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Reactive Power Flow Controller

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Abstract: Wind energy's presence in the electric power system has dramatically grown over the past decade and will continue to grow worldwide as many countries have planned future developments. As wind power penetration into the grid increases, the influence of wind farms on the power system operation is becoming more and more important [1]. Wind power is gaining momentum in the world's energy balance. Several issues have to be addressed whenever power-generating devices are interfaced to the grid. Two of the main requirements are reactive power control in normal operation conditions and fault ride-through capability during fault conditions. The main purpose of normal operation requirements is to maintain the voltage between admissible limits both for security and power quality purposes. Since reactive power cannot be transmitted over long distances, it has to be provided locally. Therefore, in grid connection specifications, wind farms are generally required to contribute to reactive power control. Concerning fault condition requirements, they are aimed at avoiding as much as possible the loss of generation capacity in case of a fault in the transmission grid. Power system operators ensure the quality and reliability of supply to the customers by maintaining the load bus voltage in their permissible limits. Any changes to the system configuration or in power demands can result in higher or lower voltages in the system. This situation can be improved by reallocating reactive power generations in the system [5]. This paper presents the setting of FACTS devices like STATCOM as additional control parameters in the optimization of reactive power dispatch and studies the impact on system loss minimization. This proposed work is carried out in offline full-scale simulations in PSCAD simulation software. This paper concludes that STATCOM at the grid connection point can mitigate reactive power, improve voltage profile.

Keywords: STATCOM, Reactive Power Dispatch, PSCAD.

I. INTRODUCTION

The optimal power flow problem is to minimize the fuel cost, system losses or some other appropriate objective function while maintaining an acceptable system performance in terms of limits on generator real and reactive power output, output in compensating devices, transformer tap settings or bus voltage levels etc. When only total fuel cost is minimized the optimal power flow problem corresponds to an Economic Load Dispatch (ELD) sub problem. As the system transmission loss depends on reactive power injection, the minimization of loss problem corresponds to the Optimal Reactive Power Dispatch (ORPD) sub problem condenser. To solve this complex problem several methods based on sensitivity relationship are reported in published research literature.Optimal Reactive Power Dispatch is one of the application functions of modern Energy Management System, used to minimize total system real power loss and improve voltage profile. Optimal Reactive Power Dispatch computes optimal settings of reactive power output or terminal voltage of generating plant, transformer tap settings and output of other compensating devices such as capacitor banks and synchronous condenser. To solve this complex problem several methods based on sensitivity relationship are used [6]. The concept of using solid state, power electronic converters for power flow control at the transmission level have been known as FACTS. The idea has had some success in certain areas such as VAr dispatch and control. However, the full use of FACTS for power flow control has had limited application in part due to reliability concerns, and in part due to availability of components. The potentional improvement of the transient response of a system with FACTS devices is a very important consideration in many applications.
This paper has presented the setting of STATCOM for optimization of reactive power dispatch and studies the impact on system loss minimization. This proposed work is carried out in offline full-scale simulations in PSCAD simulation software.

II. OPTIMAL REACTIVE POWER DISPATCH

The main task before utility is to meet the load demand of system most economically while ensuring desired quality of supply to consumers. The quality of supply is judged in terms of constant voltage. Extra reactive power demand from load increases magnitude of current in the system due to which real power loss is increased. Thus voltage drop in the system is increased, which reduces terminal voltage. Reactive power developed in transmission line is proportional to voltage drop in the system. If the extra reactive power demand of load is supplied separately instead of providing it from generator keeps current magnitude constant in the system. Thus maximum real power can be transmitted in a system by reducing the supply of reactive power from generator. This can be achieved by suitably adjusting the following controllable variables:

- Transformer taps
- Generator voltage
- Switchable shunt capacitor and inductor

Optimal reactive power dispatch is used to minimize system transmission loss P_L expressed as non-linear function of reactive power generation and transformer taps subjected to satisfying various system constraints in order to determine optimal values of reactive power outputs of sources (Q_G) and tap settings (t) of transformer. Thus it can be formulated as an optimization problem solved to,

Minimize $P_L = P_L\ (Q_G\ , t)$

The conventional ORPD problem has been formulated as to minimize total system real power loss while satisfying the network performance constraints and the operating limits of control variables. The control variables considered in this formulation include generator terminal voltage and transformer tap settings, which are used to determine the optimal reactive power settings of generator and other VAR sources [3].

III. METHOD OF VOLTAGE CONTROL

The following methods are use for voltage control in power system:

1. Tap changing transformer
2. Shunt reactor
3. Synchronous phase modifier
4. Shunt capacitor
5. Series capacitor
6. Static VAR systems

Tap changing transformer:

The change of voltage is affected by changing the number of turns of transformer provided with taps. For sufficiently controls of voltage, taps are usually provided on the high voltage winding of the transformer. There are two types of tap changing transformer

a) Off load tap changing transformer
b) On load tap changing transformer

Tap changing is most widely use method of controlling voltage at all levels.

Shunt Reactor:

It is an inductive current element connected between line and neutral to compensate of capacitive current on the transmission lines or under ground cables.

Shunt reactor are connected to the tertiary windings of power transformer via circuit breakers. EHV shunt reactors may be connected between the transmission lines directly without any switching device.

Shunt capacitor:

Shunt capacitor are the capacitors connected in parallel with the lines. They are installed near the load terminals, in receiving end substation, distribution substation and in switching sub station. Shunt capacitor inject leading reactive VAr to counteract some or all of lagging inductive VAr at the point of installation. They are arranged in the three-phase bank.

To overcome the Ferranti effect difficulty the capacitor bank is provided with fixed and variable elements thus achieving flexibility.

Series Compensation:

Capacitors are connected in series with the line at a suitable location. Series capacitors increases Transmission capacity, improve system stability, control voltage regulation and ensure proper load division among parallel feeders.

Synchronous phase modifier:

Synchronous phase modifier is a synchronous motor running without a mechanical load. It can generate or absorb reactive VAr by varying the excitation of its field winding. It also improves the power factor. It is connected in parallel with the load at the receiving end of the line. Static VAr system: In static VAr system, thyristors are used as switching devices instead of circuit breakers. Thyristor switching is faster than mechanical switching and also it is

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possible to have transient free operation by controlling instant of switching. SVS schemes are at various places installed.

IV. MODELING OF STATCOM

Using sensitivity relationship method can solve the complex problem of Optimal Reactive Power Dispatch. But this is a time consuming method and control obtained is not fast due to mechanical switches. In recent years, the fast progress in the field of power electronics and microelectronics has resulted into a new opportunity for more flexible operation of power system. The Flexible AC Transmission System (FACTS) program was launched to develop a number of controllers for this purpose. These new devices have made the present transmission and distribution of electricity more reliable, more controllable and more efficient. The STATCOM (Static Synchronous Compensator) is basically a DC-AC voltage source converter with an energy storage unit, usually a DC capacitor. It operates as a controlled Synchronous Voltage Source (SVS) connected to the line through a coupling transformer. The controlled output voltage is maintained in phase with the line voltage, and can be controlled to draw either capacitive or inductive current from the line. STATCOM devices are pure power electronic systems made up of IGBT (Insulated gate bipolar transistor), IGCT (Integrated gate commutated thyristor), GTO (Gate turn-off thyristor), and IEGT (Injection Enhanced gate transistor) [1].

Types of STATCOM
1) Multipulse Converter STATCOM
2) Multilevel Converter STATCOM
3) Hybrid STATCOM

A. Multipulse Converter STATCOM:
Three-phase bridges are connected in parallel on the DC side. The bridges are magnetically coupled through a zigzag transformer, and the transformer is usually arranged to make the bridges appear in series viewed from the AC sides. Each winding of the transformer is phase-shifted to eliminate selected harmonics and produce a multipulse output voltage. Pulse Width Moderation (PWM) can be applied to improve the harmonics content, at the expense of higher switching and snubber loss, plus reduced fundamental VAr rating. The disadvantages of multipulse converter configuration are the phase-shift transformer makes the system complex and bulky.

B. Multilevel Converter STATCOM:
There are 3 types:
1) Diode-clamped converter
2) Flying capacitor converter
3) Cascade converter.

A cascade converter is constructed by standard H-bridges in series. Each H-bridge converter unit provides three voltage levels. Compared with the other two multilevel configurations and the multipulse converter, the cascade converter eliminates clamping diodes, flying capacitors, or the bulky zigzag transformer, and so requires least component mounts and the modularity of this configuration makes it much easier to implement converters with a large number of levels. Larger dc-side capacitors are required compared to the diode clamped and flying capacitor converter under balanced condition but it provides separate phase control to support significant voltage unbalance.

C. Hybrid STATCOM: It is the combination of STATCOM & other FACTS devices.
Application of STATCOM: 1) Voltage Flicker mitigation in Steel Plant 2) Balancing & active filtering of railway load 3) flicker mitigation in Arc Furnace 4) Enhancement of power transmission system performance & power quality 5) Improve transient stability, dynamic stability, power quality, reliability of Wind Farm system.

V. OPTIMAL PLACEMENT OF STATCOM

The addition of FACTS devices to the transmission system is likely to impact the losses associated with transmitting power in the system. The insertion of FACTS devices need not increase overall system losses but it may significantly reduce losses. While installing FACTS devices three main issues must be considered as,
1) What type of devices should be use?
2) How much capacity should it have and
3) Where in the system should it be place?

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Assuming that the cost of a particular device is a function of power transfer capability. It would not be desirable to install a device that is oversized for its intended purpose. Anything larger than the rating of transmission line in which it is installed would not be economical as line limit prohibits the device from being used to its full potential. If the device is too small then it cannot handle as much power as the transmission line. Therefore the size of the FACTS device should be determined by the rating of the associated transmission line [8].

Technical Benefit of FACTS

Better Utilization of Existing Transmission System Assets

In many countries, increasing the energy transfer capacity and controlling the load flow of transmission lines are becoming very important, especially in de-regulated power markets, where electricity supply and demand changes rapidly depending on the behavior of the market participants. Frequently, adding new transmission lines to meet increasing electricity demand is limited by economical and environmental constraints. FACTS devices help to meet these requirements with the existing transmission systems.

Increased Transmission System Reliability and Availability

Transmission system reliability and availability is affected by many different factors. Although FACTS devices cannot prevent faults, they can mitigate the effects of faults and make electricity supply more secure by reducing the number of line trips. For example, a major load rejection results in an over voltage of the line which can lead to a line trip. SVC's or STATCOM's counteract the over voltage and avoid line tripping

Increased Dynamic and Transient Stability

Long transmission lines, interconnected grids, impacts of changing loads and line faults can create instabilities in transmission systems. These can lead to reduce line power flow, loop flows or even to line trips. FACTS devices stabilize transmission systems with resulting higher energy transfer capability and reduced risk of line trips.

Increased Quality of Supply for Sensitive Industries

Modern industries depend upon high quality electricity supply including constant voltage, and frequency and no supply interruptions. Voltage dips, frequency variations or the loss of supply can lead to interruptions in manufacturing processes with high resulting economic losses. FACTS devices can help provide the required quality of supply. Using STATCOM with super conducting Magnetic Energy Storage (SMES) is envisaged to solve many of the power quality problems that effect sensitive industries.

Environmental Benefits

FACTS devices are environmentally friendly. They contain no hazardous materials and produce no waste of pollutants. FACTS can help to distribute the electrical energy more economically through better utilization of existing installations thereby reducing the need for additional transmission lines.

VI. PROBLEM STATEMENT

The 9-bus power system network of an Electric Utility Company is shown in fig.1. The load data is tabulated below. Voltage magnitude, generation schedule and the reactive power limits for the regulated buses are tabulated below. Bus 1, whose voltage is 11KV specified as $V_1=1.03\angle 0^0$, is taken as the slack bus.

Table 1.0: Load Data

LOAD DATA		
Bus No.	**Load**	
	MW	**Mvar**
1	0	0
2	20	10
3	25	15
4	10	5
5	40	20
6	60	40
7	10	5
8	80	60
9	100	80

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Table 2.0: Generator Data

Generator Data				
Bus No.	**Voltage Mag.**	**Generation MW**	**Mvar Limits Min.**	**Max.**
1	1.03	0	0	0
2	1.04	80	0	250
7	1.01	120	0	100

Types of Buses

All the buses in the power system network are generally classified into three categories as:
Generation Bus (or Voltage Controlled Bus): This is also called P-V bus and here the voltage magnitude |V| and the real power |P| are specified.
Load bus: This is also called P-Q bus and here real power |P| and reactive power |Q| are specified.
Slack or Swing Bus: This is also known as reference bus and the voltage magnitude |V| and phase angle Φ are specified here. This bus is selected to provide additional real and reactive to supply the transmission losses since these are unknown until the final solution is obtained. If the slack bus is not specified then a generation bus usually with maximum real power |P| is taken as slack bus.
Bus Classification
Slack Bus: Bus No.1
Generator Buses: Bus No.2 & 7
At these buses voltage and real power magnitudes are specified.
Load Buses: Bus No.3, 4, 5,6,8,9.
At these buses real and reactive powers are specified.

VII. SIMULATION RESULTS

The IEEE 9-Bus system is used for computer simulation studies. The system has 3 generators, 9 buses and 11 tie lines. Bus 1 is selected as slack bus and designated to correct transmission loss changes, and its reactive power cost is not included in the optimization procedure. The system base capacity is 100MVA. The character of the system is that power is sent from the generation area (generators on bus 2 and bus 7) to the main load center through long transmission lines. Table 2 gives generator data, which are usually used for reactive power opportunity cost analysis.
Compensators need to he installed to improve the voltage stability margin, and we select load buses three, four, five, six, eight and nine as candidates for compensator installation.
First of all Simulation of selected Model is done by using PSCAD software for load flow analysis based. The load flow results are shown in Table 3.0.It is observed that total active losses were 27.307MW and total reactive losses were 74.787 MVAr.

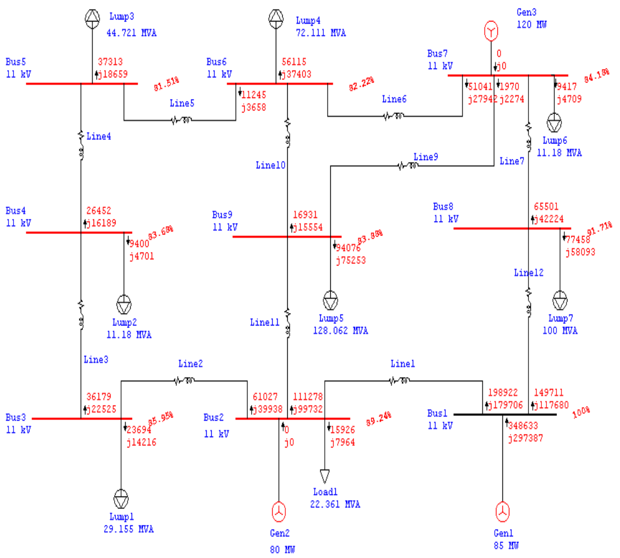

Fig.1.0: Load flow Analysis Without STATCOM

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Now, STATCOMs were installed on respective buses in steps of one at each time,It was observed that both active and reactive power losses goes on decreasing thus increasing line capability and achieving reactive power optimisation.Detailed results of simulation are tabulated below.

Final Result
Result of active and reactive losses after installing STATCOMs on various buses is as given in the table 3.

Table 3.0: System losses computed using simulation

STATCOMs on Bus No.	Active Losses (MW)	Reactive Losses (MVAr)
3	23.982	72.265
3,4	23.257	73.474
3,4,9	23.633	70.976
3,4,9,8	22.574	71.608
3,4,9,8,6	21.358	68.997
3,4,9,8,6,5	20.587	56.875
Without STATCOM on Bus No. 3,4,9,8,6,5	27.307	74.787

VIII. CONCLUSION

From the results obtained in this work on the 9-bus system, the various findings are,
1) Conventional Optimal Reactive power Dispatch with reactive power generation and transformer tap settings adjustment effectively reduces the total active power loss in the system. By including the STATCOM, reduction in the total active power loss in the system have been achieved.
2) Thus improvement using STATCOM would be significant in terms of MW loss reduction and the revenue saving per annum.

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BIOGRAPHY

Prof. Kadam D.P graduated in Electrical Engineering from Govt. College of Engineering, Amaravati in 1997, Master’s Degree in Electrical Engineering from Walchand college of Engg., Sangli, Shivaji University, Kolhapur with Power System and Ph.D (Electrical) from Savitribai Phule Pune University, Pune in 2015. He is working as a Professor at MET-IOE, Nashik, Maharashtra, India. His research area includes Power Quality, Optimization of Reactive Power & FACTS. His total experience spans over 18 years.

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