PERFORMANCE ENHANCEMENT OF POWER SYSTEM BY STATCOM -INTEGRATED ARCHITECTURE

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Abstract - The paper aims to discuss the Performance Evaluation of STATCOM integrated with 118 – IEEE Test System and the Integrated Design Architecture for Efficient Management of Power System. Modern day Power System is constituted of Electrical components integrated with electronic devices and automated with Software. The components hardware and functionality is complex. To support the enhancement of the Life Cycle activities both the physical and the abstract components are modularized. The paper discusses the Key concepts of modularization, and the Life Cycle Stages. Taxonomy of Power Systems is presented. The paper presents the implementation of a modular FACTS device - STATCOM in 118Bus IEEE Test System and the results analyzed.

Keywords*-FACTS,STATCOM. Integrated Design Architecture, Modularization, Life Cycle.*

I. INTRODUCTION

Modern power systems complexity is increasing with de-regularization and advances in Technology. The design of the power system and its components as a single unit renders difficulty of manufacturing, installation, operation and maintenance. Modularization is the process of dividing the system into modules and sub-modules each performing a specific task. The integration of the modules and sub-modules in a specific definite order constitutes the System. The Traditional Electric Power Systems constituted of Generation Units, Transmission and Distribution Lines and Loads. The Modern day Electric Power Systems in addition have been integrated with equipment that enhances the performance of the System. The Life Cycle of a device is the phases it passes through since the conception of the need to its retirement. Enhancing the performance of a Power System is a continuous process. Several devices have been developed to integrate with the existing Power System equipments at various stages to monitor and control the operating parameters such as Voltage, Current, Active and Reactive Power, Power Factor, Sensitivity Factors, Losses and Available Transfer Capability. The potential benefits of FACTS equipment are now widely recognized by the power systems engineering and T&D communities. With respect to FACTS equipment, voltage sourced converter (VSC) technology, which utilizes self-commutated thyristors/transistors such as GTOs, GCTs, IGCTs, and IGBTs, has been successfully applied in a number of installations world-wide for Static Synchronous Compensators (STATCOM) [1-6]

The rest of the paper is organized as follows: Section II – Modularization – Criteria for Efficient Management of Power Systems. Section III- Life Cycle. In Section IV 'Taxonomy of Power Systems' is presented, Section V – STATCOM Module, Section VI – Proposed Approach and Case Study, Section VII – Results and Discussion, Section VIII – Conclusion.

II. MODULARIZATION CRITERIA FOR EFFICIENT MANAGEMENT OF POWER SYSTEMS

The traditional way to develop the transmission network in order to achieve better linkage between generation and demand was reinforcement of the grid, mainly by installing new lines and substations. However, in recent years substantial changes have been implemented in the traditional structures of electric power systems throughout the world. The general reasons is raising demand of power necessitating expansion, demand for quality of service. The tools adopted are deregulation and privatization i.e. the introduction of market rules to the electrical sector. In consequence the transmission system must be adapted to the new conditions of open access and open trading. It must be ensured that adaptation of the power systems to changing generation and demand patterns, meet the equation:

Generation = Demand + Losses (1)

The changing and raising demands can be met by physical expansion of the power system. However, this would be a Long-Term Project involving large amount of finance and Time and may not be a feasible solution at all times. The other method would be adopting efficient techniques for optimum use of the existing Power System. The latter method is made conveniently possible by the advent of Modular devices such as FACTS devices. These Modules are plug-and-use devices which can be located at strategic positions for optimum performance results of the power system.

The Manufacturers of electrical equipment must be prepared to meet these new requirements, where re-locatability and flexibility will be the critical factors. The flexibility of the system also means shorter planning and decision-making, with the consequence that shorter delivery times are requested. The advancement in electrical, electronic, mechanical and Computer technology have miniaturized the components with nano-technology and extended functionality and automated. This concept of Modularization provides flexible means and methods of meeting our objective functions. The terms related to Modularization are:

MODULE: A module is an essential and self-contained functional unit relative to the product of which it is a part. The module has, relative to a system definition, standardized interfaces and interactions that allow composition of products by combination.

MODULARITY is an attribute of a system related to structure and functionality.

MODULARISATION is the concept of dividing a function into sub-functions and developing a physical unit called a sub-module for each sub-function. The sub-modules are integrated in a definite order to constitute the whole module. The sub-module must be defined together with the product and the system to which it belongs.

III. LIFE CYCLE

The Life Cycle of a concept – physical or abstract starts from the planning for the need of the concept to the retirement, going through several phases. The present day power system components are designed having the electrical functional operation automated.

Power Systems are expanding in size due to manifold increase in demand. The expansion is in terms of Geographical Expansion, Generation, Transmission and Distribution Capacity, Complexity in Functionality, increased demand for Quality Performance by the Customers. The advancements of Science and Technology in the fields of Electronics, Communications, Computer and Information Technology, Electrical Machines, Power Electronics have aided the Performance Enhancement of Power System Operation by innovative modular components. These components are automated and have the feature of Plug-and-Play.

The Figure 1 depicts the various stages of the life cycle of a component. The stages are:

Need Opportunity: Realizing the need for the concept that simplifies the operation, or enhances the functionality of a system.

Concept Development: Designing the concept for the implementation.

Product Design: Designing the hardware and software.

Production: Manufacturing of the product.

Deployment: Installation at the point of use.

Maintenance: It is the phase period during which it is in use, for the period of its life-time. As time passes due to wear and tear or due to changing needs the component may need **up gradation** or total replacement.

Retirement: Every product has a life time, it is the period during which it is in operation and serves its functionality effectively. After this duration it has to be replaced by a new one.

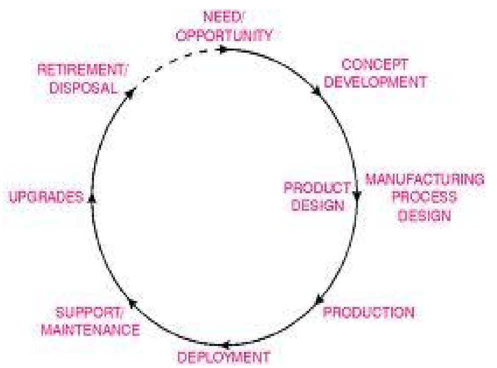

Figure.1 Life Cycle Stages

IV. TAXONOMY OF POWER SYSTEMS

Applying the concept of Modularisation to Power System, the Categorisation is as follows:*A.* Based on stage of Operation: Generation, Transmission and Distribution. *B.* Based on the the function – Generators, Motors, Transmission Lines, Loads, Switchgear and Protection, Power Quality enhancement, monitoring and control.

The paper aims to discuss one Module of the Power System – STATCOM.

V. STATCOM MODULE

A static synchronous compensator (STATCOM), also known as a “static synchronous condenser”, is a member of the Flexible Alternating Current Transmission Systems (FACTS) family of devices. It is a regulating device used on alternating current electricity transmission networks. It is based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide active AC power.

Among all FACTS devices, static synchronous compensators (STATCOM) plays much more important role in reactive power compensation and voltage support because of its attractive steady state performance and operating characteristics.

A. Modeling Of STATCOM

The Static Synchronous Compensator (STATCOM)[7] is a shunt connected reactive compensation equipment which is capable of generating and/or absorbing reactive power whose output can be varied so as to maintain control of specific parameters of the electric power system. The STATCOM provides operating characteristics similar to a rotating synchronous compensator without the mechanical inertia. The STATCOM provides rapid controllability of the three phase voltages, both in magnitude and phase angle. The STATCOM basically consists of a step-down transformer with a leakage reactance, a three-phase GTO or IGBT voltage source inverter (VSI), and a DC capacitor. The AC voltage difference across the leakage reactance produces reactive power exchange between the STATCOM and the power system, such that the AC voltage at the bus bar can be regulated to improve the voltage profile of the power system, which is the primary duty of the STATCOM. However, for instance, a secondary damping function can be added into the STATCOM for enhancing power system oscillation stability.

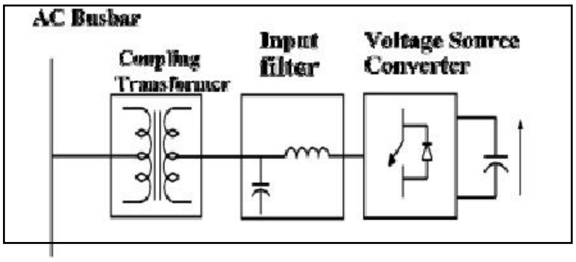

Figure 2. Connection of STATCOM to AC Bus Bar

A STATCOM can be used for voltage regulation in a power system, having as an ultimate goal the increase in transmittable power, and improvements of steady-state transmission characteristics and of the overall stability of the system. Under light load conditions, the controller is used to minimize or completely diminish line over voltage; on the other hand, it can be also used to maintain certain voltage levels under heavy loading conditions.

Figure 2. shows the connection of STATCOM to AC bus. When two AC sources of same frequency are connected through a series inductance, active power flows from leading source to lagging source and reactive power flows from higher voltage magnitude AC source to lower voltage magnitude AC source.

Active power flow is determined by the phase angle difference between the sources and the reactive power flow is determined by the voltage magnitude difference between the sources. Hence, STATCOM can control reactive power flow by changing the fundamental component of the converter voltage with respect to the AC bus bar voltage both phase wise and magnitude wise.

B. Applications Of STATCOM

Typical applications of STATCOM are: Effective voltage regulation and control, Reduction of temporary over voltages, Improvement of steady-state power transfer capacity, Improvement of transient stability margin, Damping of power system oscillations, Damping of sub synchronous power system oscillations. Flicker control, Power quality improvement, Distribution system applications.

C. Basic Operating Principles of STATCOM

The basic electronic block of a STATCOM is a voltage-sourced converter that converts a dc voltage at its input terminals into a three-phase set of ac voltages at fundamental frequency with controllable magnitude and phase angle. The basic principle of reactive power generation by a voltage-sourced converter is similar to that of the conventional rotating synchronous machine shown schematically in Figure 3.

For purely reactive power flow, the three-phase induced electromotive forces (EMFs), e_a, e_b, and e_c, of the synchronous rotating machine are in phase with the system voltages v_a, v_b, and v_c. The reactive current *I* drawn by the synchronous compensator is determined by the magnitude of the system voltage *V*, that of the internal voltage *E*, and the total circuit reactance (synchronous machine reactance plus transformer leakage reactance plus system short circuit reactance)

$$I = \frac{V - E}{X} \qquad (2)$$

The corresponding reactive power Q exchanged can be expressed as follows

$$Q = \frac{((1 - E/V)V^2)}{x^2} \qquad (3)$$

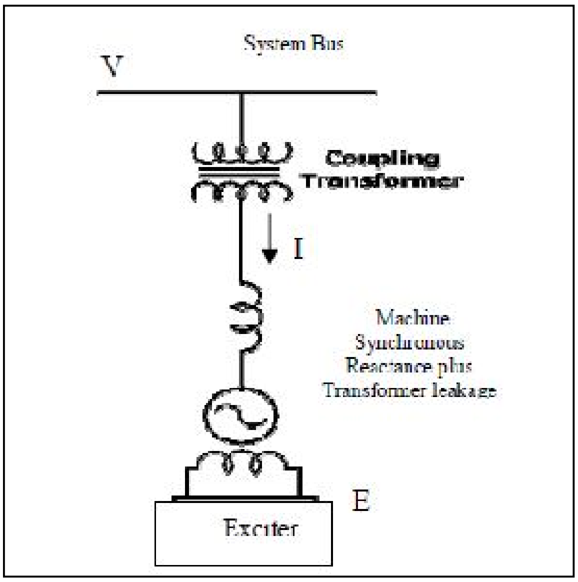

Figure 3 Reactive power generation by a synchronous compensator

By controlling the excitation of the machine, and hence the amplitude *E* of its internal voltage relative to the amplitude *V* of the system voltage, the reactive power flow can be controlled. Increasing *E* above *V* (i.e. operating over-excited) results in a leading current as a result machine acts as capacitor. Decreasing *E* below *V* (i.e. operating under-excited) produces a lagging current as a result machine acts as an inductor. Under either operating condition a small amount of real power of course flows from the ac system to the machine to supply its mechanical and electrical losses. Note that if the excitation of the machine is controlled so that the corresponding reactive output maintains or varies a specific parameter of the ac system (e.g., bus voltage), then the machine (rotating var generator) functions as a rotating synchronous compensator.

The basic voltage-sourced converter scheme for reactive power generation is shown schematically, in the form of a single-line diagram in Fig 4. If the amplitude of the output voltage is equal to that of the ac system voltage, the reactive power exchange is zero. By varying the amplitude of the output voltage produced, the reactive power exchange between the converter and the ac system can be controlled n a manner similar to that of the rotating synchronous machine. That is, if the amplitude of the output voltage is increased above that of ac system voltage, then the current flows through the tie reactance from the converter to the ac system, and the converter generates reactive (capacitive) power for the ac system. If the amplitude of the output voltage is decreased below that of the ac system, then reactive current flows from the ac system to the converter, and the converter absorbs reactive (inductive) power. If the amplitude of the output voltage is equal to that of the ac system voltage, the reactive power exchange is zero.

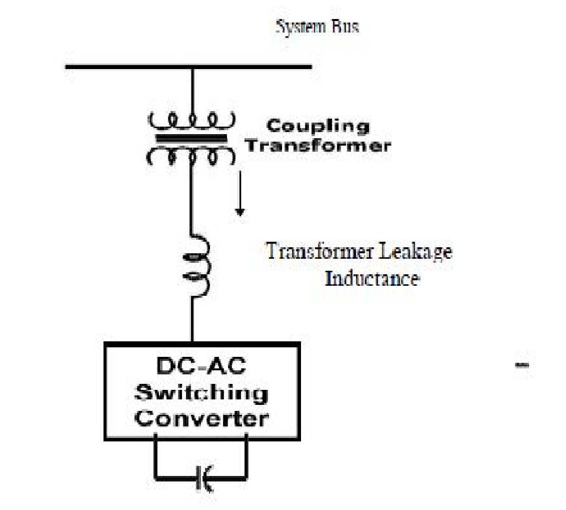

Figure 4. Reactive power generation by controlled voltage sourced switching converter

D. Optimal Placement Of STATCOM

Identifying the Location for placement of STATCOM or any FACTS device [8, 9] for that matter is a very critical decision. Simple heuristic approaches are traditionally applied for determining the location of FACTS devices in a small power system. However, more scientific methods are required for placing and sizing FACTS devices in a larger power network. FACTS sizing and allocation constitutes a milestone problem in power systems. Traditional optimization methods such as mixed integer linear and non-linear programming have been intensely investigated to address this issue; however difficulties arise due to multiple local minima and the overwhelming computational effort [10, 11]. Recently, Evolutionary Computation Techniques have been employed to solve the optimal allocation of FACTS devices with promising results. Different algorithms such as Genetic Algorithms (GA) [10], [12, 13, 14], and Evolutionary Programming [15] have been tested for finding the optimal allocation as well as the types of devices and their sizes. Particle Swarm Optimization (PSO) is another evolutionary computation technique that can be used to solve the FACTS sizing and allocation problem. It has been applied to other power engineering problems such as: economic dispatch [16], generation expansion problem [17], short term load forecasting [18], and others, giving better results than classical techniques and with less computational effort. In addition, it has been shown recently that the application of PSO is suitable in principle to optimally place FACTS devices in a multimachine power system [8].

The objective function considered in this paper is minimization of losses. Losses in Power System is defined as

$$\text{Losses} = \frac{R_t(P_i^2+Q_i^2)}{|V_i^2|} \qquad (4)$$

Where R_t = sum of the resistances of all lines associated to With bus i

P_i = active power of bus i.

Q_i = reactive power of bus i and

V_i = voltage profile of bus i.

The idea is to locate the bus that has the highest losses which could be considered as the optimal point for placing the device STATCOM.

VI. PROPOSED APPROACH AND CASE STUDY

Several Methods have been developed for decision on Optimal Placement of STATCOM and the number of devices to be placed. The proposed method considers the line with Maximum Reactive Power Losses for placement of STATCOM. The case study is conducted adopting the following procedure on 118Bus IEEE Power Test System:

1. Run Optimal Power Flow (OPF) on the IEEE 118 Bus Test System. The One-Line Diagram of the Test System is shown in Fig 5.
2. Tabulate the results of the various performance Parameters of the Test System.
3. Identify the lines with maximum reactive power losses i.e. Q in MVAr. Lines with value of Q more than 4.16% of the total Q only have been taken for the purpose of the study. The branches identified here are 7,8, 9,31,33,38,96. Total active power Loss P (MW) is 77.401 and reactive power loss Q (MVAr) is 483.52.

4. Place the STATCOM in the line with maximum Reactive Power Loss. The lines mentioned in Step 3, having more than 4.16% of total Q Loss have been selected. The reactance(X) value has been decreased between 3.0 to 47.5% of the initial value. The detail results are shown in Table I and II.
5. Run OPF after changing the reactance value. Record the results. The change in system operating parameters for the lines under study are calculated and tabulated in Table II. The performance before and after placing STATCOM is shown in Figure 6 graphically. The summary of the results is shown in Table I and II.

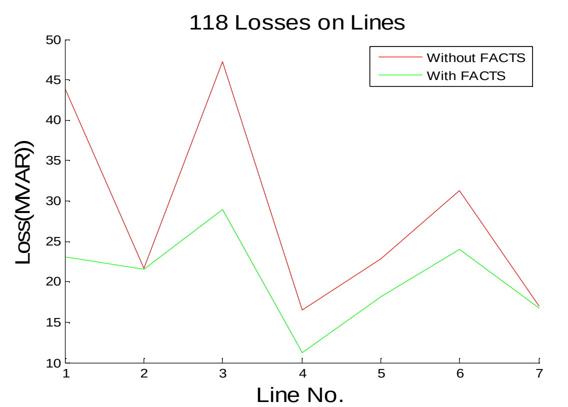

Figure 6 118 Bus IEEE System Performance Before and After Placing STATCOM

TABLE I.
VOLTAGE AND LOSSES WITH AND WITHOUT STATCOM

Parameter	**Before Placing STATCOM**		**After Placing STATCOM**	
	Min	**Max**	**Min**	**Max**
Voltage Magnitude	1.011 p.u. @ bus 81	1.060 p.u. @ bus 66	1.011 p.u. @ bus 81	1.060 p.u. @ bus 66
Voltage Angle	15.40 deg @ bus 41	37.65 deg @ bus 10	15.56 deg @ bus 41	33.37 deg @ bus 89
P Losses (I^2*R)	-	4.47MW @ line 25-27	-	4.45 MW @ line 25-27
Q Losses (I^2*X)	-	47.19 MVAr @ line 9-10	-	28.95 MVAr @ line 9-10

VII. RESULTS AND DISCUSSION

1) The FACTS device STATCOM was implemented in 118 Bus System. The study was conducted in MATLAB.2) The Power Flow study converged in 0.31sec with FACTS as compared to 0.39sec without FACTS. 3) Objective Function Value is reduced by 17.25 $/hr. **4)** For the 118 – Bus System Total Loss before placement is 77.4MW,483.52MVAR, and with FACTS Devices is 77.13MW,426.13MVAR. 5) The Minimum and Maximum Values of the System Parameters observed is Tabulated in Table I. It is observed that : No change in Voltage magnitude but Voltage Angle Maximum is decreased from 37.65 to 37.37 degrees. The reduction in Total Losses is 0.27MW and6) The graph of the Losses Vs Line No of 118 – Bus is depicted in Figure 6.

VIII. CONCLUSION

In this paper the concept of modularization and Life Cycle is presented. The STATCOM device optimal location method adopted on 118 IEEE Power System has shown good results by way of reducing computation time and losses.

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