CHAPTER 1

INTRODUCTION

1.1 REACTIVE POWER

Reactive power flow on the alternating current transmission system is needed to support the transfer of real power through transmission and Distribution system. In AC circuits, energy is temporarily stored in inductive and capacitive elements, due to this periodic reversal of the direction of power flow. A portion of power flow remaining after being averaged over a complete AC waveform is the real power and that can be used to do work. On the other hand a portion of power flow that is temporarily stored in the form of electric or magnetic fields and returned to source, due to inductive and capacitive network elements is known as the reactive power.

In a simple alternating current(AC) circuit consisting of a source and a linear load, the current and voltage are sinusoidal. The two quantities reverse their polarity at the same time, if the load is purely resistive. At every instant the product of voltage and current is positive indicating that the direction of energy flow does not reverse. Only real power is transferred in this case.

Inductive devices called reactors stores energy in the form of magnetic field. Magnetic field builds up, when a voltage is initially placed across the coil, and it takes a period of time for the current to reach full value.
Due to this, current to lag the voltage in phase, for this reason these devices are said to absorb reactive power.

The voltage and current are 90 degrees out of phase, if the loads are purely reactive. The product of voltage and current is positive in half of each cycle, and the product is negative on the other half of the cycle, indicating that on average, exactly as much energy flows toward the load as flows back and there is no net energy flow over one cycle. In this case, there is no net transfer of energy to the load, only reactive energy flows.

A capacitor is an AC device that stores energy in the form of an electric field. The capacitor takes a period of time for charge to build up to produce the full voltage difference, when current is driven through the capacitor. The voltage across a capacitor is always changing, the capacitor will oppose this change causing the voltage to lag behind the current and in other words the current leads the voltage in phase. Hence these devices are said to generate reactive power.

Both real and reactive power will flow to real loads because practical loads have resistance, inductance, and capacitance. Apparent power is the product of the root-mean-square of voltage and current. Power Engineers care about apparent power, because even though the current associated with reactive power does not work at the load, but it heats the wires, wasting energy. Generators, transformers and conductors must be sized to carry the total current.

Conventionally, inductors are consuming reactive power and capacitors are generating reactive power. If a capacitor and an inductor are placed in parallel, then the currents flowing through the inductor and the
capacitor tend to cancel rather than add. Normally this is the fundamental mechanism for controlling the power factor in electric power transmission. Capacitors or inductors are inserted in a circuit to partially cancel reactive power consumed by the load.

Energy stored in capacitive or inductive elements of the network give rise to reactive power flow. The voltage levels across the network are strongly influenced by reactive power flow. Voltage levels and reactive power flow must be carefully controlled to allow a power system to be operated within acceptable limits. Reactive power is measured in a unit called Volt-Amperes-Reactive (var). The mathematical symbol for reactive power is the capital letter Q.

Reactive power is calculated by using the voltage and current associated with the circuit reactance. The voltage of the reactance is equal to the reactance multiplied by the reactive current. Generally reactive power can be calculated by the formula

\[ Q = I^2X \]  

(1.1)

Where, \( I \) is the reactive current in amperes,

\( X \) is the total reactance in ohms.

In Figure 1.1 P is the real power, \( Q \) is the reactive power, \( S \) is the complex power and the length of \( S \) is the apparent power.
Figures 1.1 Vector diagram of real, reactive and apparent power

Reactive power represented as the imaginary axis of the vector diagram, because it does not do any work. Real power represents the real axis, because it does do work. The unit for all forms of power is the watt (symbol: W), but this unit is generally reserved for real power. The product of rms voltage and rms current is called apparent power and it is conventionally expressed in volt-amperes (VA). The unit for reactive power is expressed as VAR (Volt Ampere Reactive). Because reactive power transfers no net energy to the load, it is sometimes called "wattles" power. Understanding the relationship among these three quantities lies at the heart of understanding power systems. The mathematical relationship among them can be represented by vectors or expressed using complex numbers, $S = P + jQ$ (where j is the imaginary unit).
1.2 LIMITATIONS OF REACTIVE POWER

- Reactive power does not travel very far.
- Reactive power must be produce close to the location where it is needed.
- A supplier/source close to the location of the need is in a much better position to provide reactive power versus one that is located far from the location of the need.
- Reactive power supplies are closely tied to the ability to deliver real or active power.
- Reactive power cannot be effectively transmitted across long distances due to high \( P^2X \) losses.

1.3 IMPORTANCE OF REACTIVE POWER

Consumer loads such as residential, industrial, service sector, etc need active and reactive power demand, depending on their requirement. Active power is converted into useful energy, such as light, heat and rotation etc. Reactive power should be compensated to an efficient delivery of active power, releasing system capacity, enhancement voltage stability, reducing system losses, increasing power system security and improving system power factor.

Active power cannot be supplied, if voltage on the system is not enough. Reactive power is used to supply necessary voltage levels for active power to do useful work. Reactive power is very important to move active power through the transmission and distribution system to the customer. Reactive power is strongly related to the bus voltages and hence it has a
significant effect on system security. Insufficient support of reactive power leading to voltage collapse is a causal factor in major blackouts in the worldwide.

United States blackout, Sweden and Denmark blackout, Italy blackout and Canada blackout was reported as insufficient reactive power of system resulting in the voltage collapse. In order to operate the system in a secure manner a system operator has to procure adequate amount of reactive power from various reactive resources in the system, e.g. generators, synchronous condensers and shunt capacitors.

Voltage control in an electrical power system is important for proper operation for electrical power equipment to prevent damage such as overheating of generators and motors. It is also important to reduce transmission losses and to maintain the ability of the system to withstand and prevent voltage collapse. In general terms, voltage is fall due to decreasing reactive power, voltage is rise while increasing it. The voltage collapse occurs when the system try to serve much more load than the voltage can support.

When reactive power supply lower voltage, as voltage drops current must increase to maintain power supplied, due to this, system to consume more reactive power and the voltage drops further. Transmission lines go off line, overloading other lines and potentially causing cascading failures if the current increase too much.

Some generators will disconnect automatically to protect themselves, if the voltage drops too low. Voltage collapse occurs when an increase in load or less generation or transmission facilities causes dropping voltage, due to this further reduction in reactive power from capacitor and line charging. If voltage reduction continues, it will cause additional elements to trip, and further reduction in voltage and loss of the load. Due to these entire
progressive and uncontrollable declines in voltage is that the system unable to provide the reactive power required supplying the reactive power demands.

Voltage control and reactive-power management are two aspects of a single activity that both supports reliability and facilitates commercial transactions across transmission system. The voltage is controlled by managing production and absorption of reactive power in an alternating-current (AC) power system. There are three reasons why it is necessary to manage reactive power and control voltage.

First, both customer and power-system equipment are designed to operate within a range of voltages, usually within ±5% of the nominal voltage. Most of the equipment performs poorly at low voltages, induction motors can overheat and be damaged, light bulbs provide less illumination, and some electronic equipment will not operate. High voltages can damage equipment and shorten their lifetimes.

Second, reactive power consumes transmission and generation resources. Reactive power flows must be minimized to maximize the amount of real power that can be transferred across a congested transmission interface. Similarly, reactive-power production can limit a generator's real-power capability. Third, moving reactive power on the transmission system incurs real power losses.

Depending on system loading, the transmission system itself is a nonlinear consumer of reactive power. At very light loading the system generates reactive power that must be absorbed, whereas at heavy loading the system consumes a large amount of reactive power that must be replaced. Reactive power requirement of the system is also depend on the generation and transmission configuration.
At least a portion of the reactive supply must be capable of responding quickly to changing reactive power demands and to maintain acceptable voltages throughout the system. An electrical system requires real power reserves to respond to contingencies, so it must maintain reactive-power reserves.

Loads can also be both real and reactive. Reactive portion of the load could be served from the transmission system. In transmission system, reactive loads incur more voltage drop and reactive losses than do similar-size (MVA) real loads. Area voltages should be controlled by adjusting sinks and sources of reactive power. The sources and sinks of reactive power are shown in Figure 1.2.

![Figure 1.2 Sinks and sources of reactive power](image)
1.4 DIFFERENT TYPES OF REACTIVE POWER

There are different types of reactive power. They are as follows:

1.4.1 Displacement Reactive Power

This is caused by displacement of the angle between current and voltage. It is charged monthly on an average basis (contract with the power provider). Nowadays it is mostly compensated by reactor protected capacitors.

1.4.2 Distortion Reactive Power

This is caused by harmonics in current and voltage, provided for when connecting high-performance current converters and compensation through filter circuits (passive, active).

1.4.3 Modulation Reactive Power

This is caused by periodic load fluctuations caused by the connection of high-power welding machines, arcing furnaces etc. It is compensated through dynamic compensation (SVC).

1.4.4 Asymmetric Reactive Power

This is caused by one and two-phase loads provided for when connecting high-power converters such as welding machines and electric railways and mostly dynamic with capacitors and reactors.

1.5 REACTIVE POWER OPTIMIZATION

Reactive Power Optimization (RPO) problem is one of the difficult optimization problems in power systems. The problem that has to be solved in
a reactive power optimization is to determine the required reactive generation at various locations so as to optimize the objective function. It provides the best and most optimum practical solution to achieve improvement in a single or multiple hierarchical objectives while respecting various constraints on the system operation. An RPO can determine the most effective subset of controls and their solution for a given operating condition to improve the specified objectives. RPO can consider different objectives for improvement such as, minimization of transmission losses, improvement of voltage stability and minimization of system operating cost. RPO can be classified into three types and they are

- Reactive Power planning
- Reactive power Compensation
- Reactive power Dispatch

1.5.1 Reactive Power Planning

Reactive power (var) planning is the determination of the sizes and locations of shunt var sources (capacitors, reactors, static var systems, and synchronous condensers) and their efficient coordination with existing var sources. A problem of Optimal Reactive Power Planning (ORPP) is to determine the amount and location of shunt reactive power compensation devices needed for minimum cost while keeping on adequate voltage profile. The ORPP is one of the most challenging problems both operation cost and the investment cost of new reactive power sources should be minimized simultaneously. The ORPP is a large scale nonlinear optimization problem with a large number of variables and uncertain parameters
1.5.2 Reactive Power Compensation

Reactive Power Compensation (RPC) in power systems is a very important issue in the expansion planning and operation of power systems. Its main aim is to determine the adequate size and the physical distribution of the compensation devices to ensure a satisfactory voltage profile while minimizing the cost of compensation. The objective of the reactive power compensation problem is minimizing capacitor installation cost and minimizing system losses and determination of the size and locations for the capacitor banks to be installed.

Traditionally, this problem is considered as a single objective optimization problem (SOP). Practically most problems have more than one objective to be optimized, e.g. RPC problem requires the optimization of investment, power losses, and voltage profile. The objectives are usually contradictory. Accordingly a single objective optimization algorithm will not be preferable to solve the RPC problem. Considering this situation, multiobjective optimization algorithms (MOA) were used to optimize independent and simultaneously several objectives.

An inductive reactive power requirement of an asynchronous machine can be compensated with a capacitor bank, synchronous machine or a special current converter. Synchronous generators, SVC and various types of other DER (Distributed energy resource) equipment are used to maintain voltages throughout the transmission system. Injecting reactive power into the system raises voltages, and absorbing reactive power lowers voltages.
Series capacitive compensation is widely used in long transmission lines to maintain the overall impedance of the transmission line. Capacitive series compensation increases the power transfer capacity as well as the transient stability. The series dielectric capacitors were installed all over the world as efficient economical way of providing capacitive series compensation. With the new advances in the generation of the power electronics devices based on Voltage Source Converter (VSC) known as Flexible AC Transmission System (FACTS), more flexible operation and control of the transmission networks are possible. FACTS controllers can be classified as shunt, series, or phase angle compensating devices or devices which are a combination of the above three types such as unified power flow controller (UPFC).

These FACTS devices enable fast response using the phase locked loop (PLL) with minimum inherent time delay during severe disturbances, transient power swings, thus allowing the transmission system operating safely and close to the theoretical stability limit. Two FACTS devices can provide capacitive series compensation they are thyristor controlled series capacitor (TCSC)and static synchronous series compensator (SSSC). There are several TCSCS are widely installed. The TCSC is used in practice to significantly improve the small disturbance and transient stability of the power system.

A SSSC is one of the most important FACTS devices for power transmission line series compensation. The SSSC is a power electronic based VSC that generates a nearly sinusoidal three phase voltage. The SSSC converter block is connected in series with the transmission line by a series coupling transformer and can provide either capacitive or inductive series
compensation independent of the line current. An ideal SSSC is essentially a pure sinusoidal ac voltage source at the system fundamental frequency.

In shunt compensation, FACTS devices are connected in parallel with the line and it works as a controllable current source. There are two types of Shunt compensation. Shunt capacitive compensation is used to improve the power factor. Power factor lags because of lagging load current whenever an inductive load is connected to the transmission line. A shunt capacitor is connected which draws current leading the source voltage to compensate. So that the power factor of the system is improved.

Shunt inductive compensation is used either while charging the transmission line or while there is very low load at the receiving end due to very low or no load very low current flows through the transmission line. Shunt capacitance in the transmission line causes voltage amplification and the receiving end voltage may become double the sending end voltage. To compensate this, shunt inductors are connected across the transmission line and the power transfer capability is thereby increased depending upon the power equation.

Shunt compensation, produced either by an SVC (Static Var Compensator) or a STATCOM (Static Synchronous Compensator) is used when the utility is concerned about dynamically balancing reactive power at particular points within an AC system to prevent voltage regulation and stability issues from occurring. This is particularly the case in response to faults leading to under/over-voltage. The Shunt system can also significantly improve the transfer capacity of an AC system.
1.6 OPTIMAL REACTIVE POWER DISPATCH (ORPD)

Optimal Reactive Power Dispatch (ORPD) for improving economy and security of power system operation has received much attention at present. The purpose of the optimal reactive power dispatch in power system is to identify the optimal values of control variables like generator voltage magnitudes, tap setting of the transformer and number of compensation devices to be switched. The main objective of optimal reactive power dispatch problem is to minimize real power losses and voltage deviations and enhancement of voltage stability of the system.

ORPD is a nonlinear optimization problem and it has number of equality and inequality constraints such as load flow, generator bus voltages, load bus voltages, reactive power generation, switchable reactive power compensations and transformer tap setting. Therefore, the problem of the ORPD can be optimized to enhance the voltage stability, to minimize the system real power losses and voltage deviations.

Reactive power optimization is an approximated problem of the optimal power flow (OPF) calculation, which determines all kinds of controllable variables. Since transformer tap ratios and outputs of shunt capacitors/reactors have a discrete nature, while reactive power outputs of generators and static VAR compensators, bus-voltage magnitudes, and angles are on the other hand. The purpose of Reactive Power Dispatch is mainly to enhance the voltage stability of the system and to minimize the real power transmission loss and minimize the voltage deviations while satisfying the unit and system constraints. It can be achieved by proper adjustment of
reactive power control variables like Generator bus voltage magnitudes, transformer tap settings and reactive power generation of the capacitor bank.

Here the optimal reactive power dispatch problem involves best utilization of the existing generator bus voltage magnitudes, transformer tap setting and the output of reactive power sources so as to minimize the losses and voltage deviations, and to enhance the voltage stability of the system.

1.7 NEED FOR REAL POWER LOSS MINIMIZATION

One of the important operating requirements of reliable power systems is to maintain the voltage within the permissible ranges to ensure a high quality of customer service. Reactive power and voltage control problems has gained importance to ensure a reliable quality of power supply with minimum losses in the power system.

An increased demand for electric power and the insufficient power generation and transmission facility forces the power system networks is being operated under stressed conditions. If the power system is operated in stressed conditions, then security of a power system is under threat and may result in voltage instability. The voltage instability has become a new challenge to power system planning and operation. Insufficient reactive power availability or non-optimized reactive power flow may lead a power system to insecure operation under heavily loaded conditions.

The system losses can be minimized via redistribution of reactive power in the system. The reallocation of reactive power generations in the system can be achieved by adjusting the generator voltage magnitude, transformer tap settings, and switchable VAR sources. Large amount of
reactive power flow in a system is indicated by the real power loss in the
system. So minimizing the real power loss ensures optimized reactive power
flow (ORPF) through the lines.

Progressive increase of power demand and deregulation of power
industry have now become two major factors which increase the competition
in the market and complicate the determination of steady state of operations
of the power systems. Due to this the need for research in optimal reactive
power dispatch to minimize the power loss by increasing the capabilities of
the existing transmission system assets and voltage stability to ensure the
uninterrupted and adequate power supply to satisfy the customers. However,
it is most often conflicting to optimize the power flow to minimize the real
power loss while operating within the voltage stability margins.

1.8 NEED FOR VOLTAGE STABILITY

A power system operating condition should be stable at any point of
time, meeting various operational criteria and it should also be secure in the
event of any credible contingency. Present day power systems are being
operated closer to their stability limits due to economic and environmental
constraints. Maintaining a stable and secure operation of a power system is
therefore a very important and challenging issue. In recent year’s power
system researchers and planners given much attention for voltage instability
and is being regarded as one of the major sources of power system insecurity.

Voltage instability phenomena are the ones in which the receiving
end voltage decreases well below its normal value and does not come back
even after setting restoring mechanisms such as VAR compensators. Voltage
collapse Phenomenon (shown in Figure 1.3) is the process by which the voltage falls to a low and unacceptable value as a result of an avalanche of events accompanying voltage instability.

The time span of a disturbance in a power system, causing a potential voltage instability problem, can be classified into short-term and long-term. Automatic voltage regulators, excitation systems, turbine and governor dynamics fall in this short-term or ‘transient’ time scale, which is typically a few seconds. Induction motors, electronically operated loads and HVDC interconnections also fall in this category. If the system is stable, short-term disturbance dies out and the system enters a slow long-term dynamics.

Components operating in the long-term time frame are transformer tap changers, limiters, boilers etc. Typically, this time frame is for a few minutes to tens of minutes. A voltage stability problem in the long-term time frame is mainly due to the large electrical distance between the generator and the load, and thus depends on the detailed topology of the power system.

Long-term voltage instability problems can occur in heavily loaded systems where the electrical distance is large between the generator and the load. The instability may be triggered by high power imports from remote generating stations, a sudden large disturbance, or a large load buildup (such as morning or afternoon pickup). Operator intervention may be possible if the time scale is long enough. Timely application of reactive power compensation or load shedding may prevent this type of voltage instability.
The continuing interconnections of bulk power systems, brought about by economic and environmental pressures, have led to an increasingly complex system that must operate even closer to the limits of stability. The operating environment has contributed to the growing importance of the problem associated with the static and dynamic stability assessment of power systems. To a large extent this is also due to the fact that most of the major power system breakdowns are caused by problems relating to the system's static, as well as dynamic, responses.

It is believed that a new type of instability emerges as the system approaches the limits of stability. One type of system instability which occurs when the system is heavily loaded is voltage collapse. This event is characterized by a slow variation in the system operating point; due to increase in the loads in such a way that the voltage magnitudes gradually decrease until a sharp accelerated change occurs.

It is interesting to note that prior to the sharp change in voltage magnitudes, bus angle and frequency remain fairly constant, a condition observed in several collapses. During a collapse, voltage control devices, such as tap changing transformers, may not be activated if the voltage magnitudes prior to undergoing the sharp change lie in a 'permissible range' and, after the change occurs, the fast rate of the change trips under-voltage relays before the transformers can respond to it. Furthermore, control centre operators observe none of the classical advance warning since the bus angle, frequency and voltage magnitude remain normal until large changes in the system state cause protective equipment to begin to dismantle the network. There has been significant debate over whether voltage collapse problem is static in nature and can therefore be studied as a parametric load flow problem or whether it
is dynamic and must be studied as the trajectory of a set of differential equations.

![Voltage Collapse Phenomenon]

**Figure 1.3 Voltage collapse phenomenon**

The power system equilibrium equations typically depend on a very large number of parameters. Moreover, the number of parameters differs from system to system and from time to time. The essential problem of the analysis of power system stability is to recognize impending change in system behaviour as these parameters vary and to identify the controlling parameters. In general, loads are dependent on bus voltage. Also, it is known that load dynamics greatly affect the voltage stability. Some researchers have considered only constant \( P, Q \) loads that are independent of bus voltage. Since
voltage dependent loads play a very important role in voltage stability, more suitable constraints must be considered.

Static voltage stability is primarily associated with the reactive power support. The real power (MW) loadability of a bus in a system depends on reactive power support that the bus can receive from the system. Voltage Stability is becoming an increasing source of concern in secure operation of present-day power systems. The problem of voltage instability is mainly considered as the inability of the network to meet the load demand imposed in terms of inadequate reactive power support or active power transmission capability.

1.9 LITERATURE REVIEW

1.9.1 Introduction

Many research works are being carried out for Optimal Reactive Power Dispatch (ORPD) problem. Initially the conventional methods were used to solve the optimal reactive power dispatch problem. Recently Evolutionary computation techniques were successfully used to solve the ORPD problem. In this section the various research work done by the researchers on optimal reactive power dispatch problem were reviewed and discussed.

1.9.2 Conventional Methods

A number of conventional optimization techniques were used to solve ORPD problem. The conventional methods are interior point method, gradient method, linear programming, non-linear programming, integer
programming, quadratic Programming, sequential quadratic programming, successive quadratic programming method. The various conventional methods used for optimal reactive power dispatch problem were discussed in this section.

Lee et al (1985) presented a unified method for optimal real and reactive power dispatch for the economic operation of power systems. In other methods, the problem is decomposed into a P optimization module and a Q-optimization module. But in their method both modules use the same generation cost objective function. Their control variables are generator real power outputs for the real power module, generator reactive power outputs, shunt capacitors or reactors, and transformer tap settings for the reactive power module. Their constraints are the operating limits of the control variables, power line flows, and bus voltages. The optimization problem was solved using the Gradient Projection Method (GPM). The GPM allows the use of functional constraints without the need of penalty functions or Lagrange multipliers among other advantages. Mathematical models were developed to represent the sensitivity relationships between dependent and control variables for both, real and reactive power, and thus eliminate the use of B coefficients. They compared their results of two test systems with other methods.

Quintana & Santos-Nieto (1989) proposed Quadratic Programming based Reactive Power Dispatch. Their objective is to minimization of real-power losses in the system. The real power loss minimization can be achieved by utilizing a full set of control variables, generator voltages, transformer tap settings and switchable shunt capacitors. First and second-order loss sensitivity coefficients are derived for the quadratic problem formulation.
They used Jacobian method for sensitivity calculations and sensitivity relations for the dependent constraints are based on the complete reactive power model of the fast decoupled load flow method. They described active set projection method for quadratic programming and utilized as the solution algorithm for the quadratic reactive power dispatch problem.

Nanda Lakshman Hari & Kothari (1991) proposed a set of new loss formulae for both active and reactive power losses. A maiden attempt was made to develop an algorithm based on classical coordination equations for optimal reactive power dispatch in order to make it most challenging to other existing algorithms for real-time application. An innovative approach considering the concept of fictitious reactive powers is used for modeling onload tap changing (OLTC) transformers. A maiden attempt was made to consider constraints on bus voltages very effectively by expressing the bus voltages in terms of reactive power generations through distribution factors, which are elegantly developed from already available load flow information using a perturbation technique. Their model based on classical coordination equations was tested on IEEE 14 and 30 bus test systems and the results were compared with other methods.

Preecha Preedavichit & Srivastava (1998) has considered the setting of flexible AC transmission system (FACTS) devices as additional control parameters in the ORPD formulation and studied the impact on system loss minimization. Three FACTS devices consisting of static var compensator (SVC), thyristor controlled series compensator (TCSC) and thyristor controlled phase angle regulator (TCPAR) were included in the ORPD formulation.
Abril & Quintero (2003) presented an application of the sequential quadratic programming method to find the optimal sizing of shunt capacitors and passive filters for maximizing the net present value resulting from energy-loss reduction while taking investment cost into account. Their methodology allows the simultaneous solving for fixed and switched volt ampere reactive (VAR) compensators by considering a characteristic load variation curve for each linear and nonlinear load.

Affonso et al (2004) proposed a methodology to improve the power system economical dispatch from a voltage stability margin perspective. The proposed MW and MVAR management methodology is based on active/reactive power re-dispatch for normal operation. They also proposed minimum load shedding strategies in case of critical contingencies. Actions are taken in the direction provided by modal participation factors computed for load buses and generator. The generators with negative impact on system margin using modal index are penalized with high costs on the objective function of the optimal power flow program used to run the re-dispatch process. They decreased the system losses and significant increase on voltage stability margin as well as on system reactive reserves. In addition, their work presented a study considering critical contingencies, which is proposed an optimal load shedding strategy also based on modal participation factors to identify the most adequate buses for load shedding purposes. Their proposed methodology is applied considering a typical hour-to-hour daily load curve. Their method presented very good performance since it considerably increases voltage stability margin for the insecure intervals.

Salgado & Irving (2004) proposed a framework for the simulation and analysis of the reactive power distribution in electric energy markets of
the pool type. They proposed analytical formulation of the Optimal Power Flow (OPF) problem with three optional performance indexes for the reactive power dispatch. Optimal Power Flow objectives are used to determine the reactive power distribution for a given active power dispatch. An allocation strategy is used to assess the participation of each power system agent in the loss reactive power distribution. They used the premise of co-operative game theory. Their proposed methodology is tested with the Ward-Hale 6-bus system.

**Dong et al. (2005)** proposed an optimized reactive reserve management scheme based on the optimal power flow. In order to utilize the maximum reactive power capability of generators they used detailed models of generator limiters (armature and field current limiter), so as to meet reactive power demands during voltage emergencies. The Bender’s decomposition methodology is applied to the reactive reserve management problem. They studied the effective reserves and the impact on voltage stability on a reduced Western Electric Coordinating Council system. Their results proved that their method can improve both static and dynamic voltage stability.

**Yong-jun Zhang & Zhen Ren (2005)** proposed the Costs of Adjusting the Control Devices (CACDs) and a novel mathematical model of ORPD. Their objective function is to minimize the energy loss at the current time interval and the CACD. The proposed model reflects the principle of profit maximization and describes the ORPD problem with time varying loads appropriately since it can decrease active power loss and avoid excessive controls simultaneously.
El-Moursi & Sharaf (2006) investigates the dynamic operation of both static synchronous compensator (STATCOM) and static synchronous series compensator (SSSC) based on a new model comprising full 48-pulse GTO voltage source converter for combined reactive power compensation and voltage stabilization of the electric grid network. Their FACTS devices are power electronic GTO converters connected in parallel or series with the power system grid and are controlled by novel decoupled controllers. Digital simulation of the STATCOM and SSSC within the power system is performed in the MATLAB/Simulink environment using the power system blockset (PSB). The STATCOM scheme and the electric grid network are modeled by specific electric blocks from the power system blockset while the control system is modeled using Simulink. Based on a decoupled current control strategy two novel controllers for the STATCOM and SSSC are used to ensure stable operation of the STATCOM under various load conditions. They proposed a novel control scheme for the static synchronous series compensator (SSSC) to provide a full controllable series compensating (buck/boost) injected voltage over a specified capacitive and inductive range independently of the magnitude of the transmission line current. They used series reactive compensation scheme with an external dc power supply to compensate for voltage drops across resistive component of the transmission line impedance. They proposed novel decoupled controller uses a phase locked loop (PLL) with a novel reduced inherent time delay to improve the transient performance of the SSSC and the performance of both STATCOM and SSSC schemes connected to the 230 kV grids are evaluated.

Lin et al. (2006) proposed a practical market-based reactive power ancillary service management scheme. Reactive power ancillary service
procurement and settlement issues are addressed in their work. Least cost solution is applied to ensure optimal reactive power dispatch when procuring reactive power support. They separated the total minimum reactive cost is into two components: one is assigned to the generation side while the other to the loading side. The cost responsibility of the loading side is recovered from reactive power charge of the reactive loads taking the amount of reactive power and location into account. Cost responsibility of the generation side is equitably allocated to generators according to their different obligations of providing reactive power to support their own active power delivery in a transmission grid. Reactive OPF formulation is developed as an analysis tool and the validity of the proposed scheme is examined using a modified IEEE 14-bus system.

Amarasinghe et al (2007) investigated the simultaneous dispatch of real power and reactive power in restructured electricity markets. In their method the opportunity cost of supplying reactive power is implicitly modeled using the rating of the machine as a constraint. In their proposed model fairness of reactive power supplying obligation is also ensured by splitting the reactive power supplied by the generator into two components with the first component being proportional to real power dispatch. They used the IEEE 30 bus system for Evaluation.

El-Samahy et al (2007) proposed a reactive power dispatch model that takes into account both the technical and economical aspects associated with reactive power provision in the context of the new operating paradigms in deregulated electricity markets. They proposed a model to minimize the total amount of dollars paid by the system operator to the generators for providing the required reactive power support. The real power generation is
decoupled and assumed fixed during the reactive power dispatch procedures. Due to the effect of reactive power on real power, the real power generation is allowed to be re-scheduled within given limits. The proposed reactive power dispatch technique is tested with 32-bus CIGRE benchmark system.

Daroj & Limpananwadi (2008) presented the enhance benefit use of reactive power additional supplied by synchronous based distributed generators to reduce real power loss in distribution system. Their objective is to compare the amount of loss reduced between the Constant Power Factor (CPF) and the Optimal Reactive Power Dispatch (ORPD) schemes. Their proposed ORPD is formulated for optimizing real power loss whose obtained result is the amount of reactive power injected hourly. The linear programming method is adopted in accordance with sensitivity factors to solve for the optimal solution of the ORPD scheme. They examined 38-bus radial distribution system together with ten load profiles recorded from the Provincial Electricity Authority (PEA)'s substation in Thailand.

He et al (2008) proposed a method to optimize reactive power flow (ORPF) with regard to multiple objectives while maintaining system voltage security across a time-domain. Their objective is to minimize both losses and payment for the reactive power service in the daily balancing market of UK. In coordination with ORPF, continuation power flow (CPF) is applied to evaluate and maintain the voltage security margin of the system. Prior to the optimization procedure, the related control parameters can be grouped with the aid of a load classification method in order to simplify the control actions. During the optimization, through the application of both ORPF and CPF, multi-objective optimization can be achieved with voltage security at an acceptable level.
Abbas Rabiee & Mostafa Parniani (2009) proposed the management of reactive power generation to improve the Voltage Stability Margin (VSM), in the framework of Optimal Reactive Power Dispatch (ORD) problem. They used the concept of relative value of VAR sources for scheduling. They tested their methodology using IEEE 14-bus system. The VSM of the systems is increased considerably after their optimal reactive power scheduling, reactive power reserve is increased and active and reactive power losses are decreased.

Alturki et al (2011) introduced a new method to allocate real and reactive losses in pool-based markets. Their basic idea assumed that network users have their own effects on the system as well as their interactive effects which are based on their contributions to currents flows. Their method determines these contributions and adjusts them due to system nonlinearity and according to Current Adjustment Factors (CAFs). The proposed method can easily and effectively allocate real and reactive losses simultaneously without any additional calculation except the substitution of line reactance instead of resistance. They have tested their method on the standard IEEE-14-bus and IEEE-30-bus systems.

Aouss Gabash & Pu Li (2012) proposed a combined problem formulation for active-reactive optimal power flow (A-R-OPF) in Distribution Networks with embedded wind generation and battery storage. Their solution provides an optimal operation strategy which ensures the feasibility and enhances the profit. It can be demonstrated that more than 12% of energy losses and a large amount of reactive energy to be imported from the transmission network (TN) can be reduced using the proposed approach in comparison to the operation strategy where only active OPF is considered.
1.9.3 Non Conventional Methods

A number of Evolutionary Computation techniques were used to solve ORPD problem such as Evolutionary Programming, Genetic Algorithm, Particle Swarm Optimization Algorithm, Seeker Optimization Algorithm, etc. The various Evolutionary Computation techniques used for Optimal Reactive Power Dispatch problem were discussed in this section.

Wu & Ma (1995) solved Optimal Reactive Power Dispatch and voltage control of large scale power system using Evolutionary Programming. The Evolutionary Programming method is able to undertake global search with a fast convergence rate and a feature of robust computation and possesses an inherent capability for parallel processing. A great saving of active power is obtained using the Evolutionary programming and they compared the results with a conventional gradient-based optimization method.

Abdullah et al (1998) proposed an alternative approach to optimal reactive power dispatch based on Genetic Algorithm techniques. Scheduling of reactive power in an optimum manner reduces circulating VAR promoting flatter voltage profile which leads to appreciable MW saving on account of reduced system losses. Therefore, the optimal reactive power dispatch assumes extremely important functioning both in planning stage as well as in day to day operation of the power system. Their technique is used to search for transformer tap settings and the value of shunt capacitors of a given system such that the total system power loss is minimized. The proposed method is tested on IEEE 14 and 30 bus test systems and the results were compared with those obtained using load flow calculation.
Wang et al (1998) presented a comparative study for three Evolutionary Algorithms (EAs) to the optimal reactive power planning problem. Evolutionary programming, Evolutionary strategy and genetic algorithm. Optimal Reactive Power Planning problem is decomposed into P and Q optimization modules and each module is optimized by the EAs in an iterative manner to obtain the global solution. The proposed methods for the ORPP Problem are evaluated against the IEEE 30 bus system as a common test system and the results are compared against each other and with those of linear programming.

Venkatesh et al (2000) presented an optimal reactive power scheduling method is sought which minimizes real power transmission loss and maximizes Voltage Stability Margin (VSM) subject to the utmost satisfaction of all the violated load bus voltage constraints. They proposed Multi-objective Fuzzy LP (MFLP) method of solution in the Successive LP (SLP) framework. They used a set of least singular values of the load flow Jacobian for VSM indicator. Results of the tests of the method on modified IEEE 6 bus and 57 bus systems are presented. They studied the changes in the load flow Jacobian singular values during scheduling.

Hirotaka Yoshida et al (2000) presented a particle swarm optimization for reactive power and voltage control considering voltage security assessment. Volt Var Control can be formulated as a mixed-integer nonlinear optimization problem. The method expands the original PSO to handle a MINLP and determines an on-line VVC strategy with continuous and discrete control variables such as automatic voltage regulator operating values of generators, tap positions of on-load tap changer of transformers and the number of reactive power compensation devices. Their method considers
voltage security using a continuation power flow and a contingency analysis technique. The feasibility of the method is demonstrated and compared with reactive tabu search and the enumeration method on practical power system models.

Denget al (2002) was investigated reactive power optimization with time-varying load demand in distribution systems. The objective of their work is to determine the proper setting values of capacitor banks and transformer taps for the 24 h in the next day. They proposed a heuristic and algorithmic combined approach for their work. The approach simplifies the mathematical model of the daily setting values of reactive power/voltage control devices. They solved the temporal optimization of each control devices by heuristic rules and convert the optimization model with time-varying load into the same one as conventional optimization model with constant load. So, the algorithms applied to the conventional optimization model can be easily used to solve the optimization model with time-varying load demand. Their results show that a proper dispatch schedule for capacitor banks and transformer taps can be reached by this approach efficiently.

Wei Yan et al (2004) proposed an Improved Evolutionary Programming (IEP) and its hybrid version combined with the nonlinear interior point (IP) technique to solve the Optimal Reactive Power Dispatch (ORPD) problems. The common practices in regulating reactive power are followed in adjusting the mutation direction of control variables in order to increase the possibility of keeping state variables within bounds in their method. The improved evolutionary programming method is also hybridized with the IP method to obtain a fast initial solution and used as a highly evolved individual in the initial population of the improved EP method.
Zhao et al (2005) proposed a novel Particle Swarm Optimization approach based on multiagent systems (MAPSO) for reactive power dispatch problem. An agent in their method is represents a particle to PSO and a candidate solution to the optimization problem. Each agent competes and cooperates with its neighbors and it can also learn by using its knowledge in order to obtain optimal solution quickly. Making use of these agent-agent interactions and evolution mechanism of PSO and MAPSO realizes the purpose of optimizing the value of objective function. The proposed optimal reactive power dispatch is evaluated on an IEEE 30-bus power system.

Durairaj et al (2005) presented a Genetic Algorithm (GA) based approach for solving optimal Reactive Power Dispatch (RPD) including voltage stability limit in power systems. Their methodology for voltage stability is based on the L-index of load buses. Their control variables are bus voltage magnitudes, transformer tap settings and reactive power generation of capacitor banks. A binary-coded Genetic Algorithm with tournament selection, the two point crossover and bit-wise mutation was used to solve this complex optimization problem. The proposed algorithm was applied to the IEEE 30-bus system to find the optimal reactive power control variables while keeping the system under safe voltage stability limit.

Ahmed et al (2005) presented a Particle Swarm Optimization as a tool for loss reduction. They developed optimal power flow based on loss minimization function by expanding the original PSO. They identified the critical area of the power system under the point of view of voltage instability by using the tangent vector technique. The PSO technique is used to calculate the amount of shunt reactive power compensation that takes place in each bus.
Abido & Bakhashwain (2005) proposed a novel multiobjective evolutionary algorithm for Optimal Reactive Power (VAR) Dispatch. The ORPD problem is formulated as a nonlinear constrained multiobjective optimization problem where the real power loss and the bus voltage deviations are to be minimized. They proposed a new Strength Pareto Evolutionary Algorithm based approach to handle the problem as a true multiobjective optimization problem with competing and non-commensurable objectives. They proposed a hierarchical clustering algorithm to provide the decision maker with a representative and manageable Pareto-optimal set. A fuzzy set theory is employed to extract the best compromise solution over the trade-off curve. Their results demonstrate the capabilities of the proposed approach to generate true and well-distributed Pareto-optimal solutions of the multiobjective VAR dispatch problem.

Furong Li et al (2005) proposed an Integer-coded, multiobjective Genetic Algorithm (IGA) applied to the full Reactive-power Compensation Planning (RCP) problem considering both intact and contingent operating states. Their method is used to simultaneously solve both the sitting problem optimization of the installation of new devices and the operational problem optimization of preventive transformer taps and the controller characteristics of dynamic compensation devices. Their objective is to produce an optimal sitting plan that does not violate any system or operational constraint and is optimal in terms of the voltage deviation from the ideal and the cost incurred through the installation and use of reactive power compensation devices.

Their algorithm is tested on the IEEE 30-bus system and on a reduced practical system that was developed with the cooperation of the National Grid. They developed the Linear Programming- based (LP) planning
tool (scorpion software package) and used by the National Grid for the England and Wales transmission system. They compared their results with LP-based method. The system performance is optimized via the adjustment of tap settings and controller characteristic across multiple operating states.

Juan Jimenez et al (2005) presented a Particle Swarm Optimization approach for solving the reactive power dispatch problem. Their objective is to minimize the transmission real power losses by controlling the generators voltages magnitudes, the transformers taps settings and the adjustable capacitor banks capacity while satisfying the operating constraints of the system. The proposed method was tested on the IEEE 30 Bus System.

Jiang Chuanwen & Torre Bompard (2005) proposed a method combining Particle Swarm Optimization with linear interior point to handle the ORPD problem. Their method introduces chaos mapping into the particle swarm optimization. They presented a new arithmetic based on a hybrid method of chaotic particle swarm optimization and linear interior point. Their method is proved effective and practical in the optimization of shunt capacitors and tap position of load-ratio voltage transformer.

Lai et al (2005) proposed swarm intelligence to solve optimal reactive power dispatch (ORPD) problem. They have compared their results with improved genetic algorithm and a conventional gradient-based optimization method. Their comparison shows that swarm intelligence would produce better results on the IEEE 30-bus system as those from improved genetic algorithm and conventional method for solving ORPD problem.
Wei Yan et al (2006) proposed a novel hybrid method for the optimal reactive power flow (ORPF) problem by integrating a genetic algorithm (GA) with a nonlinear interior point method (IPM). The proposed method can be mainly divided into two parts. First part is to solve the ORPF with the IPM by relaxing the discrete variables and the second part is to decompose the original ORPF into two sub-problems and they are continuous optimization and discrete optimization. Genetic Algorithm is used to solve the discrete optimization with the continuous variables being fixed. The IPM solves the continuous optimization with the discrete variables being constant. They get the optimal solution by solving the two sub-problems alternately. A dynamic adjustment strategy is also proposed to make the GA and the IPM to complement each other and to enhance the efficiency of the hybrid method.

Guo Chuang xin&Zhao Bo (2006) proposed a Pooled-Neighbor Swarm Intelligence Approach (PNSIA) to optimal reactive power dispatch and voltage control. Their approach uses more particles information to control the mutation operation. Their PNSIA algorithm is also extended to handle mixed variables, like transformer taps and reactive power source installation. Their optimal power system reactive power dispatch algorithm is evaluated on an IEEE 30-bus power system in which the control of bus voltages, tap position of transformers and reactive power sources are involved to minimize the transmission loss of the power system.

AlirezaAbbasy&Seyed Hamid Hosseini (2007) proposed different Ant Colony Optimization (ACO) algorithms to the Reactive Power Dispatch (RPD) problem. They introduced ant colony optimization algorithm such as, Ant system (AS), Elitist Ant System (EAS), rank based Ant System (AS rank) and max-min Ant System (MMAS) for the reactive power dispatch problem.
The proposed methods were applied to the IEEE 30-bus system to analyze the efficiency of these modern search algorithms and the results were compared to those of conventional mathematical methods, evolutionary programming, geneticalgorithm and particle swarm optimization.

Subburaj et al (2007) presented a Genetic Algorithm (GA) approach for solving the reactive power dispatch problem including the line flow constraint. The objective of their reactive power optimization problem is minimizations of real power loss with FACTS and without FACTS devices. The proposed algorithm was applied to find the optimal reactive power control variables in IEEE 30 and IEEE 118-bus systems.

Varadarajan et al (2008) presented Differential evolution based optimal reactive power dispatch for real power loss minimization in power system. Their control variables are generator terminal voltages, transformer tap positions and the number of shunts to be switched. Their objective is to minimize the real power in the transmission system. They employed a generic penalty function method which does not require any penalty coefficient for constraint handling. Their approach also checks for the feasibility of the optimal control variable setting from a voltage security point of view by using a voltage collapse proximity indicator. Their algorithm is tested on standard IEEE 14 and IEEE 30-Bus test system and the results were compared with Sequential Quadratic Programming and Particle Swarm Optimization.

Wen Zhang & Yutian Liu (2008) proposed a new formulation of multi-objective reactive power and voltage control for power system and the load constrains and operational constrains are also taken into consideration. A pseudo goal function derived on the basis of the fuzzy sets theory gives a
unique expression for the global objective function is proposed. The membership functions were used to evaluate both objective functions and constraints. The inequality constrains are embedded into the fitness function by pseudo goal function which guarantees that the searched optimal solution is feasible. They proposed a new type of evolutionary algorithm and particle swarm optimization. To improve the performance of PSO, a fuzzy adaptive PSO (FAPSO) is proposed. A fuzzy system is employed to adaptively adjust the parameters of PSO.

LotfiKrichen et al (2008) developed a method aimed to impose an acceptable voltages profile and to reduce active losses of an electrical supply network including wind generators. Their tasks are ensured by acting on capacitor and reactor banks implemented in the load nodes. To solve this problem, they minimize multi-objective functions associated to the active losses and the compensation devices cost under constraints imposed on the voltages and the reactive productions of the various banks. The minimization procedure was realized by the use of evolutionary algorithms. Their neural model has the capacity to provide a good estimation of the voltages, reactive power productions and the losses for actual curves of the load and the wind speed.

Sharifzadeh&Jazaeri (2008) presented a Particle Swarm Optimization (PSO) method for reactive power dispatch optimization problem. Their RPD problem involves nonlinear objective function with multiple local minima. Their constraints are nonlinear and discontinuous, and continuous and discrete variables. Simulation results on the IEEE 14-bus test system and IEEE 30-bus test system are presented and compared with genetic algorithm and differential evolution.
John Vlachogiannis & Jacob Stergaard (2009) presented an improved evolutionary algorithm based on quantum computing for optimal steady-state performance of power systems. The proposed general quantum genetic algorithm (GQ-GA) determines the optimal settings of control variables for optimal reactive power and voltage control of IEEE 30-bus power systems. The results of GQ-GA are compared with the classical primal-dual interior-point optimal power flow algorithm, multi-objective evolutionary algorithm, genetic algorithm and particle swarm optimization algorithms.

Carlos Henggeler Antunes et al. (2009) presented the problem of locating and sizing capacitors for reactive power compensation in electric radial distribution networks is modeled as a multi-objective programming problem. They proposed an evolutionary approach consisting of an elitist genetic algorithm with secondary population is used to characterize the Pareto optimal frontier. In their model, two objective functions of technical and economical nature are explicitly. Their objectives are minimization of system losses and minimization of capacitor installation costs. The performance of the distribution network before and after the reactive power compensation is exploited.

Vaisakh & Kantarao (2009) proposed a self-adaptive differential evolution (SADE) and self-tuning Hybrid differential Evolution (HDE) methods for dealing with optimal reactive power dispatch aiming at power loss reduction. Their objective is to minimize the active power loss and improve the voltage profile. The proposed method is used to determine the optimum settings of reactive power control variables. The IEEE 14-bus test system is used to exemplify the performance of the proposed method.
Ying Li et al (2009) proposed Message Passing Interface (MPI) based parallel computation and particle swarm optimization algorithm are combined to form the parallel particle swarm optimization method for solving the dynamic optimal reactive power dispatch problem in power systems. Their problem is divided into smaller one and which can be carried out concurrently by multi-processors. Their method is evaluated on a group of IEEE power systems test cases with time-varying loads in which the control of terminal voltages of the generator, tap position of transformers and reactive power sources are involved to minimize the transmission power loss and the costs of adjusting the control devices 

Subbaraj & Rajnarayanan (2009) presented self-adaptive real coded genetic algorithm (SARGA) is used as one of the techniques to solve optimal reactive power dispatch (ORPD) problem. In their method by applying the simulated binary crossover (SBX) operator the self-adaptation in real coded genetic algorithm (RGA) was introduced. The binary tournament selection and polynomial mutation are also introduced in real coded genetic algorithm. Their problem formulation involves continuous (generator voltages), discrete (transformer tap ratios) and binary (var sources) decision variables. They proposed stochastic based SARGA approach and handle all types of decision variables and produce near optimal solutions.

Roy et al (2009) proposed a new Particle Swarm Optimization (PSO) algorithm namely Turbulent Crazy Particle swarm Optimization (TRPSO) is introduced to solve multi-constrained optimal reactive power dispatch in power system. The proposed optimal reactive power dispatch problem is a multi-objective optimization problem that minimizes bus voltage deviations and transmission loss. The efficiency of the proposed algorithm is
demonstrated for IEEE 30-bus system and it is compared to other well established population based optimization techniques like conventional PSO, general passive congregation PSO (GPAC), local passive congregation PSO (LPAC), coordinated aggregation (CA) and Interior point based OPF (IP-OPF).

Durairaj & Devaraj (2009) presented an improved Genetic Algorithm (IGA) approach to solve the Reactive Power Dispatch (RPD) in power system incorporating thyristor controlled series capacitor (TCSC) devices. The optimal location of the TCSC devices is found by sensitivity analysis for a given test system. A binary-coded genetic algorithm with tournament selection, the two point crossover and bit-wise mutation is used to solve this mixed-integer non-linear optimization problem. In order to take care of the discrete nature of transformer tap setting and capacitor bank, some modifications were made in the representation of the solution variables in the genetic population. The test and validation of proposed algorithm are conducted on two test systems: one is the IEEE 30-bus system, and the other is a reduced practical 76-bus Indian power system and is found to be more effective than the conventional methods.

Chaohua Dai et al (2009) proposed a seeker optimization algorithm (SOA) based method for ORPD considering static voltage stability and voltage deviation. Seeker optimization algorithm is based on the concept of simulating the act of human searching where search direction is based on the empirical gradient by evaluating the response to the position changes and step length is based on uncertainty reasoning by using a simple fuzzy rule. The algorithm’s performance is compared with differential evolution, genetic algorithm and particle swarm optimizations algorithm.
Bhattacharyya & Goswami (2009) presented a new idea with in the evolutionary algorithms for solving the optimal Reactive Power dispatch problem. They developed the Loss sensitivity approach and used in each of the evolutionary algorithms such as Differential Evolution (DE), Particle Swarm Optimization (PSO) And Genetic Algorithm (GA). Their objectives are to minimize real power loss and to improve the voltage profile of a given interconnected power system. A term “Loss sensitivity” at each bus is defined which depends on variation of real power loss with respect to the voltage at that bus. Corrective action is taken based on the values of the loss sensitivity by adding shunt capacitor at the weak buses identified by weak bus analysis by controlling reactive generations at the generator buses by judging the sensitivity at these buses. The tap changing positions are controlled if the tap changing transformers are in between the loss sensitive buses. Evolutionary Algorithms are run to make one iteration complete and the whole process is allowed to continue for the specified number of iterations. The solutions obtained by this method are compared with the solutions obtained by each of these evolutionary algorithms separately and also with their hybrids with Simulated Annealing (SA) and with Simple Quadratic Programming (SQP).

Aruna Jeyanthy & Devaraj (2010) proposed optimal reactive power dispatch for voltage stability enhancement using real coded genetic algorithm. They proposed and formulated the reactive power dispatch as a multi-objective optimization problem. Their objectives are loss minimization and maximization of static voltage stability margin (SVSM). Voltage stability evaluation using modal analysis is used as the indicator of voltage stability. The GA search as from a population of points in the solution space and thus
improves the chances of finding a global optimum. Thus GAs has proven to be a useful approach to address a wide a variety of optimization problems.

Mahadevan et al (2010) they solved RPD problem using particle swarm optimization (PSO). A learning strategy is introduced in PSO to overcome the drawback of premature convergence and this approach called comprehensive learning particle swarm optimization (CLPSO). PSO is also applied to this problem and a comparison of results is made between these two. Their objective is minimization of real power losses, improvement of voltage profile and enhancement of voltage stability through a standard IEEE 30-bus system.

Congyu Zhang et al (2010) proposed a Multi-objective Particle Swarm Optimization Algorithm (MOPSO) for power system reactive power dispatch and considering the active power loss and voltage deviation. MOPSO incorporates non-dominated sorting, crowding distance and a special mutation operation into particle swarm optimization to enhance the exploratory capability of the algorithm and improve the diversity of the Pareto solutions. The performance of the proposed algorithm is tested with four benchmark test functions. They made performance comparison between MOPSO and other typical algorithms. The standard IEEE-30-bus power system is used as a test system.

Abou El-Ela et al (2010) proposed a procedure for solving the optimal reactive power dispatch (ORPD) problem using ant colony optimization (ACO) algorithm. The objective of the ORPD is to minimize the transmission line losses under control and dependent variable constraints using proposed sensitivity parameters of reactive power that dependent on a
modification of Fast Decoupled Power Flow (FDPF) model. The ACO algorithm is applied to the IEEE standard 14-bus and a real power system at west delta network as a part of the Unified Egyptian Network (UEN). The proposed ACO algorithm for the ORPD problem compared with those obtained using the conventional optimization techniques as linear programming (LP), genetic algorithm (GA) and particle swarm optimization (PSO) technique.

Zechun Hu et al (2010) proposed a chance-constrained programming formulation for Optimal Reactive Power Dispatch (ORPD) that considers uncertain nodal power injections and random branch outages. They proposed a solution method combining both probabilistic load flow and a genetic algorithm for ORPD. Simulations on several test systems show that their method can prevent under-compensation or over-compensation of reactive power and increase voltage security margins.

Devaraj&Preetha Roselyn (2010) presented an improved Genetic algorithm (GA) approach for voltage stability enhancement. Their technique is based on the minimization of the maximum of L-indices of load buses. Their optimization variables are Generator voltages, switchable VAR sources and transformer tap changers. The approach permits the optimization variables to be represented in their natural form in the genetic population. The crossover and mutation operators which can directly deal with the floating point numbers and integers are used for effective genetic processing.

Arya et al (2010) presented a new approach for scheduling of reactive power control variables for voltage stability enhancement using particle swarm optimization (PSO). Cost function selected is maximization of
reactive reserves of the system. To obtain desired stability margin a Schur’s inequality based proximity indicator is selected whose threshold value along with reactive power reserve maximization assures desired static voltage stability margin. Reactive generation participation factors are used to decide weights for reactive power reserve for each of generating bus. The proposed algorithm was implemented on 6-bus and 25-bus standard test systems.

Worawat Nakawiro et al (2011) proposed a novel optimization algorithm for Optimal Reactive Power Dispatch (ORPD). They proposed Mean-variance mapping optimization (MVMO) algorithm and was a better method to solution of optimization problems. The goal of ORPD in their method was to determine the optimal settings of reactive power control variables leading to the minimum power losses while maintaining several constraints. They analyzed fitness function and finding optimum solution.

Ramesh et al (2011) presented a multi-objective solution set for RPD problem. Their objective functions are minimization of real power loss and minimization of control variable adjustment costs. They have considered the setting of Flexible AC Transmission System (FACTS) device as additional control parameter in the RPD formulation. They proposed a Modified Non-Dominated Sorting Genetic Algorithm version II (MNSGA-II) for solving RPD problem. The concepts of Dynamic Crowding Distance (DCD) are implemented in NSGA-II algorithm for maintaining good diversity in the performance of NSGA-II and given name as MNSGA-II. The algorithm is tested in standard IEEE 30-bus test system. The results obtained by MNSGA-II are compared with NSGA-II and validated with conventional weighted sum method using Real-coded Genetic Algorithm (RGA). The
performance of NSGA-II and MNSGA-II is compared with various multi-objective algorithms.

Juan Ramirez et al (2011) proposed an optimal reactive power dispatch strategy taking care of the steady state voltage stability. They studied the two power systems of the open publications. Power flow analysis was carried out for which are the initial conditions for Transient Stability (TS), Small Disturbance (SD), and Continuation Power Flow (CPF) studies. The impact of the optimization strategy is verified by steady state voltage stability analysis. The demonstration of the proposed method was analyzed by PV curves, Eigen value analyses, and time domain simulations.

Li et al (2011) proposed a parallel particle swarm optimization (PPSO) approach for solving the distributed optimal reactive power dispatch (ORPD) problem. Their method is a combination of parallel computation based on Message Passing Interface (MPI) and particle swarm optimization algorithm. The large scale power system is dividing into a group of small subsystems and optimal reactive power dispatch problem of each subsystem is solved. They reduced the size of each ORPD problem and it became easier to solve the optimization problem. To find the solution of whole system results from each subsystem will be combined together.

Abou El Ela et al (2011) presented an efficient and reliable evolutionary-based approach to solve the RPD problem. Their approach employs differential evolution (DE) algorithm for optimal settings of RPD control variables. Their approach is examined and tested on the standard IEEE 30-bus test system with different objectives that reflect power losses minimization, voltage profile improvement and voltage stability
enhancement. The simulation results of their approach are compared with other algorithms.

Marcela Martinez-Rojas et al (2011) proposed an optimization method for the reactive power dispatch in wind farms (WF). Particle swarm optimization (PSO), combined with a feasible solution search (FSSPSO) is applied in order to optimize the reactive power dispatch and taking into consideration the reactive power requirement at point of common coupling (PCC), while active power losses are minimized in a WF. Reactive power requirement at PCC is included as a restriction problem and is dealt with feasible solution search. They found an individual set point particular for each wind turbine (WT). Their algorithm is tested on a WF with 12 WTs and taking into consideration different control options and different active power output levels.

El-Araby& Naoto Yorino (2011) proposed a new market-based technique for acquiring VAR ancillary service in the electricity market. The main objective of their work is to enable Transmission Operator (TO) to procure VAR service in a long term contract from the critical VAR providers that satisfy minimum VAR service payment while maintaining system security. They introduced reactive power control problem for voltage stability into the VAR market problem in an explicit manner for normal and emergency states. They integrate the particle swarm optimization (PSO) with successive linear programming (SLP) for solving VAR ancillary service problem. Their problem is formulated as a large-scale nonlinear constrained optimization problem with a non-differentiable objective function representing VAR payment and operational costs. They proposed a two-layer hybrid PSO/SLP approach. Their method is suited for carrying out the
difficulties associated with non-differentiable and discontinuous objective functions. Their algorithm was examined on the standard IEEE 57 bus-system and compared with GA/SLP method.

Jeyadevi et al (2011) presented an application of modified NSGA-II (MNSGA-II) by incorporating controlled elitism and dynamic crowding distance (DCD) strategies in NSGA-II to multi objective optimal reactive power dispatch (ORPD) problem by minimizing real power loss and maximizing the system voltage stability. Reference Pareto-front is generated using multiple runs of single objective optimization with weighted sum of objectives to validate the Pareto-front obtained using MNSGA-II. The performances of MNSGA-II, NSGA-II and multi objective particle swarm optimization (MOPSO) approaches were compared with respect to multi objective performance measures. They applied TOPSIS technique on obtained non-dominated solutions to determine best compromise solution (BCS). Karush–Kuhn–Tucker (KKT) conditions are also applied on the obtained non dominated solutions to substantiate a claim on optimality. The result of the MNSGA-II performs better than NSGA-II in maintaining diversity and authenticates its potential to solve multi objective ORPD effectively.

Azzam & Mousa (2012) proposed a new approach to solve the multiobjective reactive power compensation (RPC). Their approach is based on the combination of genetic algorithm (GA) and the ε-dominance concept. Based on the concept of ε-dominance, their algorithm maintains a finite-sized archive of nondominated solutions (Pareto solution) which gets iteratively updated in the presence of new solutions. The use of ε-dominance makes the algorithms practical by allowing a decision maker (DM) able to control the resolution of the Pareto set approximation according to needs. Their approach
is suitable to RPC problem where the objective functions may be ill-defined and having nonconvex Pareto-optimal front. Their method gives a reasonable freedom in choosing compensation devices from the available commercial devices and also save computing time in cases of small archive. A TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) method is adopted to help the DM to extract the best compromise solution from a finite set of alternatives. It is based upon simultaneous minimization of distance from an ideal point (IP) and maximization of distance from a nadir point (NP). The proposed approach is carried out on the standard IEEE 30-bus 6-generator test system. Their results show the capabilities of the proposed approach to generate true and well-distributed Pareto optimal nondominated solutions of the multiobjective RPC problem.

Abou El-Ela et al (2012) proposed a procedure to solve the optimal reactive power dispatch (ORPD) problem using ant colony optimization (ACO) algorithm. The objective of their ORPD problem is to minimize the transmission power losses under control and dependent variable constraints. Based on a modified model of fast decoupled power flow the proposed sensitivity parameters of reactive power at generation and switchable sources are derived. Their algorithm is applied to the IEEE standard 14-bus 30-bus systems. Their method is also tested on a real power system at West Delta Network as a part of the Unified Egyptian Network. They compared their results with conventional linear programming, genetic algorithm and particle swarm optimization technique.

Chao-Ming Huang & Yann-Chang Huang (2012) proposed a hybrid approach to solve the optimal reactive power dispatch (ORPD) problem. Their objective is minimization of active power transmission losses by
controlling a number of control variables. Their approach combines variable scaling mutation and probabilistic state transition rule used in the ant system to deal with the ORPD problem based on the original differential evolution (DE) algorithm. They compared performance of the proposed method with the similar evolution approaches such as the evolutionary programming (EP) and particle swarm optimization (PSO) are also implemented using the same study case.

Yinliang Xu et al. (2012) proposed a fully distributed multiagent-based reinforcement learning method for optimal reactive power dispatch. In their method, two agents communicate with each other only if their corresponding buses are electrically coupled. Consensus-based global information discovery algorithm is used to obtain the global rewards that are required for learning. A distributed Q-learning algorithm is implemented to minimize the active power loss while satisfying operational constraints based on the discovered global rewards. The proposed method does not require accurate system model and can learn from scratch. Their results compared with power systems of different sizes.

Rabice Abbas et al. (2013) proposed a method for management of on-load tap changers (OLTCs) and dynamic VAR sources to improve voltage stability margin (VSM) of power systems. The main contribution of their work is to introduce a new objective function for the ORD problem. Their objective function is derived based on a local voltage stability index (DSY) and has a strong correlation with VSM. Their strong correlation makes the objective function effective for improving VSM. The proposed objective function is tested on the New England 39-bus test system and its performance is compared with other methods. The obtained results show that solving ORD
problem using the proposed objective function yields considerable increase in VSM.

Julio Cesar et al (2013) presented a model for long-term reactive power planning where a deterministic nonlinear model is expanded into a multi-stage stochastic model under load uncertainty and an N-k contingency analysis. They introduced reactive load shedding in the objective function to measure the reactive power deficit after the planning process. The objective of their work is to minimize the sum of investment costs (IC), expected operation costs (EOC) and reactive load shedding costs optimizing the sizes and locations of new reactive compensation equipment to ensure power system security in each stage along the planning horizon. They used an efficient scenario generation and reduction methodology for modeling uncertainty. Their method is used to calculate the performance of the expected value with perfect information (EVPI) and the value of the stochastic solution (VSS) methodologies. The efficiency of their model is tested and justified by the simulation results using the Ward-Hale 6-bus and the IEEE 14-bus systems.

Barun Mandal & Provas Kumar Roy (2013) presented a newly developed teaching learning based optimization (TLBO) algorithm to solve multi-objective optimal reactive power dispatch (ORPD) problem by minimization of real power loss, minimization of voltage deviation and voltage stability index. In their method, to accelerate the convergence speed and to improve solution quality quasi-opposition based learning (QOBL) concept is incorporated in original TLBO algorithm. The TLBO and quasi-oppositional TLBO (QOTLBO) approaches are implemented on standard IEEE 30-bus and IEEE 118-bus test systems. Their results demonstrate the superiority in terms of solution quality of the proposed QOTLBO approach.
over original TLBO and other optimization techniques and confirm its potential to solve the ORPD problem.

AmitSaraswat&AshishSaini(2013) proposed a new hybrid fuzzy multi-objective evolutionary algorithm (HFMOEA) based approach for solving complex multi-objective, mixed integer nonlinear problems such as optimal reactive power dispatch considering voltage stability (ORPD-VS). In their approach two parameters like crossover probability ($P_c$) and mutation probability ($P_m$) are varied dynamically through the output of a fuzzy logic controller. Based on the expert knowledge the fuzzy logic controller is designed to enhance the overall stochastic search capability for generating better pareto-optimal solution. The performance of HFMOEA is tested on five benchmark test problems and also applied to multi-objective ORPD-VS problem. The optimization results obtained from HFMOEA are analysed and compared with the same obtained from two versions of elitist non-dominated sorting genetic algorithms such as NSGA-II and MNSGA-II in terms of various performance metrics.

1.9.4 Conclusion

Based on the literature survey, it is concluded that, various mathematical techniques were adopted to solve optimal reactive power dispatch problem. These include the gradient method, Newton method, interior point, quadratic programming and linear programming. The gradient and Newton methods suffer from the difficulty in handling inequality constraints. The input- output function is to be expressed as a set of linear functions which may lead to loss of accuracy in linear programming. Drawbacks of these algorithms can be declared insecure convergence
properties, long execution time, algorithmic complexity and solution can be trapped in local minima.

Recently global optimization techniques such as genetic algorithm and particle swarm optimization algorithm were to solve the optimal reactive power dispatch problem. However, these methods also have some disadvantages in the process of solving the complex ORPD problem. In this work recent evolutionary algorithms, such as Differential Evolution with Global and Local Neighbourhood algorithm (DEGL), Bacterial Foraging algorithm (BFA), Gravitational Search algorithm (GSA) and Artificial Bee Colony algorithm (ABC) are used to solve the ORPD problem. The proposed algorithms are evaluated on an IEEE 30-bus and IEEE 57-bus power systems and results of the proposed algorithms are compared with previous approaches.