Implimentation Of Linear PI And Non Linear Fuzzy Control With Variation Of DC Link Voltage in STATCOM for Compensation Of Reactive Power

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Abstract— **This paper deals with a modern approach of controlling the power flow in AC transmission lines. The control and distribution of power flow in two parallel transmission lines will be implemented by applying one of the flexible AC Transmission System (FACTS) which is STATic COMpensator (STATCOM) device. The STATCOM device is installed on one line of the two parallel transmission lines to design the controllers for such a system using Electromagnetic Transients Program (EMTP). The closed-loop STATCOM system as a terminal line voltage regulator is designed with fuzzy logic controller. The dynamic performance of the controller is tested. It is found that, the fuzzy logic controller forces the system to settle to the steady state value fast. The fuzzy logic controller is robust, it has a fast response during disturbance and parameters variation. The fuzzy logic controller can be tuned fast in EMTPSTATCOM is installed to support electricity networks that have a poor power factor and often poor voltage regulation.**

I . INTRODUCTION

The STATCOM (STATic synchronous COMpensator) is a shunt connected voltage source converter using self-commutating device and can be effectively used for reactive power control. Its principle of operation is similar to that of a synchronous condenser. Now-a-days power systems have become very complex with interconnected long distance transmission lines . The interconnected Grids become unstable as the heavy loads vary dynamically in their magnitude and phase angle and hence power factor . Commissioning new transmission systems are extremely expensive and take considerable amount of time to build up. Therefore, in order to meet increasing power demands, utilities must rely on power export/import arrangements through the existing transmission systems.

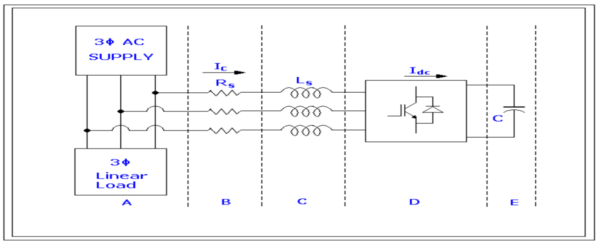
The initial investigation points to the question whether the project is feasible. The feasibility is conducted to identify the best system that meets all the requirements. This includes an identification description, an evaluation of the proposed systems and the selection of the best system for the job. The requirements of the system are specified with a set of constraints such as system objectives and the description of the output. It is then duty of the analyst to evaluate the feasibility of the proposed system to generate the above results. Three key factors are to be considered during the feasibility study.

1. A complete understanding of the requirement for the new system is very important for the successful development of a software product. Requirement Specification is the foundation in the process of software development. All further developments like system designing and coding will depend on how accurate and well documented the Requirement Specification is.
2. Requirement specification appears to be a relatively simple task, but appearance is often deceiving. There is always a chance of wrong specification because of communication gap between the user and the Developer. Requirement specification begins with a clear statement of the problem and the task to be performed. Then the requirement is described in a technical manner in precise statements.
3. After the initial specification reports are received, they are analyzed and redefined through customer interaction improvement is in terms of introduction of some harmonics, which requires separate handling using active filtration techniques. Moran et al have shown in details how the utilization of Sinusoidal Pulse Width Modulation (SPWM) techniques reduces harmonic distortion.
4. It has also been shown that an increase of modulation index reduces the size of the link reactor and stress on switches which are significant issues in practical implementation. The modeling and analysis of STATCOM steady state and dynamic performance with conventional control method have been studied by Schauder and Mehta using non-linear controller.

A long transmission line needs controllable series as well as shunt compensation for power flow control and voltage regulation. This can be achieved by suitable combination of passive elements and active FACTS controllers. In thispaper,series passive compensation and shunt active compensation provided by a static synchronous compensator (STATCOM) connected at the electrical center of the transmission line are considered. It is possible to damp sub synchronous resonance (SSR) caused by series capacitors with the help of an auxiliary subsynchronous damping controller (SSDC) on STATCOM..

II. OVERVIEW OF PI CONTROL

As is well known, the STATCOM is, in principle, a static (power electronic) replacement of the age-old synchronous condenser. Fig.4.1 shows the schematic diagram of the STATCOM at PCC through coupling inductors. The fundamental phasor diagram of the STATCOM terminal voltage with the voltage at PCC for an inductive load in operation, neglecting the harmonic content in the STATCOM terminal voltage, is shown in Fig.4.2. Ideally, increasing the amplitude of the STATCOM terminal voltage *oa V* above the amplitude of the utility voltage *sa V* causes leading



The 3-phase stationary *abc* coordinate vectors with 1200 apart from each other are converted into □2-phase stationary coordinates (which are in quadrature). The □axis is aligned with *a* axis and leading □axis and both converted into *dq* two-phase rotating coordinates. The Park's *abc* to *dq* transformation matrix is used here.

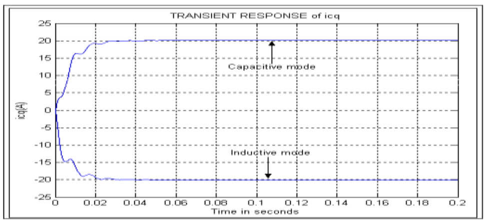


Fig. 2. Transient responses in capacitive and inductive mode : (a) *cq i* and **(b)**

DESIGN OF VOLTAGE CONTROLLER

The relation between dc voltage *v dc* and dc current *i dc* is

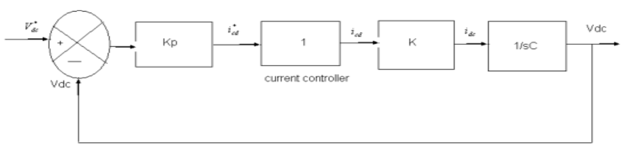


Fig.3 DC link voltage control loop

The DC bus voltage is maintained at 400 volts. With *dc V* as the reference, the voltage control loop is shown in Fig.4.4 and it consists of inner *d* – axis current control loop. The active power is supplied by the *d* -axis current which is nothing but the ripple current of the capacitor. To make the steady state error of the voltage too zero Proportional control is adopted here and it produces the reference *d* -axis current for the control of the *d* - axis current. The design of voltage controller is as follows: Then Proportional Integral controller is considering for the voltage control. Hence, the transfer function of PI controller is associated with the transfer function on dc side is After taking *C v* and on simplification So the system behaves like a second order system. As magnitude plot in Fig.10 shows the initial slop at break point is approximately –20db/decade and hence it reduces to first order system. The value of K can be determined form root locus with approximate settling time.

III. SIMULATIONS USING PI CONTROLLERS

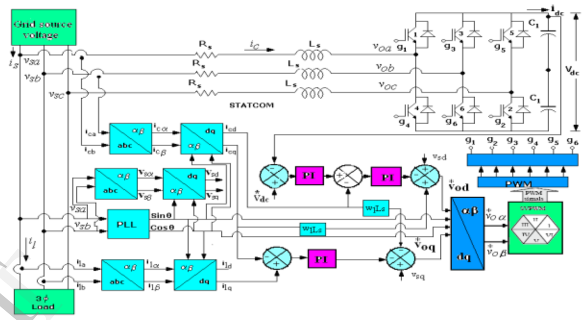


Fig. 4 **SIMULATIONS USING PI CONTROLLERS**

The proposed control strategy will help for improving the power factor from 0.7 to nearly unit and this logic will also derive the conclusion for using DC link voltage. These controllers work and STATCOM functions at initial value of DC link voltage of 100V with larger current peak1)

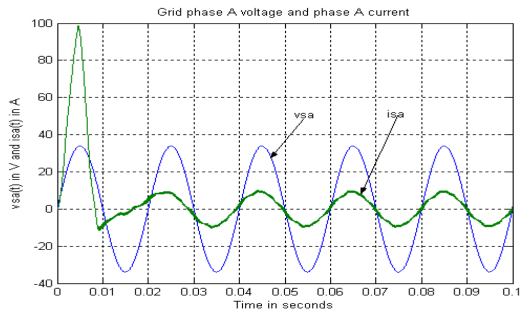


Fig. 5.**Grid phase A voltage and phase A current**

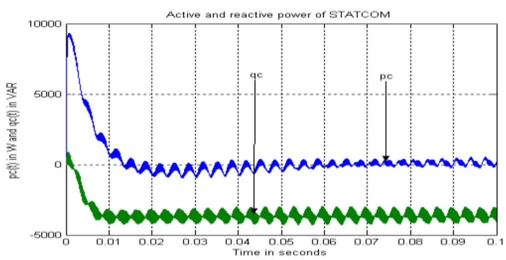


Fig 6 Active and reactive power of statcom

DC link capacitor charged to 550V At initial value of DC link voltage of 550V, the STATCOM operates well and the relevant outputs are shown in Fig.5.2. Fig.5.3 shows the dynamics of grid phase A voltage and phase A current and it shows the over shoot of only 8*A* and the same dynamics is obtained in case of STATCOM phase. A current with a over shoot of 1*A* as shown in Fig.5.4.That shows the dynamics of active and reactive components of the STATCOM current. The dynamics of active and reactive power of STATCOM is shown in Fig.12.DC link voltage with over shoot of 640*V* and settles at two power cycles

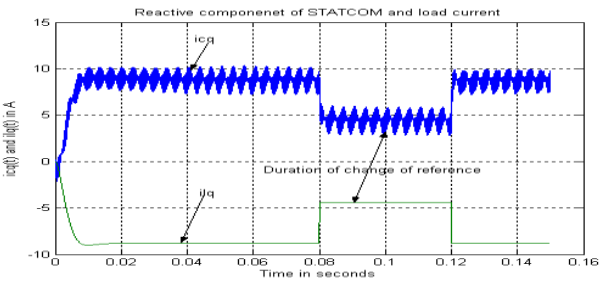


Fig 7 Reactive componenet of STATCOM and load current

These controllers work well with a very small spike and improves power factor in a half a power cycle at initial voltage of 600V as shown in Fig.5.7 of grid hase A voltage and phase A current.

IV NON LINEAR SYSTEM

Nonlinear control is the area of control engineering specifically involved with systems that are nonlinear, time-variant, or both. Many well-established analysis and design techniques exist for linear time-invariant (LTI) systems (e.g., root-locus, Bode plot, Nyquist criterion, state-feedback, pole placement); however, one or both of the controller and the system under control in a general control system may not be an LTI system, and so these methods cannot necessarily be applied directly. Nonlinear control theory studies how to apply existing linear methods to these more general control systems. Additionally, it provides novel control methods that cannot be analyzed using LTI system theory. Even when LTI system theory can be used for the analysis and design of a controller, a nonlinear controller can have attractive characteristics (e.g., simpler implementation, increased speed, or decreased control energy); however, nonlinear control theory usually requires more rigorous mathematical analysis to justify its conclusions

Some properties of nonlinear dynamic systems are

- They do not follow the principle of superposition (linearity and homogeneity).
- They may have multiple isolated equilibrium points.
- They may exhibit properties such as limit cycle, bifurcation, chaos.
- Finite escape time: Solutions of nonlinear systems may not exist for all times.

ANALYSIS AND CONTROL OF NONLINEAR SYSTEM

There are several well-developed techniques for analyzing nonlinear feedback systems:

- Describing function method
- Phase plane method
- Lyapunov stability analysis
- Singular perturbation method
- Popov criterion (described in *The Lur'e Problem* below)
- Center manifold theorem

FUZZY CONTROL

Fuzzy controllers are very simple conceptually. They consist of an input stage, a processing stage, and an output stage. The input stage maps sensor or other inputs, such as switches, thumbwheels, and so on, to the appropriate membership functions and truth values. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value.

The most common shape of membership functions is triangular, although trapezoidal and bell curves are also used, but the shape is generally less important than the number of curves and their placement. From three to seven curves are generally appropriate to cover the required range of an input value, or the "universe of discourse" in fuzzy jargon.

As discussed earlier, the processing stage is based on a collection of logic rules in the form of IF-THEN statements, where the IF part is called the "antecedent" and the THEN part is called the "consequent". Typical fuzzy control systems have dozens of rules.

Consider a rule for a thermostat:

IF (temperature is "cold") THEN (heater is "high")

This rule uses the truth value of the "temperature" input, which is some truth value of "cold", to generate a result in the fuzzy set for the "heater" output, which is some value of "high". This result is used with the results of other rules to finally generate the crisp composite output. Obviously, the greater the truth value of "cold", the higher the truth value of "high", though this does not necessarily mean that the output itself will be set to "high" since this is only one rule among many. In some cases, the membership functions can be modified by "hedges" that are equivalent to adjectives. Common hedges include "about", "near", "close to", "approximately", "very", "slightly", "too", "extremely", and "somewhat". These operations may have precise definitions, though the definitions can vary considerably between different implementations. "Very", for one example, squares membership functions; since the membership values are always less than 1, this narrows the membership function. "Extremely" cubes the values to give greater narrowing, while "somewhat" broadens the function by taking the square root.

In practice, the fuzzy rule sets usually have several antecedents that are combined using fuzzy operators, such as AND, OR, and NOT, though again the definitions tend to vary: AND, in one popular definition, simply uses the minimum weight of all the antecedents, while OR uses the maximum value. There is also a NOT operator that subtracts a membership function from 1 to give the "complementary" function.

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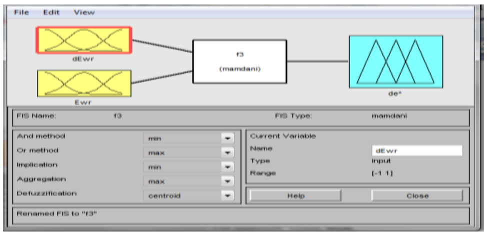
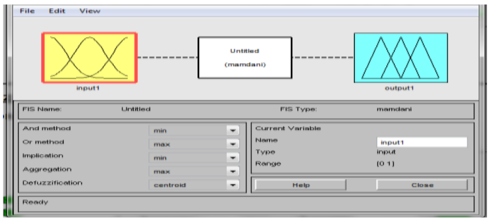


Fig 8 fuzzy control simulation block



There are two types of fuzzy inference systems that can be implemented in the fuzzy logic toolbox which are Mamdani-type and Sugeno-type

1-**<u>Fuzzification</u>**, which converts controller inputs into information that the inference mechanism can easily uses to activate and apply rules.

2-**<u>Rule-Base</u>**, (a set of If-Then rules), which contains a fuzzy logic quantification of the expert's linguistic description of how to achieve good control.

3-**<u>Inference Mechanism</u>**, (also called an "inference engine" or "fuzzy inference" module), which emulates the expert's decision making in interpreting and applying knowledge about how best to control the system

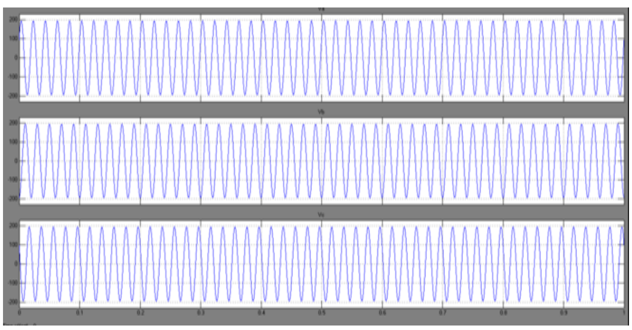


Fig Non linear control with STATCOM 3 phase output result

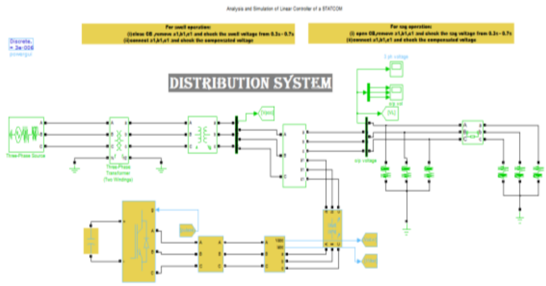


Fig 9 Analysis and simulation of Non linear control of a STATCOM

V CONCLUSION

The complete analysis and models of reactive current and voltage controllers of the STATCOM application are presented. The controllers are designed on the basis of parameters of the STATCOM and time constant. The simulated figures with designed controllers and on variation of DC link voltages are given which have been controlled the desired values. The settling time of the system by using the PI controller is faster than other controllers. In this paper, the proposed scheme is easier to implement compared to and .However, in practice the issue of the charging the DC link voltage to the required value is quite significant. On increasing the magnitude of DC link voltage, the overshoot of all signals decreases. DC link voltage at 600V is suitable for proper operation of the STATCOM. In most cases, there is a separate charging circuit for the DC link voltage. The authors are working on a plausible method of eliminating such an extra starting arrangement, so that the controller may become operational while the DC link voltage is at a low value.

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