Adaptive Distance Protection with UPFC using GWO Technique

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CANDIDATE’S DECLARATION

I, ATUL MAURYA, Roll No. 2K18/PSY/03 student of M. Tech (Power System), hereby declare that the dissertation titled “ADAPTIVE DISTANCE PROTECTION WITH UPFC USING GWO TECHNIQUE" is the outcome of my own bona fide work and is correct to the best of my knowledge and this work has been undertaken taking care of Engineering Ethics. It contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

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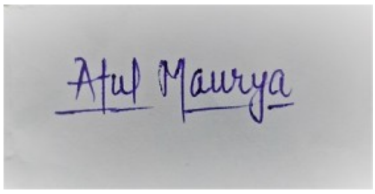

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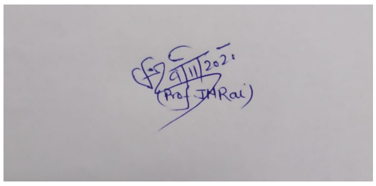
CERTIFICATE

I hereby certify that the major project titled "ADAPTIVE DISTANCE PROTECTION WITH UPFC USING GWO TECHNIQUE" which is submitted by ATUL MAURYA, Roll No-2K18/PSY/03 ELECTRICAL ENGINEERING DEPARTMENT, Delhi Technological University during the academic year 2018-20 is a record of bona fide piece of work, undertaken by him/her with the supervision of the undersigned**.**



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ABSTRACT

The protection of transmission lines is an imperative task to achieve a smooth transmission of power through transmission lines. There are several factors that affect the performance of these systems. The occurrence of faults is the most common reason of instability of power system. The detection and elimination of the faults is significant in order that the system remains reliable and stable. To this end, A literature survey is performed and it is observed that a number of techniques have been designed to protect the transmission lines. The relays are the most commonly used devices and amongst them distance protection is the suitable method to be applied on power systems. Further with the growing technology, FACT devices are introduced in this field to improve the protection method. There are number of FACT devices that are being used, however, many relays have the capability of protecting the model in effective way. The amalgamation of relays and FACT devices give better performance as per the survey. The most commonly used FACT device is UPFC. It is being widely used in the power systems to inject the power without causing any trouble to the system. In a recent study, UPFC is utilized with distance protection method and the results were considered effective. However, the system can be optimized by introducing the optimization algorithms. It is the best approach to obtain the optimal solution. Thus this dissertation presents the designing and development of a novel adaptive method. Different algorithms are studied and Grey wolf optimization is applied on the existing work so that the pulse can be automatically generated by the optimization algorithm and UPFC can easily operate them to inject power into the system and provide protection from the unnecessary faults. The simulation of the model is done in MATLAB software and the effectiveness of the model is determined by measuring impedance and fitness function. The comparison with existing approach ensured that the GWO based UPFC model outperformed the results of UPFC.

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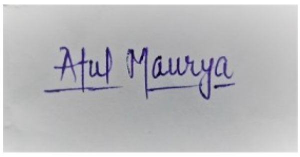
Last, but not the least, the love given by my parents is beyond any thanks. This work could be completed only because of them and I will never be able to repay them ever.



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List of Abbreviations

FACT	Flexible Alternating Current Transmission
UPFC	Unified Power Flow Controller
GWO	Grey Wolf Optimization
GA	Genetic Algorithm
PSO	Particle Swarm Optimization
VSC	Voltage Source Converter
MATLAB	Matrix Laboratory
DC	Direct Cycle
AC	Alternating Cycle
D-FACT	Distribution Power Flow Controller
IGBT	Insulated Gate Bipolar Transistors
GTO	Gate Turn Off Thyristor
BFA	Bacterial Foraging Algorithm

CHAPTER 1

INTRODUCTION

1.1 PREFACE

1.1 preface

Recently, due to the major demand for power, power transmission networks have become narrower. The output of several stability issues for example overloading in certain transmission lines after a disruption. Multifaceted as well as the interlinked power grids can produce a certain type of technical issue as a system stability issue. So, the main transmission-limiting factor is the transitory stability issue after the major defect [1]. For the huge system, the constancy of the power system is an essential and fundamental issue for secure functioning of the system. Furthermore, the constancy of electrical systems all over the world, even in innovative and secure systems, is vulnerable to the instability of the system as a result of unexpected modifications on the network [1, 2]. The temporary stability indicates the power system capacity to conserve the synchronization when discovered to the critical transient interruptions for example sudden modification of faults and load [3]. Include the response of the system resulting from the huge variations in the speed of the generator as well as from the rotor angle. The temporary stability of the complex power system should be improved by applying the FACTs devices [4].

A conventional alternate for supporting the power network contained the advance structure of the electrical transmission system by modifying the new transmission lines, associated equipment, and substations. Thus, the procedure to allow, site, and generate the latest transmission lines has become more complex, costly, and consuming the time.

The application of the present power system should be enhanced by applying the advanced technology of the electronics power system. Flexible Alternating Current Transmission Systems (FACTS) gives the technical resolutions to refer to the latest operating challenges which are existing today. The system, like SVC, UPFC, STATCOM, and SSSC, can be linked in the sequence or shunt to accomplish the several functions that consisting of the control of power flow, voltage regulation, and damping of system. In this, the potential advantage of FACTS tools is massively identified nowadays through the community of power system engineering, but the main task is to achieve the highest efficiency using these devices at less price. This optimization issue basically contained the three views: locating the best place of the device in the power system network, locating its size, and enhancing its regulator parameters so that the highest advantage should be achieved in both the transient as well as in steady state operation. As these three parts, that develops a multi-objective optimization problem that includes a difficult to formulate and is surely tough to resolve effectively. On the second hand, the system itself is a not stationary as well as a highly nonlinear system focus on the disturbances and uncertainties. Contrary, the function of the Flexible Alternating Current Transmission Systems is quite difficult to improve due to its complexity in the managed approach, mainly if the flexibility or the intellectual scheme are measured. As the optimization view, the presence of a non-convex feasible region, the insertion of the complex objectives, multiple local minima, irregular and distinct domain variables, all these make it challenging to locate the appropriate algorithm with the capability of pursuing the global optimum with sensible computational effort.

The FACTS controllers are capable to regulate the rapid condition of the network. This existing network can use efficiently and thus to avoid the necessity for making new transmission lines [5]. The best modeling of Flexible Alternating Current Transmission Systems for dynamic stability development for MMPS studied in [6]. Currently, Flexible Alternating Current Transmission Systems are separately controlled. In any situation, the creative technique and method have been capable to manage the power systems, improvement in the reliability and efficiency of the electric power transmission, and also retain the stability of the system. The managers are increasing the capacity of the power transmission accessible to give the more suitable and quiet the electricity coefficients to create the system more robust [7]. In FACTs, the UPFC is the most commonly used device that can deliver effective control of power system constraints in the direction of the phase angle, line impendence, and voltage transmission. Thus, the UPFC can give either negative or positive power injections positive or interactive. Thus, it can improve the function of the device because it permits the spare efficient super-control system, control of power flow, and stability [8]. In current years the PI-controller become popular to use in order to enhance both fixed and temporary performance, as well as to avoid the noise produced by the startup events [9-11]. This study designed the latest M-PSO; the alteration was established by new weight of inertia (Wnew) as well as adapted a new acceleration aspect (Cnew1, Cnew2) dependent on the decreasing linearly. Our main focus is on enhancing the behavior of the UPFC linked to the grid in order to reduce the noise that arises in the network by monitoring the PI through applying the two scenarios; initial is, (PI-C-PSO); next is, (PI-C-M-PSO). Lastly, the designed approach displayed the effective in stabilization, undershoot and overshoot already being reduced in the transition.

1.2 UPFC DESCRIPTION

The overall design of the UPFC includes the back to back Alternating Current to Direct Current voltage source change to operated with a common Direct Current linked capacitor. Initially, the converter is linked with a shunt that regulates as STATCOM and in the next converter in sequence with the line which works as SSSC. The important function of the shunt converter is to give the actual power to the sequence converter by a mutual DC link. Series Converter has the central function of inserting the phase angle and controlling the voltage magnitude in series with the line. Both the converters should produce or engage the reactive power if required, thus give the self-regulating shunt reactive power compensation for the line.

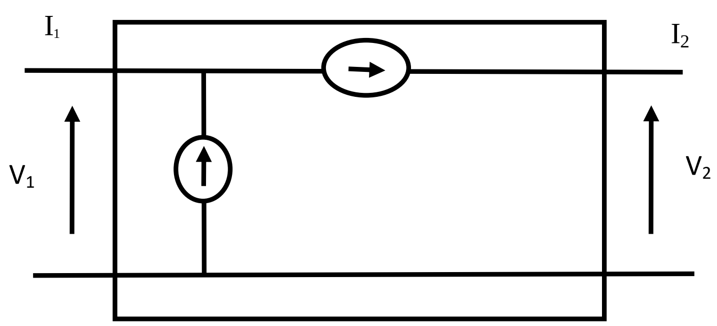

Fig. 1: UPFC equipment circuit

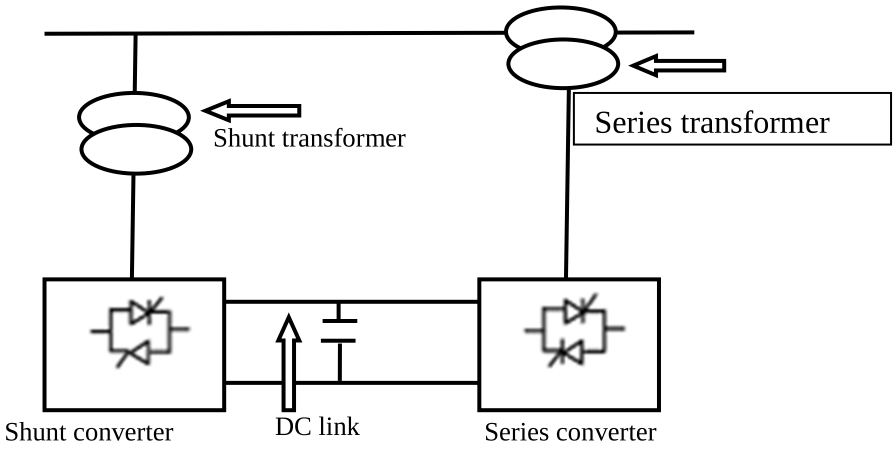

Figure 2: UPFC diagram

1.3 ARTFICIAL INTELLIGENCE TECHNIQUES FOR STABILITY OF POWER SYSTEM

Several evolutionary methods such as Genetic Algorithm, Bacterial Foraging Optimization, PSO, and water droplet optimization method have been designed through several publishers [14-21] to optimize the constraints of FACTS controller. Genetic Algorithm is faster than the Particle Swarm optimization as PSO has an issue in trapping to local minima because of their large computations. Bacterial Foraging optimization technique has been designed through passino [18, 19] where the number of functions is applied to search the total resolution space is considerably higher than the GA and PSO, so that the suitable solution can be achieved. From several techniques of optimization, Bacterial Foraging is designed for its better capability of discovering the best result as well as the higher convergence rate. Still, it should be too early to terminate that Bacterial Foraging is the best suitable algorithm from the rest of the other existing optimization algorithms.

1.4 CONTROL STRATEGY OF THE UPFC

The main base of the control scheme of UPFC is its series and the shunt converters, containing the voltage control of DC and AC, alteration in the power flow, and the start control. Moreover, a MMC (modular multilevel converter) based UPFC in maximum-voltage, high-power conversion conditions which displayed several benefits, but its topology causes certain exceptional problems for control of UPFC. From these problems, the suppression of circulating current, as well as the sub module capacitor voltage control, stand out. These issues examine deeply and the. Analyzed.

Regardless of the topology accepted by a UPFC, it is always a mixture of a sequence converter, a shunt converter that is coneected back to back through a mutual Direct Current bus. The shunt converter grasps the active power from the grid, and give it to the series converter and then recompenses the loss of active power for the circuit devices, and tried to eliminate the system failure generate by a Direct current voltage drop of capacitor. The converter that connected in parallel also gives the reactive power to the grid through the transformer of the shunt to retain the power constancy of the UPFC connecting point. Also, the converter inserts a phase through a series transformer and the voltage with flexible amplitude, to manage the flow of the line. So, the shunt converter required to retain a stable Direct current voltage(bus) as well as gives a reactive power for the grid, although the series-side converter needs to achieve the active and reactive power controller of the line through modifying the amplitude & output voltage phase of the inverter.

UPFC is the most inclusive multi-operational FACT device from all Flexible Alternating Current Transmission Systems controllers. The UPFC is one of the main FACTS devices that provide synchronized control of all the constraints of the power system (phase angle, line impedance, and transmission voltage) and give the dynamic benefit to the system. The Unified power flow controller can execute the functions of the phase shifter, SSSC, and STATCOM, and various content control objectives can be applied for loop-flow control, power flow control, load distribution between the parallel corridors, improvement of transient stability, mitigation of system oscillations as well as the voltage regulation [13] [14].

The Unified power flow controller contains the two voltage-source converters, that are linked back-to-back via a Direct Current capacitor [Fig.3][14]. It inserts an Alternating Current series voltage into the broadcast line and synchronizes the flow of the power by monitoring the phase and amplitude of the injected voltage. The series inverter is measured to insert a set of synchronous voltages, V in series with the line. Various procedures are involved in this, the series inverter will interchange the reactive as well as the real power with the line. The reactive power is automatically given by the series inverter, and the real power is transferred through direct current terminals. The shunt inverter is worked in such a direction that the direct current terminal power (positive or negative) from the line, thus to modify the DC voltage the net real power grasps from the line through the Unified power flow controller is equal to the losses of the two inverters and their transformers. The capacity which is left behind the shunt inverter can be applied to interchange the reactive current with the line.

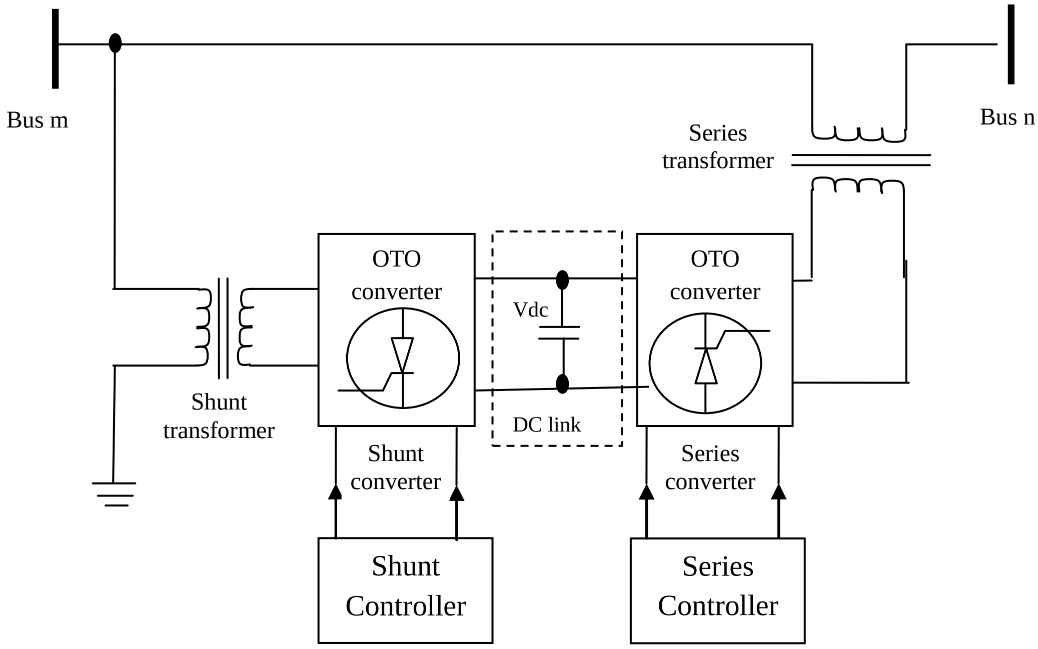

Fig. 3: general UPFC configuration [15]

The shunt inverter is worked in such a direction that draws a controlled current from the transmission line. One section of this current is automatically detected by the requirement to balance the real power of the series inverter. The left component is reactive as well as set to preferred addressed level (inductive or capacitive) within the capability of the inverter. The reactive compensation control modes of shunt inverter are parallel to mutual working on traditional static VAR compensators(SVC) [16], [17].

1.5 Transmission lines

Transmission lines are an important part of the electrical distribution system, as they give the route to transmitted power among the load and generation. Communication lines worked at the voltage levels from 69kV to 765kV, and are preferably tightly interlinked to reliable operation. Factors such as economics, right-of-way clearance, de-regulated market environment, and the environmental necessities have pushed functions to work the operate transmission lines close to their operating limits. Any damage, if not found then isolated rapidly will cascade into a system-wide disruption producing the widespread outages for a tightly interconnected system operating close to its limits. Transmission protection systems are developed to recognize the location of faults and isolate only the defaulted section. The main challenge in protection of communication line is to reliably detect and to isolate the damage compromising the security of the system.

1.5.1 Factors Influencing line Protection

The factors which affect the line protection containing the criticality of the line (in case of system stability and load transfer), clearing the damage that needs the time for system stability, line length, the arrangement of the line (the number of terminals, the physical manufacture of the line, the existence of parallel lines), the loading of the line, the category of interaction available, and the damage modes of the several protection equipment. The complete factors for the secure communication line straightly referred to the dependability and security for a particular application. The security system should give the redundancy to restricted effect of the device failure, and maintain the backup protection to secure the dependability. Reclosing may be applied to keep the line in service for temporary faults, such as lightning strikes. The highest load current level should affect the sensitivity of secured functions and should need the flexibility to secure the settings of the functions during some working conditions Single-pole tripping applications affect the required behavior of the distance elements, differential elements, and communications schemes. The physical construction of the transmission line is also a factor in the protection system application. Additionally, the load as well as default current flow determines the number of line terminals, that must be accounted for by the protection system. Similar lines can affect the relaying; as common coupling impacts, the ground current evaluated by the secure relays. The existence of selected transformers on a line, for example series capacitor banks or shunt reactors, also effects the selected secure system and the real protection device settings. Distance protection relays have been massively used to protect the transmission lines for many years.

1.6 Principle of Distance Protection

In Protection system, the distance protection is a non-unit,that calculates the Impedance among the location of the relay, and the point in which the damage is incident and set value can be compared with it. If the calculated Impedance is minimum than the required Set Value, the Relay works and separates the damaged part.

Hence, the line Impedance is directly proportional to the length of the Line; the research ensured that the accurate position of the Fault is achieved in Km.

Meanwhile, it secures the Length of Transmission Line, which is known as distance relay. If the impedance calculated is less than the setting Impedance, then the relay works.

The introduction gives the general overview of the devices that are used for the protection of the transmission lines.

1.7 Objectives of thesis

The main aim of this research is to meet the following objectives:

- To study the effect of FACT devices by implementing UPFC based relay protection system.
- To design dynamic UPFC system for enhancing the efficiency of protection system by applying GWO optimization technique
- To perform the analysis of proposed work performing its comparative analysis to validate the performance of the proposed work.

CHAPTER 2

LITERATURE REVIEW

2.1 OVER VIEW

This chapter portrays the different studies that have been performed in the field of transmission lines for their protection. The detailed study is performed in order to understand the works done using Relays and FACT devices. Different papers are studied that shows that power transmission is the area of research and has attracted many researchers to cope with the issues faced and improve the performance. The survey showed that distance protection relays and UPFC are utilized by a number of researchers. Along with this, the optimal solutions are achieved by applying optimization algorithms. The protection of transmission lines is performed by detecting and eliminating faults occurred at several locations. Following are the outcome of the paper that are studied to design a novel model for transmission line protection.

2.2 LITERATURE SURVEY

- **Vikram Singh R Parihar,** [18]**:** This paper mainly emphasized on distance relay applications to protect the transmission systems utilizing controllers of electric power transmission such as Unified Power Flow Controller (UPFC). At first, UPFC comprehensive model and control of it was presented and then it was integrated to the gear for requirements of precisely simulating the transients of fault. The results of the simulation represented the UPFC effect on distance relay performance for different conditions of fault and for different locations of fault.

- **Xiaoyao Zhou, et al. [19]** In this paper, author had presented analytical as well as simulation results of distance relays application for transmission systems' protection using FACTS like unified power flow controller (UPFC). In order to simulate the fault transients correctly, initially an extensive UPFC model and control was presented and afterwards it has been merged into the transmission system. A clear impedance calculation process was then examined for a UPFC transmission line on the basis of the component for the power frequency sequence. The results of the simulation revealed UPFC effect on the productivity of a distance safety relay in various conditions of failure; also, these analyses considered the impact of the UPFC control parameter setting and UPFC operating mode.

- **Kazemi, A. et al.:** In paper [20], author introduced a dynamic distance protective approach in the existence of UPFC, one of FACTS system. The fact that UPFC was present on a transmission line had major effect on the impedance evaluated on the relaying line. The evaluated impedance on its own relies on the structural factors of the power system, loading of pre-fault and in particular fault tolerance. The control and structural and installation parameters of UPFC affected the impedance evaluated. The previous distance systems could therefore not satisfactorily attain the protection obligations and thus innovative methods were necessary.
- **Pandey, Sonu & Tripathy, Manoj. [21]** In order to improve power transmission capabilities and reactive power management, the FACT controller was installed in the transmission line. The FACT systems that integrate the shunt fact component functionalities with series fact components were taken into account, i.e. th e UPFC was concerned with the dynamic protection of transmission line in which the unit was being situated at various location of the transmission line as a center of the transmission line, the transmission line's send and receiving end. The PSCAD / EMTDC software was used to design and simulate the UPFC integrated into the transmission line. UPFC effect on the distance relay was defined by impedance trajectory. In the existence of UPFC in various fault calculation, current and voltage disturbance and prevalent impedance was performed.
- **T. Manokaran and v.karpagam,[22]:** In this paper, author had presented simulation results of distance relays application for transmission systems' protection using FACTS like UPFC. In order to simulate the fault transients correctly, initially an extensive UPFC model and control was presented and afterwards it has been merged into the transmission system. The results of the simulation revealed UPFC effect on the productivity of a distance safety relay in various conditions of failure and in various locations of fault.
- **Z. Moravej, M. Pazoki, and M. Khederzadeh[23]** This article scrutinized the distance relay efficiency for a compensated and uncompensated UPFC transmission line under power swing settings. UPFC controls independently the

transmission line's voltage and flow of power ,thus it effects the prevalent impedance observed via distance relay. The prevalent impedance observed by distance relay was extracted while power swing to assess the case and the results were graphically presented. The effect of UPFC was analyzed from an impedance perspective on various transmission-line factors. In addition, comprehensive simulations were used to assess the effects of various UPFC operating modes and its reference value on the prevalent impedance shown on focused circles as a power swing identification approach.

- **L. Yusuf and M. N. Nwohu, [24]*:*** Author in this paper had examined the implications of UPFC, in the Nigerian 330kV (North-Central) Network, on features of distance relay tripping. The impedance evaluation at the point of transmission was the one on which its operation was based upon. Nevertheless, specific structural for operational factors like load angle, magnitude ratio of voltage at the ends of the line, pre-default line loading and short-circuit levels at the ends of the line often hinder the performance of system. The UPFC, built into the Nigerian north center (330kV) network, was designed in the PSCAD environment and maintained within the relay's protected area to enhance the appearance of resistance to malfunction of the relays. The study of a simulation therefore demonstrated that the existence of UPFC in a weak, distance relay-protected transmission line loop greatly influences the trip limits of a distance relay by putting it over reach or below reach state. Therefore, the distance relays' tripping features including its UPFC situated at various locations in terms of a transmission line fault resulted in 3 situations, the findings of which were described in this paper.
- **Albasri, F.A. et al. [25]:** In this paper, the efficiency of transmission lines' distance security was presented when provided with shunt FACTS devices/controllers. For shunt-FACTS devices deployed for middle point voltage control, the efficiency of distance protection was assessed. For various fault varieties, fault positions and System scenarios, the effect of two kinds of shunt FACTS devices i.e. SVC and STATCOM were examined on the distance protection of transmission line. The characteristics of the shunt-FACTS were regarded and simulated with the help of RSCAD / RTDS testing environment with the related control system. The performance of fundamental/non-pilot distance

approach as well as directional comparison blocking (DCB) approach was assessed in the presented paper. The outcomes of viable relay testing represented the poor impacts of transmission lines' mid-term shunt-FACTS compensation on DCB and non-pilot approaches.

- **W. Zhang, et al., [26]:** The distance relay significantly protects the transmission lines and FACTS controllers' application like STATCOM will have a compensatory effect on performance of distance relay. The study and simulation outcomes of distance relay application to secure the transmission line comprising STATCOM were presented in this article. Matlab /Simulink modeled a standard 500 kV transmission network utilizing STATCOM, and STATCOM's impacts on the distance security approach were analyzed for various failure types, fault positions and configuration of the system. The distance relays performance was assessed and a novel distance relay theory system was introduced for the STATCOM transmission line on the basis of these simulation and analytical results.

- **Wei-Feng Li, et al. [27]:** VSC based FACTS was utilized in distribution and transmission systems for voltage control applications. Flexible VARs needed for voltage support system failure can quickly be supplied by FACTS. The actual impedance was determined by the injected or absorbed reactive power of FACTS, which allows the distance relay to be under or over reached. In this paper, the simulation outcomes of the use of distant relays to protect transmission systems using FACTS controllers were presented. In the MATLAB / Simulink, the full virtual FACTS simulations were performed via the Power System Block (PSB) set in a transmission system. Using the ANN method, which is independent of the impedance of the fault, the distance of the fault and the starting angle of the transmission line of defect currents of FACTS controllers, an efficient wavelet-based method was proposed to detect and classify the failures and their locations.

- **Sadhu, Rajib & Bhowmik, P [28]:** The inclusion of FACTS controllers in the transmission line can significantly influence the distance relay performance. With varying FACTS controllers, the prevalent impedance and the related distance relay reach can change. In the presented paper, a comprehensive model of FACTS unit based on VSC such as UPFC and its function as a series, shunt and shunt-series unit during fault of single-line to ground was presented. In addition to a more comprehensive discussion on the concepts of the distance protection approach, inclusive and exclusive of FACTS controllers, the proposed STATCOM and Static Synchronous Series Compensation Series (SSSC) models were also precisely simulated, together with their respective operations, at the fault time. An apparent process for computing impedances was developed for distance relays with STATCOM, SSSC and UPFC installations. Distance relay behaviors when connected with an offset line were also examined with these devices.

- **Dash, Pramod et al. [29]** In a two-terminal system, existence of a supreme FACTS device like UPFC can rigorously influence the performance of a distance relay attached by a double-circuit transmission line. Some of the restraint features of the UPFC are, its position on the transmission system and the fault resistance, mainly the high ones make this issue more critical and intricate. Also, UPFC locality with respect to the fault location considerably impacts the trip boundaries of the distance relay. With fluctuating UPFC parameters and location, the presented paper showed recognizable impedance calculations for disseminating of a double-circuit transmission system. The study showed the flexible nature of the protection approach that entails the utilization of an artificial neural network (ANN) based process for the creation of trip boundaries while fault events.
- **Kalair, Ali Raza; et al. [30].** Distribution FACTS (DFACTS) equipment are developing techniques to reduce voltage swells, sags, flickering and harmonics while transitory and steady state operations. The concept of the application of FACTS to damp larger or smaller power changes to enhance stability appears unstable in traditional grid intellectual algorithms, however, was based on simulation research. Electronics and communication technology have enabled traditional grid smarter and artificial intelligence-based algorithms even intelligent. SVC, STATCOM, SSSC, UPFC, UPQC, DVR, TSC and TSR are all advanced FACTS devices. A real-time reference that endures from limitation of communication delay has been required by utilization of STATCOM, SSSC and UPFC. The 4PU to 5PU high voltage pulses and current pulses were generated by STATCOM and SSSC that are large enough for insulator puncturing to undermine coordination of insulation. Working with STATCOM and SSSC

ineffectuates security relays and pollutes the quality of electricity. Optimal control systems oscillate between 0.1 and 2Hz for the period from 2.5 to 7 seconds and protective relays for 0.05 to 0.5 seconds to remove defects. Power engineers assume that FACTS equipments destabilize the electricity system because of their own existence so they may be restricted to distribution and generation sides with certain snubbing circuits.

- **S. Mishra, at al. [31]** Due to development in technology, there is a precipitous increase in power utilization and its requirement in present time. Therefore, to fulfill the requirement of never-ending power demand, electric organizations are thinking to reconstruct the existing networks as well as to enlarge the capacity. In modernization, incorporation of FACTS devices into existing system intensity the dissemination line capacity of the existing network which prohibits the organizations to go for capacity extensions that is why it is one of the most favored option. In addition to this, FACTS devices amplify the standard of power and accuracy of the system. Due to its adaptability in synchronizing voltage and power transfer, UPFC was most favored FACTS device. Despite that, in the transmission system the incorporation of FACTS devices may hinder the security system. However, in various researches it was observed that FACTS devices influence the cooperation between defensive relays consequences of which are either under-reaching or overreaching of the relays. .Hence, this paper demonstrated the study of contrasting factors which impact the distance protection scheme of UPFC employed lines. The examined characteristics in this occasion were installation point of UPFC, operating modes of UPFC, location of fault, different fault resistances, different fault inception angles, different type of faults and external faults. For all simulation analysis, MATLAB environment was selected as the simulation platform.
- **B. Kumar, et al. [32]:** Author in this paper had presented an IDP character trait to protect compensated transmission line FACTS utilizing 2-terminal synchronized metrics. All shunt failures in a safe zone were accurately defined with the proposed technique. In a intricate plane, a restraint area was established with the impedance ratio information and the angle difference between both terminals in order to identify a short-circuit shunt failure in its protection zone. The y-axis represents the impedance ratio in a complex plane and the x-axis

represents the angle difference. In a three-machine with a comprehensive UPFC and Western System Coordinating Board of the 9-bus Systems, the proposed IDP features were assessed. The results of simulated test were demonstrated to be more accurate and sensitive. The assessment of IDP properties in various error situations proved their precision, selectiveness and robustness. Simulation studies had taken into account various UPFC operating modes, UPFC compensation levels, noisy situations and errors of CT and CCVT. The supremacy of the IDP feature was shown by simulation results.

- S. **Mishra, et al. [33]:** The technological advances in today's world have led to a sharp increase in power utilization and demand. Electronic services decide to expand capacity and modernize the existing networks in order to meet the ever-growing demand for electricity. The integration of FACTS controllers into the current system has been one of the favored modernization choices, as it improves the capacity of the existing network's transmission line, restricting utilities from expanding capacity. FACTS devices also enhance the system's power efficiency and reliability. Because of its versatility in voltage regulation and power transmission, UPFC is the FACTS most popular device. The inclusion in the transmission system of FACTS controllers however impedes the security system. In various studies, FACTS devices have been found to impact the protective relays coordination that either under do the relays or overrun them. This paper therefore analyzed various factors that influence the UPFC distance security system. The regarded factors in this case include UPFC, UPFC installation point, operational modes, fault location, various failure resistance, various angles for starting faults, various types of failures and external failures. The simulation studies were performed in the MATLAB environment.
- **M.Y.Ali Khan, [34]:** Day after day, electricity demand is on the rise and more power needs to be produced to meet the demands of load. Many experts gave preference to expand existing electricity systems by designing a new system with higher expense. This paper explained how the FACTS devices can be applied in a simplified electrical system. The FACTS equipments improve the line's capacity for power transmission without establishing a new transmission line. In the case of a failure in the electrical grid, these tools often protect the network from overload. In addition, this paper delineated the effects of FACTS on enhancing the stability

and power handling capacities of the transmission line. The introduced approaches were also known for regulating the reactive and active power flow in a transmission line. A basic electrical system was analyzed to illustrate the enhancements in power system limitations utilizing FACTS.

- **Mohamed I. Mosaad et al., [35]:** DFIG is widely used in wind energy conversion systems (WECSs) because of its low rating and cost of converters and DFIG's ability to operate at changing wind speeds. However, DFIG's output was prone to changes in the grid operating conditions and disturbances. This covers wind blowing, fluctuation in voltage and defects at the point where the DFIG and the grid are joined together. In this research, a Model-Free Adaptive Control (MFAC) for a UPFC was built to enhance the dynamic efficiency of the WECS based on DFIG in wind turbines and to improve the failure of the DFIG during different trouble events. The presented controller's efficient performance was evaluated by contrasting it with traditional PI controller which was optimized via improved flower pollination algorithm. From the obtained results, it has been demonstrated that the proposed UPFC-MFAC approach was superior to traditional PI controller.
- **S. Biswas and P. K. Nayak, [36]:** There is a rising trend these days to include huge capacity offshore wind farms in power networks via UPFC offset TLs to accommodate the huge power flows. Owing to the unpredictable change in the speed of wind and the varied UPFC operating modes, nonlinear variations in power output have a major effect on the performance of the traditional distance relay TL safety technique. This paper explored the effect of these TL on the efficiency of distant relays and introduced a new fault classification and identification strategy based on two criteria. The approach used both ends of the failure identification line and the transitory monitor index abstracted from the locally evaluated 3-phase fault classification current as a symbol of a change in the positive sequence current magnitude. The proposed system performance was assessed on different transients produced on 2 standard test systems via EMTDC / PSCAD in various UPFC operating modes and at varying speed of wind. dSPACE DS 1103-based, real-time computer simulation system further validated the effectiveness of the new approach. At last, some significant current

approaches were used with comparative evaluations findings to demonstrate the efficiency of presented approach.

- **Zahra Moravej, et al. [37]:** Loss of excitement (LOE) can severely affect the generator and the power system in synchronous generators. LOE has been identified with the use of a mho negative offset in the traditional procedure. Here, the identification speed was low and a reliable power swing can also be erroneously detected in some conditions. The malfunctioning of traditional LOE relays can lead to an outage. In addition, the FACTS modify the LOE relay impedance which thus impacts the behavior/performance of the LOE relay. This paper discussed the applicability of electrical and mechanical fractions. Consequently, some relevant mechanical and electrical characteristics were extracted between quantities. The classifier was then used and few cases of LOE, partial LOE and stable power swing (SPS) were simulated to determine the efficiency of the proposed approach. The results attained represented that the method developed was indeed strong and safe to distinguish LOE from SPS. Furthermore, in the existence of FACTS controllers, the suggested technique was quick and sufficient to identify LOE by the delay increased with compensation tools.
- **Rashid and Luay G. [38]:** The demand for electricity has risen significantly over the last few years, while electricity generation and transmission have been broadened viciously owing to environment and resource limitations. Most power lines were heavily loaded; the strength of the power grid therefore was a major bottleneck for the electric power transmission. Consequently, it is necessary and demanding to maintain secure and reliable electricity grid service. The FACTs devices that allow the power and damping oscillations to be managed were being utilized. Thus, in this paper, author highlighted the modified PSO (M-PSO) algorithm for identifying optimal design parameters of PI controller (PI-C) which enhances the reliability of Multi-Machine Power System (MMPS) along with UPFC by using MATLAB environment. The performance of power system in fault condition was examined by using introduced two approaches for simulating the operational features of the power system via UPFC by utilizing: first, traditional PSO based- PI-C (PI-C-PSO) approach; second, M-PSO based -PI-C (PI-C-M-PSO) approach. The results of the simulation represented the power

system behavior inclusive and exclusive of UPFC, which revealed that introduced PI-C-M-PSO approach has high response to system than other approaches that minimized the previous under and over shoot in the transitions. The results obtained delineated that simulation model's transient stability was enhanced considerably with the help of proposed approach.

- **Luay G. and Rashid H,[39]:** Over the last period and in recent years, the numerous power cuts in the energy grid have shown a great deal of work still required to tackle the voltage of uncertainty and the resulting failure. The present study illustrated the way in which the Hybrid Line stability Index (HLSI) for prediction of collapse of voltage in power system networks can be used to select and place optimally the FACTs tools. These HLSIs were achieved using the simple expressions Line Stability Index (Lmn) and Fast VSI (FVSI) and combined with the voltage angle variation-based logic to indicate the collapse of the nearness voltage. The testing of the HLSI was performed on IEEE 9-bus system which gave same results like the other indicators (FVSI and Lmn). For the basic state, IEEE 9-bus system was stable, with approximately the same value < 1 for every line for each three indicators. The contingency condition identified the rank of bus 5 which was the most weak bus in system having lowest reactive charge (120 MVar), and that the critical line of bus 5 is the line connecting bus 5-7. The values of FVSI, Lmn and HSLI, had almost equally improved the precision of HLSI.

- **Shobhit Nandkeolyar ,[40]** The mho relay is the most popular of the numerous LOE relay systems in use today. The impedance shown to the relay was introduced in protection zones during LOE which were set up in line with the generator and system specifications. In the event of a failure, it produces a trip signal to isolate the damaged alternator from the device. Today's power systems provide FACTS equipment to deal with different tasks such as voltage regulation, enhanced transient stability, voltage instability protection, and power oscillation damping. The reactive potential of the shunt-FACTS systems has been shown to prevent a collapse of the terminal voltage of the LOE alternative, which leads the LOE relay to be delayed. The existence of shunt-FACTS devices can lead to the relays under-reach in some conditions, like partial LOE or even during the condenser operating mode of a shut-off alternator. This paper examined the impacts on the LOE safety of an alternative by shunting FACTS tools, such as SVCs. Simulations have been conducted for different LOE relay strategies, during failures on the excitation system, in the MATLAB / Simulink environment.

- **Sergio Bruno, et al. [41]** The renewable sources great penetration, integrated with restrained likelihood of extending the infrastructure of transmission, expands the stability of system in event of faults. Due to this, extra control flexibility has been called by operators in grid. The author in paper [41] presented the implementation of switchable capacitors and reactors that are distributed over grid in the form of control resource to secure the operations while stern incidents and prevent possible shutdowns. Based on principles of operation, a line reactance changes by turning particular quantity of distributed series capacitors and reactors on and off and, thus, stabilizing control rule has been dependent on stepwise time-discrete operation. The control approach, dependent on dynamic optimization, was introduced and its testing was performed on transmission system of realistic-size.
- **Yamen R.Alsyoufi and Ammar A.Hajjar, [42]:** Distance relay while power swing must be blocked, however reliably operated if there is any fault during power swing. This study therefore presented a high-speed algorithm dependent on transformation of wavelets to differentiate among symmetrical/ asymmetric failures and a power swing. The model utilized a quick-mother wavelet with a high-pass filter of 3 coefficients to break down current and voltage signals to their appropriate frequency ranges. Two different levels were selected in this respect. A fault and a power shift were detected by 1^{st} level of voltage signal and 18^{th} level of current signal. The distance relay can differentiate among power swing as well as any failure which may arise during power swing, based on the percent change in spectral energy of such discriminatory signals. A standard additional large voltage transmission system by using MATLAB was used to simulate the power swing events for assessing the output of the implemented algorithm with several errors, including high-resistance failures. Simulations demonstrated that, even when the signals were noisy, the proposed algorithm had a fast speeds and had effective performance in which the power swing was identified in the appropriate time and failure was identified in one or less cycle.
- **Rahul Dubeya et al. [43]:** The paper outlined the pliable distance relay system for parallel transmission system linking wind farms. In the existence of a

reciprocal coupling of the parallel transmission lines, appropriate trip properties of a distance relay were heavily influenced by the apparent impedance. Likewise, because as end voltage of the relay fluctuates constantly, the relay configuration for the wind farms connection lines was greatly affected. The study presented therefore focused on creating a pliable relay system for parallel network which includes large variations of wind farms' operating conditions and the effects of mutual interaction between them. In addition, the proposed parallel line adaptive relay systems performance including UPFC showed the potential efficacy of the presented analysis method to handle the transmission system distance relay.

- **Susant Duttait et al. [44]:** A novel method of optimization of hybrid chemical reactions (HCRO), based on optimization of the chemical reactions (CRO) and differential evaluation (DE), was presented in this paper in order to identify the best positioning and parameter settings for UPFCs for effective network performance. Four basic reactions, i.e. inefficient collision on the wall, inefficient inter-molecular collision and decomposition & synthesis, were produced in the presented algorithm. In addition, the DEs mutation operation was merged with an inefficient inter-molecular collision and operation of crossover was proposed in synthesis, inter-molecular collision, and breakdown operation, to speed up convergence and enhance CRO algorithm quality. In this, 3 separate main targets were used, namely the total cost minimization, transmission loss, deviation of voltage and one multi-target was used that concurrently reduces loss of transmission and deviation of voltage. For effectiveness testing, IEEE 14-bus and IEEE 30-bus power systems was used on which the presented HCRO method was implemented. In addition, the results of simulations of introduced HCRO method were contrasted with CRO and other algorithms already presented in literature like, GA, PSO, immune PSO (IPSO), immune GA (IGA) and hybrid immune algorithms (HIA) to demonstrate their superiority. The findings of the suggested HCRO method were found to be superior to other presented algorithms.
- **R. Jordehi and J. Jasni, [45]:** In this paper, author comprehensively discussed various techniques for solving the FACTS problem of power systems optimization. First, the needs were explained as an optimal solution

for optimization of the FACTS issue, and then the techniques utilized by researchers were classically classified in 4 major groups, including technical approaches, heuristics and mixed approaches, and the character traits, potential benefits and inconveniences of every group of techniques were presented attentively. At last, few suggestions for further research in this field were provided.

- **M. Saravanan et al. [46]** By applying PSO approach, this paper identified the ideal positioning for FACTS devices with increased system loading (SL) and least installation cost. The thermal and voltage limit for lines and buses respectively were used as restrictions when the optimum location was determined. 3 kinds of d FACTS systems were taken into account i.e., TCSC (thyristor controlled series compensator), SVC and UPFC. The parameters for optimizing the location, environment, form and cost of installation of FACTS were explicitly determined. Two examples, specifically, single devices (similar FACTS devices) and multi-type devices (TCSC, SVC, UPFC combinations) were taken into account. IEEE 6, 30 and 118 bus systems and the 69-bus Tamil Nadu Electricity Board (TNEB), a practical system available in India to locate FACTS devices optimally, were used to perform simulation. The findings were efficient and beneficial in the process of reforming electricity.

CHAPTER 3

MATHEMATICAL FORMULATION OF UPFC

3.1 INTRODUCTION

Electricity demand rises exponentially every day worldwide, which means that the most superior supply quality of transmission and distribution systems is required. Flexible AC Transmission Systems (FACTS) are critical for enhancing existing transmission line's power transmission capacities and increasing distribution line's quality of power in the last two decades. The emergence of FACTS devices in power system, however, has a major effect on the performance of current protection relay, making system protection difficult. Various research works were conducted that examine the effect of different FACTS controllers on relay protection and assesses practical solutions for alleviating these issues.

3.2 OVER VIEW OF THE FACTS CONTROLLERS

3.2.1Need for FACTS Devices

The demand for electricity is rising dramatically on the whole, requiring an extension of the interconnection of the transmission network. Extra costs, problems relating to the environment and social ills limit the creation of new installations, and that in turn leads the sharing of previous transmission systems. Such limitations have driven the development of novel approaches and strategies for enhancing the use of transmission systems available. One of such alternative is to use FACTS devices to eliminate these limitations and to fulfill the objectives of planners, operators and investors without massive system changes. This enhances the capacity for transmission of power under ideal circumstances without building new transmission lines. Because of the advent of the semiconductor industry and applications of it in power systems, the notion of FACTS is being provided. [47]. The major benefit is that reactive power is generated and absorbed without using devices such as capacitors or reactors. The FACTS systems are ideal for use in series, shunt or shunt series in transmission lines and operating parameters can be controlled in a steady state transmission system and the dynamic system output in a transient condition can be attained [48]

3.2.2 Definition of FACTS

The word FACTS encompasses a set of static power electrical devices and appliances which controls one or even more parameters of AC distribution and transmission system. This is a system that increases quality of power, flexibility, and controllability and enhances power transmission capacity of distribution and transmission system. The FACTS definition is- system based on energy electrical device and other static device, which offers control over one AC transmission system or more and enhances the power transfer capacity [49].

3.2.3 BENEFITS OF FACTS TECHNOLOGY

FACTS controllers have potential advantages as following [50].

- Power flow control as requested. Increased loading power, including short-run and seasonal, of the lines.
- Increased system safety by increasing the limit on transitory stability, reducing currents and overloads on short circuits, controlling cascading power outages and steaming electromechanical power system and machinery oscillations.
- Ensure secure links to adjacent utilities and fields, thus lowering entire reserve generation requirements on both ends
- Making the new generation more flexible.
- Reduction of flow of reactive power that enable lines for carrying more active power.
- Loop flows' reduction.
- Maximize use of least expensive production.

3.2.4Classification of FACTS Controllers

The controllers of FACTS are grouped into two types; the first is the previous generation controllers that depend on well-established thyristor valve technologies, and the second is the new VSC (Voltage Source Converter) technology that is mainly based on Insulated Gate Bipolar Transistors (IGBT). Although the two categories offer similar services, the biggest difference is that VSC technique is much speedier and also consists of wider range of controls. The FACTS devices can generally be subdivided into 4 categories: Shunt FACTS controllers, Series FACTS controllers, integrated series-series FACTS controllers, and integrated series-shunt FACTS controllers. [51].

Some of the FACTS controllers which offer enhanced reliability, quality, control of system and operational flexibility are:

- Static Synchronous Compensator (STATCOM)
- Static VAR Compensator (SVC)
- Static Synchronous Series Controller (SSSC)
- Unified Power Flow Controller(UPFC)
- Inter Phase Power Flow Controllers (IPFC)
- Inter Line Power Flow Controllers (ILPFC)
- Distribution Static Synchronous Compensator (D-STATCOM)
- Distributed Power Flow Controllers (D-FACTS).

3.2.5 TECHNICAL ADVANTANGS OF FACTS CONTROLLERS

It is quite important here to indicate that the power systems are facilitated by these controllers to control the majority of parameters. The significant technical advantages are [52][53][54]:

- Control of power flow
- Increase of the line 's voltage, thermal and SSS limit load ability
- Enhance transitory and dynamic stability, reduces current and overload in short circuit and thereby makes the system safer.
- Ensure reactive power compensation
- Enhanced new generation flexibility.

The FACTS controllers list was created to take these potential advantages into consideration when one or even more advantages could be overlapped by the majority of controllers since most of the power system parameters are interconnected. With different controllers, measuring variables such as transient and voltage stability, can be different and this has been overlooked in [55] [56] [57]. Although, a tabular representation of FACT devices is presented (table 1) that delineates the contribution of each device in various applications.

Table 1: Technical Contribution of FACT controller

Sr No.	FACTS Controllers	Technical contribution
1	Static Synchronous Compensator (STATCOM)	Control of voltage Dynamic and Transitory stability Stability of voltage VAR compensation Damping oscillations
2	Static VAR Compensator (SVC,TSC,TCR)	Control of voltage Dynamic and Transitory stability Stability of voltage VAR compensation Damping oscillations
3	Static Synchronous Series Compensator (SSSC)	Control of current Dynamic and Transitory stability Stability of voltage Damping oscillations
4	Thyristor Controlled Series Compensator (TCSC/TSSC)	Control of current Dynamic and Transitory stability Stability of voltage Damping oscillations
5	Unified Power Flow Controller (UPFC)	Control of active and reactive power Dynamic and Transitory stability Stability of voltage VAR compensation Damping oscillations
6	Interline Power Flow Controller (IPFC)	Control of voltage Control of Reactive power Dynamic and Transitory stability Stability of voltage Damping oscillations

3.3UPFC

There are several feasible and cost-effective solid-state deployment projects for UPFC, considered to be technology now available. Recent developments in the field of power in electronics have allowed high-power switching devices in FACTS applications, such as the GTO Thyristors . A UPFC basic structure schematic map is shown in Fig. 1. UPFC consists of a serial connecting transformer with a GTO, a shunt connected transformer connecting converter 1 to the transmission line and a serial transformer connecting converter 2, as well as a dc connection supplied by a dc condenser.

The converters main task is to transform the input DC voltage in connection with the selected reference phases into the symmetrical output AC voltages of the desired magnitude and frequency and phase shift. The purpose of the coupling transformers is to isolate UPFC and the transmission line and to comply with the voltage levels between the transducer line and the voltage produced by it. In series with the transmission line via series connected transformer, Series converter inserts the voltage of controlled magnitude and controllable phase angel, thereby providing real and reactive power flow control on the transmission line.

The real power injected into the system by the series branch must be taken from the parallel branch and transmitted to the series branch over dc link. With this respect, series branch provides the main function by injecting an ac voltage V seat system frequency with variable magnitude and phase angle in series with the line. During the operation, Vse is added to the AC system terminal voltage Vs, by the series-connected coupling transformer. Transmission line current IL flows through voltage source, Vse, resulting in real and reactive power exchange between UPFC and the power system. The conceptual series inject power into system by the series branch. Phase angle of output voltage of converter could be selected independently of the phase angle of IL, that in turn lead to output voltage of series branch, thus, voltage V_{se} is controlled with ease. This enables free flowing of real power in either direction between ac terminals.

3.3.1 MATHEMATICAL FORMULATION OF UPFC

Two voltage sources representing critical components of the output voltage wave types of the two converters and the impedance are described in UPFC. Figure 5 is the

the UPFC configuration of two voltage sources. Reference vector $V_i = V_i \angle 0°$ and $V_i' = V_{se} + V_i$ is considered as reference. Voltage sources V_{se} and V_{sh} are controllable in pu (r) and phase angle (γ) of serial tension source within the defined limits set out in Eq.(1). V_{se} and V_{sh} are controllable in their scope and phase angles.

$$0 < r < r_{max} and\ 0 < \gamma < 2\pi \qquad (1)$$

V_{SC} should be defined as:

$$V_{SC} - rV_i e^{ft} \qquad (2)$$

The voltage source V_{SC} is replaced and the model is designed by using a current source I_{SC} connected parallel with the transmission lines, where $b_{SC} = 1/X_{SC}$.

$$I_{SC} = -jb_{SC}V_{SC} \qquad (3)$$

The current source I_{SC} can be modeled by injection powers at the two auxiliary buses i and j.

$$S_{iS} = V_i(I_{SC})^* \qquad (4)$$

$$S_{jS} = V_j(I_{SC})^* \qquad (5)$$

Injected powers S_{iS} and S_{jS} can be simplified according tp the following operations by substituting eq 2 and 3 and eq. 4.

$$S_{iS} = V_i(jb_{SC}rV_i e^{ft})^* \qquad (6)$$

By using Euler identity, ($e^{ft} = \cos\gamma + \text{j}\sin\gamma$), eq 6 takes the form of

$$S_{iS} = V_i(e^{-j(\gamma+90)} jb_{SC}r\, V_i^*) \qquad (7)$$

$$S_{iS} = V_i^2 b_{SC}r[\cos(-\gamma - 90) + \sin(-\gamma - 90)] \qquad (8)$$

By using trigonometric identities eq. 8 reduces to

$$S_{iS} = -rb_{SC}V_i^2 \sin\gamma - jb_{SC}V_i^2 \cos\gamma \qquad (9)$$

Eq 9 can be decomposed into its real and imaginary components.

$$S_{iS} = P_{iS} + jQ_{iS}, \qquad (10)$$

where

$$P_{iS} = -rb_{SC}V_i^2 \sin\gamma$$

$$Q_{iS} = -rb_{SC}V_i^2 \operatorname{Cos}\gamma$$

Similar modifications can be applied to equations 5 and final equation takes form of

$$S_{iS} = V_iV_jb_{SC}r\sin(\theta_i - \theta_j + \gamma) + jV_iV_jb_{SC}r\cos(\theta_i - \theta_j + \gamma) \quad (11)$$

Eq 11 can also be decomposed into its real and imaginary parts,

$S_{iS} = P_{jS} + jQ_{jS}$, where

$$P_{jS} = V_iV_jb_{SC}r\sin(\theta_i - \theta_j + \gamma) \quad (12)$$

$$Q_{jS} = V_iV_jb_{SC}r\cos(\theta_i - \theta_j + \gamma) \quad (13)$$

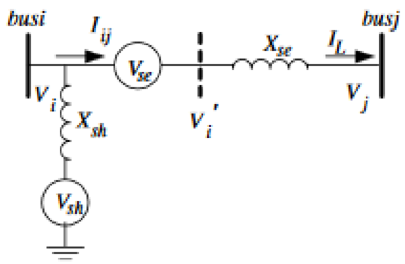

Figure 4: two voltage source model of UPFC

OVERVIEW OF THE PROTECTIVE RELAYS

3.3.1 Protection Relays

Relay is the predominant component of a power system protection. To begin suitable power system changes and identify unusual power system conditions, protective relays devices are formulated. When an unfamiliar situation takes place, they rapidly segregate the faulty section or electrical equipment so that it does not harm the equipment and also to make sure a reliable operation. They are categorized correspondingly to input quantities, principles of operation, performance features and technology.

3.3.2Distance Protection Relays

It is necessary to accurately identify, classify, and locate the faults, and clear the faults on transmission lines as soon as possible. There are several types of relays utilized to provide security to the power lines but distance relays are most appropriate to fault locators. For the fault location process in the transmission line, a number of new and efficient methods have been in execution. These approaches can be widely categorized as approaches based on travelling wave, approaches based on Impedance, and approaches based on Artificial Intelligence [58]. Due to its simple operating principle, distance relays based on impedance are utilized widely to keep safe transmission lines and also used to calculate the impedance between the relay location and the fault point. From the relay to the fault, the calculated impedance is proportional to the distance, if the resistance of the fault is low. When a fault appears betwixt the relay location and the selected reach point and remains steady for all faults outside this zone [59] then it works. Following are the some fundamental types of distance relays based on impedance:

- Simple impedance relay
- Mho or admittance relay
- Reactance relay
- Ohm or angle impedance relay and
- Offset mho relay

In the transmission line, the most significant protection devices are the Distance relays. At times, these relays can be set on the basis of line impedances percentage, for instance: for zone 1, the usual setting is 80% of the line impedance for not reaching remote end, the setting of zone 2 can be done at 120% of line impedance for reliably overreaching the line, and the Zone 3 can be disabled or can be set for covering the adjacent line.

3.3.3 Principles of Distance Relays

As the transmission line impedance is proportional to the length, the relay that can calculate the line impedance up to a default point (reach point) is suitable to be used for measuring distance.

The distance protections' underlying principle is that the voltage is separated by the calculated current at the point of relaying. This measured apparent impedance has been contrasted with the impedance of the reach point. If the calculated impedance is lower as compared to impedance of the reach point, the line between relay point and reach point shall be assumed to have a fault.

The point of reach of a relay is along the locus of the line impedance intersected via relay's boundary feature.

This can be plotted on R / X diagram as it depends on the voltage-current ratio and their phase angles. In the context of faults, swings of power and load changes, the loci of impedance to the power system as seen by the relay can be plotted on the same chart and thus the relay performance can be studied with system error and disturbances. [60].

3.4 RELAY PERFORMANCE

The performance of the distance relay is delineated as accurate reach and operating time. Accuracy of reach is the contrast of the relays' exact ohmic reach in practice with the value of the Relay in ohms.

There is also an impact of the impedance measurement approaches used in specific designs of relay. Times of operation can change with the fault current, fault position in relation to the relay setting and with point on which the fault arises on the voltage wave.

Evaluating signal transient failures like those made by Capacitor Voltage Transformers and diluting CT's, may detrimentally delay the relay operation for failures near the reach point, based on the measurement methods used in the specific relay design. The higher and lower operating times are typically estimated for electric-mechanical and static distance relays.

The variance among these is low over a broad range of operating system parameters and positions of fault, for advanced digital or numerical distance relays.

3.5 DISTANCE RELAY CHARACTERISTICS

Certain numerical relays calculate the absolute failure impedance and then decide if the impedance limits specified in the R / X diagram must be operated accordingly.

Conventional distance and numerical relays, which imitates the conventional relay impedance elements, don't calculate absolute impedance. They contrast the fault voltage determined with the fault current replica voltage and the impedance of the zone settings to assess if the fault is in or out of-zone. The distance relay impedance algorithms or comparators emulating conventional comparators are categorized as per the number of inputs they are given, polar features and approach that compares the signal.

The general forms contrast the relative amplitudes or the phases of 2 inputs to acquire operational features which, if plotted on R / X diagram, are either circles or straight lines. At every phase of the evolution of the design of the distance relay, developing impedance operating properties and complexity is controlled by the available technology and the efficient cost.

As numerical relays imitate the strategies of conventional relays and several conventional relays are still used, thus concise analysis of impedance comparator has been justified.

CHAPTER 4

OPTIMIZATION OF FACTS DEVICES

4.1 Introduction

In this chapter, the general background on the theory of optimization and the present optimization techniques for solving the issue of optimum placement of FACTS in power system is presented. There are mainly two parts which defines the general outline of optimization theory:

(i) Classical optimization techniques

(ii) Evolutionary computation techniques (ECTs).

In this, the prior one defines various techniques like quadratic programming (QP), linear programming (LP), non linear programming (NLP), dynamic programming (DP), integer programming (IP), and mixed integer programming (MIP). And the later one generally describes ECTs like genetic algorithm (GA), particle swarm optimization (PSO), tabu search (TS), evolutionary programming (EP), and simulating annealing (SA). The kind of issues which can be resolved by using these techniques, along with their pros and cons are been delineated. The techniques of optimization that can be employed for solving the issue of FACTS devices' optimum allocation are mainly categorized into following three categories:

(i) Classical optimization algorithms

(ii) Technical criteria-based devices allocation

(iii) ECTs.

To solve the FACTS allocation problem in the power system, various algorithms like Enhanced-PSO formulation and various other techniques of optimization like genetic algorithm (GA), bacterial foraging algorithm (BFA), Grey Wolf Optimization (GWO) etc are introduced. Some of the major optimization techniques are discussed in this section as below:

4.2Genetic algorithm

The inspiration of Genetic algorithms is the natural evolution, which were first introduced by Holland in 1975. Genetic algorithms are evolutionary algorithms aimed at better solutions over time. The basic motive for development of genetic algorithm is Darwin's theory of evolution. A population of rules is utilized to discover the solution of specific problems. The population rule is made at first and randomly. Genetic algorithm (GA) is one of the meta-heuristic algorithms which is derived from the evolutionary natural selection and genetic ideas. GA is appropriate for multi-objective optimization issues and can provide better optimal solutions. Generation of offspring by using mutation and crossover methods is the basis for the GA. The knowledge of these methods is dependent upon the type of chromosomes either by using the numeric coding or tree coding, binary coding. In GA, generating two children by exchanging the parts of two parents is the main aim of the crossover method. Two crossover points are used for implementation but depending upon the programming. The crossover follows the mutation.

Selection, mutation and crossover are the basic operations of GA. GA basic ideas are dependent on biological processes of a survival and adaptation. In this, only optimal ones of the populations get survived and propagated to next generations.

- Thus, objective function's derivates is not required in GA for solving intricate and discontinuous optimization issues.
- Also, GA supports multi-objective optimization.
- GA is robust in terms of local minima/maxima.
- It works efficiently on mixed continuous/ discrete problems.

The primary reason for using GM algorithms is that they conduct a worldwide search and deal with attribute interactions better than greedy rule induction algorithm. The most common reason is to find high level predictive laws. A genetic algorithm (GA) is a heuristic search which mimics the natural evolution process. This heuristic is commonly used to provide helpful alternatives to search and optimization problems. Genetic algorithms belong to the broader evolutionary algorithms (EA) class, which provides optimized alternatives with natural evolution-inspired methods such as heritage, mutation, choice and intersection.

This algorithm (i.e. GA) is the process of identifying the appropriate chromosomes which form the population in probable solution space. This type of search endeavors to balance 2 different aims i.e., searching the optimal way out (exploit) and increasing the search space. Therefore, genetic algorithm became a robust optimization tool for resolving the issues associated with various technical and social sciences field, this algorithm is global optimizing one which depends upon natural selection and genetics methods. The algorithm utilizes the corresponding process and structured approach, but arbitrary, intending to support maximum aptitude point's searching. With the help of GA, the intricate non-linear optimization issues such as, non-continuous objective functions, non-convex issues, can be resolved by repeatedly utilizing the 3 operators in the arbitrary manner but depends upon fitness function evolution in order to carry out the essential tasks of replicating strings, swapping string's portions and converting strings' few bits, and at last identify and decode the way outs to the issue from the mature strings' final pool.

4.3 PSO

In the n dimensional space an optimal resolution as a point or a surface is presented by the Particle Swarm Optimization (PSO) that is a global optimization paradigm to deal among the issues. In this position the Hypotheses are located and started at early velocity with communication channels in the particles. By the resolution position the particles shifted and are estimated due to various criteria afterward every time step. In the communication set the particles are speed up to the particles among improved fitness significances on time. The major advancement of this mechanism is that the huge count of members constructing the particle set structures this scheme flexible to the negligible issue comparative to another global minimization mechanism that is the simulated annealing. PSO is based on the intelligence thus it has the following advantages that make it more prior to other optimization techniques:

1. **Features of Self-Organization:** The major concern of Swarm Intelligence mechanism is self-organization. In this procedure the coordination of the location interaction takes place in the components of a firstly disordered method. It is a spontaneous procedure that is not controlled by some agent of the mechanism. By three basic ingredients, the self-organization in swarms is inferred as follows:
    - Strong dynamical nonlinearity (often involving positive and negative feedback): The generation of convenient structures is promoted by the positive feedback whereas positive feedback is counterbalanced by the negative feedback, as well as aids to stabilize, the collective pattern.
    - Balance of exploitation and exploration: In order to offer a valuable mean artificial creativity method, an appropriate balance is detected by the swarm intelligence.

- Multiple interactions: In order to spread the data in the entire network, the data coming from neighbor agents is used by the agents in the swarm.

2. **Principles of SI:** Additionally, Swarm Intelligence should be satisfied by the projected five principles that are illustrated as follows :
   - Proximity principle: In order to do easy space and time calculations, the swarm must be capable.
   - Quality principle: In the condition, the swarm must be capable to respond to quality factors.
   - Diverse response principle: The swarm must not submit its exercises along extremely restricted channels.
   - Stability principle: As the condition alters, the swarm must not alter its mode of behavior every time.
   - Adaptability principle: According to the worth computational price, the swarm must be capable to alter its mode of behavior

4.4 Grey wolf optimization

Grey wolf optimization is a smart method that Mirjalili et al. have created in 2014 and which illustrates the management of wolves known for their group hunting. The GWO imitates gray wolves ' chasing and social hierarchy. It is a meta-heuristic algorithm, and the wolves belong to a Canidae family. The leaders are male or females, called alpha (α) and have a rigid social leading ruling structure and mostly they are the choice maker. The dominant wolf's commands should be followed. The Betas (β) are subordinate wolves that assist the alpha to make choices. The beta is an alpha consultant and pack discipliner. The grey wolf of the reduced classification is Omega, who must present all other wolves of dominance. If a wolf is not alpha, beta and omega then, it's named delta. Delta (δ) dominates the Omega and accounts to alpha and beta.

In order to create and optimize GWO, wolves ' hunting methods and social Hierarchy are mathematically modeled. In addition, the GWO was effectively implemented to solve multiple issues of engineering optimization.

Apart from the social structure of gray wolves, pack hunting is another attractive social activity of gray wolves. Circling, hunting, and attacking the prey are the primary sections of GWO.

GWO algorithm consists of only few parameters and its implementation is simple due to which it becomes greater as compared to conventional ones. This algorithm has versatile features and that's why it is used for tackling the various optimization issues. Grey wolf optimizer finds the best solution in the followed way: first encircling is done, prey is attacked and then another existing prey is searched if it is present.

4.5 Firefly Algorithm

Firefly algorithm is one of the optimization algorithms developed by Yang. It is swarm intelligence based on the meta-heuristic approach which is inspired by the flashing behavior of the fireflies. These are the insects living in groups whose flashes treat as a signal system to other flies. Thus flies based on these patterns interact or communicate with each other. Main characteristics of the firefly algorithms are as:

1. Fireflies are unisexual to attract one firefly, no matter what their gender.
2. The attraction is proportional to the luminosity, which both decrease with an increasing range. Thus, the lighter one moves to the lighter one of any two fireflies. It will move at random if there is no brighter than a firefly.
3. Firefly brightness is defined by the objective function environment.

Consequently, firefly algorithm is based on these two concepts, as variation of the light intensity and formulation of attractiveness whereas attractiveness of a firefly can be firmed by the brightness of a firefly. And it has treated as an objective function of the optimization problem. As firefly's attractive is directly propositional to the light intensity which can be seen by adjacent fireflies.

Thus, it is a meta-heuristic algorithm that relies on fireflies ' blinked conduct in order to find a solution to specific issues in the search area. Indeed, FA is higher in solving non-linear issues of noisy optimization. The FA appears to be an excellent optimization instrument partly because of the results of the firefly-only appeal feature. Firefly algorithm can perform better than many other algorithms. FA has the same benefits as other Swarm-based Algorithms, which are based on Swarm-Intelligence.

FA has, however, two main benefits over other algorithms: automated subdivision and multimodality. Firstly, FA is based on attraction and attractiveness reduces with distance. This leads to the automatic sub-grouping of the whole population, and each group can swarm optimally around each mode and locally. The best worldwide solution can be discovered among all these methods. Secondly, this division permits the fireflies to simultaneously discover all the optimum if the population is larger than the amount of modes. It is particularly appropriate for extremely non-linear multimodal issues with sub-divisioning.

Furthermore, FA parameters can be adjusted to regulate randomness while iterating to speed up convergence by adjusting those parameters. These benefits enable flexibility when addressing ongoing issues, classification and combinatory optimization..

4.6 BFO

Bacteria Foraging Optimization (BFO) algorithm has been used in optimization and proposed by Passino. It has been added in the nature inspired family of optimization algorithms. Trends in last five decades include genetic algorithm, evolutionary programming, and evolutionary strategies which dominates the field of optimization algorithm. Along with these optimization algorithms, there is also nature inspired algorithms named as Particle Swarm Optimization, Ant colony optimization etc. each algorithm have their own unique effectiveness so as bacteria foraging optimization algorithm. In this algorithm bacteria look for nutrients so that energy can be maximized per unit time. There are various bacteria which send the signals to each other for the communication purpose. Foraging decisions have taken by the bacteria after the consideration of two previous factors. The process involved in such algorithm called by scientific names as chemotaxis which considered small steps taken by the bacterium to search nutrients. The main idea of using this algorithm is to imitate those small movements of virtual bacteria in problem search space. Due to its structure and biological behavior it has been a research area and captures the attention of the researchers. This technique can also be used collaboratively with other technique so that one can explore its local as well as global search properties.

The motility is attained through compressive flagella while real bacteria's foraging. Flagella allow an E. coli bacterium to fall down or swim that are the fundamental operations performed during foraging by a bacterium [66]. Every flagellum pulls the cell when it rotates in the clockwise direction. This leads to an independent move of the flagella and after this the bacterium falls down with fewer drops while it often drops to find a nutrient gradient in a harmful place.

The Fig. 4 illustrates the bacteria movement in clockwise and anti-clockwise direction that occurs in nutrient solution.

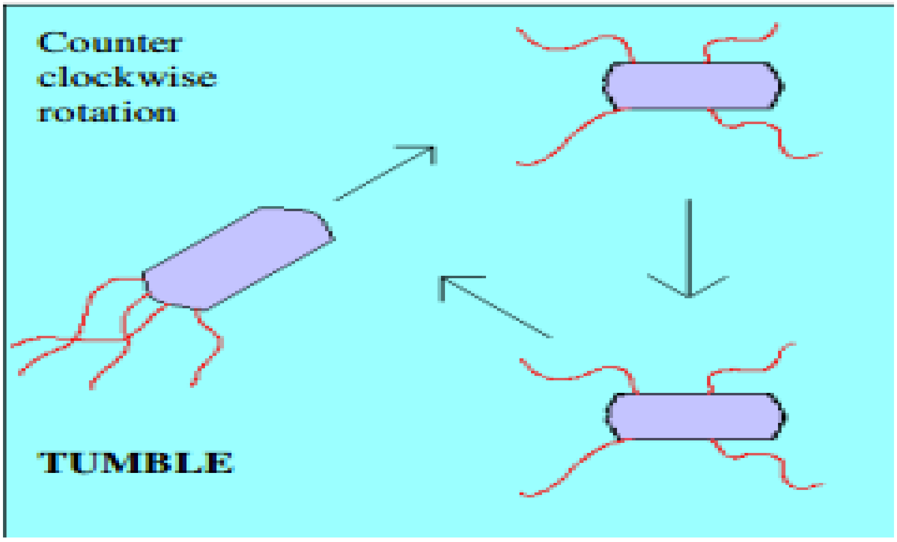

Fig. 5: Tumble of bacteria

Real world problems can be solved with this technique and used over GA and PSO algorithms. In future various researches can be possible in terms of mathematical modeling, adaption, and modification of Bacteria Foraging Optimization Algorithm

The major 4 steps involved in BFOA are described as below:

i. **Chemotaxis**: This method simulates an E. Coli cell movement by swimming and flagella tumbling. E. coli bacterium can biologically move in 2 manners. They may swim in a similar direction for duration of time, or they may fall and reverse between those two operational modes for the whole of life. Suppose $\theta^i(j,k,l)$ delineates the i^{th} bacterium at j^{th} chemotactic, the k^{th} reproductive and the l^{th} dispersal phase removal. C(i) is the step size taken at the tumble specified random direction (run unit length). Then the bacterium's movement can be represented in computer chemotaxis by:

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}} \qquad (1)$$

ii. **Swarming:** Several moving bacterial species such as E.coli and S. Typhimurium have been discerned with the interesting groups, in which complex and robust spatio-temporal (swarm) designs are produced in a semisolid nutrient channel. A community of E. coli cells organize themselves into a moving ring by increasing the nutritional gradient in one nutrient chemo-effecter when positioned within a semi-solid matrix. The cells produce an attractive aspertate when they have been stimulated by a high degree of succinct, which enables to group them and move them like concentric structures of swarms with high density of bacteria. The signal in E.coliswarm from cell to cell can represent the functions.

iii. **Reproduction:** The less healthy bacteria eventually die, while every healthy bacterium is divided asexually into two bacteria (the ones with a lower value of the objective function) and put on the same site. Thus, the swarm size tends to be constant.

iv. **Elimination and Dispersal**: The local environment in which bacteria population lives may be gradually or suddenly affected by several reasons, such as a considerable local temperature rise, could kill a group of bacteria currently present at high nutrient gradient concentration in the region. Events may occur in a manner which kills every bacterium in a region or disperses a group in a new place. Some bacteria are expropriated randomly with a low possibility in order to simulate the BFOA phenomenon while the newer substitutes are initialized at random over search space.

CHAPTER 5

PROBLEM STATEMENT

5.1 INTRODUCTION

In electrical power systems, the major role is played by the transmission lines which are delineated as the conductors designed for transmission of electrical energy from the generating c entre to load centre. Mainly, the performance of the power system gets affected due to the occurrence of the faults. It can lead to over or under voltage, over-current, impedance, power factor, frequency and power or current direction. In most of the cases, almost 90% of fault occurs on the transmission lines and the remaining on substation equipments. There is a challenge in protecting the transmission lines that includes detection of reliability and isolation of the faults responsible for compromising power system security. No detection or elimination of the faults in the lines may eventually lead to instable power system.

Therefore, there is need of a protection system that assist in offering detection and isolation of different fault in a rapid way in order to minimize the damage & disruption of power system is minimized. Different technologies are involved to this end. Following section describes the various approaches utilized from the beginning.

As it is known that power system protection has emerged in the start of the last century, and first application was developed as electro-mechanical over current relay. Amongst all the major principles of protection that are presently being used by the developers were designed in first three decades of the last century. These relays are over-current, distance, directional, and differential protection. However, with the advancements in the technology, the relay approach is promoted its developmental process of components, materials, and also manufacturing hardware arrangement of relay protection device. Simultaneously, relays experienced a theoretical improvement in context of protection software, algorithms, etc. The evolution of the modern techniques the progress in modern technology rouse the growth in developing power system protection.

The relay protection methods have undergone different developing phases in the last century till the end of the 1990s due to emergence of protection. The phases include utilization of semiconductors, integrated circuit and then microprocessor technologies. These days, digital and numeric relays are observed as a replacement of traditional relays in various applications of power system protection. Although, many traditional relaying principles of protection plays an important role till date and are capable of giving effective results.

The commonly used protection is distance protection. In an existing study it has been observed that distance protection is applied on transmission lines

Distance protection is a framework that offers excellent financial and technical advantages for non-unit protection. The key advantage of distance protection is its short circuit current coverage of protected elements is, unlike phase and neutral overcurrent protection arrangements, that the source impedance changes are almost independent.

The operations depend on the distance between the feeding point and the fault. The principle of the distance protection relay differs from other protective forms, because its performance is not dependent on current magnitude or voltage in a protective circuit, but on the relationship between these two quantities. The relay only works if the voltage-current ratio falls below a certain amount. Also during fault, the current magnitude increments and the voltage tends to decrease at the fault point. At the point of the transformer current and potential, the current and voltage ratio is measured. When the fault is closer, the voltage measured is less and the voltage measured is more large if the fault is more remote. Thus, every value of the voltage-current ratio from the position of relay calculate equal to the distance between the point of relay and the point of defect along the line assumes a constant fault impedance.

When the measured impedance is below the reach point impedance, the line between the relay and the target point is considered to be a loss. Therefore, this protection is known as protection against distance or impedance.

5.2 INTRODUCTION OF FACTS WITH RELAY

In the case of faults, the system parameters are changed, namely voltage level, current value, impedance and its angle, to offset the system parameter of devices FACTS that are incorporated into the transmission line. the distance relief measures impedances between the fault-point and real 10 cations. For instance, Thyrister Controlled Series Capacitor (TCSC) has a serial connection with the transmission line in order to compensate for system parameters of the FACTS device. When TCSC is entering the network, the relay is not operating given the massive change in impedance shown by the transmission line and Distance Relay is used for protection.

While the protection of the distance is better for power systems, the efficiency of the relays is still improved. FACTS is a technology which provides the necessary transmission corrections in order to fully use existing transmission systems, thereby minimizing the difference between stability and thermal limits. The main feature is that electronic power shifting devices can be accessed that can switch electricity at unit levels (kV levels). Evidence regulations tend to have a significant effect on grid networks worldwide on transmission systems. The various types of FACTS devices available for this function include Static Var Compenser (SVC), Thyristor Controlled Capacitor (TCSC) and Interlink Power Flow Controller (IPFC), as well as the Static Synchronous Compensator (STATCOM) [67]. UPFC is also among those FACTS devices capable of controlling transmission line power streams by injection in series of active and reactive voltage components[68] [66].

UPFC is one of the most effective control models for power flow in the various variants of FACTS controllers.

It consists of 2 subsequent gate-turn-off thyristors (GTO) based on VSCs, connected by an electrical dc-link condenser. A spelling electrical device is arranged to attach one VSC and an electrical boosting device is inserted into the conductor connecting the second VSC.

5.3 PROBLEM STATEMENT

Unified Power Flow Controller (UPFC) is a FACTS system designed to regulate power flow in the transmission line via series connected power converter by combining STATCOM with SSSC.

A recent study used UPFC controller along with distance protection in order to find the fault in the system and eliminate it from the transmission system. It is observed that the system was capable of giving better results but sill there are several limitations of UPFC that contributes in the lack of better performance of the system.

The decision is made by UPFC to control the flow of power on the basis of the parameters given to it. Pulses generated from the system plays a major role that informs the controller to inject the power into the system. But, generation of pulse is a complicated task that consumes time and increases complexity. Thus, it shows the need of an adaptive system to be used for power transmission system.

To this end, the efficacious performance can be attained by tuning the parameters of UPFC controller with the optimization techniques. The main objective of this thesis is to introduce an effective optimization method to transmit the power without experiencing any instability. The next chapter defines the implementation of the proposed model.

CHAPTER 6

IMPLEMENTATION OF PROPOSED MODEL

6.1 PROPOSED MODEL

As discussed in the previous chapter, the limitation of the existing techniques can be enhanced by using optimization techniques. There are several approaches that already have been designed using different optimization methods. Though, FACTS devices along with the distance protection system offer ease of implementing the model and transmitting the power through transmission lines. This model enhances the performance and stability of model.

However, optimization algorithms are designed in a way to improve the existing operations and achieve optimal results. To this end, different algorithms are studied which are used for the enhancement of the power system. The observed algorithms are BFO, PSO, ACO. A detailed study is performed which is delineated in chapter 4 and it is decided to use Grey wolf optimization technique to be applied on the UPFC to tune its parameters. GWO is decided due to its following advantages that it is free from the initialization of input parameters.

6.2 GWO

Grey wolf optimization is an intelligent swarm technology developed in 2014 by Mirjalili et al[71] that reflects wolves' leadership hierarchy, which is well known for hunting their group. Grey wolf is part of the family of Canidae and prefer to live in a package. The leaders are a man or woman named Alph$a$ (α). He is a strictly social hierarchical leader. It is mainly the alpha that makes decisions. The order should be followed by the package of the dominant wolf. The Beta**s** $(\boldsymbol{\beta})$ are subordinate wolves that help the alpha to make decisions. Beta is an alpha consultant and pack discipliner. The gray Omeg$a$ $(\omega)$is the lower classification that all other dominant wolves must be submissive. If the wolf is not alpha, beta or omega, the wolf is known as delta. Omega dominates Delta wolves and alpha and beta reports. The level of these wolves are demonstrated in fig. 5. Wolves are mathematically modeled on hunting strategies and the social hierarchy to build GWOs and to maximize them. The GWO algorithm is tested with standard test functions which show that it has better scanning and exploitation than other swarm intelligences. In addition, GWO was successfully used to solve various problems with engineering optimization. Furthermore, most swarm intelligent techniques used to solve problems with optimization cannot be controlled over the whole period. In GWO, the gray Wolves have natural mechanisms of management, this drawback is rectified. Furthermore, this algorithm has only some easy and superior parameters to implement. GWO has made attempts to implement GWO to resolve optimization problems, because of the versatile characteristics of the GWO algorithm.

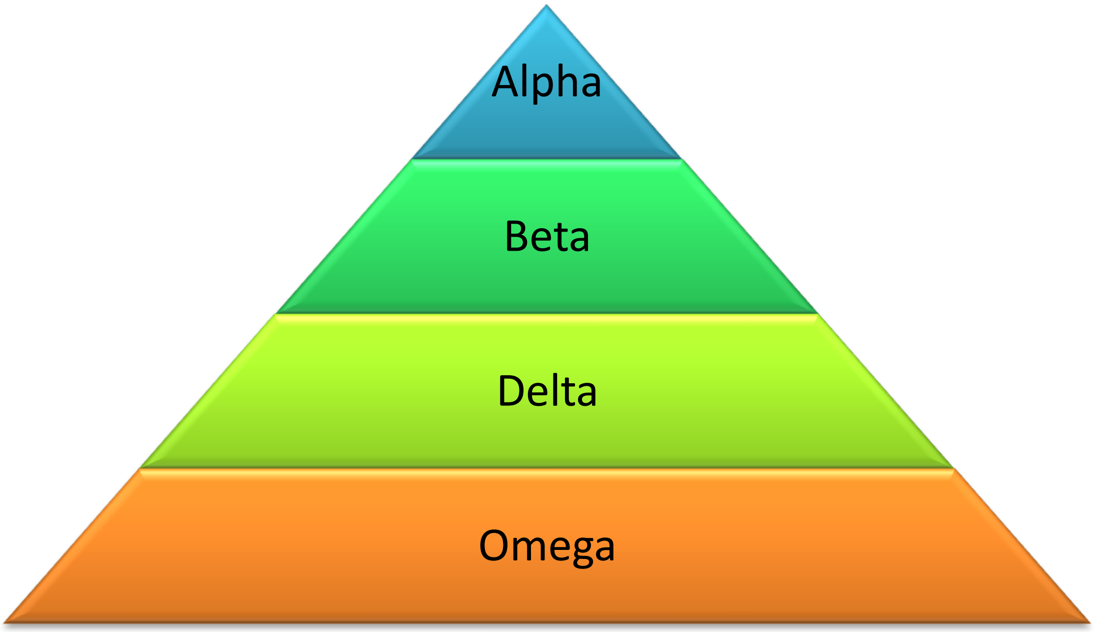

Fig 6: Hierarchy of wolves in GWO

The gray wolves have various groups, such as making groups for hunting prey. Grey wolves living in the top of the hierarchy are known as Alpha Wolves and are the group leader. They have power of decision to hunt, sleep, wake up, etc. The decisions of the other members of the group are communicated. The gray wolves of the 2nd hierarchy are called wolfs of the beta class and are subordinated to wolves of the alpha class. They assist wolves in decision making in the alpha category. The beta wolves occupy the place of the alpha in the event that the alpha wolves are lost or very old. The wolves who take part in the third phase of hierarchy are called omega wolves. It plays a subordinate role with alphas in the group. They always follow the instructions of other wolves. Although the pack does not contain omega types of wolves, the entire packing will face inner challenges, if it loses its omega. The Omega wolves still maintain the dominant hierarchical structure.

Delta category wolves are the wolves that are not of the alpha, beta and omega categories. Five fundamental wolves, such as:

(i) scouts,
(ii) sentinels,
(iii) the eldest,
(iv) hunters
(v) carers,

The above list is subject to this ruling. This is the case in Delta wolfs.

Scouts must watch the borders and alert the pack for any hazards. Sentinels are the experienced wolves and are used for attacking the proud or any target elements by their experiences. Hunters help the prey to be inhunted and the pack to provide food. Finally, caregivers have to care for the poor, sick and wounded wolves [70]. Following are the steps involved in the mathematical model [71]:

$$D^{\rightarrow} = |D^{\rightarrow} \cdot (X\_q)^{\rightarrow}(t) - X^{\rightarrow}(t)|$$

$$X^{\rightarrow}(t+1) = (X\_q)^{\rightarrow}(t) - A^{\rightarrow} \cdot D^{\rightarrow}$$

$$A^{\rightarrow} = 2a^{\rightarrow} \cdot (r\_1)^{\rightarrow} - a^{\rightarrow}$$

$$C^{\rightarrow} = 2 \cdot (r\_2)^{\rightarrow}$$

$$X^{\rightarrow}(t+1) = (((X\_1)^{\rightarrow} + (X\_2)^{\rightarrow} + (X\_3)^{\rightarrow}))/3 \qquad (2)$$

Where t is a present iteration, A and C are coffee vecto$rs, \overrightarrow{X_q}\ is$ a position vector for that quarry, $\overrightarrow{\square}$ is a position vector for that gray wol$f..\overrightarrow{r_2}\ and\ \overrightarrow{r_2}$ are random vectors with values of [0 , 1] as t increase$s\ \vec{a}$ reduces from 2 to 0.

6.2.1 GWO Algorithm

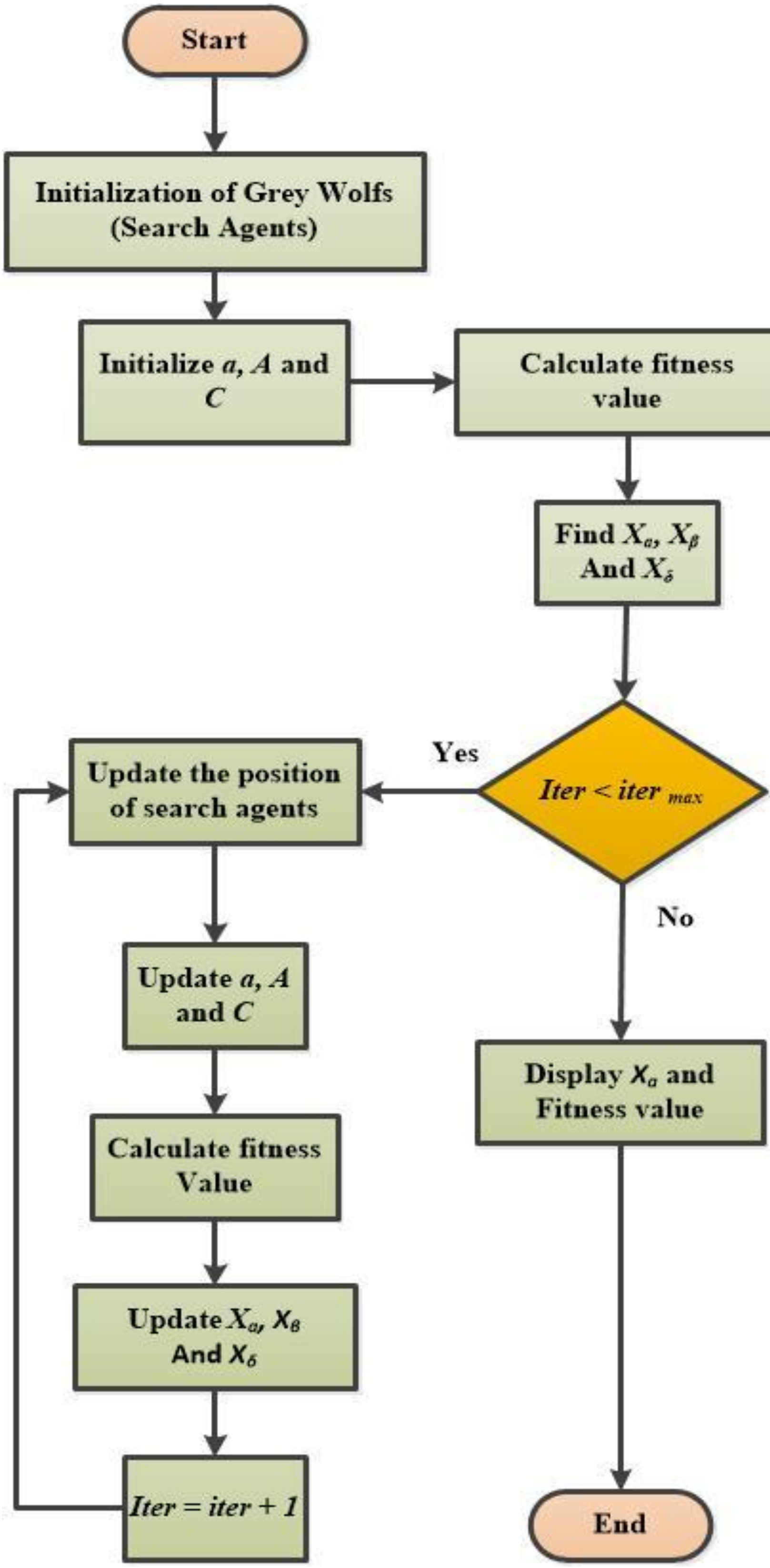

Fig.7: Flowchart of GWO Algorithm

The GWO algorithm is described briefly with the following steps:

1. *Generate initial search agents Gi (i=1, 2,…., n)*
2. *Initialize the vector's a, A and C*
3. *Estimate the fitness value of each hunt agent*
   Gα=the best hunt agent
   Gβ=the second best hunt agent
   Gδ=the third best hunt agent
4. *Iter=1*
5. *repeat*
6. *for i=1: Gs (grey wolf pack size)*
   Renew the location of the current hunt agent using Equation (2).
   End for
7. *Estimate the fitness value of all hunt agents*
8. *Update the value of Gα, Gβ, Gδ*
9. *Update the vectors a, A and C*
10. *Iter=Iter+1*
11. *until Iter>= maximum number of iterations {Stopping criteria}*
12. *output Gα*

6.3 PROPOSED MODEL

Eventually the model is designed for the transmission of power. Following Fig. 6 represents the schematic of the proposed model. The model shows the conductor with UPFC.

UPFC comprises STATCOM and SSSC that assists the controller to take the possible decisions according to the input given. The GWO algorithm applied in the model generates the pulses that act as the input of the controller.

These pulses help the controller to perform the operation of UPFC while injecting power in DC to AC conversion in the transmission lines. GWO enables the model to perform operations with the precision and accuracy. The proposed model is shown in fig. 7 and 8.

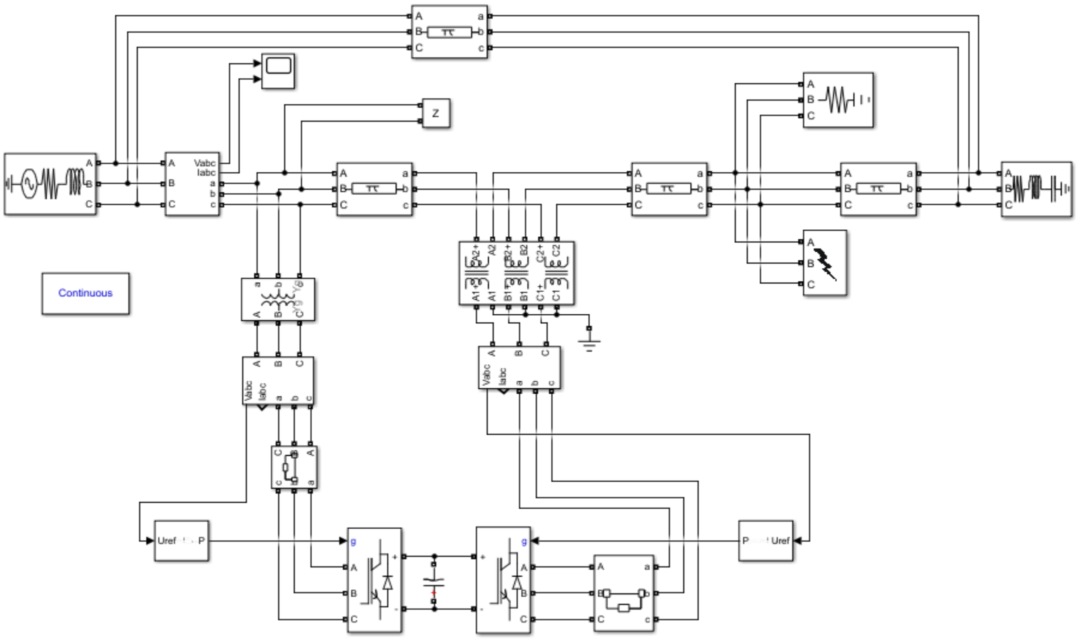

Fig. 8: Model of conductor with UPFC

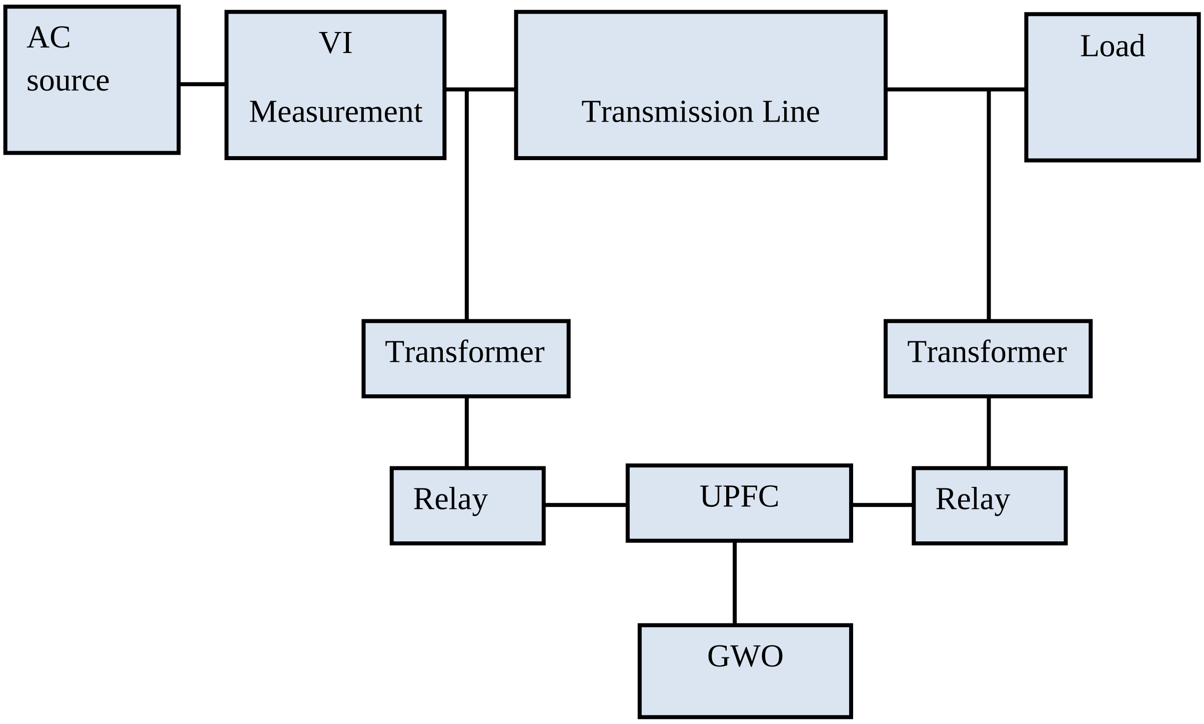

Figure 9: Block diagram for simulation.

CHAPTER 7

RESULTS AND DISCUSSION

7.1 INTRODUCTION

This chapter deals with the results obtained from the GWO based UPFC for the protection of transmission lines from faults occurred due to instability. UPFC has the capacity to deal with resistivity, voltage and section and section angle. The pulses generated from the GWO algorithm are directly sent to the UPF controller that further used different section angles with respect to different iteration to eliminate faults by using distance protection.

In the proposed model, total 10 iterations are considered to detect the performance of the model. The rest of the parameters of GWO are recorded in table 2.

Table 2: GWO Parameters

No of iteration	**10**
No of population	**10**
a constant	**0-2**

To measure the performance of the model, following parameters are taken into consideration.

- **Impedance (k):** It is the computation of the opposition to current into the load network.
- **Fitness function:** Fitness function is the type of objective function that is used as a single value of how close the out is obtained as per the desired achievement.

The simulation of the model is performed in the MATLAB software and the graph is obtained for the modification of the positions of the faults. During the simulation, the capacitance is taken $as\ 0.1\ \mu F$. The graph shown in Fig. 9 illustrates the values according to different fault positions obtained by the existing techniques The graph shows the relation between the impedance with respect to the different locations in Km. The close examination of the Figure reveals that the range of distance is from 0 to 150 km. and the impedance varies from 2 to 20. As the distance increases for the fault locations the impedance is reduced. It is considered that greater the distance, smaller is the impedance. The minimum value of impedance fetched at highest distance is 0. The impedance should be higher than 0 to be effective. Here the highest impedance is 20.

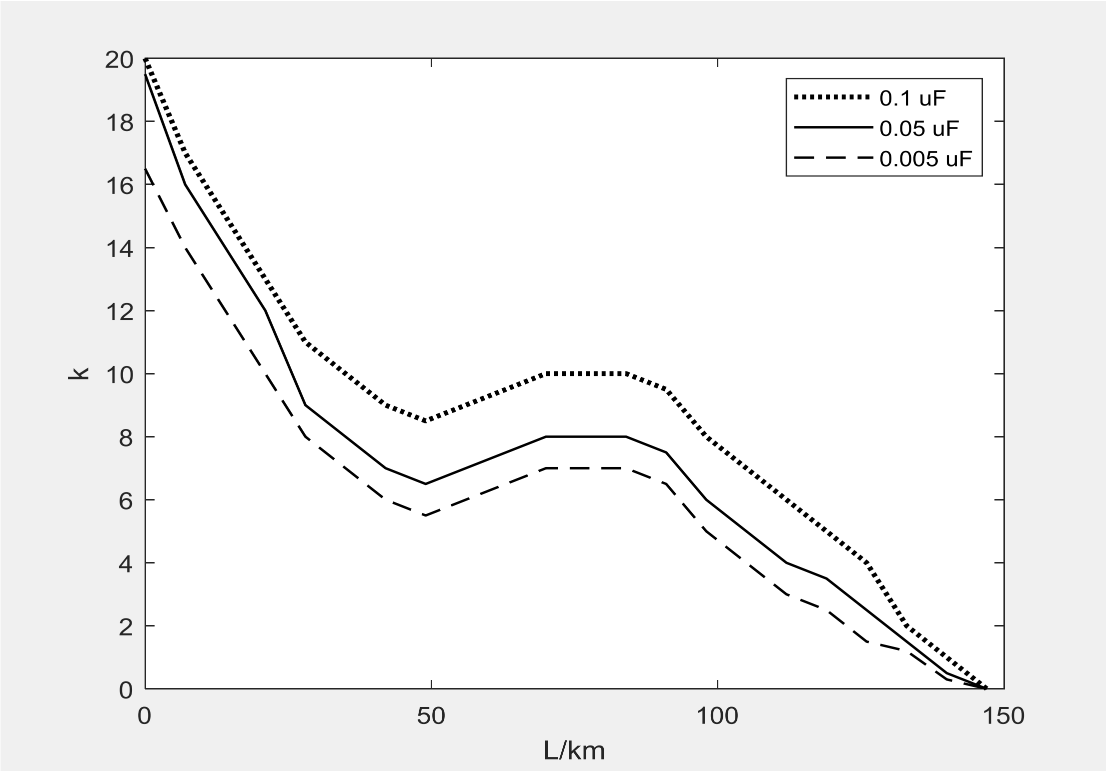

Fig.10: Modification of fault position in existing work.

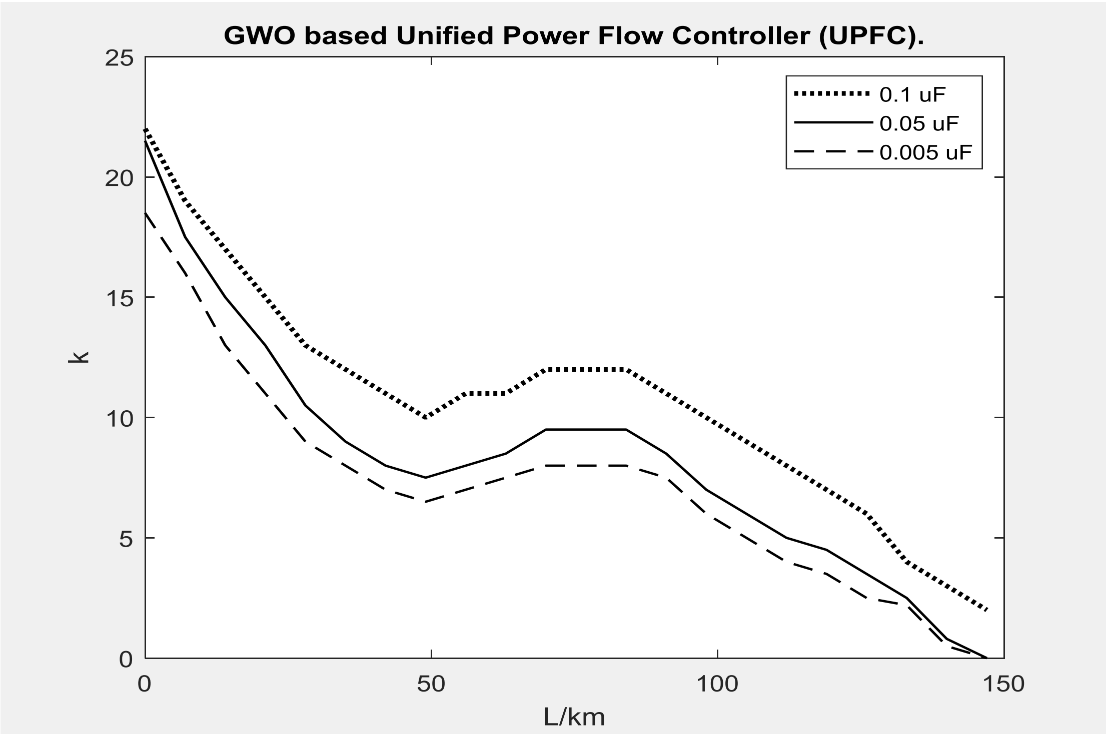

Fig.11: Results of proposed approach.

However, In order to validate the efficacy of the proposed model, the comparison analysis is performed for the proposed and the existing model. The results are obtained in the graphical form shown in Fig. 10. While performing simulation the capacitance is kept same for both the model and the simulation is performed for three different values of capacitance (0.1 μF, 0.05 μF, 0.005 μF). The graph shows the relation between the impedance with respect to the different locations in Km. The range of distance is from 0 to 150 km and the impedance varies from 2 to 25 on x-axis and y-axis respectively. The line graph represents the each line for different capacitance values and for 0.1 μF the highest value is 22 and for 0.5 μF, it is just below 22. The impedance decreases as increase in the distance.

5.2 Comparative analysis with existing technique

This section compares the results of the proposed techniques with that of existing techniques in terms of different capacitance values. The graph for each capacitance value is represented separately to understand the performance of the work proposed in this research.

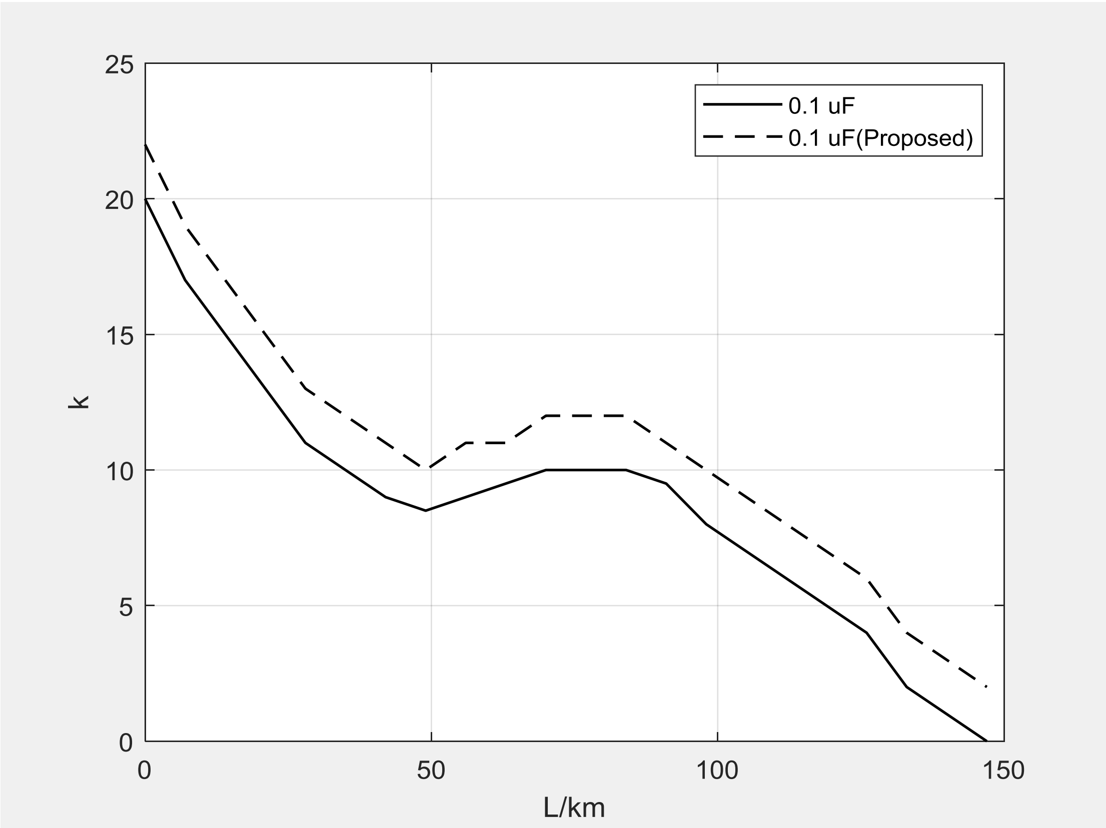

Fig.12: Comparison of Results at 0.1 μF

The graph in fig. 11 is representing the values of impedance (k) on ordinate and location as per km on abscissa. The results are presented for 0.1 μF. The range of impedance lies between 0 to 25 and the fault locations lies between the distances of 0 to 150 Km. Examination of the figure leads to the observation that states that the impedance of the proposed model is higher than that of the existing model. The values of both the techniques show a noticeable difference. The minimum value of k in existing technique is 0 and in proposed model it is 2. The highest value is 20 and 22 for existing and proposed model respectively. The corresponding values of impedance for different locations are recorded in the tabular form (table 3). Thus, it ensures that the performance of the proposed model is better than that of the existing technique. The optimization of UPFC using gray wolf optimization algorithm resulted in better performance.

Table 3: comparison of proposed and existing technique w.r.t 0.1 μF

L/km	**k (0.1 μF)**	**k (0.1 μF) Proposed-UPFC**
0	20	22
50	8.5	10
100	8	10
150	0.3	2

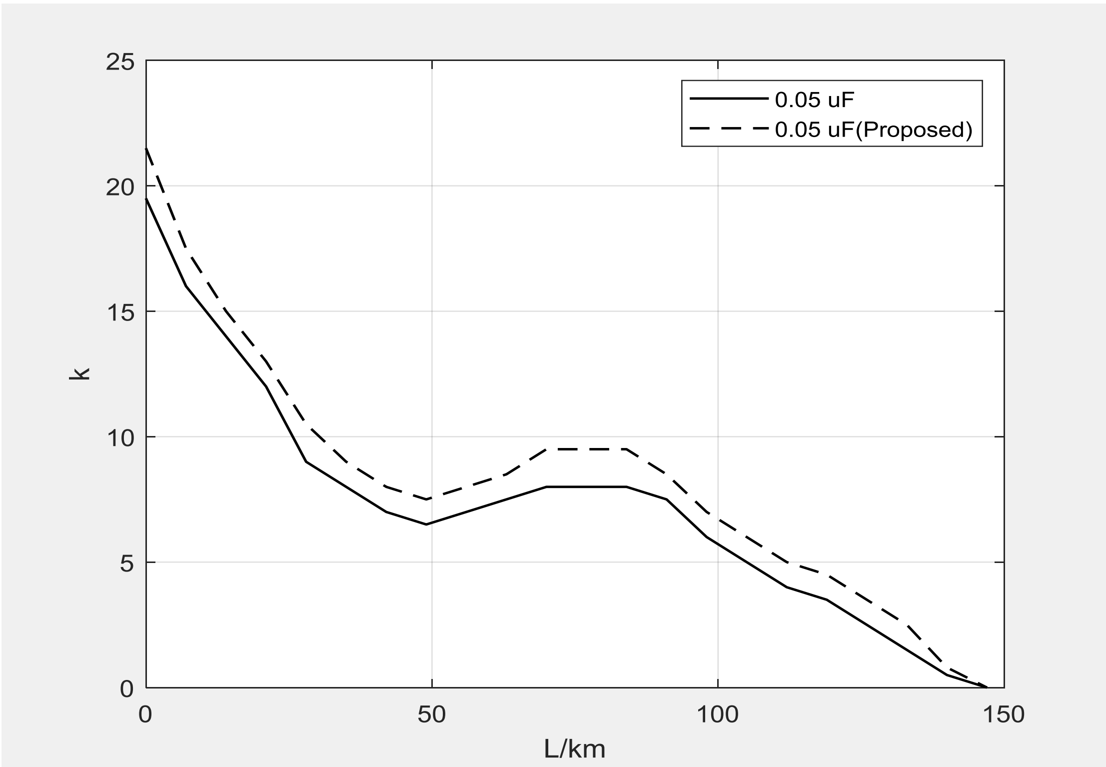

Fig.13: Comparison of Results at 0.5 μF

Further, for 0.5μF, results are shown in Fig 12. The impedance at this capacitance is higher than that of existing techniques. The highest value observed for proposed work is nearly 21.5000 and for existing method, it is 19.5000. Also, for the existing technique the minimum impedance is 0.2 whereas for proposed it is nearly 0.5. The comparison showed that the values of the proposed approach are better than that of previously designed technique at 0.5μF. Moreover, the corresponding values of impedance for different locations are recorded in the tabular form in table 4. It validates the proposed method as more effective technique.

Table 4: comparison of proposed and existing technique w.r.t 0.5 μF

L/km	**k (0.05 μF)**	**k (0.05 μF) Proposed-UPFC**
0	19.5000	21.5000
50	6.5000	7.5000
100	6.0000	7.0000
150	0.2000	0.5000

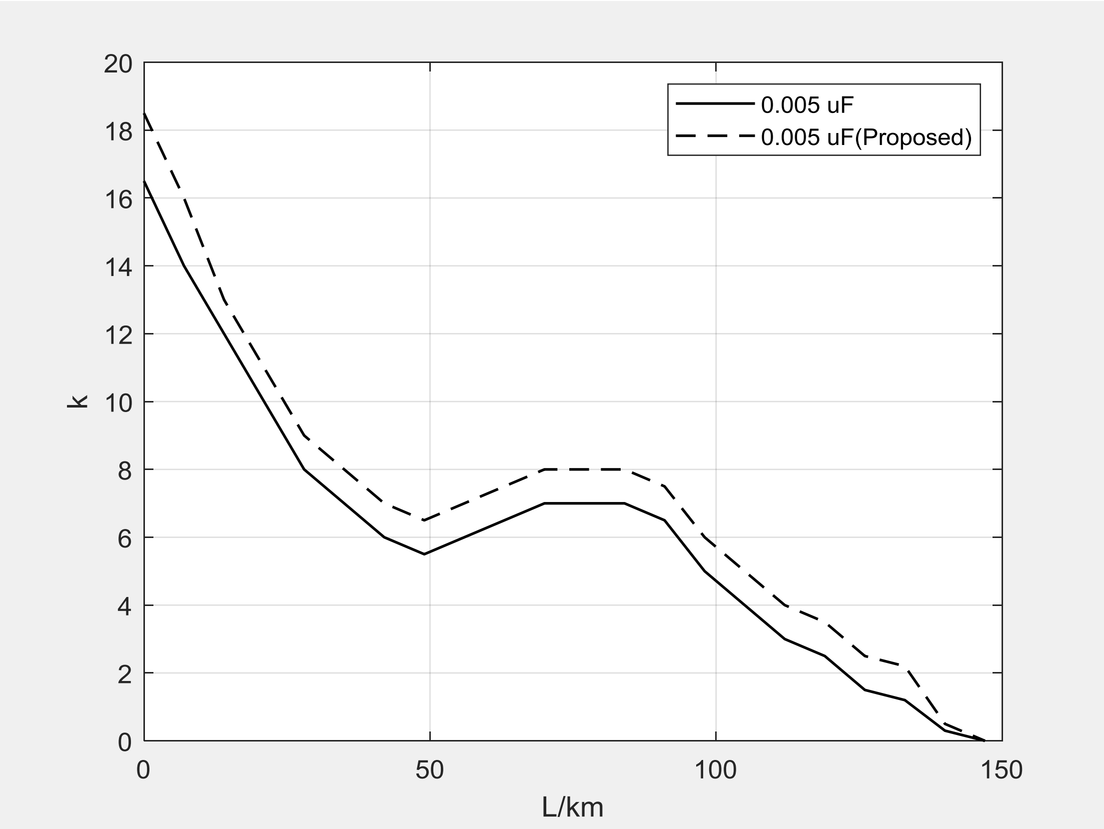

Fig.14: Comparison of Results at 0.005μF

Finally, the comparison of proposed and existing techniques for modification in faults at 0.005μF is presented in Fig.13. The highest and minimum impedance for existing technique is 0.1 and 16.5 and for proposed work it is 0.3 and 18.5 respectively. The impedance is highest than that of existing. It is finally concluded that the proposed model is more effective model as it is optimized by applying Grey wolf optimization technique.

Table 5: comparison of proposed and existing technique w.r.t 0.05 μF

L/km	**k (0.005 μF)**	**k (0.005 μF) Proposed-UPFC**
0	16.5000	18.5000
50	5.5000	6.5000
100	5.0000	6.0000
150	0.1000	0.3000

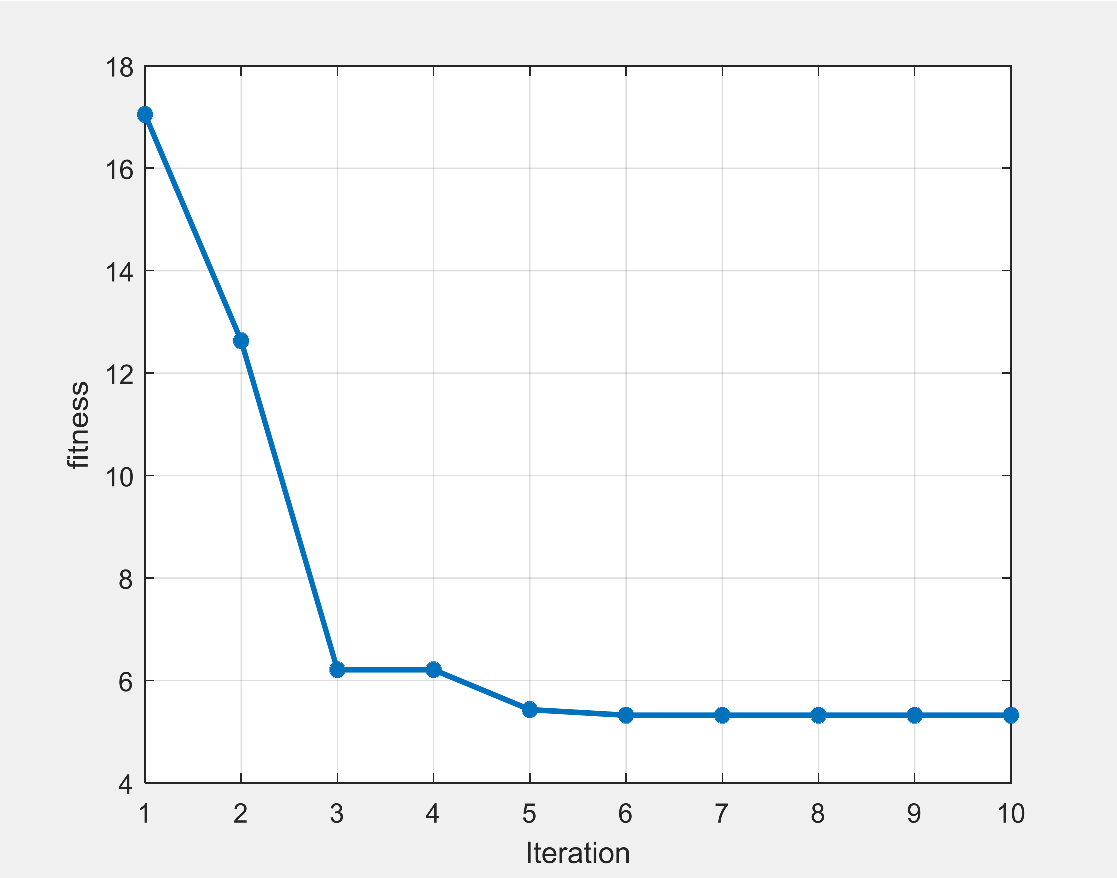

Fig.15: Fitness function of the proposed model.

Fitness function of the proposed model is demonstrated in the graph shown in Fig. 14. X-axis and y-axis of graph represent iterations and fitness value respectively. It can be observed from the graph that the fitness value decreases with the increase in number of iteration. The first iteration gives 17 as fitness that rapidly decreases to 13 in second iteration. A steep decrease in the fitness value can be seen when third iteration is performed and the value accounted to 6. After half iterations were performed the value of fitness becomes constant till last iteration.

Eventually, the fitness of the proposed model is considered as effective fitness function and the impedance achieved for the novel model ensures the better working in terms of protecting the transmission lines while supplying the power.

CHAPTER 8

CONCLUSION AND FUTURE SCOPE

8.1 CONCLUSION

Power systems are the most widely used systems for the supply of power. The methods of transmitting power are changing with the advanced technology. The protection of the system has become a significant task because it can reduce the instability of the model. Relays are the commonly used devices that were developed in the last century. The principles of certain relays are sill effective and are in use. Further to improve the efficiency, FACT devices are also introduced. The amalgamation of the relays and UPFC resulted in better performance. Amongst different relays and FACT devices, Distance protection and UPFC are utilized together to eliminate the faults and inject the power into the system. From the literature survey, various techniques are studied and one of the methods was required to be improved in which UPFC is used to deal with the issues of transmission line. After analyzing different techniques, this dissertation presented an adaptive approach of UPFC by incorporating optimization techniques.

GWO is considered as the best algorithm to apply on the model as it eliminated the need of extra input parameters. The simulation is performed in MATLAB and during the implementation of model, GWO bears the responsibility of generating and transmitting the pulse to UPFC which further consider the pulses according to different section angles and eventually decided to inject the power into the system.

The simulation results were obtained in the form of impedance and fitness function. The impedance $at\ 0.1, 0.5\mu F\ and\ 0.005\mu F$ was determined for existing as well as proposed mode. The comparison showed that the GWO based UPFC as able to achieve higher impedance and better fitness function.

8.2 FUTURE SCOPE

Although, the performance of the proposed work is proved to be effective in terms of offering protection to the transmission lines, however, in the future, the enhancements can be made in this field by using different FACT devices and applying different or hybrid optimization algorithms in order that fault detection can be enhanced which in turn would assist in transmitting the power in an efficacious way along with its protection.

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