bus system is taken and it is built in MATLAB software. By connecting IPFC, it enhancing the voltage stability and real power flow of transmission lines. Optimal location of IPFC has to be found by PSO algorithm technique. The results are verified through waveforms using MATLAB SOFTWARE.

Keywords— *voltage stability, maximum loading point, IPFC particle swarm optimization (PSO), MATLAB simulink.*

1.INTRODUCTION

Power systems deliver energy to loads that perform a function. These loads range from household appliances to industrial machinery. Most loads expect a certain voltage and, for alternating current devices, a certain frequency and number of phases. The appliances found in your home, for example, will typically be single-phase operating at 50 or 60 Hz with a voltage between 110 and 260 volts (depending on national standards). An exception exists for centralized air conditioning systems as these are now typically three-phase because this allows them to operate more efficiently. All devices in your house will also have a wattage, this specifies the amount of power the device consumes. At any one time, the net amount of power consumed by the loads on a power system must equal the net amount of power produced by the supplies less the power lost in transmission.Making sure that the voltage, frequency and amount of power supplied to the loads is in line with expectations is one of the great challenges of power system engineering. However it is not the only challenge, in addition to the power used by a load to do useful work (termed real power) many alternating current devices also use an additional amount of power because they cause the alternating voltage and alternating current to become slightly out-of-sync (termed reactive power). The reactive power like the real power must balance (that is the reactive power produced on a system must equal the reactive power consumed) and can be supplied from the generators, however it is often more economical to supply such power from capacitors (see "Capacitors and reactors" below for more details).A final consideration with loads is to do with power quality. In addition to sustained overvoltages and under voltages (voltage regulation issues) as well as sustained deviations from the system frequency (frequency regulation issues), power system loads can be adversely affected by a range of temporal issues. These include voltage sags, dips and swells, transient overvoltages, flicker, high frequency noise, phase imbalance and poor power factor. Power quality issues occur when the power supply to a load deviates from the ideal: For an AC supply, the ideal is the current and voltage in-sync fluctuating as a perfect sine wave at a prescribed frequency with the voltage at prescribed amplitude. For DC supply, the ideal is the voltage not varying from a prescribed level. Power quality issues can be especially important when it comes to specialist industrial machinery or hospital equipment.

2.MATLAB DESCRIPTION

MATLAB is a multi-paradigm numerical computing environment. A proprietary programming language developed by Math Works, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, C#, Java, Fortran and Python. Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine, allowing access to symbolic computing abilities. An additional package, Simulink, adds graphical multi-domain simulation and model-based design for dynamic and embedded systems.As of 2017, MATLAB has roughly 1 million users across industry and academia. MATLAB users come from various backgrounds of engineering, science, and economics. The MATLAB application is built around the MATLAB scripting language. Common usage of the MATLAB application involves using the Command Window as an interactive mathematical shell or executing text files containing MATLAB code.

2.1 Variables

Variables are defined using the assignment operator, =. MATLAB is a weekly typed programming language because types are implicitly converted. It is an inferred typed language because variables can be assigned without declaring their type, except if they are to be treated as symbolic objects, and that their type can change. Values can come from constants, from computation involving values of other variables, or from the output of a function.MATLAB has structure data types. Since all variables in MATLAB are arrays, a more adequate name is "structure array", where each element of the array has the same field names. In addition, MATLAB supports dynamic field names (field look-ups by name, field manipulations, etc.). Unfortunately, MATLAB JIT does not support MATLAB structures, therefore just a simple bundling of various variables into a structure will come at a cost. When creating a MATLAB function, the name of the file should match the name of the first function in the file. Valid function names begin with an alphabetic character, and can contain letters, numbers, or underscores. Functions are often case sensitive.

2.2 Simulink

Use Simulink to model algorithms and physical systems using block diagrams. You can model linear and nonlinear systems, factoring in real-world phenomena such as friction, gear slippage, and hard stops. A comprehensive library of predefined blocks helps you to build models. You add blocks from the library to your model using the Simulink Editor. In the editor, connect blocks by way of signal lines to establish mathematical relationships between system components. You can also refine the model appearance and add masks to customize how users interact with the model. You can design your models to be hierarchical by organizing groups of blocks into subsystems. This approach enables you to build discrete components that reflect your real-life system and simulate the interaction of those components. Blocks are the main elements you use to build models in Simulink. Use the Library Browser to browse and search the block libraries. When you find the block you want to use, add it to your model.

3.FACTS DEVICE

In conventional AC transmission, the power transfer capability has been limited by various dynamic and static limits such as transient stability, voltage stability, thermal limits, etc. These inherent power system limits led to the under utilization of existing transmission sources. Traditional methods of solving these problems use fixed and mechanically switched series and shunt capacitors, reactors and synchronous generators. However, desired response has not been effective due to slow response, wear and tear of mechanical components. With the invention of thyristors devices, power electronic converters are developed that led to implement FACTS controllers. These power electronic based controllers can provide smooth, continuous, rapid and repeatable operations for power system control.FACTS is an acronym for Flexible AC Transmission System and it is an application of power electronic devices to electrical transmission system. It is an AC transmission system that incorporates a power electronic controller and other static controllers to improve the controllability as well as power transfer capability. It improves the performance of electrical networks by managing active and reactive power.The IEEE definition for FACTS controller is stated as , it is a power electronic based system and other static equipment that provides the control of one or more AC transmission parameters (such as voltage, impedance, phase angle and power).

3.1 IPFC

An Interline Power Flow Controller (IPFC) consists of a set of converters that are connected in series with different transmission lines. The schematic diagram of IPFC is illustrated in Figure.1. In addition to these series converters, it may also include a shunt converter which is connected between a transmission line and the ground. The converters are connected through a common DC link to exchange active power. Each series converter can provide independent reactive compensation of own transmission line. If a shunt converter is involved in the system, the series converters can also provide independent active compensation; otherwise not all the series converters can provide independent active compensation for their own line. Compared to the Unified Power Flow Controller (UPFC), the IPFC provides a relatively economical solution for multiple transmission line power flow control, since only one shunt converter is involved.

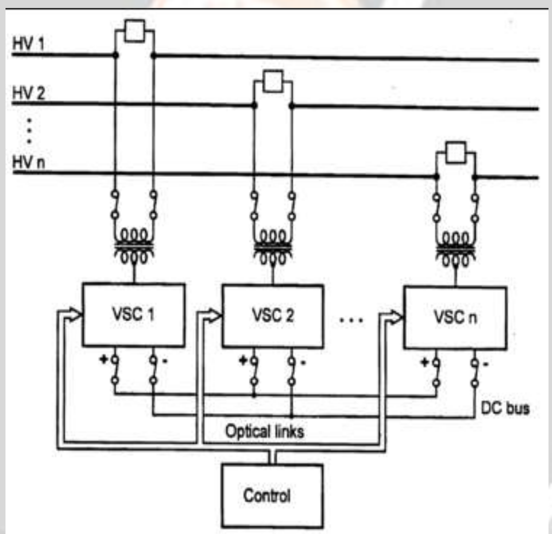


Fig - 1 Schematic diagram of IPFC

The IPFC also gains more control capability than the Static Synchronous Series Compensator (SSSC), which is like the IPFC but without a common DC link, because of the active compensation. From probabilistic point of view, the performance of the IPFC will be better when more series converter involves in to the IPFC system. However, because the converters are connected through the common DC link, the converters should be physically close to each other. The common DC link will become a location constrain for the IPFC and limits its commercial application in the future network. Therefore, a method which can eradicate the IPFC common DC link and provide the active power exchange between converters will be interesting.

3.2 Criteria for Placement of IPFC

In order to increasing the performance of transmission lines, locating these types of devices optimally at the time of no load and overloaded conditions are important. So it is achieved by using IPFC based on PSO algorithm.

4.PARTICLE SWARM OPTIMIZATION TECHNIQUE

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling. PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. The detailed information will be given in following sections.Compared to GA, the advantages of PSO are that PSO is easy to implement and there are few parameters to adjust. PSO has been successfully applied in many areas: function optimization, artificial neural network training, fuzzy system control, and other areas where GA can be applied.As stated before, PSO simulates the behaviors of bird flocking. Suppose the following scenario: a group of birds are randomly searching food in an area. There is only one piece of food in the area being searched. All the birds do not know where the food is. But they know how far the food is in each iteration. PSO learned from the scenario and used it to solve the optimization problems. In PSO, each single solution is a "bird" in the search space. We call it "particle". All of particles have fitness values which are evaluated by the fitness function to be optimized, and have velocities which direct the flying of the particles. PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. In every iteration, each particle is updated by following two "best" values. The first one is the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called gbest. When a particle takes part of the population as its topological neighbors, the best value is a local best and is called lbest. After finding the two best values, the particle updates its velocity and positions with following equation (a) and (b).

v[] = v[] + c1 * rand() * (pbest[] - present[]) + c2 * rand() * (gbest[] - present[]) (a)
present[] = persent[] + v[] (b)

v[] is the particle velocity, persent[] is the current particle (solution). pbest[] and gbest[] are defined as stated before. rand () is a random number between (0,1). c1, c2 are learning factors. usually c1 = c2 = 2.

4.1 Comparison between genetic algorithm and PSO algorithm

Most of evolutionary techniques have the following procedure:

1.Random generation of an initial population
2.Reckoning of a fitness value for each subject. It will directly depend on the distance to the optimum.
3. Reproduction of the population based on fitness values.
4. If requirements are met, then stop. Otherwise go back to 2

From the procedure, we can learn that PSO shares many common points with GA. Both algorithms start with a group of a randomly generated population, both have fitness values to evaluate the population. Both update the population and search for the optimum with random techniques. Both systems do not guarantee success. However, PSO does not have genetic operators like crossover and mutation. Particles update themselves with the internal velocity. They also have memory, which is important to the algorithm. Compared with genetic algorithms (GAs), the information sharing mechanism in PSO is significantly different. In GAs, chromosomes share information with each other. So the whole population moves like a one group towards an optimal area. In PSO, only gBest (or lBest) gives out the information to others. It is a one -way information sharing mechanism. The evolution only looks for the best solution. Compared with GA, all the particles tend to converge to the best solution quickly even in the local version in most cases.

4.2 Implementation of PSO Algorithms

STEP 1: Initialization

STEP2: Calculation of fitness function

STEP3: The inertia weight and acceleration coefficients are taken.

STEP4: New velocity and location for each particle is calculated using (1) and (2)

STEP5*:* The iteration need to reach global minimum of fitness value (computation speed) and best fitness value.

4.2.1 PSO Parameter Control

From the above case, we can learn that there are two key steps when applying PSO to optimization problems: the representation of the solution and the fitness function. One of the advantages of PSO is that PSO take real numbers as particles. It is not like GA, which needs to change to binary encoding, or special genetic operators have to be used. For example, we try to find the solution for f(x) = x1^2 + x2^2+x3^2, the particle can be set as (x1, x2, x3), and fitness function is f(x). Then we can use the standard procedure to find the optimum. The searching is a repeat process, and the stop criteria are that the maximum iteration number is reached or the minimum error condition is satisfied.

There are not many parameter need to be tuned in PSO. Here is a list of the parameters and their typical values.The number of particles: the typical range is 20 - 40. Actually for most of the problems 10 particles is large enough to get good results. For some difficult or special problems, one can try 100 or 200 particles as well. Dimension of particles: It is determined by the problem to be optimized, Range of particles: It is also determined by the problem to be optimized, you can specify different ranges for different dimension of particles. Vmax: it determines the maximum change one particle can take during one iteration. Usually we set the range of the particle as the Vmax for example, the particle (x1, x2, x3)X1 belongs [-10, 10], then Vmax = 20 Learning factors: c1 and c2 usually equal to 2. However, other settings were also used in different papers. But usually c1 equals to c2 and ranges from [0, 4] The stop condition: the maximum number of iterations the PSO execute and the minimum error requirement. for example, for ANN training in previous section, we can set the minimum error requirement is one mis-classified pattern. the maximum number of iterations is set to 2000. this stop condition depends on the problem to be optimized.Global version vs. local version: we introduced two versions of PSO. global and local version. global version is faster but might converge to local optimum for some problems. local version is a little bit slower but not easy to be trapped into local optimum. One can use global version to get quick result and use local version to refine the search.Another factor is inertia weight, which is introduced by Shi and Eberhart. If you are interested in it, please refer to their paper in 1998. (Title: A modified particle swarm optimizer).

5. IEEE 14 BUS SYSTEM

In this project IEEE 14 bus system is taken as the test system and it is built in MATLAB software. Load data, bus data and generator data are taken and it is drawn by means of MATLAB.

CASE 1: In IEEE 14 bus Test system was strained by using MATLAB simulink and by using PSO algorithm to determine the bus which is low performance in the test bus system.

CASE 2: By connecting Interline power flow controller facts controller in the test bus system which is low voltage profile and real power flow, and to improve the voltage stability.

From the standard IEEE 14 bus data the bus system has

a) 3 slack bus

b) 6 generator buses

c) 4 load or PQ buses

The main reason for reactive power compensation in a system is: 1) the voltage regulation; 2) increased system stability; 3) better utilization of machines connected to the system; 4) reducing losses associated with the system; and 5) to prevent voltage collapse as well as voltage sag. The impedance of transmission lines and the need for lagging VAR by most machines in a generating system results in the consumption of reactive power, thus affecting the stability limits of the system as well as transmission lines. Unnecessary voltage drops lead to increased losses which needs to be supplied by the source and in turn leading to outages in the line due to increased stress on the system to carry this imaginary power. Thus we can infer that the compensation of reactive power not only mitigates all these effects but also helps in better transient response to faults and disturbances. In recent times there has been an increased focus on the techniques used for the compensation and with better devices included in the technology, the compensation is made more effective. It is very much required that the lines be relieved of the obligation to carry the reactive power, which is better provided near the generators or the loads.

6.RESULTS AND DISCUSSIONS

6.1Voltage and Current Flow Result

IEEE 14 Bus system

Case 1: In this case the IEEE-14 bus system is analyzed without IPFC using PSO analysis.

Case 2: In this case the voltage and current flow result is analyzed by considering the IPFC connected to the low voltage bus.

In both the cases, it shows the results of both voltage and current profile of each and every bus connecting with IPFC and without IPFC respectively.

Table -1 voltage and real power flow of each bus without IPFC

BUS	V(P.U)	REALPOWER FLOW (P.U)
1	0.85	0.58
2	0.30	0.63
3	0.82	1.32
4	0.83	1.89
5	0.62	0.51
6	0.43	0.69
7	0.40	2.65
8	0.89	3.53
9	034	1.24
10	0.89	0.68
11	0.76	0.71

12	0.89	2.64
13	0.81	2.18
14	0.57	2.57

In case 2 the voltage and real power get increased with connecting IPFC. And the power flow results are given in the table 4.2. Power flow results for IEEE-14 bus system (with IPFC)

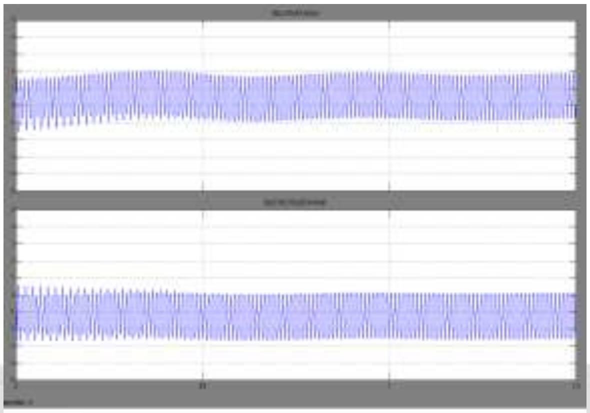
Table -2 voltage and real power flow of each bus with IPFC

BUS	VOLTAGEV(P.U)	REALPOWER FLOW (P.U)
1	0.98	0.59
2	0.91	0.71
3	0.79	1.20
4	0.83	1.91
5	0.82	0.81
6	0.73	0.56
7	0.72	2.73
8	0.80	3.51
9	0.63	1.26
10	0.67	0.62
11	0.81	0.78
12	0.90	2.19
13	0.91	2.75
14	0.97	2.58

In table 4.1, while the load is increasing, the voltage profile will decrease on bus 6, 7, 2, 9. The voltage profile will increase in the bus 6, 7, 2, 9, by connecting IPFC in the bus no. 9 In the case 2 the voltage is increased and real power flow also increased when connecting IPFC.

6.2 Waveform for IEEE 14 Bus Systems

CASE 1: voltage & current profile without IPFC



CASE 2: Real &Reactive power without IPFC

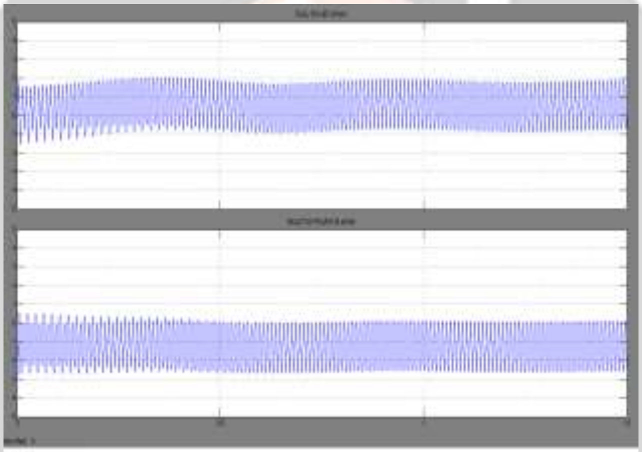


Fig - 2 Waveform for Real &Reactive power without IPFC

In the IEEE-14 bus system the loadability limits are analyzed in the bus 8 without connecting IPFC. Figure 4.1 shows that waveform of voltage and current variations in bus 8. Figure 4.2 shows that the waveform of real and reactive power variations.

CASE 2: VARIATIONS DUE TO INCREASING LOAD

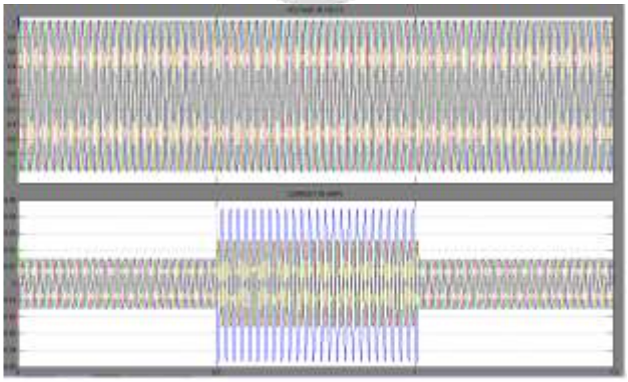


Fig - 3 Waveform for voltage & current profile

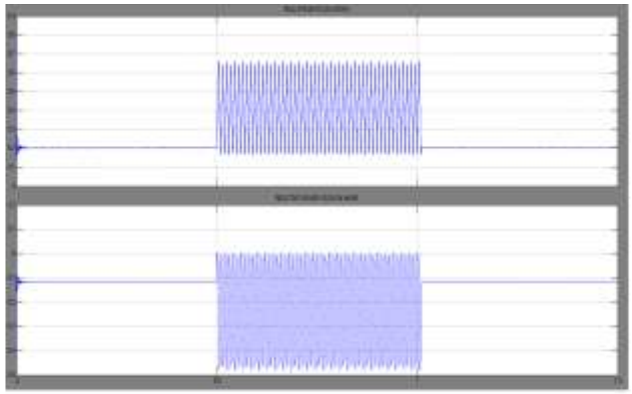


Fig-4 Waveform for Real &Reactive power

The variations in loadability limits due to increasing the load are to be analyzed in the bus 9.When the load is increased in bus 9 there are some variations in loadability limits. Figure 4.3 shows that voltage and current variations. Figure 4.4 shows that the waveform of real and reactive power variations.

CASE 3: WITH IPFC

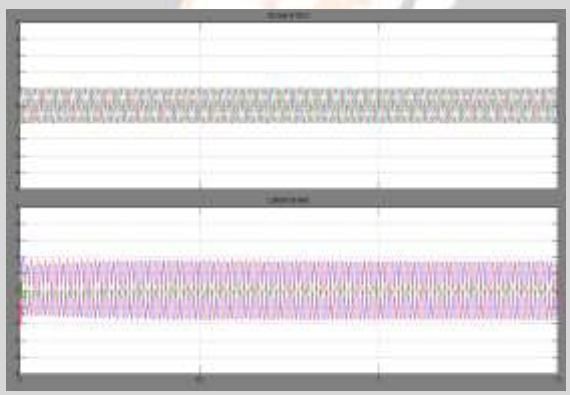


Fig -5 Waveform for voltage & current profile with IPFC

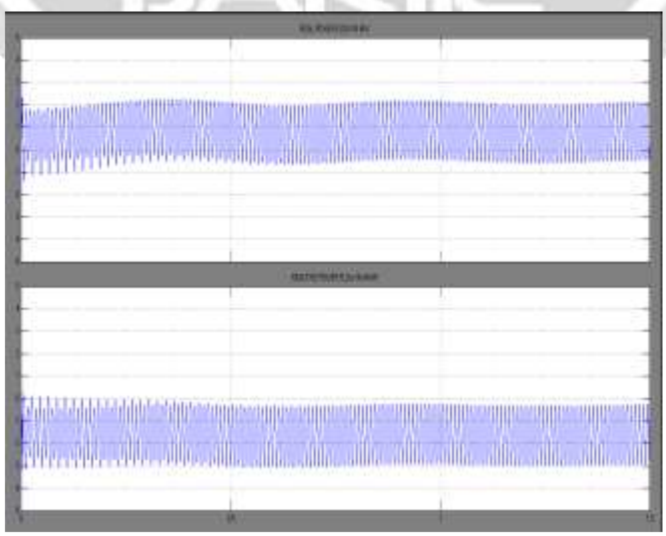


Fig - 6 Waveform for Real &Reactive power with IPFC

A similar analysis can be carried on the 14 bus system after connecting the IPFC in the bus 7. Figure 4.5 shows that voltage and current variations. Figure 4.6 shows that the waveform of real and reactive power variations.

7.CONCLUSION

The IPFC is simulated for the compensation and power flow management of the multiline transmission system. In the IPFC structure, the converters are linked together at their DC terminals. Each inverter can provide a series reactive compensation, as an SSSC, for its own line. However, the converters can transfer real power between them through their common DC terminal. This capability allows the IPFC to provide both real and reactive compensation for some of the lines and thereby optimize the utilization of the overall transmission system. In particular, the IPFC can equalize both real and reactive power flow in the lines, relieve the overloaded lines from the burden of the reactive power flow, compensate against resistive as well as reactive voltage drops, and provide a concerted multiline counter measure during dynamic disturbances. When the IPFC operates at its rated capacity, it can no longer regulate the line active power flow set point or the reactive power flow set point or both. The power circulation between the two VSCs can be used to adjust bus voltages to improve the voltage stability limit transfer. The simulation results are in line with the predictions. The IPFC is capable of balancing the power through the lines. The power quality is improved since the IPFC permits additional power. The circuit models for the IPFC system are developed using MATLAB. The simulation results using MATLAB are presented. The IPFC increases the real power transfer and improves the voltage profile.

The determination of optimal location of IPFC has to be done in my future work to increase the damping and to make the stable system. The objective of the optimal location of IPFC is to minimize the overall cost function, which includes the investment costs as FACTS and the bid offers of the market participants. The optimal IPFC planning is treated as a multi-objective optimization for maximizing the system reactive power margin, minimizing system real power losses and voltage depressions ate critical points.

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