ijournals International Journal of Software & Hardware Research in Engineering
ISSN No: 2347-4890 Volume 2 Issue 1/ January 2014

Transient Stability Enhancement Using STATCOM with Adaptive Control

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ABSTRACT

In this paper we propose the utilization of a Static Synchronous Compensator (STATCOM) with adaptive control to enhance the transient answer of the synchronous generator. To estimate the best control constant of a FACTS device we make use of a Quality Response Index (QRI) and use a genetic algorithm to resolve an optimization problem. For real-time applications a neural network is employed to control the STATCOM, to be able to receive an adaptive control of the generator through the fault. Results of a case study, considering operating points, faults, and clearing-times, show that the adaptive control technique is the better solution for damping the transient answer of the synchronous generator.

Keywords

Adaptive control, STATCOM, neural network, transient stability.

1. Introduction

The transient stability of a generator is dependent upon the difference between mechanical and electrical power. Throughout a fault, electrical power is reduced instantly while mechanical power remains constant, thus accelerating the rotor. To keep transient stability, the generator should transfer the excess energy toward the system. For this specific purpose, already existing Flexible AC Transmission Systems (FACTS) devices could be employed.

Applying FACTS devices increases the performance of the electrical power system, however they present new problems that are difficult to solve applying traditional techniques. Regarding this subset, power flow and transient stability types of FACTS aspects are shown in [1]. In [2] a concept to analyze power system damping development by application of a Static Var Compensator (SVC) was developed. Essential problems as how to control an SVC to enhance system damping, and the difference between continuous and discontinuous control of SVC reactive power output, are discussed. The advancement of power system stability situations utilizing a thyristor-controlled series capacitor and SVC was studied in [3]. A control technique for for damping electromechanical power oscillations using energy function approach was derived.

An method to design a damping controller for energy storage devices like STATCOM is explained in [4]. They use both reactive and active power injection/absorption to control the power system, providing good power–swing damping. A new approach for increasing the transient stability limit is shown in [5], applying SVC and STATCOM devices which are controlled for the objective of raising the decelerating area to compensate the accelerating one. A strategy predicated on genetic algorithms was planned in [6] to determine the optimized number and location of FACTS devices to be able to maximize the transmission capacity of a power system; while in [7] a sensibility approach is employed for the suitable placement of SVC to expand the voltage security.

The output current of the STATCOM could be adjusted to change the power flow in the system during, and following dynamics disturbances so as to increase the transient stability limit and offer effective power oscillation damping, as shown in [8] and [9]. As always the control technique to enhance the dynamic response of the synchronous generator has been considered in a heuristic manner.

In this paper we make use of a quality index as planned in [10] to create an objective evaluation of the transient response of a synchronous generator under fault conditions. This index is placed on calculate the most effective control constant of the

STATCOM in a machine-STATCOM-infinite bus system, in order to improve the transient response of the generator. The optimization problem is resolved by genetic algorithms, but since the calculation of the optimal values for the control parameter turns out to be slow for real-time applications, a neural network is employed. Data for training the neural network are obtained from the genetic algorithm by applying the adaptive control in real-time. This shows better results than using a fixed constant.

2. Some Basic Aspects of Transient Stability

Each time a traditional transient stability strategy is put on a machine-infinite bus system (neglecting losses), the dynamics of the synchronous machine are defined by the following second-order differential equations [11]:

$$\frac{2H}{\omega_s}\frac{d^2\delta}{dt^2} = P_m - P_e = P_a \qquad (1)$$

whenever a δ is the electrical power angle, ω_s is the synchronous angular velocity, H is the inertial constant, and P_m, P_e, P_a are the mechanical, the electrical, and the accelerating powers, respectively. During the transient period, the electrical power transferred between the generator and the external bus is given by:

$$P_e = \frac{E'V}{X}\sin\delta \qquad (2)$$

wherever E' *is* the component of the internal transient voltage of the synchronous machine, V could be the module of voltage at the external bus, and X is the equivalent reactance involving the buses with voltages E' and V respectively.

Whenever a system fails the resulting accelerating power is positive, the rotor is accelerated within the synchronous speed, storing kinetic energy, and δ increases. To compensate for this case, it's attractive to improve the electrical power transfer during the fault at the maximum stage possible. To rapidly release the kinetic energy stored in the rotor when the fault is eliminated, it is advisable to transfer more electrical power than input mechanical power. At this time, the rotor starts to brake and the rotor speed reaches the synchronous speed. When the speeds are equal the reduction of δ starts. To be able to reduce a scenario wherever electrical power is less than mechanical power, it is essential to reduce the electrical power. In this way, the generator quickly recuperates their equilibrium with small oscillations.

In Fig.1, if changes in P_a are such that the accelerating area (A_a) is less than or equal to the deceleration area (A_d), then the first swing is stable. Depending on the evolution of the fault condition, the initial operation angle d_0 is maintained or a new operation angle d_e can be reached. On the other hand, if the clearing time of the fault is such that the first oscillation of angle d goes beyond p–d_e, the accelerating power is positive again, and the system becomes unstable.

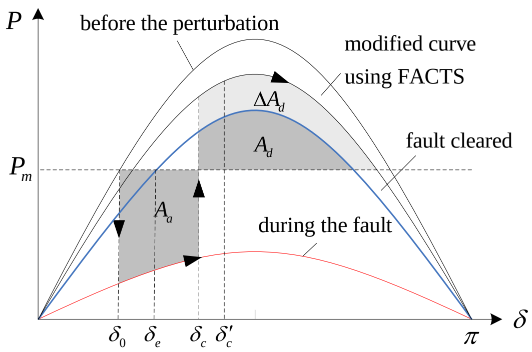

Fig. 1. Accelerating and decelerating places throughout a fault.

Fig.1 also reveals how FACTS may increase transient stability. When we contemplate A_a and A_d as equal, and δ_c may be the critical angle, we observe that FACTS may enhance the amplitude of the power angle curve, and then increment the deceleration region in ΔA_d, thus achieving a larger critical angle.

3. Modeling of Control Scheme

The issue of transient stability control includes of controlling the accelerating power P_a by changing the mechanical power and/or the electrical power. Considering that the mechanical power control reaction is slow, the alternative throughout the transient period is to act on the electrical power transferred. This can be accomplished using a STATCOM, as represented by a shunt current source revealed in Fig.2, which modifies the correct variables in formula 2.

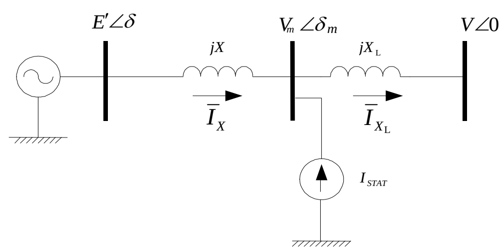

Fig. 2. Single machine–infinite bus system, including a STATCOM represented as a current

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ISSN No: 2347-4890 Volume 2 Issue 1/ January 2014

source.

The current injection by STATCOM is described by:

$$\bar{I}_{STAT} = I_{STAT} e^{j(\delta_m - 90)} \quad (3)$$

At bus m: $\bar{I}_X + \bar{I}_{STAT} = \bar{I}_{X_L}$ (4)

The magnitude and angle of the voltage in the connection bus *m* [12], receive by:

$$V_m = \frac{E'X_L \cos(\delta - \delta_m) + V X \cos(\delta_m) + X X_L I_{STAT}}{X + X_L} \quad (5)$$

$$\delta_m = \tan^{-1}\left(\frac{E'X_L \sin(\delta)}{V X + E'X_L \cos(\delta)}\right) \quad (6)$$

Term *X* in equations (5) and (6) also reveals the effect of the STATCOM position. The electrical power moved by the generator to bus *m*, is distributed by:

$$P_e = \frac{E'V_m}{X}\sin(\delta - \delta_m) \quad (7)$$

To change the voltage at the connection bus in real-time and to change the curve of the power-transfer as is suggested in Fig.3, we propose the application form of a flexible control technique on the STATCOM.

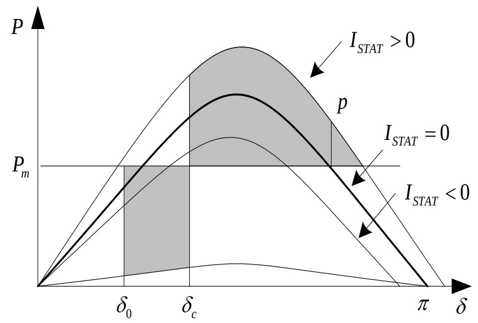

Fig. 3. Effectation of the STATCOM in power-transfer curves.

When the compensator is utilized in a capacitive mode, the existing is positive ($I_{STAT} > 0$). In addition to the power amplitude modification, the power-angle curve is shifted to the right, increasing the deceleration area and therefore augmenting the transient stability limit. Considering this effect, the best strategy to augment the deceleration area is to increase the maximum current of the STATCOM ($I_{STAT} = I_{STAT}^{max}$) while the rotor speed is greater than the synchronous speed. This value is maintained up to the point where the value of δ reaches point *p* during the return of the first oscillation. To reduce the rotor oscillations, one can change the STATCOM current, applying a proportional velocity current such as $I_{STAT} = K\omega$, where *K* is a positive proportionality constant. For certain values of *K*, the results show that δ presents fewer oscillations and the system needs less time to reach equilibrium. This effect can be valued in Fig.4 for different values of *K*.

(6)

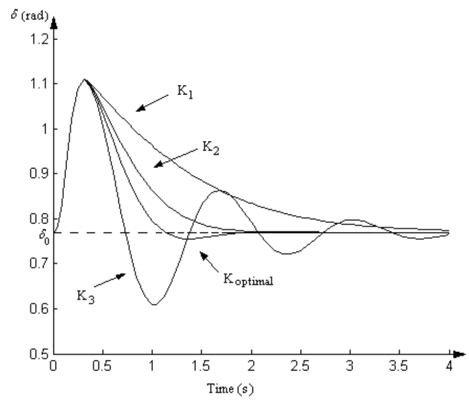

Fig. 4. Graphic of angle $\delta(t)$ for various values of *K*.

To find out the very best value of *K* that assures the effectiveness of the control strategy we planned the evaluation of a Quality Reaction Index (QRI) [8], that is described whilst the integral of the absolute value of the deviation between δ and an equilibrium angle δ_e, reached after a fault. This method was used to resolve the following optimization issue:

minimized QRI

subject to:

$$I_{STAT} = \begin{cases} I_{STAT}^{max} : \text{Until } \delta \text{ reaches the point } p \text{ during} \\ \qquad \text{the return of the first oscillation} \\ I_{STAT}^{min} \le K\omega \le I_{STAT}^{max} : later \end{cases} \quad (8)$$

4. Adaptive Control

Solving this issue applying genetic methods is slow. Thus their application is unfeasible for transient stability control in real-time. As a result of this, we use a neural network to apply real-time control, utilising the results received from the genetic algorithm because of its training.

The neural network applied is a *feed-forward back-propagation* type with three layers. In the first and

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ISSN No: 2347-4890 Volume 2 Issue 1/ January 2014

second layers, a a move function type *logsig* can be used, while in the third layer we make use of a transfer function type *purelin*.

To acquire the data for the neural network learning process, the behavior of angle δ has been studied by making use of a simulation process, which views a three-phase fault at point *F* in the system revealed in Fig. 5, where *H=5* s, the internal voltage of the synchronous generator is E'=1.2065pu., X'_d = 0.3pu., X_T = 0.1pu, and X_L = 0.4pu.

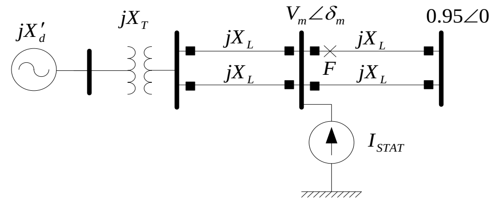

Fig. 5. One-line diagram of the system for applications.

For various loading situations and clearing times, the very best value of *K* for each simulated situation has been acquired by applying a genetic algorithm, generating the data revealed in Table I.

Table I. - Simulation Data for Training the Neural Network

		Optimum *K* according to clearing time		
P_e (pu)	δ_0(rad)	t_1=0.1 (s)	t_2=0.15 (s)	t_3=0.2 (s)
0.1	0.0699	6.3258	6.3462	5.7278
0.2	0.1401	4.0397	6.5517	2.8213
0.3	0.2110	2.0414	6.4490	1.7821
0.4	0.2829	2.0516	6.4746	2.3207
0.5	0.3565	2.2075	6.4507	1.4073
0.6	0.4321	1.5152	5.8612	1.0250
0.7	0.5105	0.8704	5.7492	0.8254
0.8	0.5924	0.8455	0.7696	0.4574
0.9	0.6792	0.4350	0.6945	-
1.0	0.7726	0.4479	0.2654	-

The transient behavior of angle δ depends on its initial value (δ_0), as well as on the type of fault and the fault clearing time (t_f). Therefore, for training the neural network, the fault has been specified utilizing P_e , δ_0 , and t_f as input parameters. With these parameters, the neural network automatically determines a better value for *K* in real-time.

From Table I, it can be seen that for this system the range of optimal values for *K* is found to be between 0.2654 s and 6.5517 s. Also, it is observed that for a specified clearing time with an increased load, the value of *K* is reduced in all cases. At the end of the training process (for the purpose of real-time simulation tests) the neural network was exported to SIMULINK.

5. Case Study

To show the performance of the adaptive control by a neural network, four cases of the electrical system shown in Fig. 5 were simulated.

Since in Cases 1 and 2 the fault is auto-clearing, the system returns to the initial condition of operation (Figs. 6 and 7).

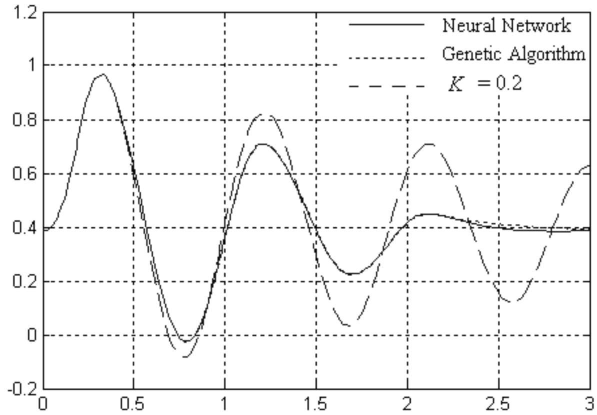

Fig.6. δ-time behavior according to genetic algorithm and neural network, compared with proportional control strategy in Case 1.

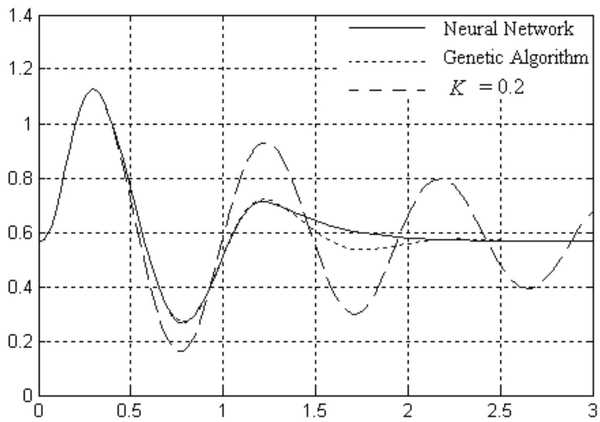

Fig.7. δ-time behavior according to genetic algorithm and neural network, compared with the proportional control strategy in Case 2.

In Figs. 6, 7, the good quality of the response can also be appreciated when the neural network is used, compared with the optimized response of a genetic algorithm. Though the neural network produces a different value of *K* as compared with those obtained from a genetic algorithm; both cases show that the control was successful in improving the transient stability and reducing the rotor oscillations.

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ISSN No: 2347-4890 Volume 2 Issue 1/ January 2014

6. Conclusion

In this work we used a QRI to evaluate the transient angular response in a single machine-STATCOM-infinite bus system, obtaining the best value of a proportionality control constant of the STATCOM, while applying a genetic algorithm. To implement the optimized control strategy of the STATCOM in real-time, a neural network was used. The optimization algorithm was applied to obtain the required training data. Case study results show that adaptive control with a neural network produces good to near optimal responses. So, we can see that angle *d* behaves as is expected, improving the damping of the generator oscillations despite the fact that the same fault type and location were considered in the data used for the neural network training.

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